Reciprocity, Emulation and the Spread of Collective Action: An Agent Based Model

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Abstract

In Mancur Olson's 1965 classic, *The Logic of Collective Action*, he theorized that attempts at collective action by large groups are bound to fail due to individuals' self-interested motives. In my research, I develop an agent based model using boundedly rational agents whose behavior is driven by social norms. It is observed that when a reciprocity norm in which some agents sanction free riders is established, small groups can successfully coordinate collective action. Also, this cooperative behavior can spread throughout a population of small groups from neighbor to neighbor if there is a mechanism for inter-group emulation. With the same set social norms, it is also seen that large scale collective action can emerge and spread throughout the population.

1 Introduction

It has been noted repeatedly in various economic experiments and field studies that small groups of individuals can be very effective at solving the problems of collective action and avoiding dilemmas that arise from narrow self interest such as the tragedy of the commons and the free rider problem. An example of a mechanism adopted by small groups would be pro-social norms (Carpenter, Matthews, and Ong'ong'a O, 2004; Ostrom, 1998). A pro-social norm is one which increases the payoff to other members of a group, such as the punishment of free-riders (Bowles and Gintis, 2005; Carpenter, Matthews, and Ong'ong'a O, 2004).

However, these observations at the level of small groups do not yet present a complete picture of how collective action emerges in large groups. In this latter case, the incentives to free ride are magnified and social contact between members of the group is minimal. Despite these difficulties, we have observed throughout history that large masses of people can gather around a common goal from time to time, as seen from peasant revolutions that have toppled central governments to modern activists who have assembled in worldwide demonstrations that number in the hundreds of thousands. These real world findings provide motivation and an intuitional backdrop for the current project.

One promising way of modeling large, complex systems of heterogeneous actors is through the use of computational agent based models. Various socio-political behaviors have already been successfully modeled using this technique, including the emergence of classes (Axtell, Epstein, and Young, 2001), cooperation in heterogeneous populations (Bowles and Gintis, 2004), and civil violence (Epstein, 2002). These models seek, among other things, to recreate qualitative patterns observed in the real world from the interactions of computer agents that are programmed to follow simple rules and interact among themselves. Agent based models are one way of studying complex adaptive systems, which exhibit phenomena such as path-dependency and punctuated equilibria, that are difficult to capture using traditional analytical models used in social science (Miller and Page, 2007).

The aim of my research is to build an agent based model in which certain social norms are allowed to evolve, and to see if the agents can tackle both small and large scale collective action problems through their decentralized interactions. The simulated interactions of agents will be used as a testing ground for various inductive explanations for the causes of large scale collective action.

The project can be divided into two parts. The first will be to implement an agent based model (ABM) which demonstrates that collective action problems can be solved in small groups. The motivation behind this approach to the problem of collective action comes from Carpenter, Matthews, and Ong'ong'a O (2004); Bowles and Gintis (2004, 2005); Ostrom (1998). In the first paper, the authors observed that reciprocity plays a major part in deterring free riding behavior in small groups. In the second and third papers, Bowles and Gintis provide both an analytical evolutionary model and an agent based model that incorporates prosocial emotions to explore the problem of cooperation in an N-player public goods game. In the Ostrom piece, the author proposes the use of second-generation models of rationality to explain collective action. The models assume bounded rationality and incorporate the effects of reciprocity, trust and reputation to explain cooperation within groups.

My model incorporates the insights from above papers by implementing an ABM in which the norms described above are programmed into the agents behavior. More specifically, the model implements an N-player public goods game in which different agents within and across groups are programmed to exhibit social norms. The hypothesis being that free-riding can be deterred by the implementation of social norms. The first norm that is implemented is reciprocity, which is a commonly observed norm in economic experiments, and is cited by all the authors mentioned in the above paragraph. In the context of the model, this simply means that some of the agents are programmed to punish free-riding behavior, providing an incentive for the other agents to contribute to the public good. The other social norm in the model is emulation. This means that the agents are programmed to adopt the strategies of their most successful neighbors. In order for this adaptive behavior to serve its function, the agents should have certain variations in their strategies across time, this is brought about through random mutation. More specifically, the agents can change from one behavioral type to another at random, while more successful types will spread through the process of emulation.

It is seen in the model that the implementation of these two very simple social processes brings about collective action in the small scale. Collective action in the small scale will be defined as a situation in which agents within a group manage to improve collective outcomes by deterring free riding behavior. The small groups are explicitly defined so that players will be interacting with the same set of agents in every round of the public goods game.

In the second part of the model, we move beyond collective action in the small scale to try to model the emergence of large scale collective action. A large group is defined as one is one in which agents face a collective action problem (i.e. there is a large incentive to free-ride at the cost of a reduced collective payoff), but in which any two agents have a low probability of facing an interaction involving the implementation of a social norm. For example, a free rider who might be punished in a small group can get away with its actions in a large group. In the model, the agent population is divided into the small groups mentioned above, with whom they play a "small scale" public goods game. Successful cooperation in this small scale game is taken as the emergence of small scale collective action. Large scale collective action, however, is interpreted as successful cooperative behavior in a "large scale" public goods game involving the entire population of agents. The results from the model show that the two social norms described above are sufficient in bringing about collective action in the large scale. In the context of the model, it is seen that when the agents are given a choice to contribute to a N-player public goods game that is played with a much larger population then the agents' predefined small group, the types of agents who choose to contribute to the large scale public good can come to dominate over the other agent types. It is also observed that the formation of large scale collective action is dependent on the success of small scale collective action as a precursor.

2 Literature Review

The problem of collective action is one that has long been studied in the social sciences. Some of the concepts associated with the topic, such as the prisoners dilemma, the tragedy of the commons, and moral hazard, have even drifted into everyday language. All these terms present some form of social dilemma, which have to be somehow tackled with in order for voluntary collective action to occur. The central problem can be illustrated with an example borrowed from (Hardin, 1982, p. 8), suppose "if all individuals refrained from doing A, every individual as a member of the community would derive a certain advantage. But now if all individuals less one continue refraining from A, the community loss is very slight, whereas the one individual doing A makes a personal gain far greater than the loss that he incurs as a member of the community."

Mancur Olson's 1965 classic, *The Logic of Collective Action*, played a major part in establishing what has become known as the rational choice approach to the problem of collective action. In the book, he overturned the prevailing view in his day that political actors will band together to tackle their collective problems as long as they have a common interest. Olson argued that due to the large incentives available for individuals to free ride on non-excludable public goods, collective action becomes increasingly harder to achieve as the size of the group becomes larger. Olson divides groups into the categories of privileged and latent. In the former, which tend to be small in size, certain individuals' payoffs from the success of collective action outweigh its total cost and as such, these individuals will bear the entire cost of collective action even when seeking their narrow self interest. In the latter, which tends to be the case for large groups, the defection of one member does not affect the success of the group and thus provides large incentives for defection. In short, Olson asserts that large groups will fail, while small groups may succeed.

In Hardin's 1982 critique of Olson, he made a case for why large, latent groups might succeed. He dissected Olsons argument about how latent groups are bound to fail and proposed a more specific typology of collective action problems. The main difference between Hardin and Olson's argument is Hardin's idea of subgroups, in which he differentiates between groups according to the size of the smallest subgroup that would still benefit from collective action if they bore the entire cost of collective action, while the rest of the group free-rides. Therefore, if collective action can be sustained within this subgroup, the entire group stands to benefit. Hardin also argues that the affects of political entrepreneurship, and extrarational motivations such as morals and participatory joy might cause a latent group to successfully form and sustain itself. Later in the book, Hardin talks about conventions, which are tacit agreements between individuals facing a certain social dilemma that each of them will conform to a particular course of action. In the case of the collective action problem, one convention could be that if an individual in a group knows that free-riding behavior will carry negative repercussions, they will all choose to cooperate. This is an example of sanctioning and shared knowledge, which Hardin describes are some of the ways in which conventions can be maintained. He also emphasizes that iteration is also important in the successful maintainence of a convention. By that, he means repeated encounters between individuals, insuring that free riding in the present will not go unnoticed in the future. In conclusion, he says that the "sociologist's traditional notion that a weave of mutual expectations holds society together is not an extrational notion" (Hardin, 1982, p. 187), echoing Ostrom's 1998 idea of second-generation models of rationality, described below.

This brings up the question of the extent to which the rational choice approach accounts for the motivations behind the potential participants of collective action. Critiques of the rational choice approach have been manifold and have had a long tradition. Amartya Sen, in his essay "Rational Fools" 1977 argues that rational individuals do not merely have a single ordering of preferences but multiple ones which are themselves ranked in certain meta-rankings according to moral judgments. He also emphasizes the relevance of sympathy and commitment in making economic decisions. Mark Granovetter 1985 also notes that the methodological approaches of the various social sciences tend to either use over-socialized (which is the case in sociology) or under-socialized (as is common in economics) models of human behavior, without a comprehensive take on how human actors act in their self interest but at the same time, their actions are embedded within the protocols and norms of various social structures.

In recent years, following the advent of behavioral economics, the assumption of narrow self interest has been repeatedly brought into question. Ostrom 1998 presents evidence from experimental economics and ethnographic studies which suggest that human subjects do not play nor learn Nash equilibrium strategies in repeated games in which they face a social dilemma. She instead advocates for the use of second-generation models of rationality that appreciate the importance of social norms.

Experimental evidence also suggests that humans are influenced strongly by prosocial norms such as strong reciprocity and social reciprocity (Bowles and Gintis, 2005, 2006; Carpenter, Matthews, and Ong'ong'a O, 2004). A prosocial norm is a rule of thumb for social interaction, which induces behavior that increases the average payoff to others but not necessarily to oneself. Bowles and Gintis define strong reciprocity as "a predisposition to cooperate with others, and to punish (at personal cost, if necessary) those who violate the norms of cooperation, even when it is implausible to expect that these costs will be recovered at a later date" 2005. Carpenter and Matthews propose a variant called social reciprocity. Both strong reciprocators and social reciprocators "are motivated more by intentions than by payoff differentials, but social reciprocators differ from strong reciprocators because they punish all norm violators regardless of group affiliation" 2004. In Carpenter and Matthews' framework, strong reciprocators are second party punishers while social reciprocators are also third party punishers. Strides have also been taken to advance the simple rational choice framework through the use of analytical tools such as evolutionary game theory. Representing the social dilemma of collective action as an N-player public goods game, Bowles and Gintis (2004); Gintis (2000); Carpenter and Matthews (2002), among others, have shown that prosocial behavior can be an evolutionarily stable strategy.

In extending the work of such models, one of the ways to approach the modeling of a wide array of social phenomena is agent based modeling. Unlike closed form models like those discussed in the preceding paragraph, agent based models (ABMs) can be used to simulate models that are too complex to be analytically tractable. Although a technique that is relatively new to the social sciences, computational modeling has become increasingly accepted as a viable alternative to analytical modeling (Miller and Page, 2007; Epstein, 2007). Some of the models that bare some relevance to the current research agenda include Axtell, Epstein and Young's model for the emergence of classes 2001, and Epstein's 2002 model of civil violence. Although these models have not studied collective action in the context that I have approached it, they nonetheless show that certain features of social interactions that are difficult to model analytically can be captured in computational models.

In Axtell, Epstein and Young's model, agents interact with each other through a Nash demand game. It was observed that when agents were tagged with one of two arbitrary identifiers and changed their strategies depending on their opponent's tag, the situation quickly developed into one where the group of agents with one type of tag was always getting the higher payoff in the Nash demand game while the agents with the other tag were getting the lower payoff. The authors assert that even though the model can be presented in terms of a stochastic dynamical system, the analytical solutions can only be derived for the very long run, while the short and intermediate run behavior, in which these interesting dynamics occur, could not be observed analytically.

In Epstein's model, he sought to model civil violence by creating a population of "activist" and "cop" agents, whose individual behavior is determined by certain factors such as government illegitimacy, cop-to-activist ratio and risk aversion. He observed the phenomenon of punctuated equilibrium, in which the activists would be latent for long periods and then display sudden outbursts of activism. The waiting times between these outbursts was seen to follow a lognormal distribution.

The point illustrated here with these models is that ABMs' ability to detect certain emergent properties of complex adaptive systems means that they can become a useful tool for social science. Although lacking in the rigor of analytical deduction, ABMs can nonetheless aid social scientists if they are used in conjunction with traditional analytical models. In a broader sense, ABMs allow social scientists to construct rigorous thought experiments (Axelrod, 1997, p. 4), that are limited only by the increasing capability of computers to process and store information.

The model in this paper consists of an N-player public goods game with second party punishment, evolving through repeated interactions, mutation and emulation. There has been several ABMs that have been built around the setting of a public goods game, such as Bowles and Gintis (2004); Wendel and Oppenheimer (2008). In the former, the authors construct an evolutionary model for a public goods game which allowed second party punishment to model the evolution of strong reciprocity in human populations. In the latter, the authors try to reconstruct an empirical observation in public goods experiments in which the players' contribution to the public good seemed to be fluctuating throughout the game. The authors used their ABM to test various conjectures that have been proposed to account for the phenomenon. The Bowles and Ginits piece especially serves as a good starting point for my research because their model has some allusions to the problem of collective action that was described earlier. The observation from their ABM was that contrary to Olson's argument, cooperative behavior and strongly reciprocity does evolve and maintain a sustained presence within the agent populations.

My interest in using the framework of a public goods game will be to study the emergence of collective action. I seek to begin by using the least amount of ad hoc assumptions and incrementally adding different behavioral mechanisms for the agents that are well established and have been observed in an experimental context. Examples include second and third party punishment, which although cannot be explained by narrow self interest, nevertheless is observed in economic experiments (Carpenter, Matthews, and Ong'ong'a O, 2004; Fehr and Fischbacher, 2004). My choice of using the public goods game also stems from the fact that there is a considerable literature on both experimental and evolutionary game theoretic implementations of the game, whose results I can draw on to check for robustness in my ABM.

Returning to the earlier citations form Olson and Hardin, note that the question of collective action is not readily explained by the experimental, analytical or computer simulation results that I have described. The problem as Olson identified it was the inability of large groups to form and sustain themselves. This is precisely the question I hope to tackle in my research.

On the topic of large scale collective action, Daniel Sabia 1988 argues for a kind of microfoundations of large scale collective action. He joins the debate on the logic of collective action with a critique of Olson's classic. Sabia argues that the Marxist view of proletarian collective action based on class consciousness has not been wholly discredited by Olson. His take on Marx's theory relies on the importance of the success of ongoing local and communal collective action. "Large scale, persistent class action", according to Sabia, "must be built upon ongoing, class-conscious, small-scale associations and communities of workers." He ties together Hardin's concept of conventions with real world examples of how collective action has been maintained through the use of sanctioning, knowledge and iteration as Hardin described. For example, Sabia cites McAdam's 1982, p. 128-30 account of the U.S. civil rights movement, where close knit communities of black churches and colleges kept a close watch on free riding behavior within their local communities, even though there was much free riding taking place in the wider black community. He argues that these small groups formed a bedrock from which the larger collective movement spread. In my model, I have tried to implement this behavior of sanctioning free riders at the local level so as to serve as a cornerstone for large scale collective action.

Another work that ties together theory and real world evidence on collective action is Elizabeth Woods' 2003 book on the civil war in El Salvador. Her analysis tries to find the impetus behind the participation of rural peasants, who took extraordinarily high risks to support armed insurgents in the civil war in their fight against the government, despite very low chances of potential success. She claims that the answer must involve to some extent, the pleasure derived from participation in the movement. Related to that observation, an important inspiration for my model is her claim that the participation by the rural peasants were highly path dependent. Specifically, she found that areas with geographical proximity to insurgent forces sparked more peasant participation. She describes a recursive process by which successful local collective action spreads:

> "Where such successful collective actions took place, pleasure in agency motivated further collective action through a recursive process. Those who participated experienced the pleasure in agency. Their success *reinforced* insurgent values and norms, beliefs and practices. Part of the new political culture was a new collective identity as a member of a new community that together carried out challenging deeds and celebrated together their success. As yet inactive neighbors who valued insurgent goals witnessed their success and reevaluated the likely costs and benefits (including pleasure in agency) of joining in. For some, the reevaluation met their threshold for likely success, and they joined the next round of insurgent activity. Once begun, the process reinforced insurgent political culture,

> insurgent social networks, and thus collective action as the cycle of action, success, pleasure in agency, and reinforcement of insurgent culture recurred." Woods (2003, p. 238)

My model tries to take into account the presence of social norms, specifically reciprocity, and this process of recursion that causes successful local action to spread throughout a population via the process of emulation. It is observed that such a model can produce large scale collective action, which is in turn based first on the success of small scale collective action.

3 Original Model: Small Scale Collective Action

The model that forms the basis of this study consists of multiple groups of agents each playing a series of public goods games. The agents in the model interact with each other via the following processes, which we will examine in turn:

- Playing the public goods game
- Punishment
- Intra-group emulation
- Inter-group emulation
- Mutation

The current version of the model is implemented using the Agent Based Simulation environment Netlogo.

3.1 Public goods game

The world of the simulation model is made up of g groups, each consisting of n agents. Agents within each group play an iterated public goods game. For each round of the game, an agent is given an endowment of w 'points', which is permanently set at 2. The agent can then either contribute part of this endowment to a common pool, in which case, every agent in the group receives a benefit of the contribution multiplied by a factor c, or the agent can keep its endowment for itself. For example, in a 10 agent group, with $w = 2$ and $c = 0.4$, in which there are $n_c = 9$ agents who commit their entire endowments to the public pool while one keeps its endowment for itself ($n_s = 1$), the payoff to the members of former agent type (the cooperators) will be $(wn_c)c = 7.2$ points, while the payoff to the latter type (the shirkers) will be $(wn_c)c + w = 9.2$.

In this particular agent based implementation of the public goods game, the model is populated with agents which follow very simple rules. They can be of three different types, as described in Bowles and Gintis (2004): 'the shirkers', who free-ride on the public good and keep their entire endowment of 2 points to themselves; 'the cooperators', who contribute their entire endowment to the public pool; and the 'reciprocators', who contribute half of the endowment to the public pool and spend the other half to punish free-riders.

3.2 Punishment

In every round, if there is one or more shirkers within their group, reciprocator agents will pick with equal probability one agent from among the shirkers in their group to punish. In doing so, the punisher agent will lose s 'points' (s is permanently sent to 1 for this model) while the agent that gets punished will lose sp 'points' where p is a constant, the punishment payoff.

As the number of rounds of the public goods game progresses, the agents will receive a final score in each round after taking into account gains from the game and losses due to punishment. The following represent the expected final score (or 'points') for each of the agent types.

$$\text{Shirkers: } E[\pi_s] = cw(n_c + n_r/2) + w - sp(n_r/n_s), \text{ if } n_s \neq 0. \tag{1}$$

$$\text{Cooperators: } E[\pi_c] = \begin{cases} cw(n_c + n_r/2), & \text{if } n_s \neq 0. \\ cw(n_c + n_r), & \text{if } n_s = 0. \end{cases} \tag{2}$$

$$\text{Reciprocators: } E[\pi_r] = E[\pi_c]. \tag{3}$$

3.3 Intra-group emulation

At the end of each round, the agent's final score is added to its memory. The number of previous scores that the agents remember, or m, the memory length, can be adjusted. For the next stage of the model, each agent, with a certain probability of initial emulation α, will sample one of the agents in its group with equal likelihood. If the sampled agent's average score for the previous m rounds is higher than its average score, it will change its type to emulate that of the agent with the higher score.

3.4 Inter-group emulation

One of the way this model expands on the current literature on prosocial norms is by adding third party effects to the iterated public goods game. Beyond their own groups, the agents are part of a larger population of groups that are arranged in a grid. Each group interacts with its von Neumann neighborhood of surrounding groups, that is, the groups that are immediately to the North, East, South and West of itself. In order for the groups on the edges and corners of the grid to also have four von Neumann neighbors, the grid wraps around on itself in the shape of a torus, so that the northernmost groups will be neighbors with the southernmost groups, etc. In the initial setup, all groups are identical in that they start with the same numbers of each agent type in the group, and each agent has a clean memory. Figure 1 shows a screenshot of an initial configuration of 49 groups with 10 members each, comprised of 5 shirkers (red), 2 cooperators (dark blue) and 3 reciprocators (light blue).

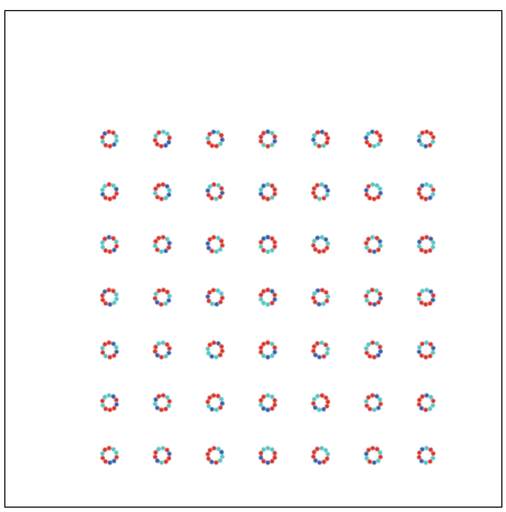

Figure 1: Initial configuration of groups of agents arranged in a grid.

When an agent has been initially selected to sample a random agent to emulate, the model can be set so that it will pick an agent not from its own group to emulate but instead from its neighboring groups. This is subject to a probability of inter-group emulation β. In this setup, with a probability of $\alpha\beta$, in each round, an agent will pick another agent from its neighboring groups to emulate and follow the same procedure as outlined above. Depending on whether the sampled agent is doing better than itself, the agent will change its type. The probability that it will emulate another agent in its own group thus reduces to $\alpha(1-\beta)$.

3.5 Mutation

In any evolutionary model, random mutations play an important role. After playing each round of the public goods game, every agent, with a probability of mutation ϵ, can mutate with into any of the other agent types, or keep its current type. As there are 3 agent types, shirkers (S), and two strains of cooperators (R and C), if an agent can mutate with equal probability into any of these types, the shirkers would be at a disadvantage. Therefore the probability of changing into the various agent types is set as follows: $P(S) = 0.5$, $P(R) = P(C) = 0.25$, ensuring that an agent equally likely to mutate into a shirker or a cooperator.

4 Observations

The model is intended to explore the effects of (1) pro-social norms, in this case punishment, and (2) third party effects, which for now consists of inter-group emulation, on the emergence of collective action. A series of initial baseline runs of the model were conducted to make sure the model's results corroborate with intuition. This section is intended to present some interesting observations that were made as additional features of the model are implemented. Table 1 parameter values that were used in the baseline runs.

Table 1: Parameters for baseline runs.

Parameter	Symbol	Value
Number of groups	g	100
Agents per group	n	10
Endowment	w	2
Contribution Payoff	c	0.4
Punishment	s	1
Punishment Payoff	p	2
Memory Length	m	5
Prob. of emulation	α	0.5
Prob. of inter-group emulation	β	0.5
Mutation rate	ϵ	0.01

Below are descriptions of particular runs of the model that illustrate its typical behavior. In the next section, results from more extensive runs are compiled and the model is tested for robustness across various changes in the parameter values.

4.1 No reciprocators

In the initial case, the agents consist only of two types, cooperators (C types) and shirkers (S types). The only behaviors that they engage in besides the iterated public goods game is the basic evolutionary mechanism of mutation and selection in the form of intra-group emulation. There is no interrelationship between any of the groups. The predicted outcome of this setup is that the cooperators will 'die out' rather quickly as the free-riding shirkers will have a payoff premium in every game. This is exactly the behavior that is observed in the model no matter what the initial population of the agents are, even if the groups consisted entirely of cooperators to begin with.

4.2 With reciprocators

With the addition of reciprocators (R types) into the mix, the benefits to free riding are no longer as clear. Depending on the ratio of shirkers to reciprocators within a group, the shirkers' expected payoff drops from $cw(n_c + n_r/2) + w$ to that described in Equation 1. In the baseline runs of the model, we observe in the medium run that some of the groups end up consisting of a combination of cooperators and reciprocators, while other groups end up consisting almost entirely of shirkers. Due to the fact that the random mutation component of the model causes each agent to possibly transform into any other agent type in any given round, the groups' populations are never entirely of one type. In the long run, however, these groups of cooperators and reciprocators are successfully 'invaded' by shirkers and the entire set of groups end up being dominated by shirkers.

The sequence of screenshots in Fig. 2 show the evolution of a particular run of the model with the baseline parameters as shown in Table 1, and with an initial configuration of 5 shirkers (red), 2 cooperators (blue), and 3 reciprocators (light blue). The graphs in Fig. 3 show the evolution of the population of each agent type and average score of each agent type for up to 50 rounds and the graphs in Fig. 4 show the same data for the same run, but up to 1000 rounds.

If there is a significant population of reciprocators in a group that is already dominated by R and C, a shirker that is introduced into the group via random mutation will not last long. This is because it will be subject to punishment from all the reciprocators in the group, causing its payoff to be significantly below that of the rest. Thus, it is induced to change to another type when the time comes for it to emulate. The evolutionary stability of a group dominated by R and C depends on a significant presence of reciprocators in the group.

In a group dominated by R and C types with no shirkers present, the payoffs to both the R and C types will be the same as they will all be contributing their entire endowment to the public pool. In this scenario, due to the equal payoffs for each type, neither the R nor C will come to dominate the group via emulation. However, should the population of agents in such a group change through random mutations so that there is no longer a significant presence of reciprocators, there is a increased likelihood for a shirker that is introduced through random mutation to survive. At this point, the group is at risk of being 'invaded' by shirkers, who will reap higher payoffs through their free-riding behavior and eventually overwhelm the group through intra-group emulation. This is the process through which, in the long run, all groups are eventually dominated by shirkers.

4.3 With inter-group emulation

The next stage of the model implements inter-group emulation. In this scenario, as described in section 3.4, agents emulate not only those within their own group, but also the agents who are in the four neighboring von Neumann groups. With this configuration, the model settles into one of two observed equilibria.

The first is a situation in which all the groups are dominated by shirkers in the early rounds of the game. This results in a situation in which shirkers continue to dominate all the groups in the population with no significant change throughout the course of the repeated games. If a cooperator or reciprocator enters a group dominated by shirkers via random mutation, it will have a lower payoff than the shirkers in the group. This is because the shirkers are free riding on the benefits provided by the lone cooperator or reciprocator. If the reciprocator picks a random shirker to punish, that particular shirker might end up having a lower payoff than the reciprocator, but the rest of the shirkers are enjoying a higher payoff and goes away unpunished. This means that when this lone reciprocator samples any member of its group to emulate, it will find that most of the shirkers are doing better than itself and will change to become a shirker itself. This explains why a group already dominated by shirkers remains so. This is only the case, however, when its neighboring groups are also dominated by shirkers. We now look at the case in which shirker dominated groups have neighbors that are dominated by R and C types.

The other equilibrium outcome is achieved when the early stages of the game leave at least one group dominated by R and C types. An interesting observation made under this scenario is that cooperative behavior eventually spreads throughout the population. Initially, there is an increase in the population of shirkers, leaving only some groups with a population of R and C types. The agents in these groups, however, will have average scores that are higher than those in the groups dominated by shirkers. As a result, due to the fact that agents now emulate across groups, cooperative behavior begins to spread. Figure 5 shows a sequence of screenshots of this process taking place, after only 300 rounds, all the groups have emulated the cooperative behavior. Figure 6 shows the plots of population and average scores for the three agent types for the first 500 rounds, for the same run for which the screenshots were taken. The initial configuration for this run was with the baseline parameters specified in Table 1, and with 5 shirkers, 2 cooperators and 3 reciprocators in each group to begin with.

The particular run represented in the screenshots and plots was allowed to go on for 10,000 rounds, and it was observed that the R and C groups continuously dominated the entire population. It might be the case that, via the process described in the previous section, R and C dominated groups can lose their reciprocators via mutation and hence lose their 'defense' against free riders. Thus, individual groups can become dominated by free riders who will have a payoff premium when compared with other members of the group. However, with inter-group emulation, it will never be the case that a shirker dominated group will have average scores higher than a neighboring group which is dominated by R and C types. Thus, as long as there is at least one group dominated by R and C, cooperative behavior will spread and win over shirker dominated groups via emulation.

It might be useful here to consider the implications of this observation on the larger question of collective action that this model seeks to explain. A loose translation of this behavior to a real world situation is that collective action in small groups can spread from one small group to another, provided that there is a mechanism for these groups to learn across their group boundaries. If an exemplary group succeeds in solving its small scale collective action problem, other groups might seek to emulate this behavior upon observing the beneficial effects of collective action. It is also worth noting that the spread of collective action in this context results from the actions of individual agents emulating other individuals who just happen to have a better average score, without being coordinated by a third party.

5 Extended Model: Large Scale Collective Action

The overall goal of this research project is to examine the causes of large scale collective action. For now, we have been able to successfully model the formation of small scale collective action through prosocial norms and also the phenomenon of the small scale collective action spreading throughout a population of small groups.

I now introduce an extension to the current model to incorporate large scale collective action. This will be done by adding a new type of game to the current small scale public goods game. After every set number of rounds, instead of playing the public goods game with just its own group members, agents will have a choice of playing a public goods game with the entire population instead. This additional feature will create four different agent types out of what is now the R and C types. There will be those agents who are reciprocators and cooperators but do not choose to play the large scale collective action game, and there will be those agents who are of R and C types as well but do choose to play the large scale collective action game (these will be denoted as R_L and C_L). As for the behavior of the two types of reciprocators, the former type, R, who do not play the large scale game, will punish only the shirkers; the latter type, R_L, who does play the large scale game, will punish both shirkers and those agents who do not play the large scale collective action game, i.e. it will punish the S, R and C types.

The goal of this extended model is to explore, within the context of this model, how large scale collective action can emerge in a population through the enforcement of social norms. As in the original model, the two social norms of interest are punishment, and emulation. I hope to also identify the relationship between small scale and large scale collective action, to see if one inhibits or gives rise to the other.

We now examine each of the following processes that take place in the extended model in greater detail:

- Playing the small scale and large scale public goods games
- Punishment
- Emulation and Mutation

5.1 Public goods game

Once every l rounds, instead of playing the game with the members of one's small group, the agents now have a choice of playing the game with the entire population of agents (set at $ng = 1000$). In these special rounds, agents can either contribute their endowments to a public pool accessible by members of their own small group, or instead contribute to a public pool accessible by members of the entire population. In the former case, the agents continue to play the game as they did in the original model, where all the other agents in the small group receive an amount equal to each point of the endowment that has been contributed, multiplied by the contribution payoff c. In the latter case, every point of the endowment that a particular agent contributes is multiplied by a large scale contribution payoff c_l, and this amount is given to every agent in every group in the population.

This choice to participate in the large scale game creates additional types of agents. For the shirkers who would not contribute any of their endowment to any public pool, they remain as they are. From the cooperator and reciprocator types from the original model, however, two new agent types are derived. The cooperator agents who choose to contribute to the large scale game are called large-scale cooperators (C_L) and they behave in exactly the same way as the regular cooperators (C), except that every l rounds, they contribute their entire endowment ($w = 2$) to the large scale pool. The reciprocator agents who choose to contribute to the large scale game are called large-scale reciprocators (R_L) and they behave similarly to the regular reciprocators (R). In each round of the game, they contribute half their endowment to the small scale pool accessible to their own group members, but once every l rounds, they contribute half their endowment to the large scale pool instead. The other half of their endowment is used for punishment, explained in the next section.

The agents can therefore be "free-riding" on various levels. They can free ride on both the small scale and large scale games, as the shirkers (S types) do. They can free ride on the large scale game, as the R and C types do. They can also free ride on the small scale game every l rounds, like the R_L and C_L types do. This creates a more complex set of dynamics for the payoffs received by each agent type, depending on the population distribution in both its own group and the global population.

5.2 Punishment

The reciprocators (R types) continue as they did in the original model to punish S types.

The large-scale reciprocators will randomly select a member of their own group who is not contributing to the large scale pool, i.e. the S, R, and C types. They will use half their endowment (1 point) to punish these free-riders. The punisher agent will lose s 'points' (s is permanently sent to 1 for this model) while the agent that gets punished will lose sp 'points' where p is a constant, the punishment payoff. If there are no S, R or C agents in their group, the R_L agents contribute their entire endowment to the respective public pool, just as the C_L types do.

Now, with both the public goods game and punishment mechanism has been specified, we can calculate the expected final score that the agents will have after each round.

For small scale rounds:

$$\text{S: } E[\pi_s] = cw\left(n_c + n_{cl} + \frac{1}{2}(n_r + n_{rl})\right) + w - sp\left(\frac{n_r}{n_s} + \frac{n_{rl}}{n_s + n_c + n_r}\right), \text{ if } n_s \neq 0. \tag{4}$$

$$\text{C: } E[\pi_c] = \begin{cases} cw\left(n_c + n_{cl} + \frac{1}{2}(n_r + n_{rl})\right) - sp\left(\frac{n_{rl}}{n_s+n_c+n_r}\right), & \text{if } n_s \neq 0. \\ cw\left(n_c + n_{cl} + n_r + \frac{1}{2}n_{rl}\right) - sp\left(\frac{n_{rl}}{n_s+n_c+n_r}\right), & \text{if } n_s = 0. \end{cases} \tag{5}$$

$$\text{R: } E[\pi_r] = E[\pi_c]. \tag{6}$$

$$C_L\text{: } E[\pi_{cl}] = \begin{cases} cw\left(n_c + n_{cl} + \frac{1}{2}(n_r + n_{rl})\right), & \text{if } n_c + n_r \neq 0,\ n_s \neq 0. \\ cw\left(n_c + n_{cl} + n_r + \frac{1}{2}n_{rl}\right), & \text{if } n_c + n_r \neq 0,\ n_s = 0. \\ cw\left(n_c + n_{cl} + n_r + n_{rl}\right), & \text{if } n_c + n_r + n_s = 0. \end{cases} \tag{7}$$

$$R_L\text{: } E[\pi_{rl}] = E[\pi_{cl}]. \tag{8}$$

For large scale rounds:

$$\text{S: } E[\pi_s] = cw\left(n_c + \frac{n_r}{2}\right) + c_l w\left(N_{cl} + N_{rl}^{'} + \frac{N_{rl}^{''}}{2}\right) + w - sp\left(\frac{n_r}{n_s} + \frac{n_{rl}}{n_s + n_c + n_r}\right), \text{ if } n_s \neq 0. \tag{9}$$

$$\text{C: } E[\pi_c] = \begin{cases} cw\left(n_c + \frac{n_r}{2}\right) + c_l w\left(N_{cl} + N_{rl}^{'} + \frac{N_{rl}^{''}}{2}\right) - sp\left(\frac{n_{rl}}{n_s+n_c+n_r}\right), & \text{if } n_s \neq 0. \\ cw\left(n_c + n_r\right) + c_l w\left(N_{cl} + N_{rl}^{'} + \frac{N_{rl}^{''}}{2}\right) - sp\left(\frac{n_{rl}}{n_s+n_c+n_r}\right), & \text{if } n_s = 0. \end{cases} \tag{10}$$

$$\text{R: } E[\pi_r] = E[\pi_c]. \tag{11}$$

$$C_L\text{: } E[\pi_{cl}] = \begin{cases} cw\left(n_c + \frac{n_r}{2}\right) + c_l w\left(N_{cl} + N_{rl}^{'} + \frac{N_{rl}^{''}}{2}\right), & \text{if } n_s \neq 0. \\ cw\left(n_c + n_r\right) + c_l w\left(N_{cl} + N_{rl}^{'} + \frac{N_{rl}^{''}}{2}\right), & \text{if } n_s = 0. \end{cases} \tag{12}$$

$$R_L\text{: } E[\pi_{rl}] = E[\pi_{cl}]. \tag{13}$$

N_{cl} is the total number of C_L agents throughout the population. $N_{rl}^{'}$ is the total number of R_L agents in groups for which $n_s + n_r + n_c = 0$. $N_{rl}^{''}$ is the total number of R_L agents in groups for which $n_s + n_r + n_c \neq 0$. $N_{rl} = N_{rl}^{'} + N_{rl}^{''}$, is the total number of R_L agents in the entire population.

5.3 Emulation and Mutation

Intra-group and inter-group emulation is exactly the same as in the original model.

For mutation, the mutation rate ϵ determines the probability of whether or not any given agent will mutate in any given round. The agents can mutate into any other type (or its current type) with the following probabilities: $P[S] = 0.5$, $P[C] = P[R] = P[C_L] = P[R_L] = 0.125$. This configuration makes sure that the agents have an even chance of switching from a free-rider to a cooperator of some sort and vice versa.

6 Observations for Extended Model

Just as we did for the original model, a series of runs were conducted with a set of baseline parameters. These baseline runs for the extended models use the same values for the parameters as in Table 1.

Table 2 shows the baseline values used for the parameters that are used in the extended model, which includes the addition of two more variables, l and c_l, which are the large scale frequency and large scale contribution payoff respectively. All the results presented in this section is run with these baseline parameter values and with an initial population distribution of 5 shirkers, 2 cooperators and 3 reciprocators per group, unless otherwise specified. Both inter-group emulation and intra-group emulation is enabled, unless otherwise specified.

Table 2: Parameters for baseline runs of extended model.

Parameter	Symbol	Value
Number of groups	g	100
Agents per group	n	10
Endowment	w	2
Contribution Payoff	c	0.4
Punishment	s	1
Punishment Payoff	p	2
Memory Length	m	5
Prob. of emulation	α	0.5
Prob. of inter-group emulation	β	0.5
Mutation rate	ϵ	0.01
Large-scale Frequency	l	10
Large-scale Contribution Payoff	c_l	0.02

The rest of this section will present descriptions of the typical behavior of the extended model. There are multiple equilibria into which the model can settle, each of which will be discussed. Explanations for circumstances under and the processes by which these different equilibria come about are also discussed. The section concludes with an explanation of the conditions that give rise to and maintain large scale collective action, which, in the case of this model is the interplay between the reciprocity norm and inter-group emulation.

6.1 Domination by shirkers

Just as in the original model, one of the equilibria of the extended model is one in which all the groups are dominated by shirkers. As described in section 4.3, if the early stages of the game produce a situation in which all of the groups in the population are dominated by shirkers, this outcome persists throughout the game.

6.2 Domination by small scale cooperators

As described in section 4.3, due to the process of inter-party emulation, cooperative behavior can spread throughout the population from group to group. This occurs in both the original and extended models. In the extended model, however, we now have type "families" of cooperators, the first is the R and C types, and the second is the R_L and C_L types. Cooperating groups are now seen to consist of either of these two pairs of agent types.

A natural question to ask here is whether all four types of cooperating agents can co-exist in a single group. This can happen for short periods of time, but in the long run, the existence of R_L types in the group means that the R and C types will get punished in every round. This causes their payoffs to be lower than the other agents and in time they will change to become R_L or C_L types via intra-party emulation. Even without the punishment mechanism, there is also a slight payoff differential between the R_L and C_L types and R and C types, which we examine next.

As mentioned in section 5.2, the R_L and C_L will play the public goods game in the same way as the R and C types in the rounds of the game for which the small scale game is being played. In the rounds for which the large scale game is played, however, the R_L and C_L types will contribute to the large scale public pool while the R and C types will contribute to the small scale pool, thus free riding on the large scale public good. As such, during these rounds, the R_L and C_L types have a payoff disadvantage over the R and C types.

Due to this payoff advantage that occurs every l rounds, the small scale cooperators will sometimes be more successful than the large scale cooperators. For example, imagine a scenario in which there are two neighboring groups, one dominated by R and C types, and the other by R_L and C_L types. The group with the R and C types will accumulate a higher average score over the course of several rounds due to free riding on the large scale public good. This means that through inter-party emulation, the agents in the other group will slowly change from the R_L and C_L type to become R and C types. This is essentially the manifestation of Olson's logic of collective action, on the level of small and large groups.

In the simulations, this effect was sometimes observed. We will now examine a run of the extended model with the parameters given in the beginning of this section. The initial population does not include any R_L or C_L types but random mutations and emulation will bring significant numbers of those types into the population as time progresses. In this particular run of the model, all of the groups are eventually dominated by R and C types. However, before it settles into that equilibrium, there is a significant increase in the number of groups dominated by R_L and C_L types. Due to the process described in the preceding paragraph, these R_L and C_L groups eventually change to become R and C groups.

Figures 7 and 8 show a series of screenshots of the aforementioned run of the extended model. As before the S types are red, R types light blue, C types dark blue, and the new C_L types are green and the R_L types are yellow. The screenshots are range in time from the 50^{th} round to the 2000^{th} round.

In the early stages of the game, most groups become shirker dominated except for a few that are dominated by R and C types. The neighboring shirker groups then emulate the R and C types due to their higher payoffs and the behavior begins to spread, just as in the original model. However, beginning in the 200^{th} round, we see that a significant number of groups have become dominated by R_L and C_L types. This phenomenon of R_L and C_L groups taking a foothold early in the game will be explored in the next section. From the 200^{th} to the 600^{th} round, both the R and C groups and the R_L and C_L groups spread throughout the population, driving the shirker groups into extinction. Starting from the 600^{th} round onwards, however, the number of R_L and C_L groups begins to decline, until the entire population is dominated by R and C groups in the 900^{th} round and stays this way for an extended amount of time. Even at the 2000^{th} round, there is no visible change in the population structure.

6.3 Domination by large scale cooperators

The last type of equilibrium that is observed in the model is one where the R_L and C_L types come to dominate the entire population. This result was the motivation behind the model but in the process of building the model, care was taken to not force the model to produce this result. The extended model implements stylized versions of two very simple social interactions. The first is the punishment mechanism, where some individuals choose to punish free-riders within their own small groups despite a personal cost. This norm, identified as strong reciprocity by Bowles and Gintis (2004), is a common phenomenon experienced in everyday life in individuals' interactions with many social groups. The second phenomenon is emulation, both within and across groups. This is also a feature that is prominent in everyday life. If an individual sees that her peers are getting a higher payoff in their activities due to differences in their behavior, she may choose to adopt this more successful behavior of her peers. This emulation can take place among peers in a social group or across social groups. Neighboring families, for instance, might learn from each other and adopt behaviors that yield higher payoffs.

With the implementation of these basic social processes, and giving the agents the ability to mutate into the five behavioral types, we observe that large scale collective action can emerge, maintain itself and spread across a population of small groups. To examine the details behind this process, we look at a scenario in the context of the model.

In a group dominated by R and C types, the addition of an R_L agent via random mutation means that this R_L agent will start punishing the rest of the agents in the group. The addition of an C_L agent, however, will not effect the other members of the group adversely. In the case of the R_L agent, for every round, there will be some R or C agent(s) in the group whose payoff is less than itself. As intra-group emulation takes place, these R and C agents who have been subject to punishment might see that the R_L or C_L types that have joined their group have a higher payoff than they do, in which case they will adopt the behavior of the R_L and C_L agents. As the result, the R_L and C_L agents can successfully "invade" a group dominated by R and C types. This payoff advantage that the R_L and C_L types receive, however, must be contrasted with the payoff disadvantage that they face due to the R and C types free-riding on the large scale public good. As described in section 6.2, inter-group emulation can cause R and C groups to dominate R_L and C_L groups due to the former's free-riding on the large scale public good.

In Fig. 9, the series of screenshots shows one of the ways in which R_L and C_L types come to dominate the population. In this case, the domination by R_L and C_L types occur very early on in the game. As usual, after a few rounds of the game, the population mostly consists of shirker groups except a few that are dominated by R and C types. At this stage, a few of the R and C types can randomly mutate into R_L and C_L types. This initiates the process described in the last paragraph by which the group becomes dominated by R_L and C_L types. In the figure, we see this happening between the 50^{th} and 100^{th} rounds. The few R and C groups that were left remaining now change to become R_L and C_L groups. Compared to the other groups in the population that are dominated by shirkers, the agents in the R_L and C_L groups are doing much better. Therefore, through inter-group emulation, this cooperative behavior spreads, expanding the extant of large scale collective action along with it. By the 300^{th} round, we see the population dominated by large scale cooperators. The simulation was run up to 2000 rounds and the R_L and C_L types continued to dominate the entire population.

Figure 10 shows a different scenario under which the R_L and C_L types come to dominate the entire population. This scenario resembles the one shown in Figs. 7 and 8 in that the large scale and small scale cooperators both spread throughout the population but one of them eventually dominates entirely. Examining the screenshots for the 100^{th} and 200^{th} rounds, we see that in contrast to Fig 9, the R_L and C_L types have not come to dominate the R and C groups. As a result, through inter-group emulation, both the R_L and C_L groups and the R and C groups spread through the population, displacing the shirker groups. However, the spread of the R and C types were contained to a small number of groups, while the R_L and C_L groups dominated the rest of the population. This scenario ends with the R and C groups becoming dominated by their large scale cooperator counterparts, in spite of their payoff advantage over the large scale agents because of free-riding.

Comparing the scenario presented in Figs. 7 and 8 with the scenario in 9, we see that given an initial population divided between R and C groups, and R_L and C_L groups, the end result might turn out to be different depending on the nuances in the population distributions. In the scenario for which the R and C groups won out, their presence was more widespread to begin with. In the scenario for which the R_L and C_L groups won, the R and C groups were confined to only a small region of the population. This differences in outcomes are a result of the interplay between inter-group emulation and punishment within groups. The former process favors the R and C groups, which account for their spreading across the R_L and C_L groups. However, the latter process favors the R_L and C_L types because once a R and C group is "invaded" by a few R_L types, they start punishing the R and C types.

A natural question to ask here is that, if inter-group emulation is detrimental to the spread of R_L and C_L types, is it a necessary condition for large scale collective action to occur? The short answer is 'yes'. To more thoroughly illustrate the case, we will now conduct a sample run with an initial population consisting entirely of R and C types, and disable inter-group emulation. This means that due to the mutation of some of the agents to become R_L and C_L types, the R_L types' punishment of the others will ensure that the situation favors the large scale cooperators. Also, because inter-group emulation is disabled, the R and C groups will no longer spread to neighboring R_L and C_L groups even though have a payoff advantage. Initially this seems like that R_L and C_L types will do even better than in the previous cases shown in Figs. 9 and 10.

Figure 11 shows a series of screenshots of the run described in the previous paragraph. The initial configuration consists of 5 R and 5 C in each group. As expected, the R_L and C_L types do seem to be doing better. From the beginning up until the 200^{th} round, the R_L and C_L groups are seen to become the majority. However, some of the original R and C groups have changed to become shirkers, this is due to the shirkers' free-riding on the small scale collective action. This free-riding on the small scale is seen to have a detrimental effect on the R_L and C_L groups as well. After the 200^{th} round, we see that the shirkers eventually come to dominate the entire population. Without inter-party emulation, none of the shirkers will sample a cooperator from their neighboring group and realize that cooperation offers a higher payoff. As such, we have demonstrated that the success of large scale collective action is dependent on both the punishment and inter-party emulation mechanisms.

Another subtle point concerns the dependency of large scale collective action on small scale action. Recall that the difference between the R and C agent types and the R_L and C_L types is that the former cooperates on the small scale in every round while the latter does the same in most rounds but contributes instead to the large scale public good once every l rounds, where l is set to 10 in the baseline runs. Agents can mutate to become cooperators in a group and randomly take on either of the two "flavors", i.e. the small scale or the large scale. Also, the large scale cooperators, through their punishment of small scale cooperators and shirkers, ensure that the group eventually comes to conform to large scale cooperation. This should not be interpreted, however, as a situation where the model allows for large scale cooperation to occur spontaneously without the success of small scale cooperation preceding it. The fact that the C_L and R_L types in the model contribute to the large scale only once every l rounds is fundamental to their success. To illustrate this, when we conduct sample runs of the model where l is reduced from 10 to 1. So, the C_L and R_L types now contribute to the large scale public good for every round, while the C and R types contribute just to their group in every round. We observe that, if certain agents in a group mutate to become R_L types, they start punishing the R, C and S agents in the group and eventually get them to change through emulation to become a C_L or R_L type who no longer gets punished. In the very short run, the punishment mechanism alone can cause a group to become large scale cooperators in every round of the game (since now $l = 1$). However, this also means that in every round, the C_L and R_L agents are providing a public good to agents in other groups who are free riding off of them. Since punishment in the model is only conducted within groups, the free-riding R, C and S agents in other groups do not get punished, which means they consistently get a higher payoff then the agents in the R_L and C_L dominated groups. Through the process of inter-group emulation, it becomes very apparent to the R_L and C_L agents that their neighboring groups are doing much better and emulate their free-riding behavior, causing a collapse of the short lived run of large scale collective action. This shows that the presence of agents contributing to the large scale public good is maintained because they only do so every once in a while.

7 Discussion

In light of the outcomes that are observed from the agent based model, I now seek to interpret these results in the context of real world scenarios and evaluate the relevance of the model to real world examples of collective action. I hope to tie the model's outcomes back to the theoretical and case study literature that served as an inspiration for my research.

Sabia's 1988 paper defended Marx's vision of proletarian collective action in the face of Olson's classic critique. Although I draw a great deal of the inspiration behind my model from Sabia's arguments, it is not the particular scenario of collective action that he describes, namely the proletarian revolution, that interests me. I think his description of the formation of large scale collective action can be generalized to any scenario involving the transition from cooperation from the small scale to the large, including the examples that he cites in his paper such as the civil rights, anti-war, women's and environmental movements, the growth of medieval guilds, and the plight of rural populations in the Third World who are politically and economically disenfranchised. Sabia's argument relied on the success of small scale collective action as a precondition to cooperation on the large scale. Individuals in these "communities defined as groups of individuals involved in thick networks of ongoing mutual interactions", he argues, are induced to sustained cooperation. This is because, "should individual workers try to avoid cooperating in this sort of group context, inducements such as the awarding of trust and friendship and sanctions ranging from disapproval to banishment will be relatively easy to apply, difficult to avoid, and generally efficacious." This argument, I believe is definitely captured in my model in both the original and extended versions. The small groups of agents maintain their cooperation due to the presence of their peers who actively punish free-riding behavior.

A distinction that is seen between Sabia's argument and my model, however, is that he does not make a distinctive argument for the spread of local collective action from one community that successfully organized on the small scale to another. Instead, he seems to claim that various small scale communities emerge throughout the population simultaneously on their own and focuses his analysis on the process by which these small communities coalesce into a larger whole. In Elizabeth Wood's (2003) account of the Salvadorian civil war however, we do find that she takes into consideration the path dependent effect by which cooperative behavior spreads, as can be seen from the excerpt I quoted in section 2. There is a marked similarity by which the spread of groups dominated by cooperative and reciprocating agents are seen to spread in my model and the way in which Woods describes how the spread of collective action in El Salvador was *intrinsic* to the process itself. By this, she refers to something like a domino effect by which initially successful collective action begets even more success, due to the fact that agents respond and adapt to changing local conditions. The agents, in a sense, learn to cooperate through observation of their neighbors' behavior. In my model, this effect is captured by inter-party and intra-party emulation. It is a process by which agents are maximizing potential payoffs, but this is done without their strategic calculation of which course of action to follow but instead by simple norm driven behavior.

Having accounted for the main tenets of the original model, by which small scale collective action is maintained and spread, we now look again at Sabia's description of the transition from small scale to large scale collective action. In my extended model, there are two "flavors" of collective action, the one dominated by C and R agent types, and the one dominated by C_L and R_L types. One can imagine a scenario by which an individual in a group, say a labor union or a rural village living under an oppressive government, decides to make up her mind about how she will contribute to the community. She can either choose to focus her effort on her local workplace or village, such as organizing her peers and at the local level and ostracizing those who are not participating. Alternatively, she can choose to do these same organizational activities with a view of the big picture. Say, for instance, at every local rally and meeting, she reinforces the need for cooperation to take place across the entire country and emphasizes that her comrades across various local communities are facing the same collective problem. One can imagine that the emergence of such individuals and the formulation of their decision to look at the small or big picture is a psychological process, which can nonetheless be modeled as a probabilistic one. We can assume that different individuals' calling to think in terms of the "small" or "big picture" is random, but that once certain individuals decide to make up their minds about what to do, the process by which this behavior spreads is not random.

As described in the last paragraph of section 6.3, in the context of the model, large scale cooperation does depend on the success of small scale cooperation. Large scale cooperators only succeed in maintaining their groups because they are cooperating on the small scale most of the time and only contributing to the large scale once in a while. Even those agents who think and act in terms of the "big picture" cannot afford to forgo their roots in the local communities, lest this turn into a case of unsustainable altruism. If we allow for the fact that these selfless large scale cooperators might sometimes actually think of their personal payoff as well and choose to back off from their selflessness, large scale collective action can easily break down. Also, if free-riders are beyond the reach of punishment, there are no incentives for groups dominated by free-riders to emulate the behavior of the large scale cooperators because they are already doing better than the cooperators. This beckons an interesting interpretation. The activity that inspires free riding groups to emulate cooperative behavior seems to depend on the incentives created by the exclusiveness of the benefits received by small scale cooperators. Whereas, the behavior of large scale cooperators, who reward everybody in the population regardless of group or type affiliation, quickly turns into the failure of collective action as described by Olson. Inspiration through good deeds alone, it seems, is much less effective than inspiration through the exclusive rewards that are achieved through good deeds.

This interplay between selfless and self seeking behavior is the intuition behind my extended model and the separation of cooperators into large scale and small scale types. The spread of R_L and C_L agents in the model echoes what Sabia describes as the emergence of solidarity. In his appeal to the notion of solidarity however, he admits that Marx did not really have a systematic answer to how when these "solidaristic sentiments arise". Sabia maintains the Marxist notion that emergence of solidarity need not be explained solely by self-regarding preferences or "calculating egoism", but rather by a conception of human sociality that emphasizes the intrinsic need of individuals to commit to causes beyond themselves. A close approximation to this concept in modern behavioral economics is the presence of *other-regarding preferences*, a phenomenon repeatedly observed in experiments in which people's behavior is driven by pro-social norms, even when such behavior incurs a cost to their personal payoff. Returning to the context of the model, we can see that it implements a prominent pro-social norm, reciprocity. The R and R_L agents both exhibit this norm. Moreover, as argued earlier, the latter types' actions and the dynamical consequences of their actions in the model may explain the process by which solidarity arises, or at least show an example of how the process might play out.

One thing I disagree with in terms of Sabia's conception of solidarity and human sociality is that he sees it as a fundamental change in the way individuals behave, as a progression from self seeking towards selfless behavior. However, could it not be that, contrary to Sabia and Marx, these selfless individuals might become discouraged if their efforts do not bare fruit, or they might simply change their mind, no longer wanting to support the community for various personal reasons? In my opinion, it is a rather strong assumption to make that the inherent sociality in human beings is a one way street, which Sabia describes as follows:

> "Though Marx provides no explicit definitions, the sense of solidarity that he says will emerge from these experiences means, I think, that more and more workers come to identify with the class and to realize that the welfare of each is tied to the welfare of all. This sense of solidarity inspires a willingness - a preference - to advance the cause of the class. In other words, the workers become maximizers of class welfare - some earlier than others, some more intensely than others, but maximizers of class welfare nonetheless." Sabia (1988)

The model shows, however, that appeal to a fundamental change in the collective consciousness from being maximizers of personal welfare to becoming maximizers of class welfare is not necessary to explain large scale collective action. Rather, each individual might very well decide on their own accord to free ride even in a situation when the rest of her peers are cooperating. This can very likely lead to a situation where large scale collective action breaks down, as we will saw earlier. However, the interesting part, is that even with the heterogeneity in individuals' actions, the model allows for the maintenance and spread of large scale collective action once enough individuals commit to a reciprocating norm and retain their loyalties to their local group. It is in the free-riders self interest to cooperate in a situation in which she is outnumbered by reciprocators, regardless of whether or not she identifies with the solidarity of the group. It is also in their self interest to adopt cooperative behavior at the local level because this allows access to exclusive benefits that cannot be gained through free-riding. This offers an explanation of why solidarity arises and takes hold in the first place, which is neither entirely a process of self-regarding egoistic calculation (which is the process by which free-riders are punished and incentivized into conformity), nor is a process entirely governed by selfless sacrifice for the greater good (which is the process by which some agents mutate to become cooperators of their own accord).

Now that we have thoroughly examined the dynamics of the model, I would like to tie some of the results to real world case studies. As described in section 5, the extended model has three different equilibria that it can settle into. These consist of an all shirker equilibrium, a small scale cooperation equilibrium, and a large scale cooperation equilibrium.

The all shirker equilibrium can be interpreted as the situation that most of the world's nascent collective action movements find themselves in. It is Olson's classic scenario, where the individuals' incentives to free ride overpower the forces that might bring them together. In the realm of mass political movements, we can look for scenarios in which there seems to be a cause for beneficial collective action on the large or small scale but in which neither is seen to take shape.

The Burmese people's struggle against their long standing military dictatorship can be seen as an example of this. Through the course of the last two decades, there has been only two brief periods of truly large scale protests, once in 1988 and another in 2007. In the case of Burma, we can see that the incentive to free ride on other people's efforts is especially magnified, given the brutality of the regimes crackdowns on its own citizens. Government sponsored thugs and soldiers have been summoned on both these occasions to massacre innocent civilians, while those who escape with their lives are hunted down and subject to harsh prison sentences, often involving torture and forced labor, mostly without a proper trial. Given this situation, it is a testament to the bravery of the Burmese people that any form of collective action occurs at all. In the context of the model, we see in certain cases that certain groups of small scale or large scale cooperators can emerge, and sometimes spread for a brief time period to neighboring groups, only to be overrun eventually by shirkers.

The model however, does seem to exhibit a similar structure to what little collective action did take place in Burma in the 1988 and 2007 uprisings. In 2007's Saffron Revolution for instance, the impetus was a string of isolated marches and protests by small groups of monks and political activists that took place in late August and early September as a response to rising fuel prices. These events, and the crackdowns by the regime that followed, especially against the country's revered buddhist monks, triggered large scale protests which drew increasingly larger crowds every day, peaking in the hundreds of thousands, towards late September. This resembles the results we observe in the model, where a single successful instance of collective action can cause this to spread throughout the population.

In the case of the equilibrium of small scale cooperation, we can interpret it in general as a scenario in which individual families, firms and villages exhibit cooperation within themselves, but for which there is no overarching "solidarity" across these small groups, to use Sabia's language. One frequently cited example is the case of the lobster gangs of Maine, by Acheson (1988). He describes the lobstermen as organized into small clusters, or harbor gangs, who are fishermen from the same harbor who claim and defend certain territories for themselves. There is a clear system of exclusive benefits that are only available to those who are part of these small groups. In the context of the model, I have explained earlier about how small scale collective action can spread from group to group by winning over shirkers with the incentives of greater payoffs due to cooperation. The case of the lobster gangs corroborate with this aspect of the model.

In contrast to the first example of Burmese protests in which solidarity was precious but short lived and the second in which loyalty to the local crowded out the larger prospects for solidarity, we also have real world examples for which large scale collective movements did occur and managed to sustain themselves. I have already given the example of the civil rights movement and rural participation in El Salvador's civil war in sections 2 and earlier in this section. Another famous example is the string events that led to the fall of the Berlin Wall in 1989. The Monday Demonstrations in Leipzig began on 4^{th} September and were repeated throughout various East German cities in the weeks and months that followed, drawing increasingly larger crowds. This movement clearly involved both the incentives that accompanied being part of each local demonstration and also the shared sense of solidarity felt across people in various parts of the country who were yearning for democratic change. All the arguments I made in the analysis of Sabia's story would apply to this situation.

When looking at the vast range of examples of collective action, we must also notice successful collective action does not equate to greater social optimality. The Rwandan genocide in 1994 is also another case in which large scale collective action was successful, at least on the part of the Hutu militia. In this instance, we can see that human behavior is more complex than what is captured by either models that assume rational self seeking actors or those like my model which assumes a mix of norm driven other regarding behavior and self seeking motives. For instance, a Hutu militiaman may well decide to not take part in the killings, but this cannot be simply interpreted as an example of self seeking activity. It might be true that he might be racist and that he would like to ensure the continued political dominance of his ethnic group in the future of the country, and in the context of the model, might choose to free-ride on other Hutus doing the dirty work for him to his added benefit. However, it might very well be that he simply deemed the genocide to be the inhuman tragedy that most people would agree it is. In this sense, he is not being self regarding but rather thinking in the "big picture" of human decency and morality. Our model, however, would not be able to differentiate between the two cases.

We also can look to the failure of collective action being a more socially optimal outcome. In the case of colluding firms who might benefit from forming a cartel, or a body of water plagued by piracy, we rely on there not being successful collective action among these individuals to ensure that it is better for all.

8 Conclusion

We have seen that the instances of large scale collective action that have marked history can be replicated to an extent in the agent based model that I have described. More importantly, we identified in the model analogous abstracted representations of the processes by which these collective movements take shape and maintain themselves. The merit of the agent based modeling approach lies in the ability to construct rigorous thought experiments of complex adaptive systems. In the process, we have identified the interplay of both self regarding and other regarding preferences of individuals as playing a part in both the success and failure of collective action. The presence of multiple equilibria, even when starting from an identical set of initial conditions has also been noted.

In future research, this model might be able to serve as a building block for a more rigorous and generalized study of collective action. A thorough series of robustness tests, cycling through various initial conditions and parameter values, would yield more insights into the processes behind collective action. In terms of the model's software implementation, the use of another agent based software package to build a model that recreates these the same results would serve as a confirmation that software glitches are not responsible for any of the results. Also, the current model assumes a great deal of homogeneity for the sake of simplicity. It would be interesting to see if the current results are replicated when the population consists of varying group sizes, or if the links between the groups are not in a simple grid pattern but rather in a more realistic arrangement such as a scale free or small world network. Another interesting change would be to see how the model responds to exogenous shocks, such as a sudden change in the payoff structures, which can be a stylised interpretation of a government crackdown on a protest.

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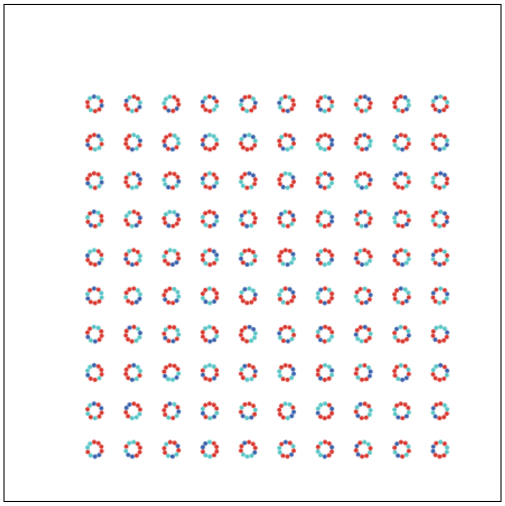
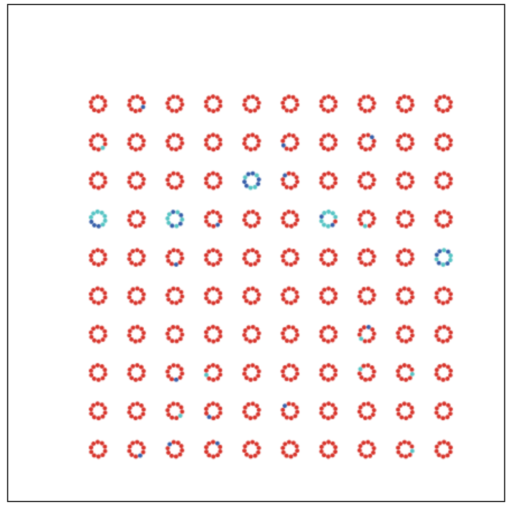
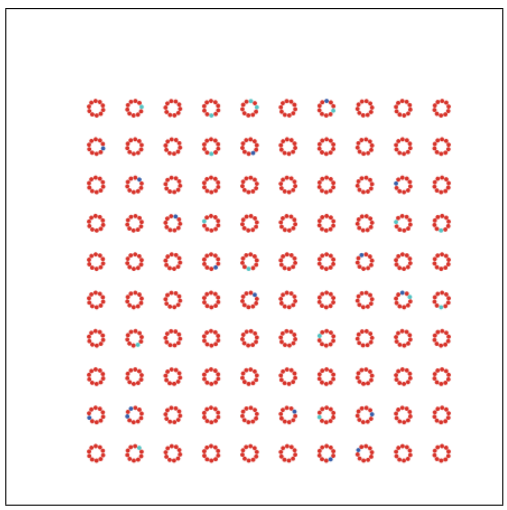


(a) Initial configuration.

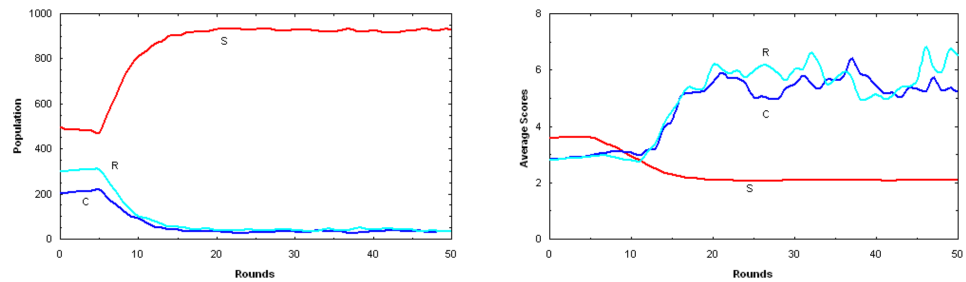


(b) Round 50.



(c) Round 2000.

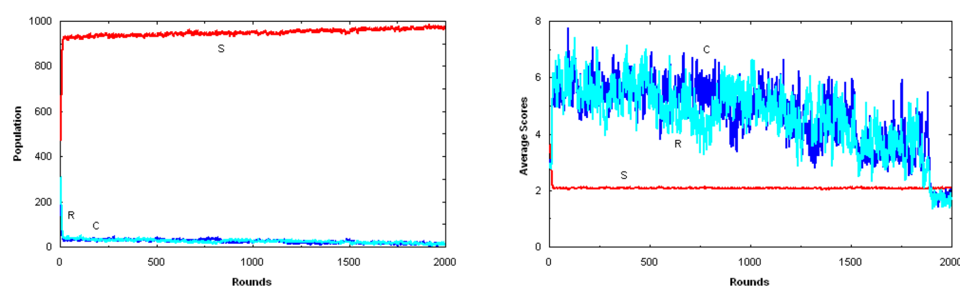
Figure 2: The evolution of a sample run of the model with baseline parameters and 5 shirkers, 2 cooperators and 3 reciprocators. Inter-group emulation was disabled. In (b), after 50 iterations, we see how only 5 groups are dominated by cooperators and reciprocators. In (c), after 2000 iterations, all the groups are seen to have become shirker dominated, with the exception of temporary mutations.



(a) Populations after 50 rounds.

(b) Average scores after 50 rounds.

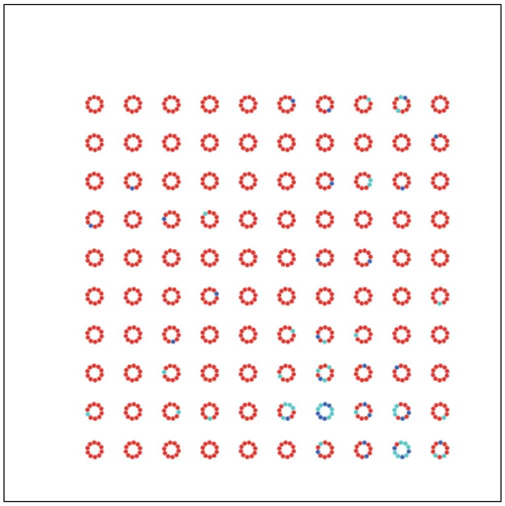
Figure 3: Populations and average scores of each agent type after 50 rounds. Intergroup emulation is disabled. Shirkers overwhelm the population very early on, leaving only small groups of R and C types. However, as seen in (b), the groups consisting of R and C types afford their members higher average scores than group dominated by shirkers.



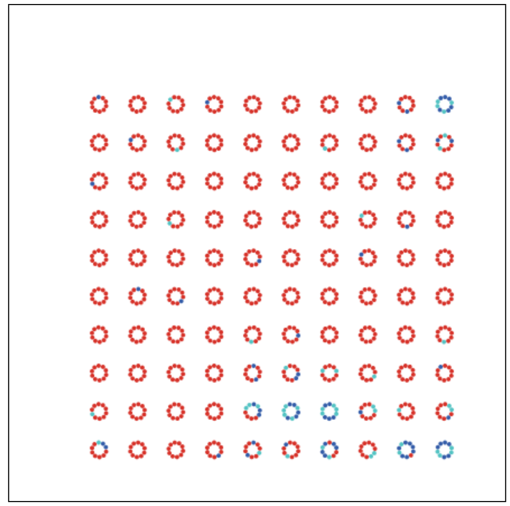
(a) Populations after 2000 rounds.

(b) Average scores after 2000 rounds.

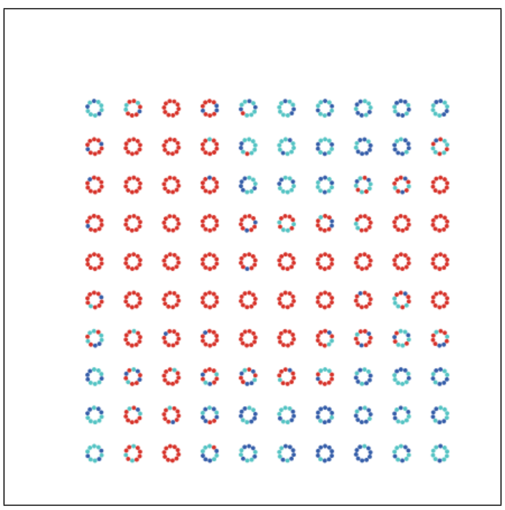
Figure 4: Populations and average scores of each agent type after 2000 rounds. Intergroup emulation is disabled. Shirkers dominate the population throughout the run, driving the R and C types slowly into extinction. In (b), the average scores of R and C types are seen to fluctuate wildly as their numbers dwindle, which increases the spread of their scores.



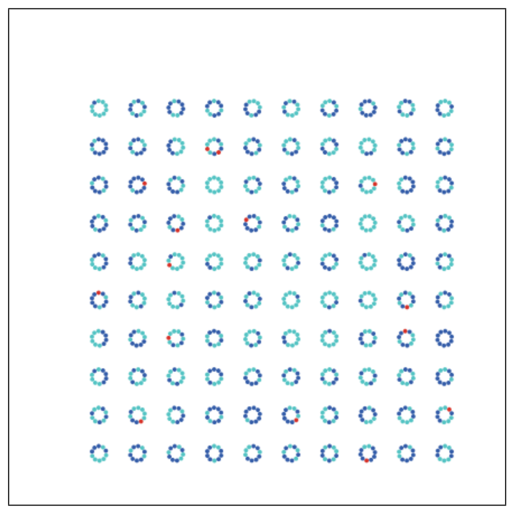
(a) Round 50.



(b) Round 100.

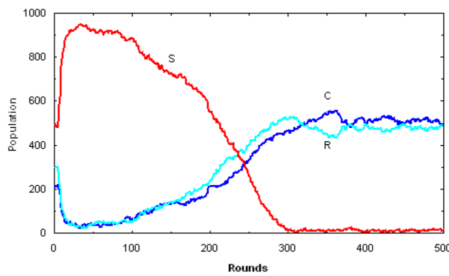


(c) Round 200.

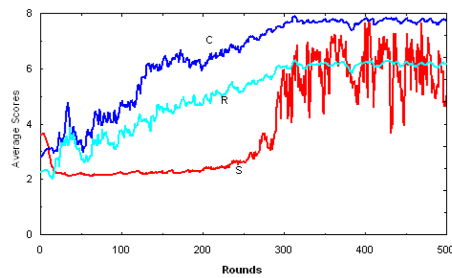


(d) Round 300.

Figure 5: The evolution of a sample run of the model with baseline parameters and 5 shirkers, 2 cooperators and 3 reciprocators. Inter-group emulation was enabled. In (a), after 50 iterations, we see how only 2 groups are dominated by cooperators and reciprocators. In (b) and (c), after 100 and 200 iterations respectively, we see cooperative behavior spreading over to neighboring groups. Finally in (d), there are no groups left that are shirker dominated.

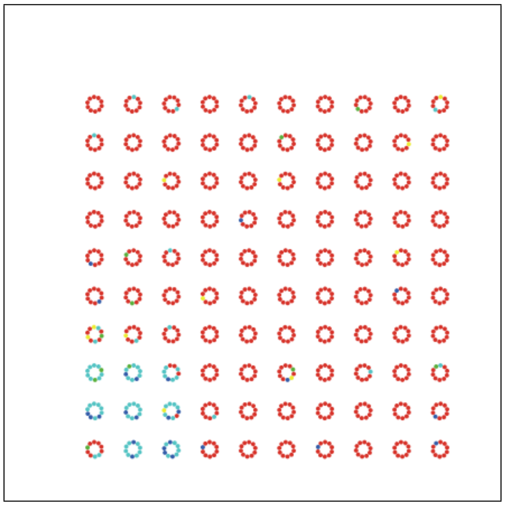
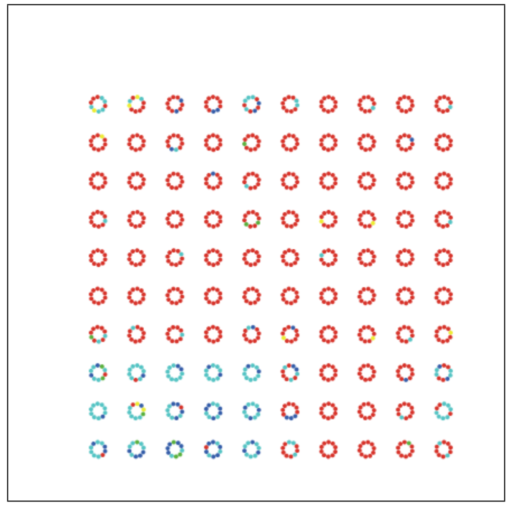


(a) Populations after 500 rounds.

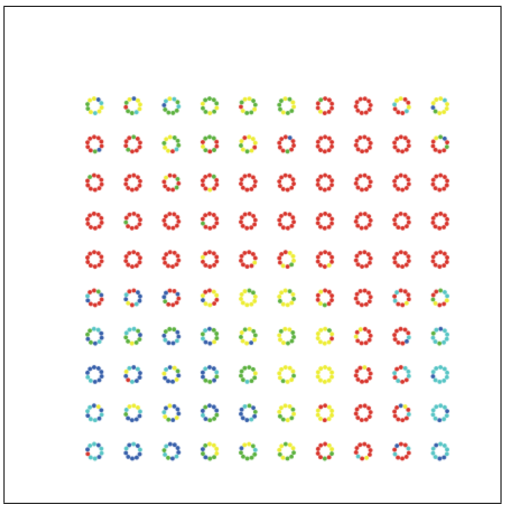
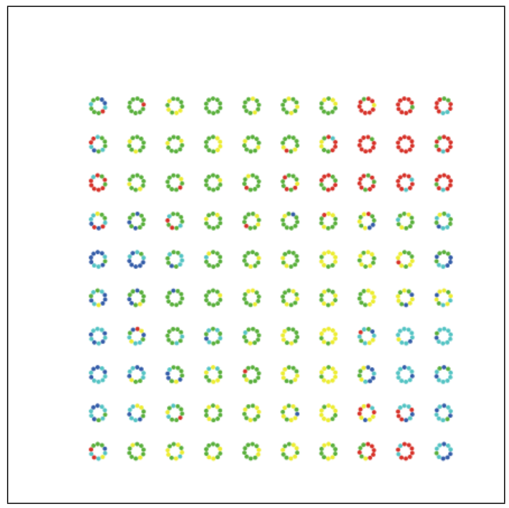


(b) Average scores after 500 rounds.

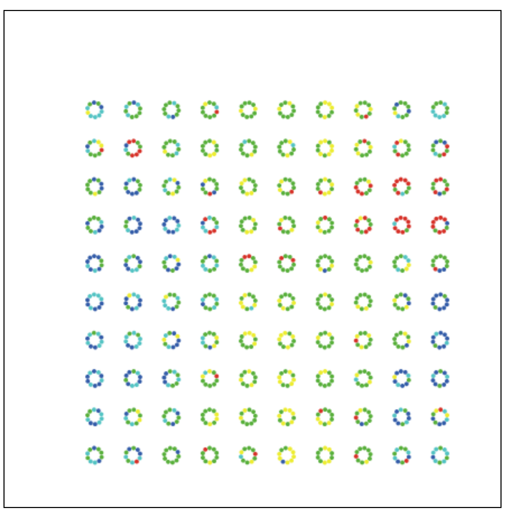
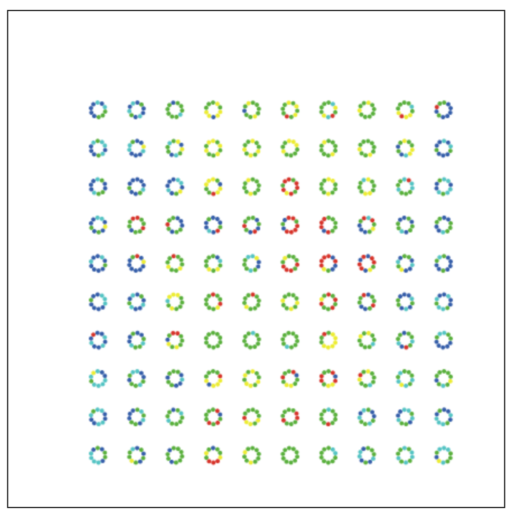
Figure 6: Populations and average scores of each agent type after 500 rounds. Inter-group emulation is enabled. After an initial rise in the population of shirkers, the R and C types spread across the population until approximately the 300^{th} round, after which the entire population is dominated by R and C types. The plot of average scores in (b) show that agents belonging to R and C groups have a score premium which allows for their types to spread via emulation. After 300 rounds, the shirker population tapers off, causing their scores to fluctuate with random mutation.

(a) Round 50. (b) Round 100.

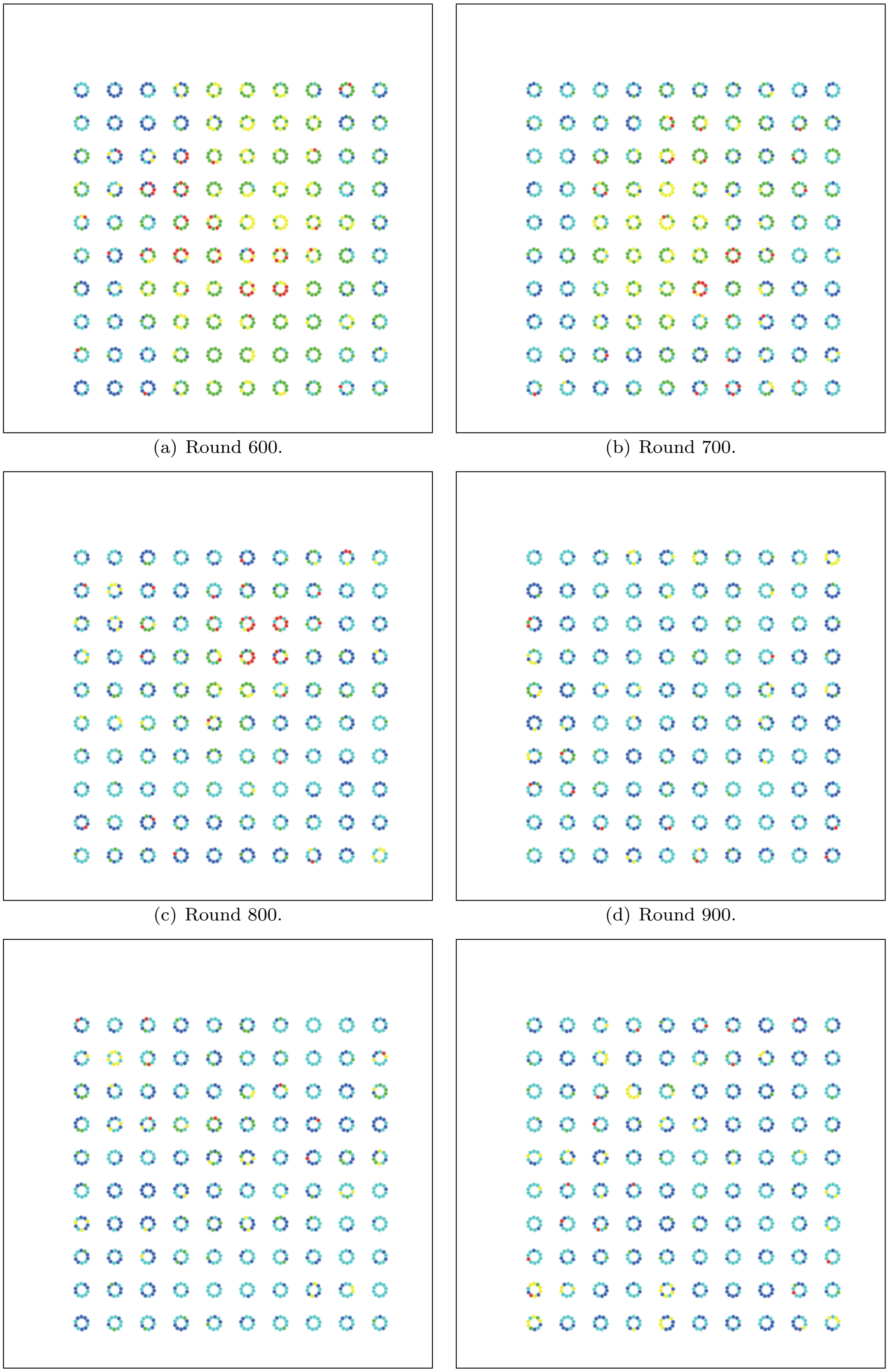



(c) Round 200. (d) Round 300.

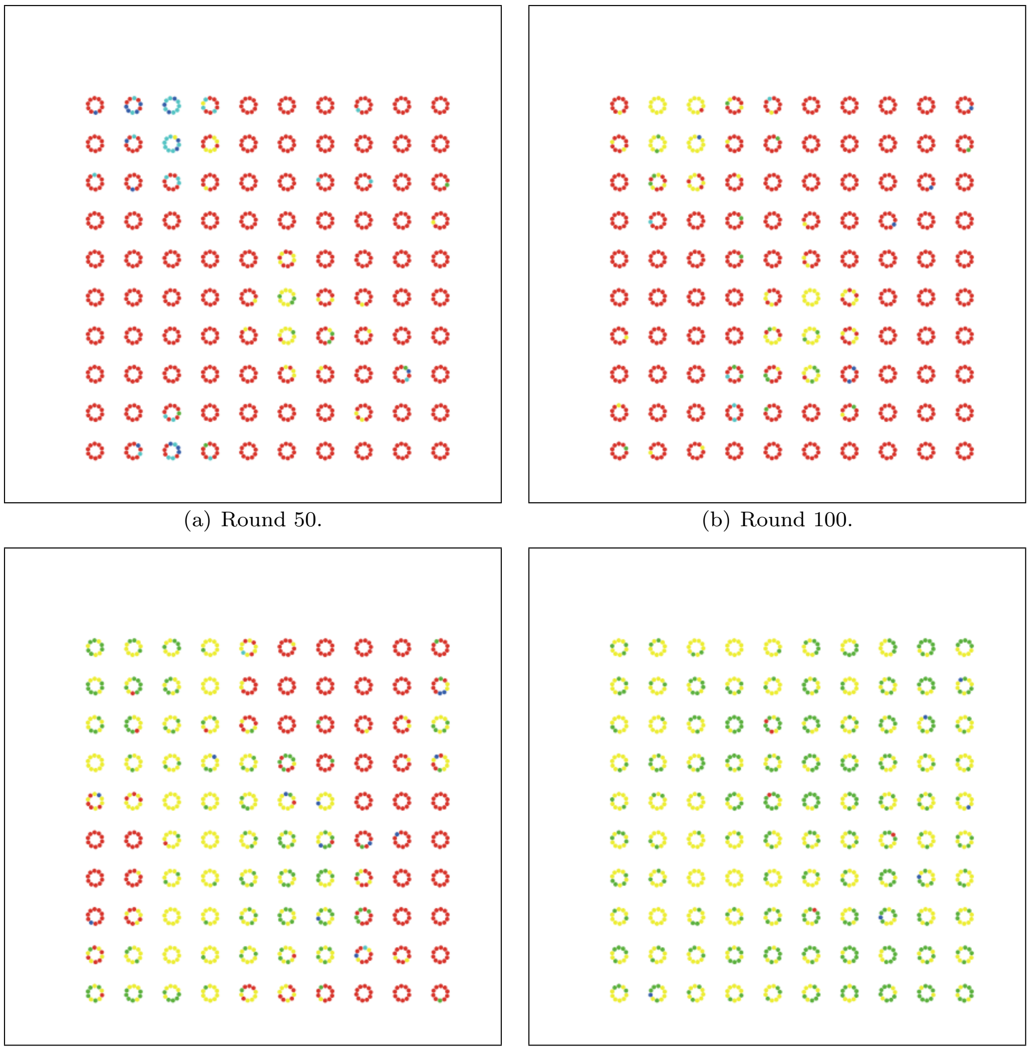
(e) Round 400. (f) Round 500.

Figure 7: A sample run of the extended model with baseline parameters and 5 S, 2 C and 3 R. In (a), after 50 iterations, only a few R and C groups survive. From (d) to (f), we see cooperative behavior spreading over to neighboring groups, and also the rise of R_L and C_L groups.



(a) Round 600.
(b) Round 700.
(c) Round 800.
(d) Round 900.
(e) Round 1000.
(f) Round 2000.

Figure 8: Continuation of Fig. 7. From (a) onwards, the number of R_L and C_L groups start declining and in the end, the entire population is dominated by R and C groups.



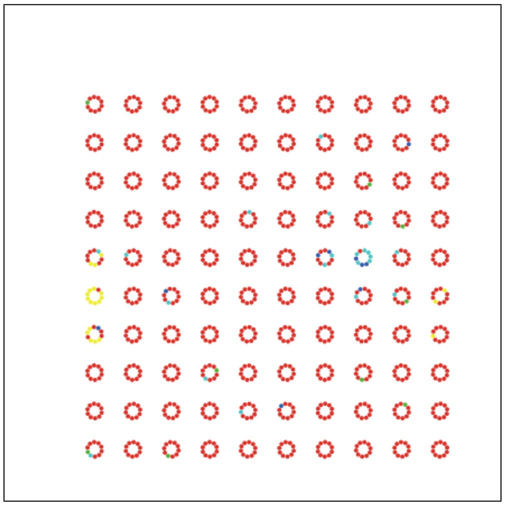
(a) Round 50.

(b) Round 100.

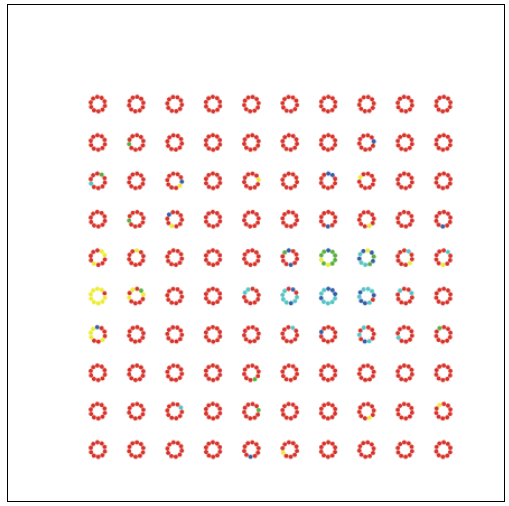
(c) Round 200.

(d) Round 300.

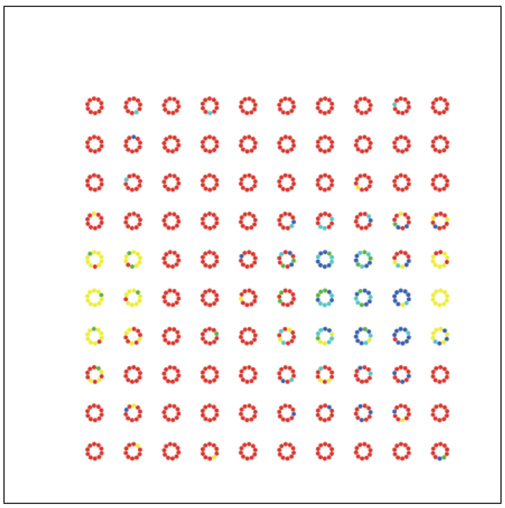
Figure 9: A sample run of the extended model with baseline parameters and 5 S, 2 C and 3 R. In (a), after 50 iterations, only a few groups of R and C types and R_L and C_L types survive. From (a) to (b), we see that the R and C types have changed over to become R_L and C_L types. From (b) to (d), we see large scale cooperative behavior spreading over to neighboring groups, and eventually dominate the whole population.



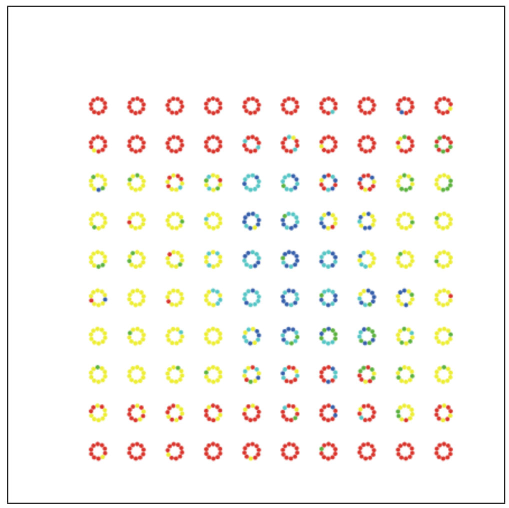
(a) Round 50.



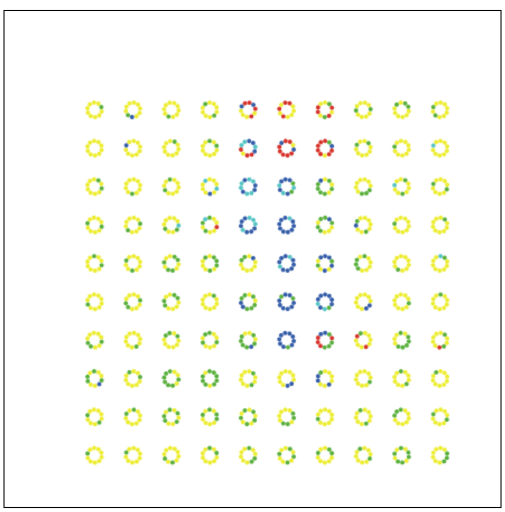
(b) Round 100.



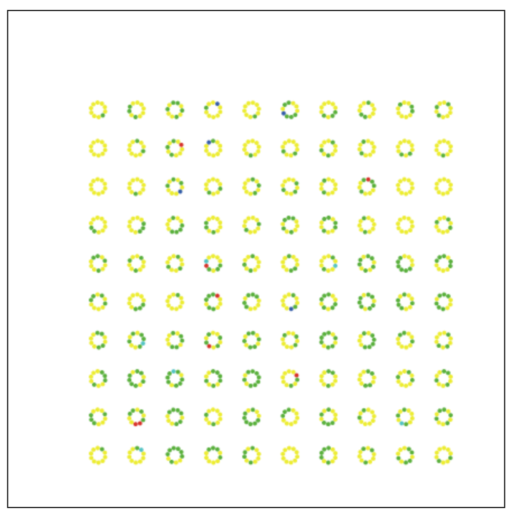
(c) Round 200.



(d) Round 300.

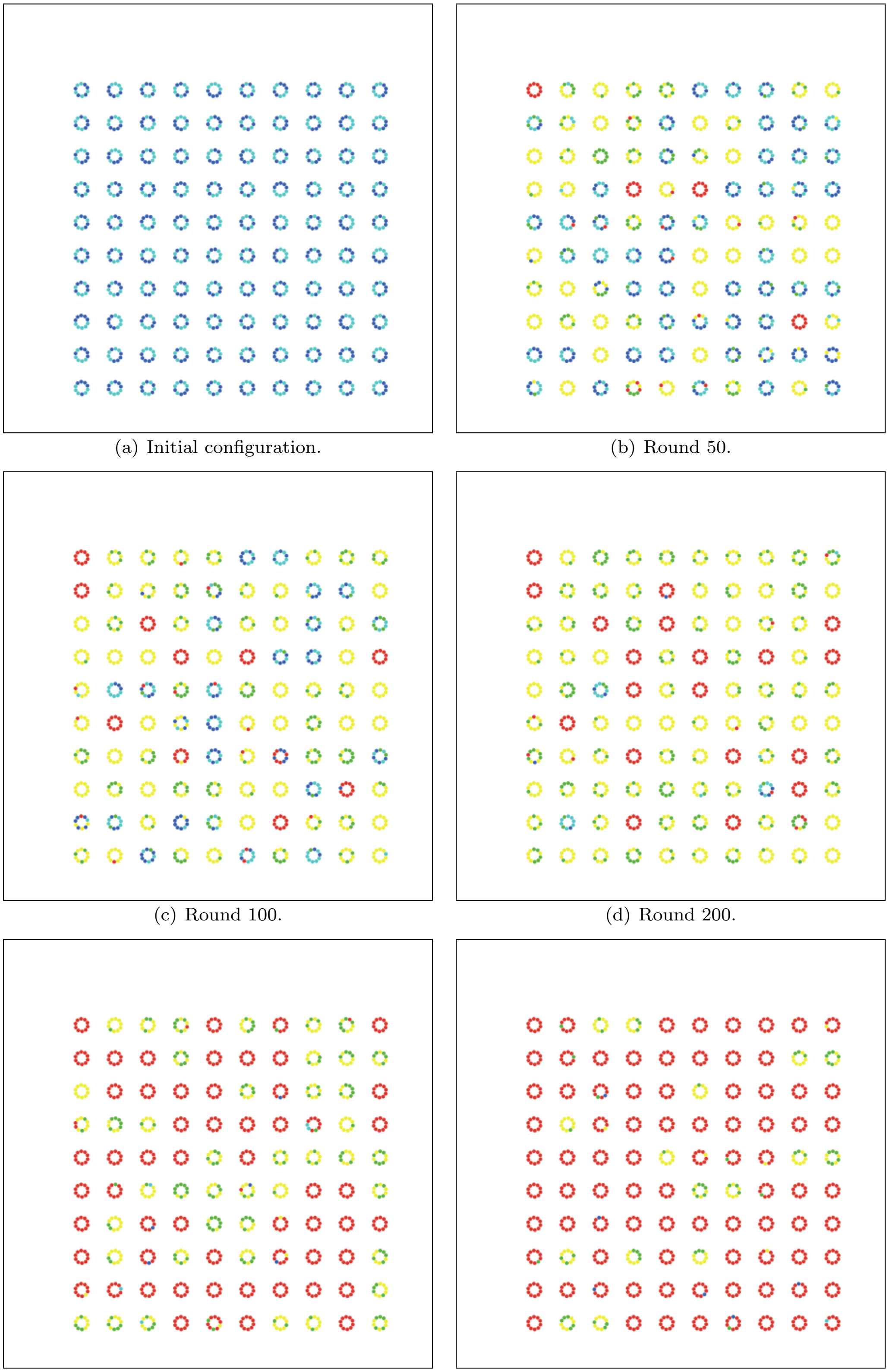


(e) Round 400.



(f) Round 500.

Figure 10: A sample run of the extended model with baseline parameters and 5 S, 2 C and 3 R. In (a), after 50 iterations, only one group of R and C types and one of R_L and C_L types survive. From (b) to (d), we see that both the R and C groups and R_L and C_L groups spread. From (d) to (f), we see large scale cooperative behavior eventually dominate the whole population.



(a) Initial configuration. (b) Round 50.

(c) Round 100. (d) Round 200.

(e) Round 1000. (f) Round 2000.

Figure 11: A sample run of the extended model with baseline parameters and 5 C and 5 R. From (a) to (d), R_L and C_L types gain control of most of the groups. From (d) to (f), small scale free-riding behavior sets in and eventually dominates the whole population.