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THE EVOLUTION OF COOPERATION IN BUSINESS: INDIVIDUAL VS. GROUP INCENTIVES

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The Evolution of Cooperation in Business: Individual vs. Group Incentives

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Abstract

Cooperative relations, within and between firms, play important roles in business. How to produce such relations, however, is less well understood. Building on work in evolutionary biology we examine the conditions under which group based incentives result in better performance than individual based incentives. We find that when individual and group interests are not aligned, group incentive systems lead to both higher group and individual performance. Hybrid reward systems, with both group and individual components, are found on average to be inferior to pure group based systems, but superior for some specific cases.

Keywords: Emergence of cooperation, Incentive systems, Iterated games, Group selection

JEL codes: D00, M52, C63

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1 Introduction

Empirical research has identified cooperative behavior as a key characteristics of groups, relations and networks associated with high performance (e.g. de Jong et al., 2005; Cummings and Cross, 2003; Spekman and Davis, 2004; Wilkinson, 2008). These studies, however, do not tell us how such cooperation can be developed and managed, only the personal and behavioral characteristics that are associated with its presence. More generally, the reasons for cooperative and altruistic behavior, the presence of which has been repeatedly demonstrated in experiments carried out across many cultures (e.g. Henrich et al., 2004), is not well understood. Recent developments in biological theories of the evolution of cooperation point to the importance of group based selection and reward mechanisms in driving the emergence of cooperative behavior and superior performance. This paper investigates the effect of individual, versus group, selection and reward mechanisms on performance and considers the implications of the results for the design of incentive systems.

Our work builds on the computational approach developed by Axelrod and Hamilton (1981) and others to examine the evolution of cooperation. This previous work focused on individual selection and reward mechanisms and, in the main, on only one type of game, the iterated prisoners dilemma (IPD). Here we use this approach to model behavior under individual, group and hybrid (i.e. mixed) selection mechanisms over a extensive space of iterated games and examine the conditions under which each type of selection mechanism results in superior performance. Our findings show that group based systems are superior when group and individual incentives are not aligned, whilst individual based systems produce better outcomes more frequently when they are. For hybrid systems the results show that, over the space of all games, they do not outperform a pure group based system. In short the outcomes of different types of selection mechanisms depend on the type of game and the type of interdependence this creates among players. We argue these results have important implications for the design of incentive systems and may explain the results of previous experiments and case studies.

The paper is organized as follows. In Section 2, we discuss the role of cooperation in business and the evolution of cooperation. Section 3 presents our model of the evolution of interaction strategies among individuals in groups. Detailed results examining the effect of individual, group and hybrid reward and selection mechanisms on performance are presented in Section 4. Section 5 concludes.

2 Cooperation in Business

Cooperative relations are increasingly seen as a source of competitive advantage for firms, industries, regions and nations e.g. Spekman and Davis (2004). Within a firm there are many formal and informal groups of people and departments carrying out interdependent activities that co-produce value (Stabell and Fjeldstad, 1998). As one manager comments: "We think everything worth doing is done by groups, not by individuals"(Weber et al., 2005). The degree of cooperation and coordination within and among groups effects firm performance (Hakansson and Snehota, 1995; Rulke and Galaskiewicz, 2000; Smith et al., 1995), however, these effects are often ignored and unrewarded (Kleiner, 2010). Similarly the value of cooperation between firms has also been highlighted (Wilkinson, 2008; Wilkinson and Young, 2002; Morgan and Hunt, 1994) yet is often neglected in government policy, e.g. Porter (1990); Wilkinson et al. (2000).

Prior research has analyzed the role of cooperation in business and identified various characteristics of agents associated with superior performance. The means by which these characteristics are encouraged and maintained, however, are not well understood. Incentives designed to reward individual effort may actually reduce overall performance if individuals hinder each other. For instance, as Henry Mintzberg observed: "We know that the most effective companies and organizations are those that embody the importance of being communities. ... But most conventional management practice and education has gone in completely the opposite direction. It's becoming more mercenary, more individualistic, less community oriented, and less nuanced." (cited in Kleiner, 2010).[1] In general it is difficult to directly control, monitor or evaluate the behavior of all actors involved

[1]This concern has been echoed by others and highlighted in recent developments in relational contract theory and research on the evolution of cooperation (e.g. Chassang, 2010; Henrich, 2004; Selten and Warglien, 2007; Weber and Camerer, 2003).

(Baker, 2000). Instead for successful cooperative relationships there must be an alignment of interests between actors such that each individual's outcomes are maximized when they behave in ways that maximize the group's total outcomes.

The design of incentive systems to align and enforce preferred behavior has received a great deal of attention in economics (e.g. Williamson, 1981) and more broadly (see for example Hunger and Stern, 1976; Day, 1999). One potential mechanism is the use of group based incentive systems which assess and reward the group as a whole, dividing the outcome in a way not directly related to personal performance (see for example Weber and Camerer, 2003; Selten and Warglien, 2007). Group based systems, however, are not the norm. In most firms individual based systems are employed in which each person is rewarded based on their own success (Pfeffer, 1998). The focus on individual-based incentive systems stems in part from a belief in the primary role of competition, in which survival of the fittest drives performance. This, however, does not have to be the case.

2.1 The Evolution of Cooperation

While the emergence and value of cooperation among people is observed throughout the social realm, the reasons for this are unclear and remains a frequent topic of articles in leading scientific journals (e.g. Hruschka and Henrich, 2006; Nowak, 2006). There are three main explanations. Firstly, those involved may have unique features that enable cooperators to recognize each other. This, however, creates opportunities for non-cooperators to emerge who mimic and exploit, cooperators (Hamilton, 1964a,b; Dawkins, 1979). Secondly, cooperation may be explained in terms of kinship, the biological relation between two actors. People are more caring, self-sacrificing and cooperative towards others they share genetic material with, e.g. siblings, children etc. (Axelrod and Hamilton, 1981; Henrich, 2004). Kinship based explanations, however, are rarely relevant for understanding cooperation in business. Third, the emergence of cooperation may be explained as a consequence of the interactions taking place over time between individuals. Repeated interactions are different from one-off interactions. Cooperative strategies can emerge because of the shadow of the past, demonstration of past altruism, and the future, value of cooperation in subsequent interaction (Axelrod, 1984). Becker (1976) motivates altruism in an economic context and this has also been demonstrated in computational simulations by Axelrod and Hamilton (1981); Bergstrom (2002); Hanaki et al. (2007) amongst others.

A fourth way in which the emergence of cooperation may be explained has recently regained favor. Group selection focuses on the group as the unit of assessment, rather than the individual actor. This theory hypothesizes that groups, with some degree of continuity of membership and interaction, provide advantage to their members and outperform groups where survival is based solely on individual performance (Goodnight and Stevens, 1997).

An illustration of the power of group selection mechanisms is provided experimentally. Selective breeding for hens which lay the most eggs has been used for many years, resulting in birds that are aggressive with high mortality rates, which undermine increased egg production (Clarke and Wise, 2009). Research by Muir (1996) has showed that selecting the most productive groups of hens, rather than individuals, results in superior egg laying performance and normal life spans. Similar findings apply in other species (Muir, 2005).

Group selection is not a new theory. It was initially embraced by evolutionary biologists (e.g. Wynne-Edwards, 1962) then rejected (e.g. Maynard-Smith, 1976; Williams, 1966), due to lack of biological evidence and its explanations being less parsimonious than those of individual selection. A re-examination of the evolutionary equations underlying group selection (Griffing, 1967; Price, 1970), however, showed that the experimental results demonstrating the superiority of individual selection did so due to the exclusion of interaction effects (Goodnight and Stevens, 1997), in other words a random mixing of the population was assumed. Group selection theories, however, rely on this not being the case. Henrich (2004) has further developed the theory of group selection in terms of social and economic systems. His work highlighted a fundamental tension, within groups, competitive behavior provides greater benefits to individuals than cooperative behavior but more cooperative groups outperform more competitive groups.

This line of work suggests a mechanism by which more cooperative behavior and better group performance can be engineered through group as opposed to individual based incentive systems. The fundamental question is: Under what conditions do group based assessment, reward and selection systems do better than individual based systems?

2.2 Group Reward Systems

In practice, group based incentive systems have been shown to be able to enhance the performance of teams (FitzRoy and Kraft, 1987; Kruse, 1992; Arya et al., 1997; Che and Yoo, 2001). The risk of free riding and the inability to detect it is often cited as the main reason against group based incentives (see for example Hamilton et al., 2003). One possible solution is the use of mixed incentive schemes, those rewarding both individual and group performance. Libby and Thorne (2009), however, show that they may not be beneficial as they may confuse employees.

Whilst group incentive mechanism may produce enhanced performance in some cases their ability to do so is dependent on the situation in which they are employed (e.g. FitzRoy and Kraft, 1995). For instance, Libby and Thorne (2009) show that group reward systems only have a significant benefit in team based tasks but have no benefit for production lines where there is limited interaction. The exact design of the incentive scheme is important. Nalbantian and Schotter (1997) show that relative performance schemes outperform target based schemes whilst the interactions between group members (Encinosa III et al., 2007), the types of incentives (Lavy, 2002), aspects such as job image (Akerlof and Kranton, 2005), group membership (Goette et al., 2006) society and company norms (Kreps, 1997; Fehr and Fischbacher, 2002) and the ability of individuals to hold up output Kvaløy and Olsen (2012) may also play a role.

The complexity of the relationship between the problem setting and the outcome makes drawing conclusions regarding the applicability of group reward systems difficult. Performing an empirical analysis within a firm is expensive and time consuming making it impossible to gain a general picture with this method. In this paper we use computational techniques to identify optimal behaviors for a wide range of games under different incentive schemes. Whilst laboratory experiments could be used to investigate individual specifications, it would be infeasible to examine the breadth of experiments considered here. Our results, however, provide a basis for designing future experimental research.

The computational approach we will set out in the next section has previously been used to examine individual selection mechanisms (e.g. Axelrod and Hamilton, 1981). The effect of group selection has been largely overlooked with a few exceptions. Axelrod (1987) considered it in terms of spatial models whilst Bowles et al. (2004) show how the existence of certain types of group level structures may encourage the evolution of group beneficial traits. Similarly Matros (2012) find that alturism may survive in groups although this is dependent on the decision rules used by agents. Work in this area has primarily focused on the IPD game rather than other types of games, which have different types of payoffs. No research has systematically compared the impact of group versus individual selection for different game conditions.

3 Model

In this section we present a model of the interaction of individuals under different situations (games). We initially examine the effect of two different reward mechanism, group selection, in which the best performing groups are rewarded, and individual selection in which the best performing individuals are rewarded. We use a computational technique, a genetic algorithm, to identify the equilibrium strategies under each mechanism. We do not argue that in reality individuals go through an evolutionary process, instead this is a mechanism to determine equilibrium behavior in different circumstances Riechmann (2001). As such this model is normative, rather than descriptive of the mechanism by which group selection occurs.

3.1 Selection Rules

We consider a model in which individuals interact within groups. The interactions take the form of two player, iterated, binary choice games. For ease of description we refer to the two actions as 'cooperate' and 'defect', they could, however, take any name. Individual payoffs are dependent on the selection and reward mechanism under which they are interacting. The population consists of n players divided into m groups, each of equal size (n/m). In each generation every individual plays a specific 2 player game with every other individual within the group in turn. Each interaction last for r rounds. By considering iterated games we allow individuals to condition their behavior on that of their partners, and their previous interactions, as is typically the case within groups and teams. Arya et al. (1997) and Che and Yoo (2001) have both shown that the ability to monitor and punish opponents is potentially important in successfully employing group reward schemes.[2]

Groups may be considered to be teams of individuals interacting in a company or similar setting. By modeling groups as a collection of individuals playing two players games we allow a wide range of strategic possibilities. Players may potentially exploit or assist different individuals within the team to maximize their payoff under the specific reward scheme. Their behavior may depend on their own strategy and the personal characteristics (strategy) of each individual with whom they interact. For example one player may exploit some members of the group to increase their personal gain but at the same time cooperate with others who show a propensity to retaliate. An alternative would be to consider n-player games, however, this would constrain the scope of strategies and interactions.[3]

Each individual has a strategy dictating how they play the game. A strategy is represented as a 'string' of zeros (defect) and ones (cooperate), which specify the players. responses to all possible game situations. The set of situations a player may face is dependent on their memory length. With two possible actions, and a memory length of k, there are 2^k possible game situations the player must be able to respond to. For example, a strategy with memory length two must be able to respond to 4 different game histories of opponent actions i.e. DD, DC, CD and CC. Throughout this paper we use the con-

[2]Here we implicitly model all members of the group as interacting equally frequently with all other members, however, this need not be the case. A network structure could be imposed on each group, which would determine the individual interactions. The network could even be determined endogenously (e.g. Fosco and Mengel, 2011). It is known that the structure of relations within a group (e.g. Cummings and Cross, 2003) or units within an organization (e.g. Ethiraj and Levinthal, 2004) can influence its performance. Here we use the simplest group structure in order to separate and demonstrate the effect of the reward and evaluation mechanism.

[3]Although this may make an interesting future extension.

vention that the most historically distant action is on the left with actions increasing in recentness to the right, for example DC means the opponent defected two periods ago, and cooperated in the last period.[4]

This strategy, however, is not complete. Players. actions depend on the history of their opponent's actions. At the start of the game, for the first k periods, the player does not have sufficient observations of their opponent's actions to be able to choose an action themselves. To resolve this, a player's strategy also contains a fictitious history of the opponents play which effect responses during the first k periods. For example with a memory of two, in addition to the 4 bits governing the players responses there are two additional bits giving the fictitious history (by convention we start the bit string with these values). A strategy of 010111 is composed of a fictitious history of 01 (first two positions) and 0111 (positions 3-6) corresponding to actions in the four states (described above). This means the individual defects if the other player defected in the previous two rounds (0 in position 3), cooperates after defection two periods ago and cooperation in the last period (1 in position 4), cooperates if their opponent cooperated two rounds ago but defected in the last (1 in position 5) and cooperates if the other player cooperated in both of the last two rounds (1 in position 6). A player's first move will be solely governed by their pre-assigned memory, in this case the memory is 01 which corresponds to D two periods ago and C one period ago. The agent therefore plays C in the first period, the response to DC (fourth position) in their strategy. In the second period the second (more recent) value in the fictitious history (here the value 1) along with one round of real history are used. Let us assume the other player defects on the first round, the history will then be 10 (or CD) so the player will therefore play cooperate in the next round. After round two, decisions are solely based on the real history of play.

We employ a simple Genetic Algorithm (Holland, 1975) to optimize strategies (in a similar manner to Axelrod, 1987; Midgley et al., 1997). At the start of the simulation individual strategies are randomly generated. In each generation each individual's score is calculated as the total value of the players payoffs from all games played against all

[4]Ho (1996) uses an alternative automate mechanism. This approach allows more complex strategies at the expense of clarity of interpretation.

other members of the individual's group. The group's score is the total score of all players within a group. Once every player has played every other player within their group a new generation of players is generated from the existing population. One of two alternative mechanisms is used to produce the groups. Under individual selection the best performing individuals are denoted as the n/2 individuals in the population with the highest total scores. These individuals are copied and inserted into random groups in the next generation. The remaining individuals are formed by randomly choosing pairs of the best performing individuals and creating a new strategy by combining the first part of one strategy with the second part of the other (crossover). The break point is chosen randomly from a uniform distribution. In biology this mimics reproduction, whilst in social systems it may be thought of as a form of learning and sharing of strategies within a population. After crossover there is also a small probability (5%) of a single point mutation in a strategy in which a 0 flips to 1 or vice versa. The set of n new individuals are then randomly allocated to groups. Under group selection the m/2 best performing groups are selected and copied directly into the next generation. The remaining groups are formed by combining pairs of individuals selected from the best performing groups at random, irrespective of their individual performance.

This mechanism identifies an equilibrium: A population of strategies in which performance is maximized for the given selection mechanism. The process is repeated for 1000 generations. Convergence, defined as group and individual payoffs being on average constant, however, occurs relatively early in this period, typically after 100 iterations. Games are played for r=200 rounds.[5] The population size, n=64, whist the number of groups, m=8. The memory length, k=3. Repeating the simulations with different population sizes and memory lengths did not qualitatively change the results but are available from the authors on request. Different group sizes have a small effect on the results, primarily for groups of size two. In this case many of the interaction effects are removed as each player only ever plays one opponent. As a consequence the population behaves like one large group. For larger groups sizes, however, the results are qualitatively similar. All

[5]Different numbers of rounds were examined but had no effect on the results.

results are averaged over 1000 repetitions with different random seeds.

4 Results

We consider a broad space of games to determine those in which individual or group selection are superior. Rapoport and Guyer (1966) identify 726 strategically distinct 2×2 games in which individuals have weak preferences over outcomes.[6] For this analysis, however, the absolute values of the payoffs rather than simply their ordering is important in determining strategy success. This is because an individuals payoff is the sum of the gains over the repeated game, i.e. the total score. Consequently there are an infinite number of possible games, making an exhaustive analysis impossible. In order to bound our analysis we restrict all payoffs to be integer multiples of 0.1 and to lie in the range [0,1]. This space consists of 14,641 games that show many different structures and include all orderings of payoffs. There are some games that cannot be represented in this format, for instance games that would produce lexicographic preferences, nevertheless, this set is substantial and sufficient for the analysis both in terms of its breadth and detail.

4.1 Group vs. Individual Selection

We first consider which selection mechanism produces the best group and individual performance for each game in the space described above. In Figures 1 and 2 a black cell corresponds to games where group selection scored higher, gray cells when individual selection scored higher and white cells indicate no significant difference. There were 1000 repetitions each for group and individual selection and all differences are significant at the 99% level. For presentation we focus on a single value of the CC payoff ($CC = 0.5$), however, different values have been analyzed. The results are qualitatively similar and are available on request. In all figures the payoffs for CD and DC vary along the x and y axis respectively, whilst changes in the DD payoff are represented in terms of different grids.

[6] If preferences are strong there are 78 distinct games.

[Figure 1 about here.]

Figure 1 shows distinct areas in which each selection mechanism produces better performing groups. The area corresponding to group selection is much larger than that for individual selection. This means that, for a larger proportion of games, group based reward mechanisms produce better performance than individual based mechanisms.

Whilst the black area appears to be contiguous it contains several distinct regions of different types of games. The first is the area bounded by $DD \leq 0.5$ and $CD + DC > 1.0$ i.e. the triangle in the upper right most clearly identifiable in the sub figure for $DD = 0.5$. In these games the highest combined score may be obtained from anti-coordination. Consider for example the game in which the payoffs are $CC = 0.5$, $DC = 0.8$, $CD = 0.4$, $DD = 0.0$. The best group payoff in this case is if one individual cooperates and the other defects, however, the defector gets a higher individual score. Under individual selection this will lead to an increase in the number of defectors and therefore more DD interactions within the population - consequently reducing group scores. Group selection is able to select the optimal mix of cooperators and defectors to maximize performance, whereas, under individual selection, this is not the case.[7]

The second segment is approximately bounded by $DD \leq 0.4$, $DC \geq 0.5$ and $CD + DC < 1.0$. This corresponds to the area of games in the upper left of the first five subfigures, although note it is contiguous with the previously described region. In this area, mutual cooperation produces the highest total score but defection against a cooperator produces a higher individual score (the prisoners dilemma exists in this segment). Like the area discussed above individual selection rewards those players who defect as they increase their individual score - even though this is at the expense of the group score. Group selection allows the population to settle on an equilibrium that is beneficial to all. The payoff favors those that mutually cooperate and it is group selection that encourages the existence of these strategies. The final area in which group selection is superior is the triangle bounded by $DD > 0.5$, $DC < 0.5$, $CD > 0.5$ (the bottom right in those figures

[7] This type of game resembles simple or modular coordination tasks in which individuals specialize in different sub-tasks that can then be assembled or added together, as when groups of workers take turns in digging a hole, recording results, or serving different customers in a market (see the experiments of Selten and Warglien, 2007; Weber and Camerer, 2003).

for $DD > 0.5$), where the combined payoff for DD is the same or more than CD/DC and more than CC. This is equivalent to the first region except that the payoff matrix is mirrored, with DD being the equivalent of CC. Hence the explanation is the same.

Individual selection does better for a range of games present in the bottom left of the sub-figures. In order to maximize group scores all players must synchronize on either CC or DD, depending on which is higher. The CD and DC scores are such that if an individual changes strategy when in the lower performing equilibria they reduce their own score but reduce the groups score by even more, i.e. they increase their relative fitness. For example for $CD = 0.3$, $DC = 00$ and $DD = 0.4$ in a group of defectors a single cooperator would receive 0.3 every time they played and their opponent would receive 0.0. For DD between 0.4 and 0.7 the pure CC and DD payoffs are sufficiently similar that the optimization method may initially identify either. The actual choice will depend on the random distribution of strategies at the start of the model. Under group selection if a population synchronizes on the wrong strategy it is very hard to change. A single player changing will reduce the group score (even though the individual score is increased) leading to the group being eliminated. Under individual selection, however, the change in strategy increases the individuals payoff leading to them spreading in the population and, in time, the whole population adopting the superior strategy.[8]

Overall group selection does better than individual selection when individual and group incentives are not aligned. To achieve the optimal performance some individuals must sacrifice their payoff for the good of the group as a whole. A Pareto optimum results when it is possible to compensate those who sacrifice their own performance from the greater returns to the group as a whole. There is a large area of the space, however, for which the two mechanisms do equally well. In these areas both individual and group selection are able to find strategies that are equally effective.

[Figure 2 about here.]

Figure 2 shows that group selection produces the best performing individual in nearly half of all games. This is surprising as the individual based selection mechanism is specif-

[8] Note for $DD = 0.5$ both DD and CC are equally good and so switching is not necessary.

ically designed to maximize this quantity. The areas in which this is true closely match those in which group selection also produced the best performing groups. The conditions which lead to high total performance also encourage the best individual performance. There is, however, a notable exception; the set of games for which $CD = DC$ and $CD > 0.5$ and $DC > 0.5$. Here the CD/DC option provides the greatest individual and combined payoff. Within this region individual scores are maximized by being in the minority of the group. The regular mixing of individuals occasionally allocates a defector (cooperator) to a group of cooperators (defectors) resulting in high individual performance but a low group score (Figure 1). Off this diagonal there is an advantage for either one action or the other. In these regions the ability to maintain a better environment provided by group selection outweighs the selection benefits of individual selection leading to higher individual scores.

A second area in which individual selection does particularly well is the small light gray triangle in the region $DD \leq 0.4$, $CD + DC < 1.0$ and $CD > 0.5$. In this region individual selection does particularly well because of the noise introduced by the selection process. Occasionally, mutations lead to individuals who defect. Defection in these games damages the defectors score but give a small increases to their opponents. As a result, the presence of one of these individuals leads to the group containing the best performing individual in the population. At the same time the groups overall score is reduced meaning that they are not the highest scoring group. The highest scoring group is one which contains only cooperators and is found under both individual and group selection.

There are other instances in which individual selection produces the best individual in a population although the areas in which this occurs are somewhat diffuse. The reason for this is that whilst a particular combination of strategies may result in a higher scoring individual, it is frequently the case that, as this individual spreads throughout the population, their performance is reduced. Consequently, the score of the best individual is partially dependent on timing and the games they happen in appear to have little pattern.

4.2 Strategies

In order to fully understand the behaviors of players under the two selection mechanisms it is helpful to consider the strategies of player in an example game. The results presented below are based on the set of strategies present in the 1000th generation for one of the games above. In particular we consider a version of the prisoners dilemma with $CC = 0.5$, $CD = 0.1$, $DC = 0.7$ and $DD = 0.2$. Each cell of Table 1 gives the fraction of individuals who had a cooperate response in that location of their strategy. The first three digits are the three period fictitious history whilst the next eight digits indicate how the strategy responds to each possible three period history (each triplet presents events oldest to most frequent, left to right).

[Table 1 about here.]

Unlike Axelrod's tournament Table 1 shows there is no one dominant strategy like TFT, instead there is a mix of strategies which result in high performance. The reason for this is that different strategies can produce the same observable behavior. For instance, against a player who always cooperates, a strategy that would defect in response to a partner's defection behaves in the same way as a habitual cooperator, despite possessing different response rules.[9] As a result cooperative behavior may be observed even when the strategies involved include non-cooperative rules, if these rules are not activated. In general the strategies produced in the group selection and individual selection cases differ noticeably. Group strategies:

Think Nice: Comparison of positions 1 to 3 shows that group selection strategies commence the game with a more positive attitude, being more likely to assume a history of cooperation.

Act Nice: In general, the strategies evolved through individual selection are more likely to defect in response to a given pattern of behavior than group selection strategies. In particular, in group selection they are more likely to cooperate after three successive defections (55.5% versus 30.8%), which avoids getting caught in cycles of defection. They

[9] In biological terms the strategies have different genotypes but the same phenotype.

are more likely to continue to cooperate when the pattern is repeatedly cooperative (DCC, CCC) and are more forgiving, being more prepared to cooperate when there is cooperation after two previous defections (58% versus 26.4%).

Provocable: Group evolved strategies are not naive cooperators, as they are just as likely as individual selection strategies to retaliate once the other starts to defect, i.e. responses to DCD and CDD.

Group selected strategies have much in common with the characteristics of successful strategies identified by Axelrod (1984) in an IPD setting: nice, provocable, forgiving and clear.

4.3 Hybrid Rules

In the previous sections we have compared two schemes: group and individual selection. Whilst group selection appears to outperform individual selection in many circumstances it may not fully differentiate in terms of rewarding self-sacrificing behavior (good) as opposed to free riding behavior (bad). As such free riders may survive in a group over extended periods of time and have a negative impact on payoffs. For example van Dijk et al. (2001) show experimentally how the extra effort induced in some individuals by team based rewards may be lost due free riders in the group. A variety of approaches for dealing with this have been considered including punishment (Gachter and Fehr, 2000) and allowing individuals a say in who they interact with (Page et al., 2005). An alternative is for firms to mix group rewards (encouraging cooperation) with individual incentives (encouraging effort). Libby and Thorne (2009) suggest that such incentive systems may be confusing to agents, however, there may be situations in which they produce superior results.

The reward mechanisms we have previously studied differ in two important dimensions - the way in which fitness is calculated, based on either that of the individual or the group total, and the way in which groups are formed. Under group selection the fittest groups are retained in their entirety whilst under individual selection no structure persists. We consider, therefore, a two dimensional space of selection schemes. The first dimension is the fitness measure. We define the fitness of individual, i, in group k as:

$$U_i = (1 - \alpha)S_i + \alpha \frac{G_k}{n/m} \tag{1}$$

Where S_i is individual i's score and G_k the total score of group k, $\frac{G_k}{n/m}$ is therefore the average score of each member of the group. The second dimension is the degree of group mixing, β. After each generation all individuals with fitness below the median are removed from their groups and the population. For each individual who's fitness is greater than or equal to the population median, with probability β they remain in the same group in the new generation. Whilst with probability $1-\beta$ they are moved to another group selected at random. The remaining empty space in all groups are filled by new individuals generated by mutation and crossover of those individuals which survived the previous generation. If $\beta = 0$ the next population is randomly mixed whilst if $\beta = 1$ the population structure is maintained with those individual who performed less well being replaced by new strategies. We consider all combinations of α and β where $\alpha, \beta \in \{0.0, 0.1...0.9, 1.0\}$. If $\alpha = 1$ and $\beta = 1$ the model matches group selection as presented in the previous section, whilst if $\alpha = 0$ and $\beta = 0$ the model corresponds to individual selection.

[Figure 3 about here.]

Figure 3 presents the best individual and best group scores for the space of reward mechanisms averaged over all games where $CC, DC, CD, DD \in \{0.0, 0.1, ., 0.9, 1.0\}$. The results show that individual performance is maximized when fitness is solely based on group performance. Hybrid rules do not enhance performance. Higher levels of β increase the best scores, however, this effect is secondary to that of α. Group scores are increasing in both α and β with the maximum occurring for $\alpha = 1$ and $\beta = 1$. Pure group selection on average produces better individuals and groups than either individual selection or hybrid rules. It also shows that both group based rewards and a stable environment contribute to this effect.

The results presented in Figure 3 show the overall pattern, however, our earlier analysis highlighted certain types of games where individual selection was superior. We go on in this section to consider the effect of α and β on three specific games. The payoff matrices are presented in Table 2. For Game 1 (Prisoners Dilemma), our previous results showed group selection produced both the best individuals and groups. In Game 2 group selection again produced the best groups but individual selection produced the best individuals. For Game 3 individual selection produced the best individuals and groups.

[Table 2 about here.]

[Figure 4 about here.]

Figure 4 presents results for the three games under the selection mechanisms. For Game 1, the prisoners dilemma, the highest average performance occurs at high levels of α and any level of β. High α means that individual fitness is principally determined by the overall group performance, which rewards co-operators. This being the case β becomes unimportant, whether group structure is maintained or new groups are formed from the successful co-operators has no effect. The best individuals for these parameter combinations also score relatively highly but they are out performed by the best individuals under high β and intermediate α. In this setting an individual's performance is partly dependent on their own score as well as the group. If one individual in a group occasionally defects they increase their own score with relatively little effect on the group component of their fitness. This is only the case if β is high. If population shuffling results in defectors coming together they potentially perform very badly - damaging the group performance and overall fitness.

In Game 2 individual selection produces the best individuals and group selection the best groups. It was argued that the highest individual scores were obtained when a player was part of a group in which the majority use the opposite strategy and that this occurred more frequently under individual selection. From the analysis of α and β in Figure 4 we can see that both contribute to this effect. More population mixing ensures that these chance pairings may happen frequently whilst an individual component to fitness means that successful individual strategies will spread in the population, changing the numbers of cooperators and defectors and making unbalanced groups more likely. Panel D shows that the key element leading to better groups under group selection is high β, i.e. stable group structure. In this game the highest scores are achieved when cooperators play defectors in equal numbers. Stable groups are better able to do this than those that are randomly mixed. α has a weak effect, particularly at high β, however, for lower values of β fitness is decreasing with increasing α - the same pattern observed for the best individual.

The figures for Game 3 show that β has very little effect on fitness, rather the apparent superiority of individual reward mechanisms comes from α i.e. group structure is unimportant but individual reward components are beneficial. This follows from the justification provided above for superior individual performance in these games. We argued that individual based selection aids individuals, and therefore the population, to move from inferior equilibria to a superior one. The results show that it is only necessary for a small individual component to be included in the fitness for this to happen. Whether or not individuals are mixed or population structure is maintained has little effect on this.

5 Conclusion

Whilst many papers have highlighted the positive effect on performance of cooperation within and between firms, little work has considered the means by which this cooperation can be developed. Our results provide a systematic basis for understanding the conditions under which group based incentives systems lead to higher group and individual performance relative to individually oriented systems. We find that group selection produces the best individual and higher average performance for a wider range of games than individual selection. The results show that group selection dominates in games where group and individual payoffs are not aligned. Individual selection only does better when group and individual payoffs are aligned and where unilateral deviation may aid the group in moving to a superior equilibrium. When interests are not aligned, group selection leads to the emergence and survival of groups of strategies in which some individuals do far better than others and the group as a whole benefits. The use of hybrid rules, those rewarding both individual and group performance does not change this key finding. The best performing groups and individuals still occur when fitness is determined purely on group score and team structure is maintained.

Our results call into question the conventional wisdom and common practice in which group formation and reward structures are designed in ways that in the main favor selection of best performing individuals. As Sutton (2007) notes a focus exclusively on individual incentives is likely to damage group functioning as this over-rewards the most visible performers, under rewards those who support them and fails to include in metrics the costs and damages associated with favoring the top performers.

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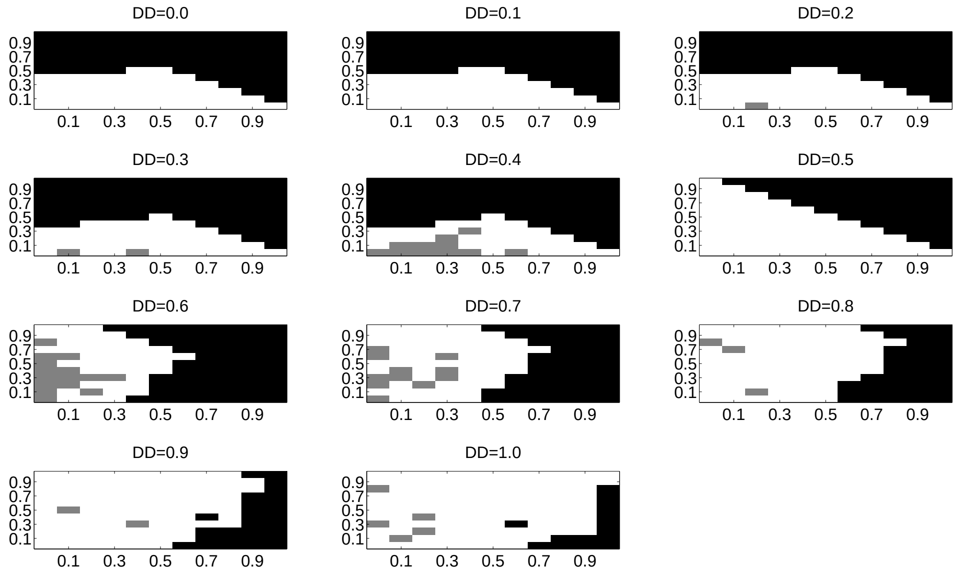


Figure 1: Comparison of group and individual selection mechanisms in terms of the best group performance across a range of games. Simulations results with $CC = 0.5$, CD on the x-axis, DC on the y-axis, 1000 repetitions each, < 0.01 t-test.

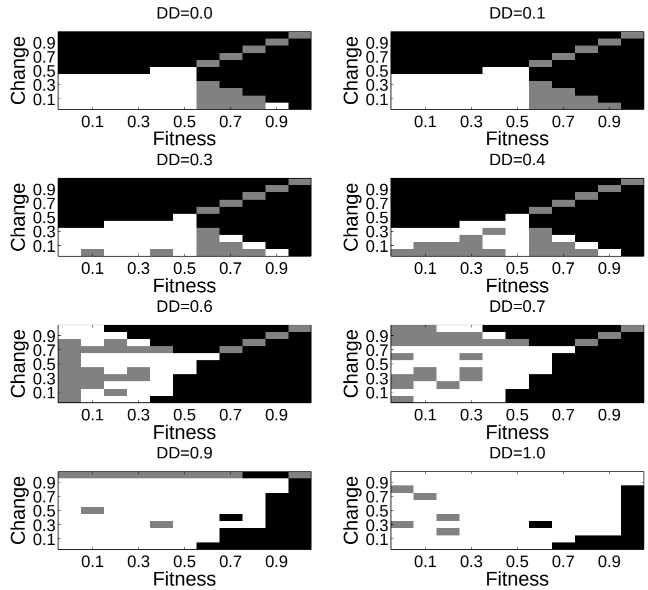
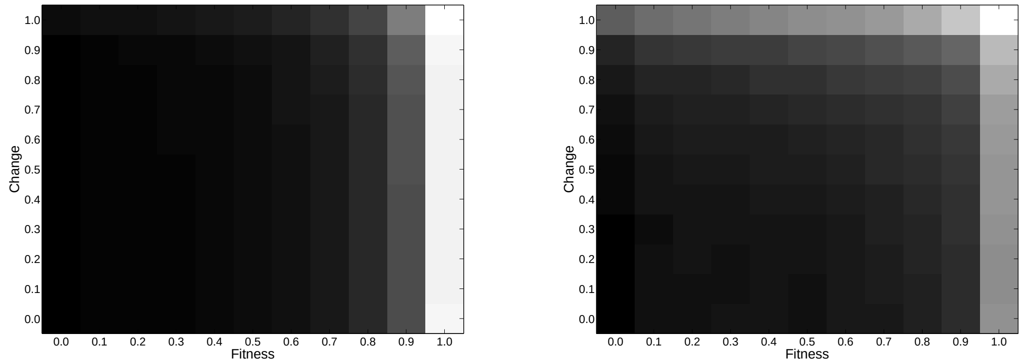


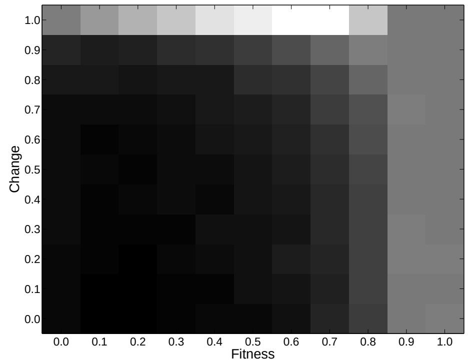
Figure 2: Comparison of group and individual selection mechanisms in terms of the best individual performance across a range of games. Simulations results with CC=0.5, CD on the x-axis, DC on the y-axis, 1000 repetitions each, < 0.01 t-test.



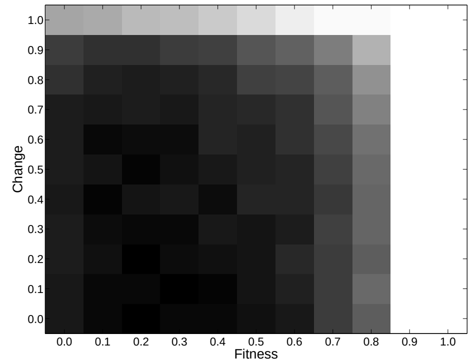
(a) Best Individual

(b) Best Group

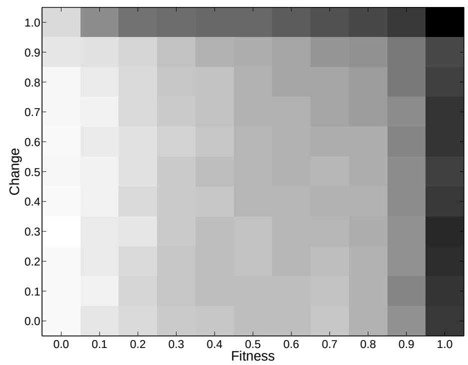
Figure 3: Scores of the best individual (Left) and best group (right) averaged over 14641 different games across a space of reward rules. The fitness measure, α, ranging from individual based to group based is given on the X axis. The group mixing measure, β, ranging from random to constant is given on the Y axis. Lighter colors represent higher scores.



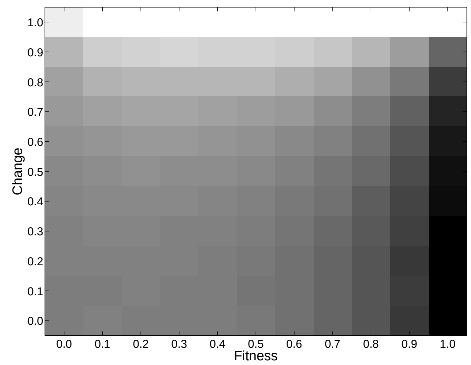
(a) Best Individual



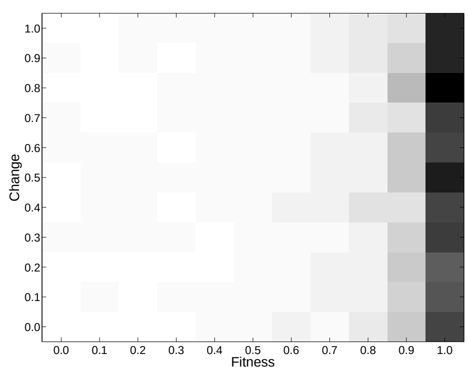
(b) Best Group



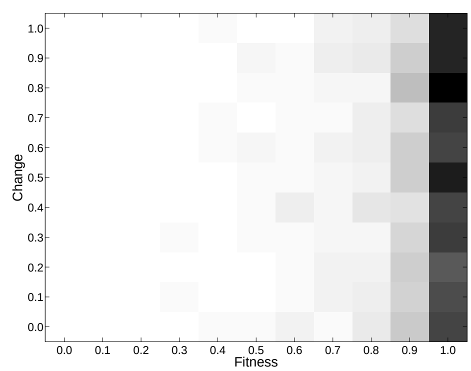
(c) Best Individual



(d) Best Group



(e) Best Individual



(f) Best Group

Figure 4: Scores of the best individual (Left) and best group (right) for four games across a space of reward rules. The fitness measure, α, ranging from individual based to group based is given on the X axis. The group mixing measure, β, ranging from random to constant is given on the Y axis. Lighter colors represent higher score. Lighter colors represent higher scores. Panels a+b: $CC = 0.5$, $CD = 0.1$, $DC = 0.7$, $DD = 0.2$, Panels c+d: $CC = 0.5$, $CD = 1.0$, $DC = 1.0$, $DD = 0.1$, Panels e+f: $CC = 0.5$, $CD = 0.0$, $DC = 0.3$, $DD = 0.6$.

Position	H_{t-3}	H_{t-2}	H_{t-1}	DDD	DDC	DCD	DCC	CDD	CDC	CCD	CCC
Group	61.9%	83.3%	88.7%	55.5%	58.0%	48.8%	84.1%	49.8%	55.6%	54.1%	98.9%
Individual	54.1%	56.1%	86.0%	30.8%	26.4%	53.4%	67.0%	48.0%	71.9%	62.3%	77.6%

Table 1: Probability of a cooperating for strategies with memory length three in the final generation. First three cells contain the fictitious history whilst the remaining eight contain the players responses.

	C	D
C	0.5,0.5	0.1,0.7
D	0.7,0.1	0.2,0.2

(a) Game 1

	C	D
C	0.5,0.5	1.0,1.0
D	1.0,1.0	0.1,0.1

(b) Game 2

	C	D
C	0.5,0.5	0.0,0.3
D	0.3,0.0	0.6,0.6

(c) Game 3

Table 2: Payoff matrices for three sample games (row player payoff, column player payoff).