Material Versus Social Payoff Tournaments

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Project Interim Report

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Introduction

1.1 The Dilemma

Popular analyses of human behaviour in the context of game theory and evolution such as Axelrod and Hamilton's *The Evolution of Cooperation* have used the well-known Prisoner's Dilemma to describe and predict how humans may or should interact [2].

While this is a good basic formula for interaction that can be analysed, the classical Prisoner's Dilemma at its core is a purely game-theoretical situation with discrete states and material outcomes [16].

The most basic form of the Prisoner's Dilemma is a canonical non-zero sum game in game theory. That is, the gain or loss in score by a player is not cancelled out by the opponent. The original situation can be described as follows:

> Two people are arrested for committing the same crime, but the police do not possess enough information for a conviction. They are separated such that they cannot communicate with each other. The police offer both of them the same deal — if one testifies against their partner (defects / betrays), and the other remains silent (cooperates / assists), the betrayer goes free and the cooperator receives the full one-year sentence. If both remain silent, both are sentenced to only one month in jail for a minor charge. If each betrays the other, each receives a three-month sentence as they will be guaranteed early release by the prosecution. Each prisoner must choose either to betray or remain silent; the decision of each is kept quiet. [15] [21] [22]

This can be rewritten as a table:

	Prisoner B cooperates	**Prisoner B defects**
Prisoner A cooperates	Each serves 1 month	A serves 1 year; B goes free
Prisoner A defects	A goes free; B serves 1 year	Each serves 3 months

Figure 1.1: Prisoner's Dilemma scenario as a matrix.

It is important to note that the original description implies a one-off decision process, with each player making one move, unknown to the opponent. To make this framework useful in the analysis of human interaction, we must extend this to an iterated system. The iterated Prisoner's Dilemma will simply be defined as:

> When two players play the Prisoner's Dilemma more than once in succession, remembering their previous actions and those of their opponents.

1.2 Interests and Reasoning

In this game system, strategies are analogues for human players acting as the prisoners. Each strategy has a set of rules that cooperates or defects in the current round based on the history of plays by itself and the opponent. This is an oversimplification of the complexity of human interaction and causes situations that do not correspond to real-world behaviour. An example of this is the statement by Axelrod and Hamilton that "`TIT FOR TAT` is an extremely robust [strategy for the Prisoner's Dilemma]". To analyse this, we take a look at what `TIT FOR TAT` means in the context of the Prisoner's Dilemma and why it can be considered unrealistic to agree with that statement in the context of real-world behaviour.

Following `TIT FOR TAT`[1], as defined in *The Evolution of Cooperation*, is to cooperate on the first move and then play the opponent's last move. This produces a pattern of passive-aggressive behaviour that, while used in society, is not the default social norm for interaction [30, p. 12].

We aim to show that it is because of the inherent materialism in the classical system that these non-cooperative plays emerge. We wish to assert that decisions in real life incorporate an additional moral or social payoff and aim to demonstrate improvements on existing research by Ghoroghi [8], Ounsley [21] and Sakellariou [24] by expanding the work into a dual game of separate material and social scores.

1.3 Aims and Questions

The main idea for this project is to develop a framework for running and documenting the performance of strategies that play a dual iterated game of the Prisoner's Dilemma and to analyse the moral implications of the submitted strategies and the system as a whole. We will build upon the previous work in this area by Ghoroghi, Ounsley and Sakellariou which in turn is based on the Axelrod's concepts and his tournaments [1].

To do this, we will use a double game where the first game is simply the standard game of material incentives for the players, whereas the second game is an independent game of prosocial behaviour and morals. Both games use the theoretical structure of the Prisoner's Dilemma but have different payoffs for each action. See the Background chapter for more details on the payoff matrices and methods for combining the games.

[1] First presented by A Rapoport as a submission to Axelrod's first Prisoner's Dilemma computer tournament.

The difference from previous works involves the separation of the material and social game scores and a deeper social consideration of the results.

Students and staff will be requested to write in either valid Java, C++ or pseudocode an algorithmic strategy for a project based on an extension of the classical problem in Mathematics and Computer Science called the Prisoner's Dilemma. Each person can submit as many strategies as they wish (each improving on the last, for example) and they will be attributed in the code and report — specifically to reinforce the concept of responsibility for materialistic actions and defection, and hence, shame and guilt. The final analysis is focussed on the concept of moral and prosocial play in this usually materialistic game theory problem and aims to examine the tension between these two sides.

This project looks to answer whether Axelrod's tournaments and similar studies since the 1980s and their statements about the applicability of materialistic strategies such as `TIT FOR TAT` are valid and accurate real world representations and predictors of collaborative human behaviour.

It also looks, via the organisation of round robin tournaments among students (and possibly staff) in the department, college and on-line, to determine optimal winning strategies.

To satisfy our aim of creating conditions that are as close as possible to the real world, we will consider a material prize for the highest total payoff among all players and a donation to a registered charity based on the total social payoff of all players. In the players' combinations, this will ensure that a real tension exists between obtaining a material prize and acting prosocial as expected by societal norms [5].

Chapter 2

Background

2.1 Summary

As described in the Introduction chapter, this project focusses on the problem of the Prisoner's Dilemma, and specifically the use of a dual game of both material and social payoffs to more accurately link the predictions and structure of the game with real-world human corporative interaction.

Before returning to a formal description of the Prisoner's Dilemma, we wish to describe the foundations and mathematics of these problems in the subject of game theory. This includes the principles of games similar to the Prisoner's Dilemma, coordination games, payoff matrices and Nash equilibria.

2.2 Game Theory

Game theory is a very wide-ranging field in mathematics primarily involved with the description and analysis of strategic gameplay. There may also be resources for which these players compete and rules for reaching a winning state. Formally, per Myerson, it is "the study of mathematical models of conflict and cooperation between intelligent rational decision-makers" [19]. This means that we are expected to "treat human beings as agents that aim to maximise their gains and minimise their losses" [24]. We will see later, based on this definition, how this project extends outside these reaches of game theory, mainly due to reasoning that humans aren't necessarily fully rational and may not be modelled as these decision-making agents. In this context, a game is any environment in which there are players that make decisions and a set of rules for the interaction between the players.

2.3 Coordination Games and Payoff Matrices

Of the many fields into which game theory delves and to which it has given much inspiration, economics is one of the most commonly-researched and practically useful areas. A class of games known as coordination games are a particularly helpful bridge into macroeconomics and implications of game theory.

Coordination games are those where the aim of players is to choose the same or corresponding strategies for play in the environment, rather than relying solely upon conflict [4]. A scenario by Schelling [25] and referenced by Cooper [4, p. viii] can be used as an example:

> Two people must make independent selections of a location. Success is only possible if their choices agree.

The most interesting idea about both coordination games and later the Prisoner's Dilemma, emerge immediately. What should the players do given that the decisions are independent and the winning scenario requires coordination[1]?

While this is an interesting problem in itself, that can be embellished further for both simplification or further complication [4, p. ix], here we will find it useful to introduce payoff matrices to allow us to interpret games such as these, later developing them to be used for the Prisoner's Dilemma.

A payoff function for a player returns the utility score (be it monetary gain or resource use or another score) based on the action of the player and their opponent for a particular round. All of the possible combinations of player and opponent parings can be sorted into a table, with their scores in a matrix. For the basic coordination game where the correct location is named l, we may have the following, using scores in the format `(Player A, Player B)`[2]:

	Player B chooses l	**Player B chooses m**
Player A chooses l	$(1, 1)$	$(0, 0)$
Player A chooses m	$(0, 0)$	$(0, 0)$

Figure 2.1: Coordination game numerical payoff matrix.

2.4 The Prisoner's Dilemma

Developing upon the basic framework of the Prisoner's Dilemma, coined and first defined by Tucker as cited in Poundstone [22, p. 8], we study the mathematical formulation of this problem. We can remove the original setting and convert the outcomes for each player (prisoner) into scored payoffs as with the coordination game. The scores are now in positive units, for example prize money.

[1] The extent to which coordination is important depends on the game. In the simplest case of the coordination game, we need exact coordination of locations. In the more embellished cases, the closer the players are to the correct location, the better. Finally, in the Prisoner's Dilemma, coordination represents the decision of whether both players cooperate or defect or play otherwise — noting that the "best" societal outcome is coordination of cooperation.

[2] Where L is the set of all possible locations and the correct location, ie: the one which both must choose to win is $l \in L$. Any other location, $m \in L, \neq l$ is incorrect.

	Player B cooperates	Player B defects
Player A cooperates	$(3, 3)$	$(0, 5)$
Player A defects	$(5, 0)$	$(1, 1)$

Figure 2.2: Prisoner's Dilemma numerical payoff matrix.

This allows us to generalise the problem and link the real-world situation with human studies that we expect to produce and those performed by, for example, Yamagashi and Kiyonari [31] and Axelrod and Hamilton [2].

As formalised by A W Tucker, abstracting this further out into prize constants will help us understand the problem even better. By noting which scores are rewards and which ones are punishments, we can relate back to the original prisoner situation easily.

	Player B cooperates	Player B defects
Player A cooperates	(R, R)	(S, T)
Player A defects	(T, S)	(P, P)

Figure 2.3: Prisoner's dilemma material game payoff matrix.

Where R is the Reward for mutual cooperation, S is the Sucker's payoff [13], T the Temptation to defect and P the Punishment for mutual defection.

There is a set of rules governing the variables that define this as a Prisoner's Dilemma and rationalise the scenario as per Axelrod [1]:

- $T > R > P > S$ — this makes it clear that while the temptation is to betray, it will be a better game for players to mostly cooperate.

In the iterative game, we also stipulate:

- $R > \frac{T + S}{2}$ — to prevent players from simply alternating between defecting and cooperating, we give them a better average score when mutually cooperating.

2.5 The Social Prisoner's Dilemma

With this theoretical framework in place, we can create the second component of our study: the social Prisoner's Dilemma. This will be played alongside and linked later in The Dual Game Prisoner's Dilemma section.

In the social version, we use a simpler scoring table to place a strong bias towards the cooperation-versus-defection aspects only and not the play of the opponent. For this we have two components:

Where M is the Moral (or social) payoff and rewards cooperation and M' is its counterpart that punishes defection.

	Player B cooperates	Player B defects
Player A cooperates	(M, M)	(M, M')
Player A defects	(M', M)	(M', M')

Figure 2.4: Prisoner's dilemma social game payoff matrix.

Now we can add a number of other rules specifically relating the social with the material Prisoner's Dilemma:

- $M > \dfrac{R+P}{2}$ — for there to be a strong incentive to play the social route.
- $R > M$ — to give a more realistic representation of today's societal structure: because charitable giving is a discretionary purchase, a material prize is often valued more than a charitable one [7].
- $M' = S$ — to remove the incentive to set the social coefficient to its maximum value and then defect, we punish defection in the social game as strongly as we do the Sucker in the material game. This also discourages bluffing and lying in general and removes this complication from this stage[3] of the game.
- Taking into account the above rules, the values are chosen according to Axelrod [1, p. 8] to be as follows: $T = 5$, $R = 3$, $P = 1$, $S = 0$, $M = 2.5$ and $M' = 0$.

2.6 The Dual Game Prisoner's Dilemma

Based on the *Double Game* concept first presented by Ounsley [21] and expanded by Sakellariou [24], we want to build the two components, of materialistic and social play, into a dual game where each player will play two games at once.

The strategy will aim to win both a material prize and also a social (charitable) prize, depending on the player's social inclination. This is determined by a social coefficient in the closed interval $[0, 1]$ which is referred to as `lambda` or λ. The most basic aim of any strategy is to be able to respond to their opponent with a `Cooperate` or `Defect` reply, optionally shifting their social coefficient further towards the material play or to the social play. These strategies will play many times, iteratively, for a variable number of rounds.[4] It is the aim of players to play in such a way as to get a maximal score — see Scoring and Winners later for how that is calculated.

The new payoff table for the two games combined is shown below. Note that in the dual game, λ_A is the social coefficient of player A and λ_B is that of player B. Finally, we need to represent the material contribution of the strategies, but since the

[3]The implication is that distinct values for M' and S could be reincorporated for further discussion given extra time.

[4]Where the total number of rounds is unknown to prevent the degenerate case of total defection.

social coefficient ranges from zero to one, we can write the material coefficient simply as $(1 - \lambda)$.

It is worth noting that "combined" above does not mean the scores are added together as in the previous works [21] [24] and simply means grouping the values together. In fact, as a continuation of the syntax in the previous section, the social and material scores are kept separate in the format $((material_A, social_A), (material_B, social_B))$. As strategies play further rounds, their material and social scores are tallied separately and recorded as two running totals that, along with λ, completely represent the current state of the player. We believe this is a better way of formulating the dual game as it does not lose the meaning of the two scores by themselves and allows us (and strategies) to measure social contribution separately and with equal importance to material contribution. This can be described in the payoff matrix defined here:

	Player B cooperates	**Player B defects**
Player A cooperates	$((1-\lambda_A)R, \lambda_A M), ((1-\lambda_B)R, \lambda_B M)$	$((1-\lambda_A)S, \lambda_A M), ((1-\lambda_B)T, \lambda_B M')$
Player A defects	$((1-\lambda_A)T, \lambda_A M'), ((1-\lambda_B)S, \lambda_B M)$	$((1-\lambda_A)P, \lambda_A M'), ((1-\lambda_B)P, \lambda_B M')$

Figure 2.5: Prisoner's dilemma dual game payoff matrix.

We can now complete the ruleset with two final restrictions for the dual game:

- The social coefficient is a discrete value to simplify the system. It is fixed to one of six values: $\lambda \in \{0.0, 0.2, 0.4, 0.6, 0.8, 1.0\}$. These values are selected to be located in each of the interesting regions of the Payoff-Lambda graph in Figure B.1 p. 37.
- To model human dynamics in social behaviour more accurately, we will limit by how much strategies may change their λ per round. A value similar in function to the δ used in [21] will restrict the maximum change in social coefficient per move. Our delta is defined as $\delta \in [-1.0, 1.0]$, but will likely be smaller to prevent abrupt changes from total material to total social contribution and vice versa.
- For the sake of privacy and the more accurate modelling of the ability of humans to discern each others' strategies, we introduce a new variable χ. This will represent how recently into an opponent's move history, χ_{move}, and social coefficient history, χ_{coeff} they can read. As an example, in Ounsley's work, strategies cannot see their opponent's social coefficient at all, so $\chi_{coeff} = 0$, but they see the entire n rounds of previous moves, making $\chi_{move} = n$. We will aim to keep $\chi_{move} = n$ but have $\chi_{coeff} \geq 1$. This will give us a more interesting view, and what it explicitly entails is that opponents can determine what their opponent's inclination was up to χ_{coeff} moves ago. See Figure 2.6 p. 14 for a diagrammatic approach.

2.7 Nash Equilibria and Pareto Optimality

An important concept in game theory, and of particular use for this project is the notion of the Nash equilibrium after John Nash [29, p. 14]. The state of Nash equilibrium is

Time step	1	2	...	$n-2$	$n-1$	n
Move history	$Visible$	$Visible$	...	$Visible$	$Visible$	$Visible$
Social coefficient history	$Visible$	$Visible$	...	$Visible$	$Hidden$	$Hidden$

Figure 2.6: Move and coefficient history and the function of χ for a strategy as seen by its opponent when $\chi_{move} = 0$ and $\chi_{coeff} = 2$.

when each player knows the equilibrium strategies of their opponents and cannot improve their score by changing only their strategy, while the others remain unchanged.

A similar concept to the above is that of Pareto optimality, or Pareto efficiency. If no player can make an improvement to their score without making another individual worse off, then we are in a state of Pareto optimality.

As Nash equilibria define stability for players only for unilateral deviations by definition, we can define a *coalition-proof Nash equilibrium*: a Nash equilibrium in which players cannot do better even when allowed to make performance promises. When a strategy is strictly dominant[5] and on the Pareto frontier (the set of choices that are Pareto efficient), it is in coalition-proof Nash equilibrium.

For the Prisoner's Dilemma, the payoff matrix is based on the tables above in The Prisoner's Dilemma section with Axelrod's $T > R > P > S$ rule [1]. Following the technique to determine a Nash equilibrium, we see that each player can unilaterally improve their situation by defecting regardless of the other's decision. Therefore, the optimal strategy is for both players to defect (D). Using the standard scoring, however, we know that the utility of a mutual defection (D, D) outcome is globally inferior than one of mutual cooperation (C, C).

Although there is only one Nash equilibrium of defection for the single game dilemma, cooperation is more favourable in a repeated game when the punishment is not too high and it is in the interest of players to consider future outcomes. We aim to investigate the impact of combining this with the social game in dual format tournaments.

2.8 Nash Equilibria Analysis

Now we describe the importance of Nash equilibria in the Prisoner's Dilemma and a series of preferred orders of play for each type of game:

2.8.1 Pure and Mixed Strategies

It is important to study the difference between pure and mixed strategies and see how we can use pure strategies to describe most, but not all, Nash equilibria for the Prisoner's

[5] A strategy X *dominates* another strategy Y if choosing X always gives at least as good an outcome as choosing Y. Further to this, we have that X *strictly dominates* Y if choosing X always gives a better outcome than choosing Y, no matter what the other strategy or strategies do.

Dilemma (later section In the Dual Game). We will then make use of mixed strategy analysis to complete the picture.

A pure strategy totally defines a player's move in the game and has a deterministic move given a game state.

A mixed strategy defines each outcome probabilistically such that there is an assigned probability for a player to making each one of the possible move given a game state.

By definition, a pure strategy is a subset of a mixed strategy where the selected move has probability one and all other moves have probability zero.

2.8.2 In the Single Game

The preferred order of play for a rational player in the single materialistic game is:

$$(D, C) > (C, C) > (D, D) > (C, D)$$

This shows that the best response to cooperation is defection ($(D, C) > (C, C)$) and the best response to defection is once again defection ($(D, D) > (C, D)$) which indicates that the best response for both players is mutual detection, as per the standard Prisoner's Dilemma Nash equilibrium (D, D) [24].

Whilst in the single social game the optimal order for player one is:

$$(C, C) = (C, D) > (D, C) = (D, D)$$

In this case, the best response to cooperation is cooperation ($(C, C) > (D, C)$) and the best response to defection is cooperation ($(C, D) > (D, D)$) which clearly shows that the best response for both players is mutual cooperation, meaning that the Nash equilibrium for the social game is (C, C) [24].

2.8.3 In the Dual Game

When we combine the payoffs in a dual game, we need to analyse this in more detail as the social coefficient, λ, directly affects the payoff for each outcome which can be seen in Figure 2.5 p. 13.

We can describe the change in the orderings mentioned above using a graph showing the payoff against social coefficient as in Figure B.1 p. 37. The values at which the different strategy lines cross are three important points (a, b *and* c) that determine the coefficient at which a player would preferably change their strategy. As can be calculated from the graph and detailed extensively in [24, pp. 27-28], the values of these points are:

$$a = \frac{P - S}{M + P - 2S}$$

$$b = \frac{T - S}{T - R + M - S}$$

$$c = \frac{T - S}{T + M - 2S}$$

From the graph, and hence these formulae, we can calculate a player's preference based on their social coefficient. Ounsley showed in his analysis on pure strategies in [21, pp. 24-25] that the Nash equilibria for the different values are as follows, notably that the outcome does not change across the c boundary but only the a and b points:

	$0 \leq \lambda_B \leq a$	$a \leq \lambda_B \leq b$	$b \leq \lambda_B \leq 1$
$0 \leq \lambda_A \leq a$	(D, D)	(D, C)	(D, C)
$a \leq \lambda_A \leq b$	(C, D)	*mixed*	(D, C)
$b \leq \lambda_A \leq 1$	(C, D)	(C, D)	(C, C)

Figure 2.7: Nash equilibria for the two players' coefficient ranges.

While this is an important summary for pure strategies, we must look at mixed strategies to determine the special centre point in our table. The reason we know this to be a valid course of action is that:

Game Theory Theorem 1 *Every finite game has a mixed strategy Nash equilibrium.*[6]

Since we don't have a pure strategy solution for the centre case, there must be a mixed strategy one available based on the theorem. Helpfully, if a player plays probabilistically in the iterative game, they are, in essence, using a mixed strategy. From formulas in both previous works, we can now specify the central region of our coefficient table as the non-deterministic set of actions $\{(C, D), (D, C)\}$ see [24, pp. 29-30][7] and [21, pp. 26-27] to complete our Nash equilibria:

	$0 \leq \lambda_B \leq a$	$a \leq \lambda_B \leq b$	$b \leq \lambda_B \leq 1$
$0 \leq \lambda_A \leq a$	(D, D)	(D, C)	(D, C)
$a \leq \lambda_A \leq b$	(C, D)	$\{(C, D), (D, C)\}$	(D, C)
$b \leq \lambda_A \leq 1$	(C, D)	(C, D)	(C, C)

Figure 2.8: Complete Nash equilibria for the two players' coefficient ranges.

2.9 Strategy Traits

According to Axelrod [1] and based on his analysis of top-scoring strategies, he determined that successful strategies necessarily need to be:

[6] The *fundamental* theory of game theory, from Nash [20] and based on earlier work by von Neumann and Morgenstern.

[7] Sakellariou develops a helpful graphic he names the (λ, γ) *diagram* which we find useful and point out here is similar to our Nash equilibrium matrices, except that the γ axis he uses is an inverted version of our λ_B range.

Nice Strategies must not be the first to punish. It was noticed that an overwhelming majority of the winning strategies were optimistic in this way.

Retaliating Strategies must not be simply blindly optimistic, however, and must respond to punishment appropriately.

Forgiving Strategies must forgive previous punishment and resume being nice after having retaliated. This prevents revenge scenarios.

Non-envious Strategies should not aim to score more than their opponent. This non-competitive nature seems counter-intuitive but is one of the qualities of the high-scoring *nice* strategies.

Not too clever Strategies that try to make inferences or overly-complex decisions about opponents and gameplay often lose out and should try not to be too clever or tricky.

2.10 Conclusions in Related Work

While there has been much work done on the Prisoner's Dilemma, this project specifically builds upon that done by Ounsley and Sakellariou both as supervised by Edalat [21] [24] with a modification of the implementation of the dual game. In Sakellariou's report, the consideration was to maximise a single variable: combining together the social and material scores using addition. Here, however, we aim to maximise the scores as separate values, with the idea that social and material scores are not to be combined but rather appreciated separately.

The previous work by Ounsley has concluded that the Prisoner's Dilemma can be successfully extended with the social considerations defined above — a social coefficient for combining two games with a social and a material gain. It also discovered that without any governing social rules, players that play prosocially (ie: prefer cooperation and hence social over material gain) are easily exploited by materialistic strategies. However, as with Axelrod's *nice* strategy rule, it was noted to be beneficial to cooperate if wishing to counter a defecting strategy. The study realised that `TIT-FOR-TAT` performs poorly in the social dual games due to its less forgiving, anti-social, retaliation trait. Ounsley's report also reveals the importance and usefulness of a dual game structure in simulating more advance scenarios and behaviours than those possible by the classical Prisoner's Dilemma, for which reason we shall also employ this technique. [21]

Further to this, Sakellariou's work developed a method for looking up the Nash equilibria for a double game and evaluated conditions for optimality for mixed strategies, determining that the best action when there are multiple Nash equilibria is to defect. Sakellariou implemented Bayesian inference for determining opponent strategy play patterns, proving them to be consistently top-scoring players and upon which we will build by making use of Bayesian strategies as competitors in our tournaments. Finally, he introduced a continuous version of the Prisoner's Dilemma which represents real-world situations more closely as it does not restrict players to total defection and cooperation. It was proved that the pure strategy Nash equilibrium for that case is mutual defection. [24]

2.11 Tournament Structure

Based on the initial thoughts given by Ounsley, Sakellariou and Edalat, particularly in [21, p. 19], we define the format of the tournaments that we will perform.

The strategies that are submitted will compete over a large number of rounds, the exact value being in the reasonable [21] range of one to two hundred. The exact number of rounds will not be given to avoid the degenerate case of total mutual defection[8]. Apart from this non-explicit limit, the strategies must follow a number of stated restrictions as set out in The Social Prisoner's Dilemma and The Dual Game Prisoner's Dilemma to participate. All of the simplifications and moral restrictions, such as using λ with discrete step-wise values and limiting the maximum change to δ, for example, are defined there.

The tournament rounds will be played in round-robin fashion[9] in the same way that previous tournaments have been played, famously with Axelrod's computer tournaments [1]. With all of this kept rigid and constant per tournament[10], the only variations should be in the strategies themselves: their strategy (and its complexity), initial social coefficient and starting move.

2.11.1 Friendly Rounds

Before running the main tournament that will generate the scores from which prizes are determined, a set of small, *low-key*, rounds are planned as friendly matches between proto-strategies[11] that will be beneficial in two ways:

- Providing early data for a better understanding and improvement of expectations for the results of the real game.
- Giving friendly strategy authors the chance to build stronger, more robust implementations for the final game in a form of trial and error, with each preliminary run counting as an evolutionary stage.

[8] If the total number of rounds, n, was known, a strategy would plan to defect at round n as there is no repercussion for doing so and they can guarantee the maximum payoff. Similarly, they can also defect in round $n-1$ because they and their opponent will have (theoretically at least) defected in round n. This continues backwards until defection is planned in all rounds.

[9] A schedule technique in which every viable pairing will eventually be chosen by the scheduler. Each strategy will compete with all other pairings and themselves once.

[10] Time permitting, we may conduct more than one main tournament, with different rules for each.

[11] Strategies that are either basic in nature and will not participate in the main game or strategies that are preliminary constructions that will be improved upon based on the results from the friendly rounds before playing competitively.

- Potentially an analysis of changed behaviours when strategies are knowingly written without the aim of winning a prize against those that are.

2.12 Considerations in Psychology and Social Sciences

There are numerous important considerations to make with this project with respect to the social component. Studies have appeared in the European Journal of Social Psychology [3] and the American Psychological Association [17] among many others, provably demonstrating that these are relevant topics to this study. A number of points are to be made:

- Players will be briefed on the importance of cooperation and the real-world social norms that approve of charitableness and disapprove of selfish play. Participants will face the consequences of defection or a low social coefficient and this will be implemented using a publicly-visible scoreboard of each player's recent play and variable states.

- Players will be made aware of the charity to which the social prize will be donated in advance, preferably using the promotional advertising supplied by the charity. This is to exploit the conclusion by Hibbert and Hoon Chuah that "moral emotional fundraising appeals are effective in soliciting donations" [11].

- The mentality of the subjects that submit strategies can greatly affect the performance of strategies. We need to be careful to solicit audiences from as many different fields and walks of life as possible. Particularly, there are stereotypes associated with computing department courses, and hence the students we will be contacting, which has the potential to skew outcomes [9]. If the audience cannot be widened we need to accommodate for any of the following variants: over- and under-engineering, aggressive and passive submitters, all linked to the social and educational background of the author.

- Players will confront the situation that they are publicly accountable for their actions, or have "lost face", if they win the material prize having contributed little to the charitable, social side. We must analyse how people apply social norms to their strategies.

- Consider and analyse the potential reasoning behind cooperation in players. Compare and contrast with the concept of altruistic punishment in humans and how it can be a cause for cooperation in games such as the Prisoner's Dilemma, as discussed by Fehr and Gächter [6].

- We will use the social coefficient of strategies as a genuine measure of prosocial behaviour, and see how pure of an indicator it is, particularly whether other facets of the game, such as starting move, affect this.

2.13 Limitations

The project is constrained by a few issues that are difficult to overcome:

- A monetary prize needs to be secured for the winner of the material game. This is limited to a reasonably low value due to the difficulty of obtaining large cash amounts from institutions that will get little benefit from the tournament. The best option is to request funds from the Department of Computing, however there may be restrictions on who is eligible to receive a prize, such as requiring them to be members of the department. We need to consider the social implications of that, as discussed in the section Considerations in Psychology and Social Sciences.

- The larger the number of participants the better, as we will have more strategies, and therefore data. However, if we petition for participation from outside the college (and even the Department of Computing) then we have to entertain the possibility of not being able to enter external strategies into the prize-eligible contests due to funding rules or limits. We will have to trust that participants will provide strategies regardless, and hope that they can take "intellectual satisfaction" as their prize.

- There is a difficulty in this topic to remain entirely quantitative. This topic reaches heavily into the psychology from its strong game theory mathematics base. As stated by Rapoport and Chammah, this means there will be a large component of "intuitively inspired knowledge" which can be in contrast to that which is "rigorously demonstrable" [23].

Chapter 3

Project Plan

The aim of this project is to discover previously unknown patterns in prosocial play between opponents during the course of these tournaments. The aim is to provide a real-world incentive to players to write and submit strategies. This is expected to make them write strategies to the best of their abilities, and resembling their own personal social inclinations as closely as possible. The real-world material game prize could be an item of some monetary value. The real-world social game prize should be a substantial contribution to a widely supported charity whom the players are made aware of at the beginning of the game — with the contribution being of a similar cash value as that of the material prize.

We expect to receive strategies in either pseudo-code or complete coded algorithms which will be converted to Java for running through the framework that has been constructed. The strategies will be run against each other in multiple tournaments, some of them scored and contributing towards prizes, and some purely for testing.

All rounds will provide useful data for later analysis, however, the scored rounds will produce scores which will be recorded publicly and be used to decide on the prizewinners.

3.1 Project Requirements

The following is a summary of the general ideas that need to be produced or completed to accomplish the project:

- A set of rules and a policy for tournament player submissions and prizes.
- A marketing strategy for obtaining submissions.
- A software framework for the running of strategies.
- A comparative and contrastive analysis of the submissions.

3.2 Scoring and Winners

With the exception of a few cases prevented by the *Rules and Restrictions* below, the winners are determined as below:

- The material winner is the player with the highest total score.
- While there is no one social winner (as this is easy to win at by simply setting $\lambda = 1$ and always cooperating), the collective score accumulated from all social contributions by all players will produce the total social win. The total charitable donation is fixed[1] but the contributions to the donation are determined by the small constituent social plays of each strategy.

The overall winner will be at the discretion of the tournament organisers and will be determined by a combination of factors:

- The difference in material score of the material and social winners.
- The difference in social score of the material and social winners.
- How much the material winner participated towards the social prize — what their ending coefficient was.
- How much the social winner participated towards the material prize — what their ending coefficient was.
- The strategy of the winner should not be expected to perform significantly worse than that of an expert strategy produced by staff or PhD students researching this very topic.

The relative importance of each criterion and the thresholds for minimal social participation, material participation and discrepancy between these participations are tournament-specific values and will be reasoned based on practical data as more and more strategy submissions are made available.

The financial values of both the material and social prizes are set in advance and a final consideration and decision for who wins should use the following reasoning:

> People who can achieve both the highest social score without compromising their material score, and the highest material score without compromising their social score, are the best candidates for winning.

And:

> The strategies that care most equally and fairly between the social and material payoff are, similarly, good candidates.

[1]Alternatively, if we can find a donation-matching funder, we will be able to have a variable and expanding donation amount

3.3 Rules and Restrictions

A number of rules and restrictions have to be implemented to maintain the integrity and meaning of the game in the context of this project in addition to those for the Prisoner's Dilemma itself and these will be:

- Participation in the prize-eligible tournaments will be public: scores and social coefficients for each participant will be displayed to all players and be publicly accessible — to ensure that we have the situation of public accountability as described in the section Considerations in Psychology and Social Sciences.

- After each round, an opponent can read the strategy's social and material scores. However, the social coefficient is private for a time. After a number of rounds, χ_{coeff}, the historical social coefficient for previous rounds starts becoming visible. This encourages more complex, realistic play but discourages cheating by not showing the latest coefficient value, requiring deduction on the opponent's part.

- It is not permitted to attempt to cooperate just after having defected and reduced one's social coefficient. Similarly, it is not permitted to attempt to defect just after having cooperated and raised one's social coefficient. Both of these measures are in place to prevent undermining the concept of the game and if a strategy attempts to perform one of these combinations, it is invalid.

- The numerical restrictions elaborated in the sections: The Social Prisoner's Dilemma and The Dual Game Prisoner's Dilemma.

3.4 Key Milestones

Now follows a summary of the important events in this project, specifically with major components that will need to be completed. Milestones that have occurred before the writing of this report, January 2012, have already been completed and those occurring after are listed with expected completion dates.

December 2011 Complete set of rules written up in a Project Background Introduction document and discussed for improvements with project supervisor Abbas Edalat and the research team.

December 2011 Complete Java framework for running tournaments of the dual game iterated Prisoner's Dilemma with separate material and social scores. Included are validation rules for checking that the strategies conform to the rules previously posed.

January 2012 Complete formal project plan in the form of this Project Interim Report, and tournament rules based on the ideas presented in the Project Background Introduction and code.

February 2012 Marketing plan for the promotion of the tournaments including[2] the following:

- Posters, flyers and other public advertisements.
- Circulated promotions to students and staff by email or otherwise.
- Confirmed material prize(s) and selected charity to support for the social prize.
- Method for (semi-)automated acceptance of strategies.

March 2012 Accumulation of participant strategies and deadline for submission.

April 2012 Completed running of tournaments and posting of results, checking validity of submissions and distribution of prizes when cleared to do so.

May 2012 Analysis and evaluation of data with inferences and conclusions made.

June 2012 Completion and submission of project, presentation and final report.

3.5 Current Progress and Next Steps

Based on the points stated in the Project Requirements and Key Milestones, we already have a completed framework, written in Java for the running of different strategies. The framework, which uses object oriented programming concepts for modularity, can determine whether strategies are valid as it implements the rules for the Prisoner's Dilemma as specified in the section on The Prisoner's Dilemma.

We additionally have a set of rules for the functioning of this theoretical system, and also rules for validating strategies to make sure they conform. These are described in part in the Project Background Introduction report and also in the Java code produced by this stage.

Once the Project Interim Report is read and analysed by markers, the main task will be to market the tournaments and solicit submissions for the contests. At this point we expect to have enough strategies to be able to run multiple rounds of prosocially extended Prisoner's Dilemma tournaments and produce substantial data which can be used for analysis. These will run alongside the preliminary strategies already produced by us and the research team, the results of which can be seen in Figure A.1, Figure A.2 and Figure A.3, p. 35, for varying χ_{coeff}.

After this stage, the data can be analysed: submitted strategies against themselves for the distribution of prizes and charitable giving as needed, and against existing data for comparison and meta-analysis.

[2]Including these items but neither limited to nor necessarily requiring all of them.

3.6 Fallback Positions

In the unfortunate event that one or more key milestones in the project are delayed, not produced on schedule or cannot be finished, and time no longer permits for the full set of tasks to be completed, then we devise a secondary plan to salvage the project to the fullest extent possible.

Possible problem scenarios and their fallback positions:

Insufficient or unacceptable third-party strategy submissions If there is not enough interest or the submitted strategies are not detailed or complex enough to perform to a reasonable standard in the tournaments, we can resort to writing our own strategies. The problem with this plan is that writing strategies knowing the research we have completed greatly skews the success of our work and modifies the analysis. Additionally, it limits the pool of potential prizewinners to a small number ≤ 5. We can attempt to mitigate this issue by requesting that lecturers participate instead — although we will still have to adjust for the different mentality and perceived higher charitableness of lecturers versus students.

Low or no support for the material prize and/or charitable donations In the scenario where there is little to no financial support for providing a material prize and/or a registered charity to which to donate could not be secured, then we must re-work the prize.

Other time constraints For any other problems related to limited time, we can cut out some less critical components of the project so that most can still be completed. Below are listed the items we can omit, starting with those that will cause the least impact to the project and that can be removed with greatest ease and benefit to saving time:

- Any additional extensions planned (see Extensions for a selection) as long as they are not part of the terms of the prize contest[3].
- Any additional *non-prize-eligible* tournaments.
- Writing extra strategies for research purposes that are not eligible to compete — for example, when the author is involved with this project.

3.7 Extensions

Given extra time or with any time remaining after having completed the core requirements of the task, up to the analysis of user-submitted strategies, there are a number of additional extensions and pieces of research that would be interesting to complete:

- Extra *non-prize-eligible* tournament runs with different variations in the visibility of lambda.

[3]From here on in *non-prize-eligible*; to avoid disappointing anybody, components that are part of the contest rules must be completed and winners remunerated.

- Extra *non-prize-eligible* tournament runs with additional stages for analysing more interesting ideas noticed from the base tournament(s).

- Perform a pair of side-studies using two small groups of participants each: how are the produced strategies affected by providing or not providing any background instructions on common Prisoner's Dilemma strategies? Ensure that the group to whom no information is given are not aware of the popular `BAYESIAN` and `TIT-FOR-TAT` strategies.

- Have users play against an evolving computer algorithm and see how they fare, with two cases: that of allowing and that of disallowing improvements to their strategies.

- Implement a strategy that uses imitation rules to copy the human test subjects and measure the success of such a strategy.

- Implement a *soft*-agreement system whereby players make promises to their opponent about the move they will make[4]. See whether players are altruistic: will they let their opponent win if their opponent promises that they will give everything to charity?

- Compare and contrast developments in this field with the related game theory problems in economics and biology "tragedy of the commons"[10] and the "assurance game" or "stag hunt"[28].

[4]In a soft agreement, these promises are non-binding and can be outright lies. The strategy's social coefficient can determine, how enforceable the promise is. For $\lambda >$ some threshold τ, the final action taken must follow the promise made.

Chapter 4

Evaluation Plan

4.1 Deliverables

The project has two sides: one of a computational component involving programmed strategies and frameworks that need to be delivered, and one of data analysis and interpretation involving mathematics, game theory and psychology.

Computing functionality that needs to be demonstrated includes:

- The ability to play pairs of strategies together and display the social and material scores, the social coefficient and a history of moves for both players.
- The ability to run multiple sets of strategies in a round-robin style tournament for a continued, iterative game where play histories are retained until the end of each round.
- The ability to check each provided strategy against a set of rules to determine its validity for the tournament.

Experiments that need to be undertaken in all fields include:

- Determine whether players attempt to observe and manipulate their opponent.
- Discover whether better strategies tend to be more altruistic and whether altruistic behaviour evolves as a form of natural selection.
- Analyse whether strategies conform to unwritten social norms.
- Compare the models that these strategies produce for the Prisoner's Dilemma with those used in the real world to model economies. Analyse whether recent situations such as Occupy Wall Street and the credit crisis could be improved upon or avoided by taking into account social views.
- Analyse how much of an indicator of a player's views and prosocial leaning their social coefficient truly is.

- Discover what players do to protect themselves from being exploited.
- Find whether it would be better to aim for cooperation, confusion, chaos or being random than following one of the more traditional Bayesian or Nash equilibrium strategies.

4.2 Measuring Success

Whether the project is a success is a combination of qualitative and quantitative analyses. While not a direct measure of the success of the project, we will use the latter to determine whether any submitted strategies perform better than the baseline `TIT-FOR-TAT` strategy and by how much better that is. For measuring the project itself we look to the following points where we measure numeric values and aim to convert many of the less well-defined measures into quantitative values.

4.2.1 Quantitative Aspects

Some examples of immediately[1] measurable metrics for the overall strategy space include, for the set of all strategies X:

$$Social\ ratio, r_s = \frac{\sum_{x \in X} Social\ score_x}{\sum_{x \in X} Social\ score_x + \sum_{x \in X} Material\ score_x}$$

$$Material\ ratio, m_s = \frac{\sum_{x \in X} Material\ score_x}{\sum_{x \in X} Social\ score_x + \sum_{x \in X} Material\ score_x}$$

And for specific strategies, $x \in X$ we may wish to see whether they lie for the scoreboard[2] by presenting a higher social coefficient than they use for the majority of their play:

$$Contribution\ index, C_x = \frac{Social\ score_x}{r_s}$$

$$Apparent\ social\ index, A_x = \frac{\lambda_x}{r_s}$$

$$Mean\ social\ index, \overline{\lambda_x} = \frac{\sum_{i=1}^{n} \lambda_{xi}}{n}, \text{ where } \lambda_{xi} \text{ is } \lambda_x \text{ at round } i.$$

From these we can find a few interesting descriptors of strategies:

$$Prosocial\ index, P_x = \frac{\overline{\lambda_x}}{C_x}$$

$$Mask\ index, M_x = \frac{\overline{\lambda_x}}{A_x}$$

[1] At the end of the tournament.

[2] It can be considered a benefit rather than a disadvantage of the scoreboard to show only the final social coefficient as it allows us to analyse whether players attempt to mask their intentions.

4.2.2 Qualitative Aspects

There are numerous qualitative areas to this project involving interpretations of social dynamics and considerations for the charitable actions of the players. We attempt to measure certain parts by using the social score as a quantitative measure of players' prosocial play. However, in terms of measuring the projects success, we can only quantify the amount of novel discovery made and number of conclusions we can make about our tournament results. The other aspects will be analysed as scientifically as possible, but potentially without many numeric outputs.

We can clarify the success of the tournaments and the marketing involved by determining how widespread the interest and submissions were. Some measures follow which can be used as percentages and ratios for qualitative measure:

- To quantify how "good" submissions were:

$$Good\ strategy\ ratio, r_{good} = \frac{Strategies\ beating\ \texttt{TIT-FOR-TAT}}{Strategies\ submitted}$$

- To quantify how "popular" the competition was:

$$Participation\ ratio, r_{part} = \frac{Strategy\ authors}{Potential\ audience}$$

  To determine the size of the audience, we will need to make a few estimates and will require knowing emailed recipients with flyers given and average poster viewers.

- To determine how "prolific" submitters were:

$$Average\ prolificness = \frac{Strategies\ submitted}{Strategy\ authors}$$

4.3 Future State of the Art

This project is expected to build upon the ideas of Ounsley and Sakellariou and develop more thought about the Prisoner's Dilemma in the fields of game theory but also in psychology and other areas that the social and moral aspects of this project touch.

It specifically wishes to challenge the assumptions and preconceptions about morality and give a stronger weighting and independence to the social Prisoner's Dilemma. It wishes to use real-world devised strategies to bring our important analyses, as listed in the Deliverables section.

We hope to produce at the very least some "intuitively inspired knowledge" [23] about all of the social issues discussed in this document as well as produce some meaningful numeric data to support this. We do not target any particular viewpoint and remain open-minded about the possible outcomes of these analyses — particularly with respect to implied social norms between players.

With these outputs and conclusions we hope to further fade the boundary between subject areas in the topic of the Prisoner's Dilemma and add to the vast academic research that it deservedly has already.

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Appendix A

Strategy Results

Strategy Name	Author	Ending λ	Material Score	Social Score
AE-GS	Georgios Sakellariou	1.00	2.40	6491.00
AE-GS-S	Georgios Sakellariou	1.00	2.40	6490.00
Always Cooperates	Theodore Boyd	0.50	0.00	6500.00
Always Defects	Theodore Boyd	0.50	5000.00	0.00
Always Random	Theodore Boyd	0.50	0.00	3227.50
Bayesian	Ali Ghoroghi	0.80	1993.40	3160.50
Nash Tit For Tat	Ali Ghoroghi	0.80	279.60	5451.00
Negative People	Ali Ghoroghi	0.00	6774.60	0.00
Nonsense People	Ali Ghoroghi	0.50	5424.00	0.00
Positive People	Ali Ghoroghi	1.00	0.00	6500.00
Social Tit For Tat	Theodore Boyd	1.00	544.00	4380.00
Tit For Tat	Theodore Boyd	0.50	6292.00	0.00

Figure A.1: Results produced by running constructed strategies for $n = 200$ total, with each strategy therefore playing 2600 games, with $\delta = 0.2$, $\chi_{move} = n$ and $\chi_{coeff} = 1$

Strategy Name	Author	Ending λ	Material Score	Social Score
AE-GS	Georgios Sakellariou	1.00	1.80	6492.00
AE-GS-S	Georgios Sakellariou	1.00	6.80	6488.00
Always Cooperates	Theodore Boyd	0.50	0.00	6500.00
Always Defects	Theodore Boyd	0.50	5000.00	0.00
Always Random	Theodore Boyd	0.50	2428.80	1289.00
Bayesian	Ali Ghoroghi	0.40	2006.60	3103.50
Nash Tit For Tat	Ali Ghoroghi	1.00	206.80	5777.00
Negative People	Ali Ghoroghi	0.00	6729.40	1.00
Nonsense People	Ali Ghoroghi	0.50	0.00	6500.00
Positive People	Ali Ghoroghi	1.00	3.60	6496.50
Social Tit For Tat	Theodore Boyd	1.00	252.80	5063.50
Tit For Tat	Theodore Boyd	0.50	6760.00	0.00

Figure A.2: Results produced by running constructed strategies for $n = 200$ total, with each strategy therefore playing 2600 games, with $\delta = 0.2$, $\chi_{move} = n$ and $\chi_{coeff} = 2$

Strategy Name	Author	Ending λ	Material Score	Social Score
AE-GS	Georgios Sakellariou	1.00	2.40	6491.00
AE-GS-S	Georgios Sakellariou	1.00	2.40	6488.00
Always Cooperates	Theodore Boyd	0.50	0.00	6500.00
Always Defects	Theodore Boyd	0.50	5000.00	0.00
Always Random	Theodore Boyd	0.50	810.60	2528.00
Bayesian	Ali Ghoroghi	1.00	1864.60	3296.50
Nash Tit For Tat	Ali Ghoroghi	0.80	316.00	5403.50
Negative People	Ali Ghoroghi	0.00	6664.20	23.00
Nonsense People	Ali Ghoroghi	0.50	5388.80	0.00
Positive People	Ali Ghoroghi	1.00	0.60	6499.50
Social Tit For Tat	Theodore Boyd	0.80	481.60	4436.50
Tit For Tat	Theodore Boyd	0.50	6302.00	0.00

Figure A.3: Results produced by running constructed strategies for $n = 200$ total, with each strategy therefore playing 2600 games, with $\delta = 0.2$, $\chi_{move} = n$ and $\chi_{coeff} = 3$

Appendix B

Payoff-Social Coefficient Graphs

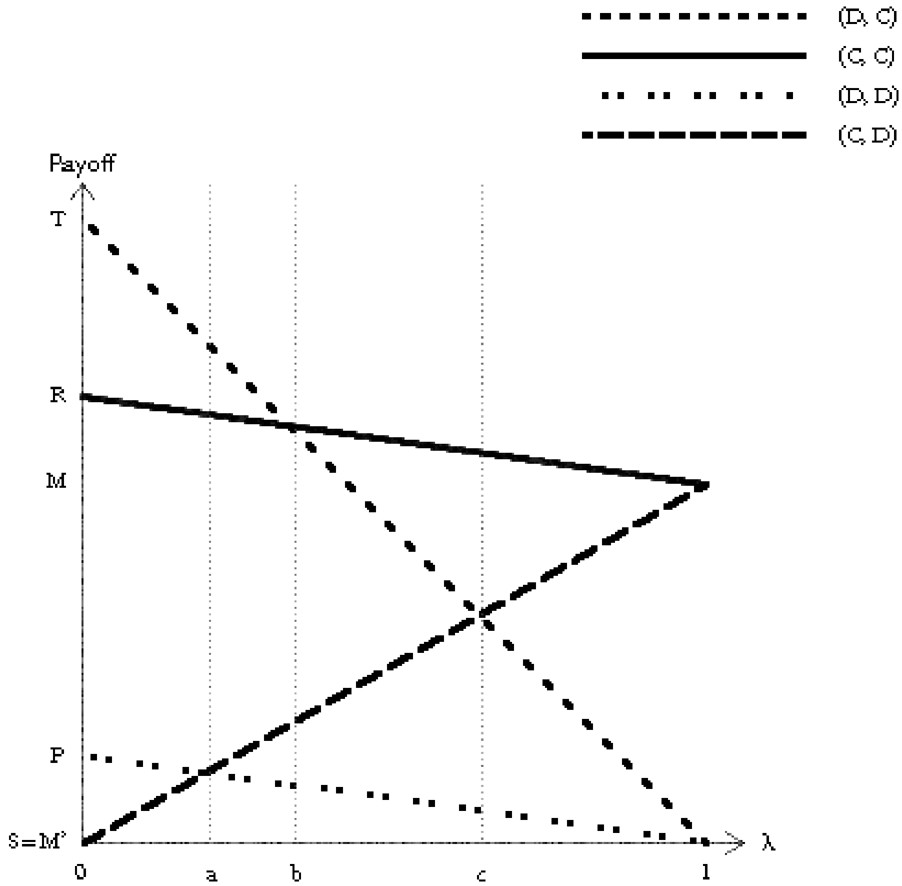

Figure B.1: Graph of payoff against social coefficient for $a < b$.

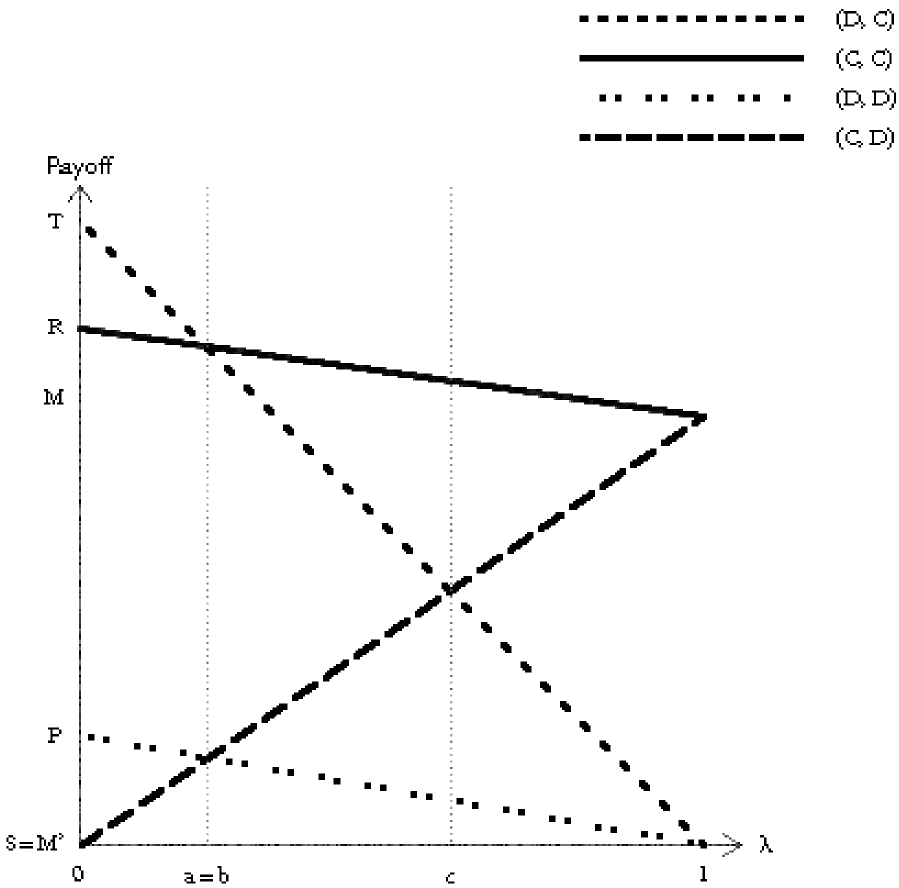

Figure B.2: Graph of payoff against social coefficient for $a = b$.

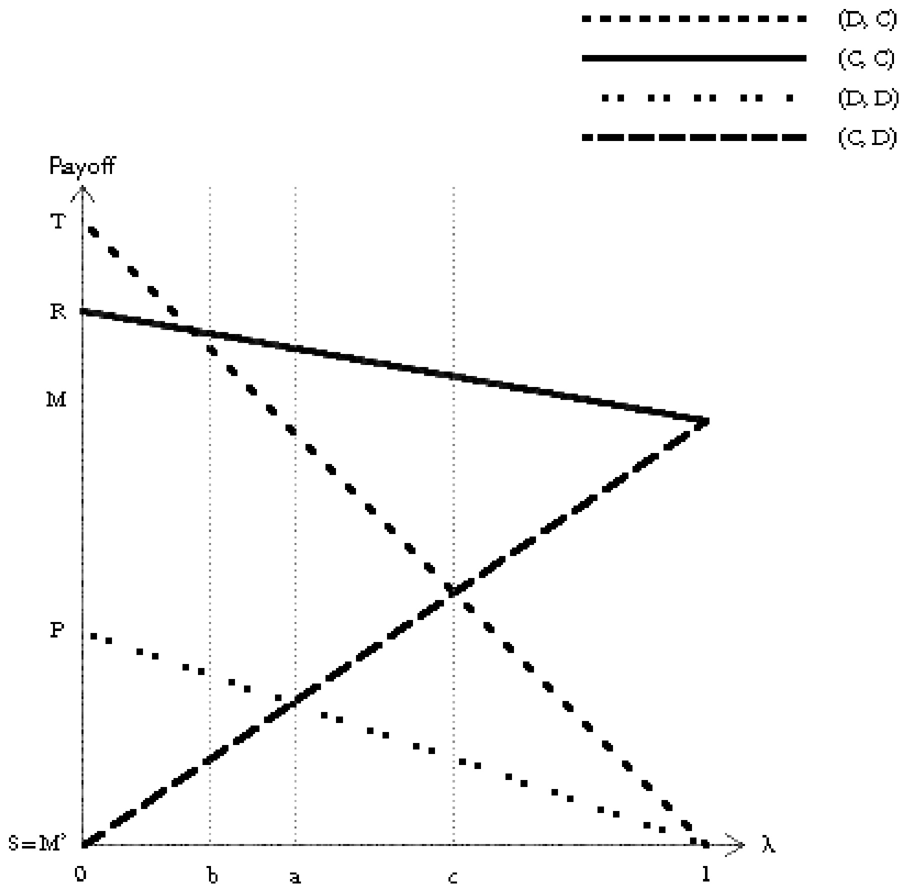

Figure B.3: Graph of payoff against social coefficient for $a > b$.