THE REPEATED PRISONER'S DILEMMA: EXPERIMENTAL RESULTS ONCE AGAIN

LISA HIGGINSON AND RICHARD SIMSON[1]

Abstract
This paper describes the process of playing the repeated Prisoner's Dilemma game in the classroom context, with Honours' students in Economics and other students from various UKZN programmes. These results are an attempt to encourage replication of these types of experiments at other tertiary institutions. We find that, in the main, our participants engage in co-operative, yet sophisticated strategies, already the subject of much computer analysis in the game theory literature.
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"Each of us wears a .45 and each of us is supposed to shoot the other if the other is behaving strangely. How strangely is strangely? I do not know. In addition to the .45 I have a .38 which Shotwell does not know about concealed in my attaché case, and Shotwell has a .25 caliber Beretta which I do not know about strapped to his right calf. Sometimes instead of watching the console I pointedly watch Shotwell's .45, but this is simply a ruse, simply a maneuver, in reality I am watching his hand when it dangles in the vicinity of his right calf. If he decides I am behaving strangely he will shoot me not with the .45 but with the Beretta. Similarly Shotwell pretends to watch my .45 but he is really watching my hand resting idly atop my attaché case..." an excerpt from the very short story Game by Donald Barthelme.

1. INTRODUCTION

The literature covering the Prisoner's Dilemma is vast. It is so voluminous that the day you meet someone who professes to have read it all, you can be sure of the validity of the dilemma. An erudite and clear explanation of the one-shot Prisoner's Dilemma is found in Blais (1987). In our short paper, the focus is rather on the repeated Prisoner's Dilemma and the literature here is also vast but mostly difficult. Another exception of particular clarity, explaining the details of the game in a repeated play setting, where the subject matter falls under the rather *un*folksy Folk Theorem rubric, is Fudenberg and Maskin (1986). One finds even more difficult analysis, incorporating special definitions of beliefs in Ely, Horner and Olszewski (2005). All this literature suggests a number of likely strategies to investigate in any simulation of such a repeated game. We report here the results of an optimization game by sixteen participants for which ethical clearance had been obtained and simulated play for strategies in this literature. These games have widespread application given current world and local politics, and economic (and trade) relations, and thus are worthy of attention, McGillivray and Smith (2005). A specific economic application is Zhang and Rajagopalan (2002). Novak and Sigmund (2000) have had some influence in finance. For an example of simulated play, with advanced techniques, Vukov, Szabó and Zolnoki (2008) is instructive. A recent contribution is André (2010). However the consensus, see for example Pennisi (2009), is that the theoretical difficulties underlying the Prisoner's Dilemma are not resolved.

Game theory has been revived in recent years. Added to this, is the current popularity of experimental testing in economics. Also, teachers of economics are being remunerated according to their innovations and developments in the class and seminar room. What we present here are

[1] UKZN, Pietermaritzburg. E-Mail: higginsonlisa@yahoo.com and simson@ukzn.ac.za . We must thank students from the 2008 Industrial Economics' Honour's class and other learners at UKZN for their helpful participation.

some experimental results testing the Folk Theorem from game theory that arise from an exercise in a classroom setting. These results are of interest as they show how easy it is to conduct experiments with learners, that can be replicated by others. Second, one obtains an insight into the increasingly required procedure of obtaining informed consent (that meets current ethical standards) from the participants in these experiments. Thirdly, we hope to begin the process of making known unusual results by actual players in order that they might be replicated by others, working in a class or seminar setting. We find evidence that, when there is a high probability of meeting co-operative human players in a repeated prisoner's dilemma game, the *Tant pour Tant* strategy is used and when the observed numbers of players of each strategy are combined in in a computer simulation as a separate exercise the *Grim* and *Tant pour Tant* strategy appear to be substitutes. It is still not clear (based on student evaluations of the course where the experiments are conducted) whether learners gain from these instructional innovations as the evaluations of the course by learners are less than enthusiastic. A cultural analysis of Game Theory that is of some interest is Belletto (2009).

2. THE REPEATED PRISONER'S DILEMMA

The participants in a Prisoner's Dilemma choose between *Deny* and *Confess* with the constraint that this decision is made together. When both prisoners *Deny* the interrogator, in the usual telling of the game, they get what is known as, rather confusingly, the reward payoff of R. If one prisoner *Confesses* and the other does not, then the one playing *Deny* gets the sucker payoff, S, and the confessor gets T. If they both *Deny* each gets a payoff P. If the Prisoner's Dilemma is repeated then the constraint 2R > T + S> 2P applies. The players in the Prisoner's Dilemma game, once they end up at the *Confess, Confess* equilibrium, possibly look to the *Deny*, *Deny* payoffs and wish for a way to tie them to that strategy.[2] But there is no way to do so if the game is played a finite number of times and this number of plays is common knowledge.

One strategy in the Prisoner's dilemma is the *Grim* strategy. Here a participant starts with *Deny* and this participant remains with this decision until they notice that the other participant decides on *Confess*. On seeing the first negative payoff, the player then chooses *Confess* perpetually. And for the other player, knowing this, they receive a gain in one period that pales as the future unfolds towards a distant horizon. So this other player hardly notices the gain after centuries and thus it becomes in his mind a "tie" and so the best response to a *Grim* strategy is a *Grim* strategy. In the simulations, which we report in Section 3, *Grim* appears to be a perfect substitute for some other strategies.

The *Grim* strategy for a participant is interesting in that if in use, and the other player wishes to "sucker" the first player by *Confess*, the "best" the first player can do is also *Confess*. Given play by the other participant that results in losses to the first, what is the latter's smallest loss or *Grim* *mini*mizes your damage when the other player *maxi*mises. *Grim* is thus known as a "minimax" strategy. In the Prisoner's Dilemma *Confess, Confess* is 'minimax' and more importantly, in this game there is a payoff for any play from another strategy greater than the minimax but not having the same value as the payoff of the other players. This allows one to punish, with a stop gap payoff to the punisher higher than the minimax payoff.

If we have the game also having a random element to the number of plays, in that there is a positive probability of the game stopping, a small rate of time preference and a payoff greater than the minimax payoff, then this, the minimax payoff, is the average payoff in a perfect equilibrium of the

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[2] For *Deny, Deny* to be an outcome, one can calculate the K ratio (Acevedo and Krueger (2005)) or (R-P)/ (T-S) which shows how high expectations of *Deny, Deny* must be to move all players to that strategy. For the experiments we conduct, the K ratios are 0.7 for the classroom game and 0.4 for the game embedded in the simulations.

infinitely repeated game. The number of plays of the game is important and we now discuss this issue in some detail.

The participants in the Prisoner's Dilemma game are better off if both can commit to denying the interrogator any information. But there is no way they can. So even if the game is repeated many times, after the penultimate repetition, it makes sense to *Confess*. Working backwards from the end then means it makes more sense to *Confess* each time one plays, from the beginning. Thus even if the game is repeated, the equilibrium is *Confess* by both players if the number of repetitions is finite. So repeating the game a finite number of times does not help avoid *Confess, Confess*. One way to resolve this is to make the situation worse and see what the outcome is. A possibly worse situation is to have an infinite number of repetitions. Then it becomes impossible to work backwards. Indeed if one has an assumption that the game is going to stop for all players in one of the "plays" of the game with some probability and θ is a popular choice to describe this outcome, then this still is an infinitely repeated game. The reason is that the players can never know for certain if the current "play" is the penultimate stage. Thus we play a repeated game with a randomly, but unknown to the participants, chosen stopping period. This has the effect of making the game, as played by student participants, effectively an infinite one.

Another issue that arises in this game is discounting. The last period acts as a "ghost" lurking to take us to a situation where we can use the just prior period to *Confess* in the "ghost" play. Allowing a discount factor, $1+\delta$ does not exorcise the ghost. In fact, if the discount factor should become high, then *Confess, Confess* is also chosen, as it would be if there is also a penultimate period. The problem is that if the discount rate is zero, then the interest rate is zero and the calculation of gains becomes meaningless. To prevent this, a "little" discounting is accepted. Fortunately it is the structure of the repeated game that provides the discounting. The discount rate in repeated games is called the "shadow of the future" and if the structure of the game in payoffs satisfies certain constraints, then co-operation is a possible equilibrium.[3] A good exposition appears in Axelrod and Douglas (1988).

3. THE EXPERIMENTAL GAME

We play the Prisoner's Dilemma in a repeated setting. Bodo (2002) is a good example where the *Tant pour Tant*[4] strategy does well. The participants, in our game are told their aim in the game is obtain the highest, additive and undiscounted payoff as they can in each play of the game. The players know they must not make interpersonal rankings' comparisons when trying for the highest payoff. This means the players are reminded to pay no heed to their neighbours; as to score just higher than them is not the aim of the experiment. The experiment consists of the players being Row and Column. However, three individuals from the group join to be the Row "player." One person is chosen to be Column and each Row triple plays against many singles of the Column type.

One objection to an experiment structured in the above manner is the experiment can go awry if the participants do not optimize. It is no good seeing a particular outcome by participants (say *Deny* if

[3] The "shadow of the future constraint" is based on (using the notation of Section 2) the maximum of (T-R)/ (R-S), and (T-R)/ (T-P), see Axelrod and Douglas (1988) and the classroom game satisfies this constraint. However the discount rate of the simulated game is one-half, below the "shadow of the future" maximum of two-thirds. This means the simulated game has a bias against *Confess, Confess* but not against other strategies.

[4] *Tant pour Tant* is a strategy that begins with *Deny*, and if the other player Confesses, *Tant pour Tant* Confesses in the next round. Thereafter *Tant pour Tant* mimics the others player's move. A tournament between this and other strategies is in Axelrod (1984) and *Tant pour Tant* wins this competition. However this tournament has *automata* and not humans as participants.

Deny, *Confess* if *Confess*) and then not being able to ascribe this outcome to actual desired play or an inability to make the necessary calculations so as to optimize payoffs. To overcome this problem, we ask the participants to perform a maximization task so as to ensure they could indeed perform a task optimally. So as not to make the task too transparent the problem given to them requires minimization for optimality. This is done, in essence, by asking them to fit the best line to data plotted in the first (I, +, +) quadrant of the Cartesian plane.[5] The participants do this rather well and we do not fail to reject the null hypothesis of no association at a *p*-value of less than or equal to the usual accepted level. Gibson (2003) posits participants can learn much from these artificial games. Unlike the reports in James and Cohen (2004) the economics' majors in the first part of this experiment do not *Defect*, and had no or little ethics instruction in their undergraduate years. Our participants are more like those in Bó (2005).

One possible way to describe a game is with one number reflecting all payoffs for participants. This is not difficult if one adopts a few conventions. Starting with the row's second action's payoff one constructs an eight digit sequence following an "omega" shape and keeping the *Deny, Deny* payoffs as the fourth and fifth digits in the sequence, and for the game for which the participants gave consent this is the rather odd looking 80-277-208. These payoffs imply a discount factor (as an end of period perpetuity) of 0,875. For the simulations, the payoffs in this notation are 51033015 and have a lower discount factor of one-half.[6] We choose different numbers for the simulation so as not to conflate the experiment for which we had clearance *and* consent, and that part for which we have consent only. The structure of both games is the same as the individual payoffs still satisfy the constraint $2R > T + S > 2P$.

In this paper we distinguish between that part of the experiment for which there is ethical clearance and that part for which there is only consent on the part of participants to play the game. Here the participants gave their consent to perform both exercises: the optimizing test and to play the repeated Prisoner's Dilemma. And we have an institutional ethical clearance that also applies to the optimizing test and playing the repeated Prisoner's Dilemma. Thus on the basis of ethical considerations, we can use the results, in terms of payoffs obtained and strategies observed, from playing the repeated game in a classroom setting knowing that the typical participant optimizes. But we report the results of play in the second experiment.

What is presented here are some experimental results that arose from an exercise run on the UKZN, Pietermaritzburg campus in 2010. The exercise, a game derived from the famous Axelrod tournament, was played with 18 randomly selected students approached on campus. Ethical clearance was obtained for the game described, in short, below.

The justification for conducting such an experiment, in addition to the partial literature review of Section 1 above, is twofold; the first is that an experiment of this type allows the researcher to design the game to the specifications and scope of the project, the second is to illustrate how similar experiments can be used to contest or verify long held beliefs, particularly in the relatively uncertain area of behavioural economics.

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[5] Projects: "Regression by Eye" - Ethical Clearance Approval Number: HSS/05217A and HSS/0293/2010 for the "Repeated Prisoner's Dilemma" project.

[6] In the general terms of Section 2 the notation produces TPSRRSPT. When one has a game in this form it is rather like a sequence. This begs the question "Is there a sequence generating function for these numbers and what are some of the other terms?" The answer is "yes" and they are -98, -688, -2562, and 7175, for 80-277-208 although it is difficult to infer anything of value from this. But for matching pennies there is the more interesting recursive relationship: $a_{(n+6)} = a_n$.

Although it has been argued that the Prisoner's Dilemma has been "exhausted" in academic discourse (Sen, 1985), there appears to be endless scope for extension and improvement. There also seem to be a number of limitations to the studies which have been conducted as the methodology is often flawed and results are largely inconclusive and insubstantial (Bȯ, 2005).

Interestingly, there seems to be little or no evidence of similar studies conducted in South African Universities, despite the overwhelming success of, and interest in, this type of experimental testing. Early experiments in Game Theory have been largely responsible for the deepening of value in the discipline and for the increased emphasis on Game Theory in the analysis of complex interactions.

The primary objectives of the experiment are; to highlight natural strategies employed by participants, highlight the effects of learning through repetition, test or verify the prevailing theory, identify and discuss unusual results and draw conclusions about the way in which participants respond in strategic interactions. Further the study aims to explore the concept of experimental techniques in economics through the problems and successes encountered in the exercise and the design thereof. Further, the second phase of the experiment, which involves a computer simulation of the strategies used in phase one is intended to test the robustness of each by means of a round robin tournament.

The design of the game is a vital component of the research presented here since the specific conditions under which the game is played can change the results of the experiment. Similar classroom type games can be found in Rasmusen (2007), Bodo (2002), Axelrod (1984). Further considerations, relating to the specific conditions necessary to yield required results are obtained from Friedman and Sunder (1994).

For the first phase of the experiment, the results of the game where individuals play the game against each other are analysed from three perspectives; first, an analysis of the individual strategies, second, an analysis of the individual actions and last, we provide an assessment of the combined outcomes for each pair of participants.

Once strategies are analysed from the first phase, the computer programme of Wilensky (2002) is used to simulate all possible plays of a repeated game and we vary the mix of the players' strategies to cover the observed possible combinations of strategies in the experiment. Average payoffs are calculated and represented on a graph showing changes over repeated rounds, and ranking the strategies accordingly. Interactions are determined by random collisions of the pre-programmed "players."

For phase one, human participants were paired randomly and asked to play the Prisoner's Dilemma game presented in Table 1 below. It is assumed that random participants would have a very limited understanding of the game from previous exposure. They were given a brief but thorough explanation of the game as depicted by Flood and Drescher (cited in Rasmusen, 2007) with the following payoffs in normal form:

Table 1: Prisoner's Dilemma Payoff Matrix

		Player B	
		Deny	**Confess**
Player A	**Deny**	**(7, 7)**	**(-2, 8)**
	Confess	**(8,-2)**	**(0,0).**

Source: Rasmusen (2007).

These payoff are adapted from Rasmusen (2007) where the prison years are converted into scores by adding 8 to each. This is done in order to make the game more intuitively sound by creating a point maximising, rather than jail sentence minimising, exercise. The highest score would correspond to the lowest prison sentence. The game still remains intact as the ordering of payoffs is unchanged.

At the start of the game players were asked to make their decision independently (players were not allowed to communicate or show their response until told to do so). Once both players had written down their chosen action, they were asked to share their moves and calculate the score according to the payoff table and the combined outcome. Players were asked to record both scores on a record sheet provided to them, and were monitored to ensure accuracy.

The game was repeated in this manner, ten times. After the tenth repetition the end point was determined by the outcome of a coin toss. If the result was heads, the game ended, if it was tails another round was played after which the coin was tossed again. This went on until "heads" came up and the game terminated. This makes the overall game, effectively, an infinitely repeated one.

One of the most significant deviations of this game from the Axelrod tournament is the fact that while Axelrod, in his initial experiment, called on prominent mathematicians, economists and game theorists, with a background in the subject and knowledge of the complexities of *automata* playing this game, our game with humans rests on the assumption of limited or no previous knowledge of the subject. This was done to illicit a more "natural" assessment of interactions in an indeterminate Prisoner's Dilemma. A study that primes participants with an introduction to Ethics prior to the experiment is Harvey and Cohen (2004).

Ethical considerations also played a large role in the design of our game and as a result previous knowledge, level of education, age, gender, race and all other background information has been deliberately excluded from the experiment.

The analysis of the results involved a fair deductive component. In order to maintain maximum accuracy in the analysis, a thorough review (a good reference in this regard is Zhong, Loewenstein and Murnighan (2007)) of the past and current literature, particularly focused on the theoretical motivations for observed behaviours and experimental results of similar studies is undertaken. Following this review, as well as a thorough investigation of common and more conventional strategies, the analysis, that follows, is undertaken. First the strategies are summarised, followed by a brief discussion of results which do not conform to the conventional theory.

In some cases strategies displayed a large adaptive or random component. These effects are examined by Lester Lave (1962) who designed an experiment involving one hundred repetitions of the game, structured like a series of one-shot games rather than a typical repeated game, in an attempt to assess and quantify the effects of learning in repeated interactions. Several other studies have confirmed that learning is a determinant of observed strategies and it is thus possible to infer that these effects are present with our participants. These effects are more easily addressed in Table 2 which analyses the individual actions on a round-for-round basis. It is worth noting, at this stage, that in many cases it is only possible to infer which strategy was at play in later rounds after the initial learning period where more random and risky moves were observed. This factor has not been integrated into the error probabilities shown in Table 2 as there was not enough evidence to make these assumptions.

Table 2: Summary of Experimental Results

Player	**Assigned Strategy**	**Explanation**	**Score**	**No. of rounds**	**Rank**
1.1	*Grim* with error	Almost always confess, tries to deny and establish cooperation but gets "sucker" payoff and then confesses indefinitely. Could say forgives 3 confessions from opponent, then plays *Grim*. Since early rounds are often when strategies are being formed the final few rounds are more instructive.	40	13	3
1.2	Pavlov with small error	Repeats action that yielded high score in previous round, if it not change. This strategy is unique in that it does not place as much emphasis on speculating what the opponent has done or will do next.	30	13	7
2.1	*Grim* with error	Tries to induce cooperation, and when found changes to confess and continues indefinitely. Form of *Grim*. Minimal cooperation.	1	10	9
2.2	Always confess	Confesses in every round except round 4 where both deny, then confesses thereafter.	31	10	6
3.1	Naïve prober	Plays mostly *Tant pour Tant* with random probability of confessing instead of denying.	39	10	4
3.2	Random	Starts by confessing and then alternates one "C" then two "D"s. Could be *Tant pour Tant* with forgiveness.	39	10	4
4.1	*Tant pour*	Largely follows *Tant pour Tant* except for	46	10	2

	Tant with small error	two deviations one to a false confession, and one a false denial.			
4.2	True peace maker with small error	Starts with deny, confesses a few times in the early rounds, then denies, when opponent continues to confess this player confessed once and then reverted to deny for the rest of the game.	46	10	2
5.1	*Grim* with small error	Only started to play grim after 2 confessions, then in round 8 tried to induce cooperation, failed and reverted to Grim.	32	11	5
5.2	*Tit pour deux Tatouages* with medium error	Largely *Tit pour deux Tatouages* and random defection, possibly an attempt to throw the opponent off strategy or purely out of temptation.	32	11	5
6.1	Random	Interesting results that do not conform to standard theory. The player has a total of 4 sucker payoffs and denied 3 rounds in a row without any reciprocation from the opponent. This shows either a highly optimistic player, a player who is not driven by the point system or one who has taken actions based on non strategic factors as discussed in Axelrod (1984).	-1	10	10
6.2	Always confess with small error	Confess every round except 2, may have thought about trying to establish a cooperative situation and maintain it through the game for the guaranteed payoff of 7 and then realised that his opponent could be suckered and confess for the rest of the game.	39	10	4
7.1	Mostly confess with small error	Denied in the first round followed by 2 confessions, possibly realised that another confession would have lead to a stalemate of Punishment rewards, denied twice and reverted to confessions thereafter. Interestingly denied in the final round.	26	10	8
7.2	*Tant pour Tant*	Perfect *Tant pour Tant* player with opponents previous move repeated every time. Started with deny.	26	10	8
8.1	Always deny with small error	Started with deny as did the opponent, succumbed to temptation once and reverted back to deny thereafter. Did not punish opponent when he	62	10	1

		confessed (to punish this player)			
8.2	*Tant pour Tant*	Perfect *Tant pour Tant*. Punished opponent for confession just once and returned to Deny for the rest of the game.	62	10	1
9.1	*Tant pour Tant* with small error	Player started with deny thereafter more or less imitated the opponents previous move.	30	11	7
9.2	*Tant pour Tant* with medium error	Player started with Deny followed by a chain of confessions, lead by the temptation payoff, after received 2 punishment payoffs denied and then followed *Tant pour Tant* strategy.	40	11	3

Authors' interpretations.

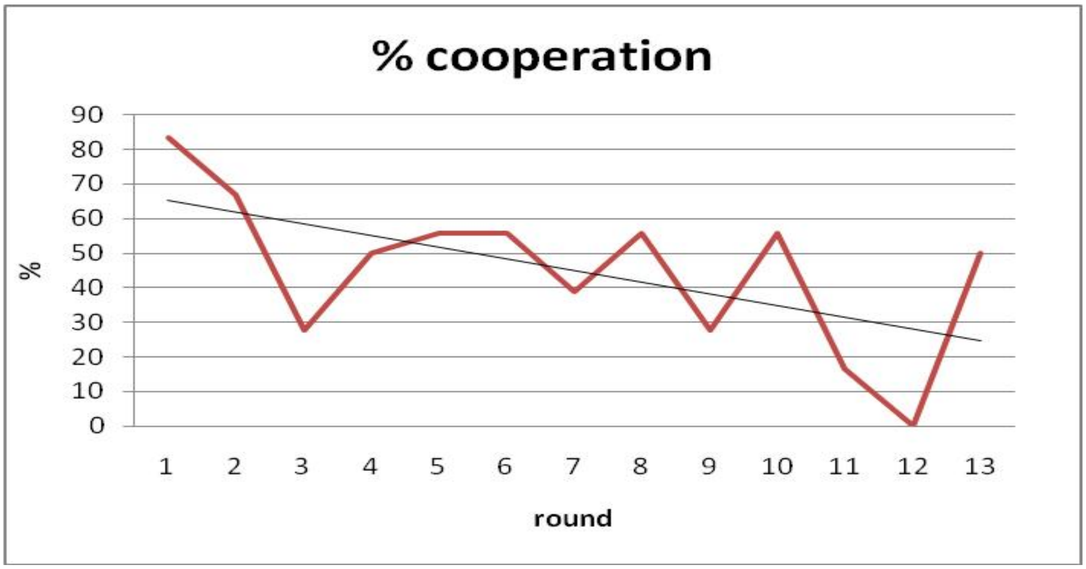
Of course, the strategies we infer above are exposed to the possibility of judgement errors by the experimenters. For instance a random strategy may appear to conform to a *Tant pour Tant* strategy with a small error. As Axelrod (1984) highlights, it is not necessary to assume that all individuals follow any particular strategy, rather in some cases actions can be completely random or based on less obvious criteria. In order to minimise this risk several strategies were considered and an in-depth analysis followed. Further decisions and strategies were analysed from three perspectives, namely; individual actions, individual strategies and collective outcomes.

Overall many of the players followed the *Tant pour Tant* strategy with two of the players following the *Grim* strategy, one almost perfectly and the other with random deviation, three played always confess, two played always deny and the rest played one of the less common strategies. *Tant pour Tant*, *Grim* and always deny were relatively successful in accumulating points ranking in the middle and upper range of the group. It is important to note that scores cannot be used to rank strategies since they are largely determined by the actions of each player's opponent. It is however, necessary to incorporate points in the game in order to create an incentive for players that resemble conditions in reality (Camerer, 2003).

One player played always confess against the *Grim* player. Interestingly it seems that the *Grim* player tried to induce co-operation with his partner and defected only after both attempts failed and he realised that his gestures were costing him points. This strategy is the only logical response to a serial defector.

The most obscure results were from the "Random" player (6.1 in Table 2). It is important to note that here the "Random" strategy is not the same as the computer programmable random strategy where cooperation and defection carry a 50 *per cent* probability. Rather, there appears to be no observable trend or pattern that resembles a conventional strategy behind the actions recorded. It could also be deemed "unknown" since, without consultation, it may is impossible to judge the intentions of the player. Interestingly this player received the lowest score in the game of -2. It is unclear as to why this occurred with the most plausible explanation being that this player's opponent played confess every time. Having recognised that the opponent was not likely to co-operate the player would have been left with only one "rational" response which would be to confess as well resulting in a payoff of zero, only marginally higher that the sucker's payoff of -2. Having received the punishment payoff in the Nash equilibrium for three rounds in a row, the player tried again to illicit a co-operative response from the opponent. Perhaps optimism led the player to continue to deny, or alternatively the lack of appropriate rewards and or punishments led the player to take more risks than would be expected. The final possibility, mentioned briefly above, is that the player made decisions based on factors not easily assessed with the tools of Game Theory such as reputation or perceived familiarity of the opponent.

Figure 1. Percentage of Participants Co-operating After Each Round



Authors' Calculations

For the first ten repetitions of the game the probability of a future encounter is unity since all players were told that there would be a minimum of ten rounds. Thus it is possible to hypothesise that players, if wise enough to recognise that defection in the tenth round would be favourable, might begin to defect in early rounds of the game following the backward induction reasoning. The likelihood of this scenario in this game is relatively small given that players are assumed to be participating in their first game of this sort and thus not able to deduce optimal strategies in early rounds based on their limited opportunity to learn the game. The short number of repetitions would also contribute to this observation. Presumably in longer games with more repetitions there is ample opportunity for players to fine tune strategies by looking at playing current moves with a view of the outcomes in later rounds.

The role of learning in a game of this sort cannot be underestimated. Numerous studies have tried to assess the magnitude of the learning factor. For this reason the results in the analysis of the first three rounds in particular cannot be used to draw strong conclusions. Rather, the initial discussion presented here offers possible explanations of the observed results, shown in Figure 1 above.

Of the eighteen players in the experiment, fifteen chose to co-operate in the first round. If players were not informed of the repeated play this result may show one of two things; either that players here did not conform to the standard theory that predicts a (P, P) outcome in a one-shot game and must then display an "unnatural" tendency to co-operate or that there was a problem with the definition of the game in this experiment. Since all players were informed of the structure of the game at the start, the high percentage of co-operative plays may show that players hoped to start by co-operating and induce co-operation in subsequent rounds or fool their opponents in the next round and claim the "temptation" payoff.

The results of the second round show significantly lower co-operation scores with 67 *per cent* of players choosing to co-operate. The thought process starts in the early stages despite a limited understanding of the mechanics of the game, and has players start by predicting their opponent's next move, and then try to ascertain what predictions opponents have made about their own strategies and each tries to manipulate the other player in this way.

In the third round only 28 *per cent* of players co-operate. This shows how co-operation deteriorates when a player defects. The fourth round sees higher rates at about 50 *per cent* where it more or less stabilises but from the graph above there seems to be a general downward trend. Interestingly, in the tenth round, the last round that players were certain would be played, ten out of the eighteen players co-operated which was unexpectedly high. There is however limited value in this observation for this game because it was not designed to assess behaviour in the finite version of the game. There is no control that can discount the weight that players put on their opponents predicted strategies and the outcomes of previous rounds.

Of the nine pairs, only three played the additional rounds determined by the coin toss. This means that there were only 6 players in total in the stages beyond ten rounds. Two pairs played only one extra round while the third pair played an additional 3 rounds. In these "extra" rounds there was only one co-operative play which translates to a co-operation rate of 1/5 (for the total number of extra rounds). This result is lower than expected given that only in these rounds can the game really be analysed as an indeterminate Prisoner's Dilemma which is supposed to yield higher cooperation rates *as per* the previous discussion regarding the effect of the "shadow of the future" which would now be relatively more uncertain bringing issues of reputation into play.

Table 3 below shows a summary of the results of the game. Confusingly "D" represents "deny" which is the co-operative action while "C" represents a confession, the equivalent of defection. The cells have been have been filled to highlight stages of sustained cooperation and defection. The results suggest that, for the most part rounds display a lack of co-ordination. Either players were unable to induce and sustain co-operation to ensure the co-operative payoff of (7,7) or they were not satisfied that this outcome was desirable given that they could achieve the higher "temptation" score if they managed to "sucker" their opponent. One would expect more results like those displayed by pair 2, where inability to sustain co-operation leads both to defect and remain stuck in the Nash equilibrium or punishment cycle.

Table 3: Individual actions and Total Scores

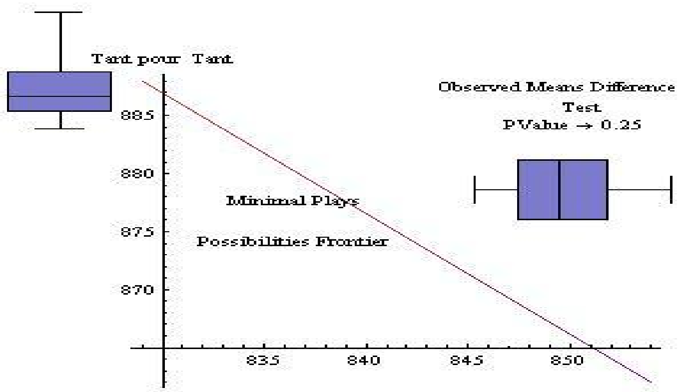
	PAIR 1		PAIR 2		PAIR 3		PAIR 4		PAIR 5		PAIR 6		PAIR 7			PAIR 8			PAIR 9		
	1.1	1.2	2.1	2.1	3.1	3.2	4.1	4.2	5.1	5.2	6.1	6.2		7.1	7.2		8.1	8.2		9.1	9.2
1	D	D	D	C	D	C	D	D	D	D	D	C		D	D		D	D		D	D
2	C	D	D	C	D	D	D	C	D	D	D	D		C	D		C	D		D	C
3	C	C	D	C	D	C	D	C	D	C	C	C		C	C		D	C		C	C
4	C	D	D	D	C	D	C	D	D	C	C	C		D	C		D	D		C	C
5	D	C	C	C	C	D	C	D	C	D	C	C		D	D		D	D		D	D
6	D	D	C	C	D	C	D	C	C	D	D	C		C	D		D	D		C	D
7	D	C	C	C	C	D	C	D	C	C	D	C		C	C		D	D		D	C
8	D	C	C	C	D	D	D	D	D	C	D	C		C	C		D	D		D	C
9	C	C	C	C	C	C	D	D	C	C	C	C		C	C		D	D		C	D
10	C	D	C	C	D	D	D	D	C	D	C	C		D	C		D	D		D	C
11	C	C							C	C										C	D
12	C	C																			
13	C	D																			
SCORES	40	30	1	31	39	39	46	46	32	32	-1	39		26	26		62	62		30	40
combined	70		32		78		92		64		38		52			124			70		

Authors' calculations.

The cells have been have been filled to highlight stages of sustained co-operation and defection. The results suggest that, for the most part, rounds display a lack of co-ordination. Either players were unable to induce and sustain co-operation to ensure the cooperative payoff of (7,7) or they were not satisfied that this outcome was desirable given that they could achieve the higher "temptation" score if they managed to "sucker" their opponent. One would expect more results like those displayed by pair 2, where inability to sustain co-operation leads both to defect and remain stuck in the Nash equilibrium or punishment cycle. The results show very few instances of sustained co-operation despite the relatively high incidence of individual co-operative moves. This might suggest that players were not trying to trick each other in order to claim the higher score but rather just unable to co-ordinate moves to reach co-operative outcomes. This is because we assume that players will only "deny" in the hopes of meeting a "deny" in return since the other option, a confession results in a sucker payoff of -2 (unless players are trying to throw opponents off of their own predictions). If the trend favoured defections it would be clear that players tend not to co-operate. This dilemma of co-ordination further highlights the difficulty of simultaneous games and how futile attempts to understand and predict the opponent's predictions of what you will do next, can prevent optimal play and co-operative outcomes. But the high incidence of *Tant pour Tant* play is worth noting.

In order to place these results in some context, we do simulate results between the same numbers (and the same type of player based on our subjective interpretation) of *automata* in a computer simulation as the human participants, and report these results.

Figure 2. Minimal Plays to Confess Having the Smallest Payoff, Possibilities' Frontier, as the number of Tant pour Tant Players rise Relative to the Number Playing Grim.



Fortunately there exist programmes that simulate the repeated Prisoner's Dilemma situation. One just has the computer simulate the game (repeated a large number of times) for strategies that are suggested in the literature and with the same type of players as is observed in the classroom experiment. This paper is thus a certain game between the author and the reader, and is one of symmetric and complete information. Here we can report the results of many computers playing against each other, with accepted strategies, but showing outcomes for all the possible combinations of our human participant's choices of strategies. Axelrod (1984) shows the *Tant pour Tant* strategy winning a round robin tournament through its mixture of camaraderie, forgiveness and not being passive. We use this strategy in the simulations as many of our human players did. In addition, always *Deny* is a strategy as is always *Confess*. The simulated tournament not only includes these strategies, but also *Grim* which Zhang and Rajagopalan (2002) apply to joint ventures. In Watkins and Hill (2004) *Tant pour Tant* does not always do well in a simulation so it is of some interest to check this result.

We use the computer programme[7] of Wilensky (2002) to simulate all possible plays of a repeated game varying the mix of the player's strategies to cover all possible combinations of strategies. So the person conducting the experiment knows the group plays optimally. Also, the actual combination of player's strategies in the repeated game is revealed. So the computer simulates all possible plays of strategies popular in the literature. For instance we might have eleven players using the *Grim* strategy and one *Tant pour Tant* (see Killingback and Doebeli, 2002) player with four others playing always *Deny* or always *Confess*. These automata play the game upwards of sixty-thousand times, which is a reasonable number of rounds, see Nowak and Sigmund (2004) and Killingback, Doebeli and Knowlton (1999). At this number of repetitions and adjusting the mix of player types, simulations show *Tant pour Tant* doing well, on average, but sometimes being beaten by *Grim*. After so many plays, always *Confess* has, on average, the worst payoff. These simulations do show that there is not much difference between the *Tant pour Tant* and *Grim* strategies. So we adopt another approach.

We define an "event horizon" as the minimum number of simulated plays that occur before always *Confess* has the lowest average payoff, but mixing the players across all types by strategy. In other words, we build, based on the simulations, a "minimal plays to the "even horizon" possibilities frontier." This is shown in Figure 2, above, where we have the "event horizon" when increasing *Tant pour Tant* players, relative to *Grim* players, shown on the vertical axis. The average "event horizon" from thirty simulations for many *Tant pour Tant* players is shown at about 888. The box and whiskers plot (for plays to the "event-horizon" (for each of *Tant pour Tant* and *Grim*)) is also shown and note the high estimated variance, but none of the thirty simulations here are considered outliers according to accepted measures, although increasing the mix of *Tant pour Tant* players skews the distribution to the right. On the horizontal axis and moving to the right is an increasing mix of *Grim* players relative to *Tant pour Tant* players. The average "event horizon" plays with many more *Grim* players, in the mixture, is in the region of 853.[8] A test of the difference in the means being zero is one where we fail to reject the null hypothesis of no difference at typical levels. The diagram reports the observed significance level. Based on these simulations, *Tant pour Tant* and *Grim* are substitutes.

4. SUMMARY AND CONCLUSIONS

The objective of this research is to begin establishing a set of experimental results based on Game Theory at South African institutions. With hindsight this is rather an ambitious ideal. Ethical considerations serve as a constraint in experiments with student participants. However we had the learners perform an optimizing task and all participants, bar one, did well on this task which also reveals our players to be interested in co-operation. Then, the participants play the repeated Prisoner's Dilemma game. The results reveal the many learners playing the game using a *Tant pour Tant* strategy. We then also use the Wilensky (2002) programme to simulate all possible combinations of popular strategies in the literature, such as *Grim* and *Tant pour Tant*. We find these strategies to be very close substitutes for a very large number of repetitions of the game and they outperform *Always Confess* in simulated play. The simulated results (using the types of players from the human experiment and in the same proportion) suggest popular strategies other than always

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[7] In essence the programme is a "black-box" here, but to make sure the programme is providing reasonable results, we subject it to a number of tests. One of these is based on the observation, that in the literature it is noted, that when there is random play by participants, then *Tant pour Tant* does not perform as well. This is indeed a feature of the programme we use for the simulations.
We cannot test for the "Win-Stay or Lose-Change" (known as *Pavlov*) strategy that beats *Tant pour Tant* in Imhof, Fudenberg, Nowak and May (2005) and Macy (1995) using our programme. We use the results in Wu and Axelrod (1995) to justify excluding the *Pavlov* strategy.

[8] The medians are 839 and 840.5 respectively. That is the reason the box plots do not align with the axes.

Confess appear to be close substitutes. One shortcoming of this work is the inner workings of the computer programme are not available for detailed scrutiny, although it is, as a programme, robust when having the programme play with strategies for which there are known and well-tested results. A critical item for future research is to construct, in conjunction with a technical expert, a computer environment whose inner workings are transparent to the experimenter.

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