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Equilibrium Behavior and Repeated Play of the Prisoner's Dilemma

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This paper examines a model of the prisoner's dilemma in which the nature of the Nash equilibria of the game can be varied. Two equilibrium indices are derived and are compared with two cooperation indices proposed by Rapoport and Chammah (1965). Preliminary experimental results indicate that the nature of the equilibria of a game affect the amount of cooperation.

Prisoner's dilemma games are models of societal and organizational conflict situations. The intriguing nature of the dilemmas and the potential importance of the situations they model has led to the study of prisoner's dilemma "problems" in several disciplines. Economists (e.g., Shubik, 1955), for instance, have used prisoner's dilemma games as a model of oligopolistic price setting. Political scientists have studied them as models of the free rider problem associated with public goods (e.g., Hardin, 1971). Psychologists have studied behavior in different forms of the prisoner's dilemma game (e.g., Rapoport and Chammah, 1965) and have often used them as a vehicle for studying personality differences (e.g., Terhune, 1968). This intense scrutiny has recently focused on techniques for increasing the amount of cooperation in prisoner's dilemma games (e.g., Dawes, McTavish, and Shaklee, 1977).

In this paper we examine a model in which the nature of the equilibria of the game (Nash, 1950) can be varied, and indicate that the amount of cooperation displayed in the game depends, in part, on the nature of these equilibria.

A *game* between two players consists of a set of strategies for each player and a real valued payoff function P, where the payoff for each player is determined by the strategy choices of both players. That is, if we let R denote the set of real numbers, and G_i denote the strategy set of player i, then $P = (P_1, P_2)$ where P_i: $G_1 \times G_2 \to R$, for $i = 1, 2$. If r and s denote two strategies available to player i, we say that s *dominates* r if player i gets a higher payoff from playing s than from playing r no matter what strategy his opponent chooses. For example, if $r, s \in G_1$, then s dominates r if $P_1(s, t) > P_1(r, t)$ for every $t \in G_2$. Thus, if r is a dominated strategy, it should never be played by a rational player interested in maximizing his payoff.

A strategy s for player 1 and t for player 2 are said to be an *equilibrium pair* of strategies if strategy s is player 1's best response when player 2 plays strategy t, and if t is player 2's best response when player 1 plays s. That is, the pair (s, t) is an equilibrium if $P_1(s, t) \geqslant P_1(r, t)$ for every $r \in G_1$, and $P_2(s, t) \geqslant P_2(s, v)$ for every $v \in G_2$. This notion of equilibrium is fundamental to the study of non-cooperative games (cf., Luce and Raiffa, 1957).

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The classical form of the prisoner's dilemma can be represented by the payoff matrices, $A_1 = \binom{a\ d}{b\ c}$, and $A_2 = \binom{a\ b}{d\ c}$, where a, b, c, and d are numbers such that $b > a > c > d$. Player 1 may choose a row of the matrices, while player 2 may choose a column. The payoff to player 1 is the element of A_1 thus specified, and the payoff to player 2 is the specified element of A_2. That is, the strategy sets G_1 and G_2 are both equal to the set of choices $C = \{1, 2\}$, and $P_i(j, k)$ is the element in row j and column k of the matrix A_i.

Each player's first choice is dominated by his second, and the unique equilibrium of this game is the strategy pair (2, 2), which yields the payoff $P(2, 2) = (c, c)$. The 'dilemma' is that if *both* players were to play their dominated strategies, each would receive a payoff higher than the equilibrium payoff. (Each player's first choice is sometimes referred to as 'cooperative', while the second choice is called 'individualistic'.)

A different form of the prisoner's dilemma is an n-period game in which the classical prisoner's dilemma is repeated at each period. In this game, a strategy is a set of rules which tells a player what choice to make at each period, based on the choices made by the players in previous periods. The payoff to a player is the sum of his payoffs in each period.

It will be convenient in what follows to consider some representative strategies for repeated games. Let $s1$ denote the strategy which tells a player to make his cooperative choice at every period, regardless of his opponent's choices. Similarly let $s2$ denote the strategy which tells a player to make his individualistic choice at every period. Let u (for 'unforgiving') denote the strategy which tells a player to make his cooperative choice at every period until his opponent plays his individualistic choice, and to play his individualistic choice at every subsequent period. Let m (for 'matching') denote the strategy which tells a player to play his cooperative choice in the first period, and in every other period to play the same choice that his opponent made in the previous period.

A sequence of choices will be denoted $(x_1, y_1), \ldots, (x_n, y_n)$ where x_i and y_i denote the choices of players 1 and 2 in period i. A pair of strategies determines the sequence of choices which will be observed when the game is played. For instance, the strategy pair $(s1, s2)$ determines the choice sequence (x_k, y_k) where $x_k = 1$ and $y_k = 2$ for each period k. Different strategy pairs may determine the same choice sequence: e.g., the strategy pairs $(s1, s1)$, (u, u) and (m, m) all generate the choices $x_k = y_k = 1$ for every period k.

In the n-period game, there is, in general, no single strategy which dominates all others. However, it is easily shown by induction (Luce and Raiffa, 1957) that any pair of equilibrium strategies in the n-period game must generate the choice sequence $x_k = y_k = 2$ for every period k.

It is instructive to consider a game repeated for infinitely many periods, in which the payoff is defined as the limit[1] as n goes to infinity of the average payoff per period. In this game there are equilibria (e.g., $(s2, s2)$) which generate the choice sequence $x_k = y_k = 2$ for every period k, but there are also equilibria (e.g., (u, u)) which generate the choices $x_k = y_k = 1$ for every period k. Thus, in the infinite case, some equilibria generate cooperative choices, and some generate individualistic choices. Although it is impossible to experimentally study infinite games, the n-period game has received intense scrutiny.

[1] When the limit does not exist, the lim inf is used.

Indeed, most of the research on prisoner's dilemma games (cf., Guyer and Perkel, 1972) has studied the n-period game. The results of these studies are not readily comparable, due to different payoff matrices and experimental manipulations. However, the data generally indicate that cooperation rates drop shortly after the start of play, and, after some delay where cooperation is not prevalent, the players move toward more cooperative choices (Rapoport, 1973).

Although several authors (e.g., Rapoport, 1971; Wolfe and Shubik, 1974) have argued for the study of one-period games, experimental data are very scarce. Morehous (1966), however, reports a study comparing one-, two-, five-, ten-, and 300-period plays of a single prisoner's dilemma game. Although there were no significant differences reported, the data suggest that cooperation rates in the first trial of the one- and two-period games were somewhat lower than the first trial of the five-, ten-, and 300-period games. The findings also indicated that the last play of an n-period game may result in a reduction in cooperative choices.

It is often contended in the literature that if subjects are not informed of the number of periods to be played, the resulting game yields the same equilibria as the infinite game, since no period is known to be the last. However, this is a considerable oversimplification. Since it is apparent that the game must eventually terminate, subjects must form subjective probabilities greater than zero that a given period might be the last. Although such probabilities have neither been observed nor controlled by experimenters, we shall see that they play a critical role in determining the nature of equilibrium outcomes.

Two Equilibrium Conditions

A paradigm which permits the nature of the equilibrium outcomes to be controlled can be obtained by considering repeated play(s) of the classical prisoner's dilemma with a fixed probability of continuing after each period. That is, after each period a random number can be generated independently of the play of the game to determine with probability p whether the game will be played again. Thus, each period has probability $q = (1 - p)$ of being the last. We adopt the convention that play begins in period 0, so p^k is the probability that the game does not terminate until after period k. If s and t are a pair of strategies which generate choices (x_k, y_k) then the (expected) payoff function Q for this game is given by $Q_i(s, t) = \sum_{k=0}^{\infty} p^k P_i(x_k, y_k)$, where P_i is the payoff function for player i in the classical game.

The nature of the equilibrium outcomes in this game depends on the value of p and the values of the payoff matrix. (Note that if $p = 0$, we have the classical game; and if $p = 1$, the game never terminates.)[2]

The strategy pair $(s2, s2)$, which generates the choice sequence $x_k = y_k = 2$ for every period k, is an equilibrium for any probability p. However, there may or may not be an equilibrium pair which generates the choices $x_k = y_k = 1$.

Since the unforgiving strategy u minimizes the gains an opponent can derive from ever making an individualistic choice, the choice sequence $x_k = y_k = 1$ can be generated by

[2] See the related discussion on page 102 of Luce and Raiffa.

an equilibrium pair of strategies if and only if (u, u) is an equilibrium. It is shown below that this occurs if and only if the following condition holds.

Condition 1: $p \geqslant (b - a)/(b - c)$

That is, when the probability of continuing is at least $(b - a)/(b - c)$, there are equilibria which may generate cooperative choices by both players at every period. When the probability of continuing is less than $(b - a)/(b - c)$, no such equilibria exist. Formally, we have the following proposition.

PROPOSITION 1. (a) *The strategy pair (u, u) is an equilibrium if and only if condition* 1 *is met.* (b) *Furthermore, if condition* 1 *is not met, there is no equilibrium which yields only cooperative choices.*

Proof. To prove part (a) we must show that if one of the players (say player 2) adopts the strategy u, then a best response of the other player is also to play u. That is, we must show that $Q_1(u, u) \geqslant Q_1(t, u)$ for any strategy t.

Let (x_k, y_k) be the choice sequence generated by (t, u), and let n be the first period in which player 1 makes his individualistic choice (i.e., $x_n = 2$). Let t' be the strategy which tells player 1 to play strategy t up to period n, and to play his individualistic choice at every subsequent period.

Then

$$Q_1(t, u) \leqslant Q_1(t', u) = \sum_{k=0}^{n-1} ap^k + p^n \left(b + \frac{cp}{1-p}\right).$$

But

$$Q_1(u, u) = \sum_{k=0}^{\infty} ap^k = \sum_{k=0}^{n-1} ap^k + p^n \left(\frac{a}{1-p}\right).$$

So $Q_1(u, u) \geqslant Q_1(t', u)$ if and only if $a/(1 - p) \geqslant b + cp/(1 - p)$, which occurs if and only if condition 1 is satisfied. This completes the proof of part (a).

If condition 1 is not met, then (u, u) is not an equilibrium: *i.e.*, there is a strategy t such that $Q_1(t, u) > Q_1(u, u)$. But, since $c > d$, for any strategy t we have $Q_1(t', u) \geqslant Q_1(t, u)$, where t' is defined as in the proof of part (a). So without loss of generality we may take $t = t'$. Now suppose that (r, s) is a strategy pair which yields the choice sequence $x_k = y_k = 1$ for every period k. Then $Q_1(r, s) = Q_1(u, u) = a/(1 - p)$. But $Q_1(t', u) \leqslant Q_1(t', s)$, since $b > c$. So $Q_1(t', s) \geqslant Q_1(t', u) > Q_1(u, u) = Q_1(r, s)$, and, thus, (r, s) cannot be an equilibrium if condition 1 is not met. This completes the proof of part (b).

Of course, when condition 1 is satisfied, other strategy pairs which generate cooperative choices may also be in equilibrium. For instance, it can be shown that the pair (m, m) is an equilibrium if and only if both condition 1 and the following condition are satisfied.[3]

[3] Since $p \leqslant 1$, Condition 2 implies $b + d \leqslant 2a$. This is sometimes taken to be part of the definition of the Prisoner's Dilemma.

Condition. 2. $p \geqslant (b - a)/(a - d)$

That is, we have

PROPOSITION 2. *The strategy pair* (m, m) *is an equilibrium if and only if* both *condition* 1 *and condition* 2 *are satisfied.*

Proof. If condition 1 is not met, then by proposition 1 (u, u) is not an equilibrium, so there exists a strategy t such that $Q_1(t, u) > Q_1(u, u) = Q_1(m, m)$. But for any strategy t, $Q_1(t, m) \geqslant Q_1(t, u)$ (since a and b are greater than d and c), so $Q_1(t, m) \geqslant Q_1(t, u) > Q_1(m, m)$, and (m, m) is not an equilibrium pair.

If condition 2 is not met, then consider the strategy t_1 which tells player 1 to play his individualistic choice exactly once, say in period n. Then $Q_1(t_1, m) - Q_1(m, m) = p^n(b - a) + p^{n+1}(d - a)$ which is greater than zero if and only if condition 2 is *not* met, so in this case (m, m) is not an equilibrium pair.

We must now show that if conditions 1 and 2 are both met, then (m, m) is an equilibrium: i.e. that $Q_1(t, m) \leqslant Q_1(m, m)$ for any strategy t. Let t be a strategy such that (t, m) yields a sequence of choices (x_k, y_k) which are not all cooperative, and let n be the first period in which $x_n = 2$.

Let t' be the strategy defined in the proof of proposition 1. Since condition 1 is met, $Q_1(m, m) = Q_1(u, u) \geqslant Q_1(t', u) = Q_1(t', m)$. Consequently we can confine our attention to strategies t which do not generate the individualistic choice at every period after n.

Let t_r and t_{r+1} be strategies such that the strategy pairs (t_r, m) and (t_{r+1}, m) generate choice sequences (x_k, y_k) and (x_k', y_k') where $x_n = x_{n+1} = \cdots = x_{r-1} = 2$ while $x_r = x_{r+1} = 1$. Suppose also that $x_r' = 2$, but that for $k \neq r$, $x_k' = x_k$. Thus the strategy t_r generates a sequence of precisely r individualistic choices, and t_{r+1} generates one more.

Then $Q_1(t_r, m) - Q_1(t_{r+1}, m) = p^{r+1}(d - c) + p^{r+2}(a - d) = p^{r+1}(d - c + p(a - d))$.

So the *sign* of $Q_1(t_r, m) - Q_1(t_{r+1}, m)$ is independent of r, and either

(i) $Q_1(t_1, m) \leqslant Q_1(t_2, m) \leqslant \cdots \leqslant Q_1(t_k, m) \leqslant \cdots$

or

(ii) $Q_1(t_1, m) > Q_1(t_2, m) > \cdots > Q_1(t_k, m) > \cdots$

Observe that t' is the limit of t_k as k goes to infinity, so that in case (i), $Q_1(t', m) \geqslant Q_1(t_k, m)$ for any k. Since condition 1 holds, $Q_1(m, m) \geqslant Q_1(t', m) \geqslant Q_1(t_k, m)$ in this case.

When case (ii) holds, we have already shown (in the second paragraph of this proof) that $Q_1(m, m) \geqslant Q_1(t_1, m)$ when condition 2 is met. This now suffices to show that $Q_1(m, m) \geqslant Q_1(t_k, m)$ for any k.

Since the strategies t_k are arbitrary, except for the specification of a sequence of precisely k individualistic choices[4], the fact that $Q_1(m, m) \geqslant Q_1(t_k, m)$ for any k is sufficient to show that $Q_1(m, m) \geqslant Q_1(t, m)$ for any t. By symmetry, $Q_2(m, m) \geqslant Q_2(m, t)$ for any t, so (m, m) is an equilibrium pair. This completes the proof.

[4] Actually, we also specified that $x_{r+1} = 1$. This was done merely for the sake of definiteness in computing the difference $Q_1(t_r, m) - Q_1(t_{r+1}, m)$. The class of strategies for which $x_{r+1} = 2$ is treated in a precisely similar manner.

We conducted an experiment to test the predictive value of this model. We chose a game with the property that Condition 1 is satisfied if and only if Condition 2 is satisfied. Thus, the critical value of p is identical for either the unforgiving or the matching strategy. That is, we chose the game in which $b = 40$, $a = 30$, $c = 10$, and $d = 0$. For either strategy then, if $p \geqslant 1/3$ both strategies result in equilibria. For $p < 1/3$, no equilibrium yields cooperative choices.

Method. One hundred and twenty-one undergraduate students participated in each of three sessions where p equalled .105, .50, and .895. Both male and female subjects played the games, and the order of the three sessions was counter-balanced. Each session began with introductory instructions about prisoner's dilemma games. In order to control for differences in subjects' behavior due to differences in their opponents, each subject played against an artificial opponent who used the matching strategy. The players were told that they played a programmed opponent, but were not told what strategy he would be using. Players were also told that "the best player" in the experiment would receive a \$10 prize.

Subjects were told that a roulette wheel would be spun after each period to determine if the game would be continued. Half of the subjects played the condition $p = .105$ first. They were told that the game would continue only if the ball fell in numbers 33 through 36 (which occurs with probability .105). Several practice games were played to familiarize the players with the game. The subjects were then told that they would play a final game, the results of which would contribute to the determination of the winner of the \$10 prize. This procedure was then repeated for $p = .50$ and $p = .895$; in each case practice games were played before a final game which contributed to the determination of the prize winner(s). The other half of the subjects played the conditions in the reverse order: $p = .895$ first and $p = .105$ last. The experimenter was seated behind an opaque partition throughout each session; he recorded the responses of each of the players after each practice and final trial. He also played the role of the programmed opponent and gave the players feedback concerning their payoffs and their opponent's payoffs after each trial.[5]

Results. A 2 (sex) by 3 (probability of continuing) by 2 (order of the probabilities: decreasing or increasing) analysis of variance of the frequency of cooperative responses for the first period[6], with probability of continuing a within factor, resulted in one significant effect, for probability of continuing: $F(2, 234) = 9.01, p < .0002$. In the ($p = .895$) condition, 44 of 121 responses were cooperative; in the ($p = .50$) condition, 36 of 121

[5] Note that the existence of cooperative equilibria for the game described depends on the fact that for any n, there is a positive probability that the game will continue for n trials. (Although for large n, this probability becomes very small). Under experimental conditions, it would of course be impossible to continue the game for, say, a million trials. But since this is such a low-probability event, the experimental design provides a good approximation of the probabilistically terminated game. In fact, no play of the game ever had to be terminated artificially.

[6] The analysis was conducted only on the first period because in many of the games, especially in the ($p = .105$) condition, only one period completed the series. Cooperative responses on subsequent trials yielded similar results: 246 of 607 (41 %) in the ($p = .895$) condition; 40 of 127 (31 %) in the ($p = .50$) condition; and 1 of 2 in the ($p = .105$) condition.

responses were cooperative; and in the ($p = .105$) condition, 23 of 121 responses were cooperative. *Post hoc* tests using the Scheffé procedure resulted in significant differences at the .05 level between the ($p = .105$) condition and each of the other conditions. Only the latter two conditions have cooperative equilibria. The difference between the ($p = .895$) and ($p = .50$) conditions was not significant. Thus, players made the cooperative choice more frequently when it resulted from an equilibrium strategy.

In order to attribute these results to the nature of the equilibria in the games, we must account for the potential effects of the associated variation in the expected duration of each game. The *expected* durations of the games in our three conditions (rounded to the nearest integer) are 1, 2, and 10 periods. Morehous's (1966) results for a game with a *fixed* duration of 1, 2, 5, or 10 periods are an important comparison. He reports no significant difference in the amount of cooperation evidenced in these games, although the results were in the same direction as our results. (Recall that in n-period games the cooperative choice never results from an equilibrium strategy.) Thus, the present results support the conclusion that the behavior of experimental subjects in a game is congruent with the nature of the equilibrium strategies.

Comparison with Previous Treatments

If the payoffs in a game are defined only up to an interval scale (e.g., in terms of an expected utility function) then meaningful statements about the game must be invariant under positive linear transformations. Propositions 1 and 2 satisfy this requirement since they are stated in terms of ratios of differences between the payoffs associated with different outcomes.

Rapoport and Chammah (1965) consider the class of such ratios, focusing on two representatives which have some desirable qualitative properties. In particular, they define the quantities r_1 and r_2 by $r_1 = (a - c)/(b - d)$, and $r_2 = (a - d)/(b - d)$.

Rapoport and Chammah note that $\partial r_1/\partial a > 0$, $\partial r_1/\partial c < 0$, $\partial r_1/\partial b < 0$ and $\partial r_1/\partial d > 0$. Consequently r_1 can be interpreted as an index of the 'cooperativeness' of a game, since it increases when the reward for simultaneous cooperation (a) increases, and it decreases when the reward for simultaneous individualism (c) increases. Also, r_1 decreases as the reward for unilateral defection from a cooperative agreement (b) increases, and r_1 increases as the penalty for being a victim of such a defection is ameliorated (*i.e.*, as d increases).

The qualitative behavior of r_2 is similar, since $\partial r_2/\partial a > 0$, $\partial r_2/\partial c = 0$, $\partial r_2/\partial b < 0$ and $\partial r_2/\partial d < 0$. Thus the partial derivatives of r_1 and r_2 agree in sign except with respect to the variable d.

Only a few experimental studies have systematically studied the validity of r_1 and r_2 as predictors of cooperative behavior. The data that have been collected, however, strongly support the predictability of r_1. Rapoport and Chammah's (1965) results on the games depicted in Table 1 indicated that increasing values of r_1 were associated with increasing amounts of cooperation. Steele and Tedeschi (1967) present a more pointed analysis of the results of several payoff matrices. They also found that increases in the value of r_1 were associated with increased amounts of cooperation. In addition, they noted a linear relationship between amounts of cooperation and the log of r_1. These results were replicated by Jones, Steele, Gahagan, and Tedeschi (1968).

TABLE 1

Entries from the Payoff Matrices and Values for the Cooperation and Equilibrium Indices for Seven Games Used by Rapoport and Chammah (1965)

Game	a	b	c	d	r_1	r_2	e_1	e_2
1	9	10	−1	−10	.50	.95	.09	.05
2	1	10	−9	−10	.50	.55	.47	.82
3	1	10	−1	−10	.10	.55	.82	.82
4	1	2	−1	−2	.50	.75	.33	.33
5	1	50	−1	−50	.02	.51	.96	.96
6	5	10	−1	−10	.30	.75	.45	.33
7	1	10	−5	−10	.30	.55	.60	.82

Propositions 1 and 2 suggest alternate indices as appropriate measures of the "cooperativeness' of a game. In particular, let the *equilibrium indices* e_1 and e_2 be defined by

$$e_1 = \frac{b-a}{b-c}, \quad \text{and} \quad e_2 = \frac{b-a}{a-d}.$$

Then, e_1 and e_2 may be interpreted as indices measuring the *difficulty* of achieving a cooperative equilibrium. Proposition 1 says that, as e_1 increases, the range of probabilities which make a cooperative equilibrium feasible diminishes in size. As e_1 increases, so does the critical value of the probability p, below which no equilibria result in cooperation. The quantity e_2 has a similar interpretation in the more limited context of equilibria involving the matching strategy.

Although the indices e_1 and e_2 were derived for games with a random termination point, they share with the indices r_1 and r_2 the qualitative properties that make them interesting for games with a fixed termination point. In particular, $\partial e_1/\partial a < 0$, $\partial e_1/\partial c > 0$, and $\partial e_1/\partial b > 0$.

Thus the partial derivatives of e_1 have the opposite sign from the partial derivatives of r_1. This is consistent with the interpretation of e_1 as a measure which increases as the difficulty of achieving cooperative outcomes increases, and the interpretation of r_1 as a measure which decreases as the difficulty of achieving cooperative outcomes increases. Similarly, $\partial e_2/\partial a < 0$, $\partial e_2/\partial b > 0$, and $\partial e_2/\partial d > 0$: the derivatives of e_2 and r_2 also have opposite sign.

Note that $e_1 = (1 - r_2)/(1 + r_1 - r_2)$, and $e_2 = (1 - r_2)/r_2$. So, as expected, the quantities $\partial e_1/\partial r_1$, $\partial e_1/\partial r_2$, and $\partial e_2/\partial r_2$ are all negative. Similarly, the quantities $\partial r_1/\partial e_1$ and $\partial r_2/\partial e_2$ are negative, but the quantity $\partial r_1/\partial e_2$ is positive.[7]

Thus, when more than one parameter is varied, the indices e_2 and r_2 respond together (i.e., they yield the same ordering of games). However, it is not difficult to verify that e_1

[7] The quantity $\partial r_1/\partial e_2 = (1 - e_1e_2/e_1(1 + e_2)^2)$ is positive if and only if $e_1e_2 < 1$, since e_1 and e_2 are both positive. Furthermore, $e_1 < 1$, and the condition $b + d \leqslant 2a$ implies that $e_2 \leqslant 1$ (see footnote 3). Here we regard this condition as part of the definition of the prisoner's dilemma, and so $e_1e_2 < 1$.

and r_1 yield different orderings, in general. To see this, see Table 1, which includes all four indices for seven games studied by Rapoport and Chammah (1965).

Both sets of indices have received some experimental support.[8] The entries in Table 1, however, suggest several critical theoretical tests. For instance, a study utilizing games 1 and 2 in the table might manipulate p in each game. The r_1 index, which has received the most experimental support, would lead to a prediction of no differences in cooperation between games for any value of p. The e_1 or e_2 indices, however, would lead to differential predictions for cooperativeness, depending on p. Other games, with or without manipulations of p, could also test differences in the indices. The present formulation, then, indicates that such studies are worth investigation.

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[8] Recently, Goehring and Kahan (1976) presented an index of competitiveness, R, for n-person prisoner's dilemma games, which, when restricted to 2 person games is identical to the second equilibrium index, e_2, that we have derived. They also conducted several n-person games, finding that cooperativeness decreased as R increased. These results, then, also support the present model. In addition, the extension of the present indices to n-person prisoner's dilemma games, similar to Komorita's (1976) extension of Rapoport and Chammah's (1965) r_1, is straightforward.

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