

AN EMPIRICAL DESCRIPTION OF THE PRISONER'S DILEMMA GAME

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Two recent papers¹ reported experimental work with the prisoner's dilemma game indicating low levels of cooperation and concluding that the Luce and Raiffa conjecture that reasonable men would cooperate if the game were iterated was unsubstantiated.² Independent work produced significantly higher levels of cooperation that would enable a case to be made for the Luce and Raiffa conjecture. Part I reports the results and techniques used to obtain them while Part II attempts to compare the results and to explain discrepancies. Differences in experimental technique are seen to account for the contradictory results. It is concluded that the principal differences in technique are methodological stemming from the dichotomous areas of interest between economics and psychology.

* I am indebted to Professor George A. Hay for supervision of the undergraduate thesis of which this paper is part, to Miss Ruth Westheimer without whose partnership the experimental work could not have been accomplished, and to the staff of The RAND Corporation, Daniel Ellsberg in particular.

¹ Alvin Scodel, J. Sayer Minas, Philburn Ratoosh, and Milton Lipetz, "Some Descriptive Aspects of Two-Person Non-Zero-Sum Games," June 1959; J. Sayer Minas, Alvin Scodel, David Marlowe, and Harve Rawson, "Some Descriptive Aspects of Two-Person Non-Zero-Sum Games - II," June 1960.

² R. Duncan Luce and Howard Raiffa, Games and Decisions, New York: John Wiley & Sons, 1957, 97-102.

Part I
THE FIRST EXPERIMENTS

Experimentation was done in two series; the criticisms of the first series were used to improve the technique of the second.¹ The physical setup of the first series had two players seated at a table with a partition separating them. Each player had a control panel which exhibited two switches marked "strategy I" and "strategy II." These switches controlled a system of lights mounted on a board before the players which was so wired that the lights indicated the choices of both players. To insure that players would be informed of each other's choices simultaneously, a master switch was controlled by one of the experimenters.

Prisoner's Dilemma Game Matrix

		Player B	
		Strategy 1	Strategy 2
Player A	Strat. I	3 / -100	4 / -3
	Strat. II	4 / -100	3 / -3

To facilitate the explanation, Player A was assigned the color red and every time Player A was written in the instructions or matrix, it was against a red background. The value of this device came in coloring the top half of each square in the payoff matrix red indicating that these were the payoffs to Player A while the bottom half was colored blue indicating Player B's payoffs.

Instruction sheets explained to players that they would be given 650 pennies with which to play a game and that the object was for each player to make as much money as he could since a portion of the money won would be

¹These experiments were performed to test a theory which attempts to answer the question: What is the minimum number of trials which will still cause players to use the cooperative strategy? The experiments are felt to provide evidence, if somewhat limited, in support of the theory.

retained at the end of the game. The instructions further explained the workings of a game matrix and commented that, while questions might be asked, they had to be of a technical nature and as limited as possible. Communication between players other than through their strategy choices were thus kept to a minimum.

Players were then presented with a trial matrix which contained one strategy which clearly dominated the other for each player. Even the players who chose the dominated strategy were allowed to play; errors in thinking were not pointed out because of a desire to avoid unformalized instructions and to avoid giving either player too much information about the other player's intelligence. These suspect players invariably stated after the game that they had not understood the technical workings of the game, and so, for all practical purposes, were acting randomly. These pairs are included in the data table at the end of this paper but are used in only the statistics compared with the Scodel paper.

A series of games was used in this first group of experiments. In one procedure players were told they would play the matrix one hundred times; after this they were told they would play the matrix an indefinite number of trials terminating at the experimenters' discretion; finally, they were told they would play the matrix for one final trial. In the other procedure they first played a single trial game, then a one hundred trial game, and finally, another single trial game. The rationale for using three games was to test the analysis presented in Luce and Raiffa. The one hundred trial game was to test the proposition that intelligent players would cooperate if the game were temporally repeated. The indefinite trial game was to test whether players would attempt cooperation in a situation

of complete uncertainty. The single trial game was to test the analysis that concludes that players won't cooperate on a single trial. Unfortunately, behavior was contaminated by previous play so that the games following the first one exhibited behavior similar to it. Since the one hundred trial game was of more interest than the indefinite trial game, there seemed no choice but to drop the latter. However, putting a single trial game before the one hundred trial game would test the single trial analysis and not greatly compromise the data of the large game. The last single trial game would then serve as a test of consistency, of cold blooded logic, and of the strength of the bond built up between players.

With two sophomore exceptions, all players were juniors and seniors selected by using those who answered a note sent to all registered students of Reed College. This was based on a belief that a junior-senior population would assure a high enough level of rationality that this would not be a significant variable. This belief proved over-optimistic.

The following criticisms were formulated after experimenting with the technique just described. The difficulties underlying these criticisms are universal enough so that some apply as well to the Scodel experiment.

1. Since the analysis assumes no explicit communication, players, being in the same room, may not have been sufficiently isolated.
2. Some players were acquainted, and behavior might be different when directed towards a friend rather than a stranger.
3. Cutting down the time given to explanation probably impeded understanding. The time set aside for each experiment was decreased in three series. In the first three games 60 minutes was allowed, in the next ten

games 45 minutes was taken, and in the remaining eleven games, only 30 minutes was given to each experiment. Both acceptable and supporting data suffered proportionally as the time given to explanations was cut.

4. Better techniques could have been used to explain the mechanics of the game since 26.1 per cent (7 of 24) of the data had to be rejected for the first analysis.

5. The board and control panels might have been distracting for the players, giving them a tendency to play eclectically.

6. It would probably have been more consistent to stop the game when either player lost the \$6.50 with which he started.

7. Players were not playing with their own money, and so, as some players pointed out, they could only lose 100 three times before they would lose interest since it was now impossible for them to make a profit (players were paid 1/10 of their winnings).

8. Since all players were acquainted with the experimenters, it might be objected that this fact increased the player's tendency to "help" the experiment. However, there is no indication that players ever found how they "should" behave.

An attempt was made to correct these difficulties in a second series of experiments. Two separate rooms were used (players did not know the identity of the other players), players were given a new set of instructions and \$1.50. These instructions briefly explained that the \$1.50 was now theirs but must be used to cover any loss in the following game. In addition players were told they would be allowed to keep one-half of the money they retained at the conclusion of the game. The mysteries of a game matrix

were left to the experimenters to explain. Players were given the same trial matrix, but now, in addition to being asked what they would play, they were questioned on what they would expect the other player to do and what would happen if the game were repeated. Warning the players that no more questions would be permitted, they were given a modified version of the matrix used in the first series.

		White Player	
		Strategy I	Strategy II
Blue Player	Strategy 1	3 / -50	4 / -3
	Strategy 2	4 / -50	04 / 3

Changing Player A and Player B to Blue Player and White Player respectively and coloring the appropriate squares was felt to be a simplification of the first procedure.

While they studied this new matrix, they were told they would play the game 50 times and that there was a player in another room who had been given identical instructions and would play the game with them. They were finally asked to choose a strategy, to indicate the reasons for choosing it on the paper before them, and then to tell the experimenter their choice. The experimenters exchanged choices privately through a special communication system and then carefully informed their players of the choices and the consequent payoffs. No gadgets were used and players handled their own money. As the instructions indicated, if either player lost his initial \$1.50, the game was stopped. The comment sheets made it possible to decide whether an individual had analyzed the game to its basic problem while his strategy choices indicated his solution.

This second series of experiments used freshmen and sophomores who responded to a note offering them "a good chance to make \$1.50." The matrix was changed and the number of trials reduced so that more significant payoffs might be used. In addition this shortened playing time so that, allowing 60 minutes for each pair, full instructions might be given. This series was felt to deal adequately with all criticisms of the first series.

Conclusions from the Experiments

On the basis of the comment sheets, players were divided into two categories: those who reduced the game to its basic problem, "yes," and those who did not, "no." To make this distinction the comment sheets were searched for mention of "trust," of "teaching," or generally for mention of interdependence that required cooperation. The "yes" group was further divided into three subgroups according to their strategy choices: "yes" indicates those players who, with more or less caution, tried strongly enough to attain the cooperative point to succeed or go broke; "yes?" indicates those players who, while not being as forceful as the previous group, did not go the other extreme of distrusting the other player; "yes*" indicates those players who stated that they did not find it a good gamble to trust the other player.

Breakdown of Understanding in Second Series (by player)

no		9	
yes	19		
yes?	8		
yes*	2		
(yes + yes? + yes*)		<u>29</u>	(those players who did reduce
total players		38	the situation to its basic problem)

Thus, 23.6 per cent of the players fell into the "no" category. When the effort is made to determine what percentage of the players who understood the game well enough to fit into the "yes" category were able to coordinate successfully, a higher proportion of the data must be left out since the nine unperceiving players took part in eight experiments, i.e., there was at least one player in eight pairs who fits into the "no" class. Thus, in only 11 of the 19 pairs was it conceivable that players would consciously coordinate. This exclusion leads to a figure of 27.2 per cent (3 of 11) for pairs who coordinated for a significant number of trials (more than 40).

While it might be argued the above classification is shaky, it is probably the most accurate indication from the data of how many players would behave in accordance with the Luce and Raiffa conjecture. Having been set down and explained, these restrictive criteria will now be loosened first for comparison with the first series of experiments and then loosened still more for comparison with Scodel's results.

In the first series data was rejected only if the player admitted his failure to understand the technical aspect of a matrix. Since all players in the second series met this minimum requirement, 15.8 per cent (3 of 19) were successful according to this first series' criterion.

The first series used 48 players; since comment sheets were not used, the data cannot be analyzed on the basis of individual players. It is possible to say that nine players involved in six experiments did not understand the technical aspect of the game and that another pair understood it too well, poking a hole where technique was softest (experiment 23).

These experiments are of interest in the cases where a rational player sat opposite a player who did not understand and so played against an essentially random device. But again, illustrating the ubiquitous mistake, the fault was in technique since these players did not seem to exhibit any common characteristic, including high or low intelligence, but merely were not given adequate explanation.

Successful Coordination Attempts in the First Series
(by experiments)

	acceptable data	total data		acceptable data	total data
successful pairs	88.3% 15	62.6% 15	benefiting pairs	70.6% 12	50% 12
unsuccessful	11.7% 2	37.4% 9	others	29.4% 5	50% 12
	<u>100.0% 17</u>	<u>100.0% 24</u>		<u>100.0% 17</u>	<u>100% 24</u>

Of the acceptable data, 11.7 per cent of the pairs failed to coordinate for a significant number of trials (at least 25). Of the 17 acceptable experiments, 70.6 per cent made more money from the teaching attempt than they would have by not cooperating. Total figures are included for later comparison with Scodel.

One further discrepancy must be overcome before the 70.6 per cent figure can be compared with the 15.8 per cent figure of the second series. First series players were given \$6.50 or just over twice as much as second series players who had only enough money to stay at the non-cooperative point for all the trials. The same figure for the first series would be \$3.00 (3¢ x 100 trials). Had games been stopped when more than \$3.00 was lost, 47 per cent of the acceptable pairs would still have been profitable. This figure can be seen to have a downward bias since players acted as if they could afford to lose the entire \$6.50. A compromise between 47 per cent

and 70.6 per cent can be seen to give a more accurate interpretation of profitable attempts at coordination.

Games Stopped When Just Enough to Minimax for All Trials Was Lost

	first series				second series	
	acceptable data		total data			
profitable pairs	47%	8	33%	8	15.8%	3
unprofitable pairs	53%	9	67%	16	84.2%	16
	100%	17	100%	24	100.0%	19

The striking difference between 47 per cent-71 per cent and 15.8 per cent merits some discussion (the contrast is between 33 per cent-50 per cent and 15.8 per cent if total figures are used). Since interpretation is as liberal as seems reasonable, this difference must be traced to either a difference in players or in technique. The former appears doubtful since the magnitude of the difference is so great that such differences could probably not be justified by value changes between freshmen-sophomore and junior-senior groups. The significant change in technique seems to be knowing the identity of the other player; players probably have more confidence in an acquaintance than in a total stranger. Knowing the identity and general characteristics of the other player are conjectured to affect action significantly.

Data of additional interest was obtained from the first series by the use of single trial games before and after the one hundred trial game. On the first single trial game 50 per cent of the players in acceptable pairs played strategy 1 and on the single trial game following the large game, 58.8 per cent played strategy 1. The argument presented by Luce and Raiffa bolstered by specific analysis leaves little doubt that this behavior is

"irrational." The conjecture is that this large percentage of irrational behavior was due to players acting as if the money was not their own.

Results of Single Trial Games (by players)
first single trial game

strategy 1	50%	14	61.8%	21
strategy 2	50%	14	39.2%	13
	100%	28	100.0%	34

The second series lends evidence to this conjecture. Here 8 players of the 19 who completely understood the game were quite reluctant to gamble strategy 1 often, although they did try once or twice. In addition two players were completely unwilling to gamble at all. The data further indicates that, of the 19 "yes" players, only 7 were willing to take the chance without caution (the criterion here is "game ending within ten trials," only 7 did). There were also no cases of a game ending in three trials as would have happened if a player were persistent. Thus, technique is again probably at fault and the irrationality of strategy 1 on a single trial is probably upheld.

Another statistic of interest is the number of players who "double-crossed" the other player by playing strategy 2 on the last trial when they had cooperated before that. In the second series of the 6 players faced with this situation, 2 played strategy 2. In the first series double-crossing extended back to the penultimate trial, for, of 30 players faced with the situation, 2 double-crossed on the 99th trial (one was due to a mistake) and 9 double-crossed on the last trial. Thus 1/3 of the players in both series double-crossed.

Double-Crossing on the Last Trial (by player)

	first series		second series	
strategy 1	70%	21	67%	4
strategy 2	30%	9	33%	2
	<u>100%</u>	<u>30</u>	<u>100%</u>	<u>6</u>

The conditions of the first series of experiments in particular are felt to closely conform to reality in many motivational ways. Using an economics example, it is precisely in the imperfections of the experiment that the closest parallels to oligopoly exist. The players not playing with their own money, for example, are put in essentially the same position as management in this country, as the Berle-Means study indicates. The condition of having to play the game for a fixed period of time has its mirror in the cost of immediate liquidation which forces firms to hang on longer than is immediately profitable. The principal likeness is the non-constant sum nature of the game which forces players to regard the other player as a combination "opponent-partner," that is, someone to dispute relative gains with while attempting to maximize absolute gains. The prisoner's dilemma nature of the game insured this kind of behavior. Another similarity is the knowledge that the other player is of a certain level of intelligence; even greater knowledge is present in oligopolistic situations where a record of the way the firm and its executives have thought in the past is available.

The argument might be advanced that actual communication takes place in real situations, that these games are more restrictive than reality since the point at stake is simply fixing the rules so that players cannot bind themselves to a given strategy. Thus, the percentage of cooperating pairs would probably rise in real situations.

This experiment leaves little doubt that people are willing to take the risks of "teaching" and of "trusting" the other player when it is to their mutual advantage. We are thus assured that tacit collusion is theoretically possible.

Part II

COMPARISON OF RESULTS AND TECHNIQUES WITH
A SIMILAR EXPERIMENT

A few comments on differences in technique must preface comparison of the results with those reported earlier. Scodel's G_1 and G_2 are probably similar to the first series insofar as knowing the other player is concerned. Although their players were said to not have been acquainted, since they came from the same introductory psychology course, a clarification of the meaning of "acquainted" would be useful. If the word is taken to refer to players who had seen each other before, who probably knew each other's name, but who had never spoken, pairs 1, 2, 3, 5, 7, 9, 12, 16, and 17 would fall into this category and pairs 4, 8, 18, and 19 probably would. While differences in players might be large, there is no way of testing the "rationality" and attitudes of the two groups. The argument might certainly be advanced that players were provided with goals in both series while Scodel did not mention a goal in their instructions. Another difference is that choices of both players were carefully announced and their consequent payoff indicated in both series while Scodel paid the players and let them infer what strategy the other player had chosen. The Scodel criteria exhibited no concern for testing rationality by the use of trial matrices, or, indeed, by any other means; since the authors do not indicate any data was excluded, they are assumed to have used all their pairs. Finally, the difference in matrices cannot be ignored. It might be argued either that the higher penalty in both series deterred players from gambling on strategy 1 or that this helped to enforce discipline by dramatizing how untenable non-cooperation was.

Comparison of Results

	second series		first series		total data		G ₁ + G ₂		G ₃	
			acceptable data							
coop. pairs	3	15.8%	12-8	70%-47%	12-8	50%-30%	2	4.9%	2	18%
non-coop.	16	84.2%	5-9	30%-53%	12-16	50%-70%	39	95.1%	9	82%
	<u>19</u>	<u>100.0%</u>	<u>17</u>	<u>100%</u>	<u>24</u>	<u>100%</u>	<u>41</u>	<u>100%</u>	<u>11</u>	<u>100%</u>

When results are compared, it should be remembered that technique of the second series was more stringent than that of any other game; next, the first series was probably more stringent than G₁ or G₂, although there is room for argument; finally, G₃ (where players were allowed to communicate explicitly) had the least stringent conditions of the four. Thus 15.8% should be the lowest figure that might be expected, 50%-30% should compare with 4.9%, and 18% should be higher than all other figures.

Attempting to explain these discrepancies will provide a summary of the comments on technique: (1) The discrepancies seem to stem from methodological differences between the economic and psychological approach; the greater part of the comments that follow are thus originated. (2) Our players might have been provided with goals by the instructions to "maximize earnings." (3) Scodel's explanation that players are more cautious with strangers might account for the high figure in the first series. (4) The two populations may simply have been significantly different in rationality and attitudes. (5) Our use of a trial matrix and the effort given to explanation and announcing results indicates our concern for defining and insuring a high level of rationality; it indicates our concern with observing the behavior of players once they have analyzed the game completely rather than a concern with player's ability to analyze the game or some

combination of these. (6) Since the matrices in both series had negative numbers for the non-cooperative strategy, it might be argued that, far from utility being linear to money, there is a sharp discontinuity at zero which made our pairs uncomfortable there, whereas Scodel's players found the non-cooperative point a tenable, profit-making position -- certainly not the highest obtainable profit, but a comfortable one.

The second series of experiments was performed by Minas, Scodel, Marlowe, and Rawson to "...produce more collaboration." When, after a series of different matrices, each making collaboration more attractive and painless than the last, the final matrix in which strategy I strictly dominated strategy II failed to produce collaboration, it was concluded that players were attempting to maximize the difference between their payoff and the other player's. Although the Luce and Raiffa assumption of independence of utility functions might be made principally for analytic convenience, the gross violation in the last game, where strategy I was rejected even though it dominated strategy II, would probably be termed "irrational" on these grounds with no great discomfort. Thus, the Scodel players were probably not "reasonable men" and were essentially irrelevant to the conjecture.

It is concluded that "reasonable men" will cooperate if guaranteed a sufficient number of iterations of the prisoner's dilemma game. The conclusion reported earlier resulted from "unreasonable players" not eliminated from the experiments because of methodological differences between psychology and economics.

Data Table

Recording of data was done in a way where 1 indicates that both players played strategy 1; 2 indicates Player A played strategy 1 while Player B played strategy 2; 3 indicates A played 2 while B played strategy 1; and 4 indicates that both A and B played strategy 2. A star (*) after a player in the first series (1-24) indicates that this player did not understand the technical aspect of the game. The notation "yes", "yes?", "yes*" and "no" in the second series is explained on page 7. N.B. The figures in the first series represent the sum of payoffs of only the one hundred trial game.

Recording Procedure

		Player B	
		strategy 1	strategy 2
Player A	strategy I	1	2
	strategy II	3	4

1. 11244132324111111111113113224112132111...1, 11111, 1.
Player A: -440, Player B: -232
2. 43344444444444444444233111...13, 1111, 1.
Player A: 112, Player B: -232
3. 11111111...1, 1. Player A: 300, Player B: 300.
4. 4421124342344334243244424444124432444224432244444124344
24442444444444422244444422244444443222444444, 2.
Player A: -2604, Player B*: - 1044.
5. 2, 243411112321223334334334344321111111111112433211334
444111...124, 4. Player A: - 602, Player B: -1328.

6. 3, 1211111134111...124, 4. Player A: 83, Player B: 187.
7. 3, 3311133323332433334412333334111113113113141131211243
111...13, 2. Player A: -240, Player B: -2112.
8. 2, 2424232111...1, 2. Player A: -123, Player B: 189.
9. 1, 11111...1, 1. Player A: 300, Player B: 300.
10. 2, 24111111111111111111111111111111111111111111111211323
111...1, 1. Player A: -13, Player B: 91.
11. 1, 11111...1, 1. Player A: 300, Player B: 300.
12. 3, 33433433333334434444344444444244444442244442444...4, 2.
Player A: -708, Player B*: -1332.
13. 3, 3444423423442344444234444111...1, 1.
Player A: -197, Player B: -303.
14. 4, 323111...13, 4. Player A: 200, Player B: -8.
15. 1, 1212211221122211211221122122424214324131313213313133
1133131133113331131332132313333333333333334233333, 1.
Player A*: -1844, Player B*: -4132.
16. 1, 11111...1, 1. Player A: 300, Player B: 300.
17. 4, 43344413444244422342243422442244444244444244442444424
42121212421422424422423442424424424424444444, 4.
Player A: -3514, Player B: -598.
18. 1, 1212313422344124334113324111114111111313423443234344
3234412234344344444344444334421111133423343342344, 3.
Player A*: -1324, Player B*: -2780.
19. 2, 4242442244424444212122434442243442444424444422222222
44444444444442222444444444222444444444, 2.
Player A: -3178, Player B: -266.
20. 4, 11111111111111111112311134111...13, 1.
Player A: 73, Player B: -31.
21. 4, 22442444444444444434244444442422223341323342341123424334
3411113434123341121113344311331113324342443332344, 4.
Player A*: -1756, Player B*: -2588.
22. 2, 224122444444444444444323111111122332332111124332344
444444444444444444442111...13, 4.
Player A: -1588, Player B: -842.

Second Series

1. 433444444444444443. Blue Player: yes, White Player: no.
2. 43442243444442. Blue Player: yes, White Player: yes?
3. 2133233. Blue Player: no, White Player: yes.
4. 4444444444444444433. Blue Player: no, White Player: yes.
5. 22322. Blue Player: yes, White Player: yes?
6. 14433424444423. Blue Player: yes, White Player: yes?
7. 4443444...4. Blue Player: yes*, White Player: no.
8. 42332111...12. Blue Player: yes, White Player: yes.
9. 4111...1. Blue Player: yes, White Player: yes.
10. 1232242. Blue Player: yes, White Player: no.
11. 4242432. Blue Player: yes, White Player: yes?
12. 44444444442444443444...4. Blue Player: no, White player: no.
13. 11344243242. Blue Player: yes, White Player: yes?
14. 422432. Blue Player: yes, White Player: yes?
15. 3222111...13. Blue Player: yes, White Player: yes.
16. 434441333. Blue Player: no, White Player: yes.
17. 4222. Blue Player: yes, White Player: no.
18. 34424424...4. Blue Player: no, White Player: yes*.
19. 44412124311124432. Blue Player: yes, White Player: no.

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