Prisoner's dilemma

The prisoner's dilemma is a fundamental problem in game theory that demonstrates why two people might not cooperate even if it is in both their best interests to do so. It was originally framed by Merrill Flood and Melvin Dresher working at RAND in 1950. Albert W. Tucker formalized the game with prison sentence payoffs and gave it the "prisoner's dilemma" name (Poundstone, 1992).

A classic example of the prisoner's dilemma (PD) is presented as follows:

Two suspects are arrested by the police. The police have insufficient evidence for a conviction, and, having separated the prisoners, visit each of them to offer the same deal. If one testifies for the prosecution against the other (defects) and the other remains silent (cooperates), the defector goes free and the silent accomplice receives the full 10-year sentence. If both remain silent, both prisoners are sentenced to only six months in jail for a minor charge. If each betrays the other, each receives a five-year sentence. Each prisoner must choose to betray the other or to remain silent. Each one is assured that the other would not know about the betrayal before the end of the investigation. How should the prisoners act?

If we assume that each player cares only about minimizing his or her own time in jail, then the prisoner's dilemma forms a non-zero-sum game in which two players may each either cooperate with or defect from (betray) the other player. In this game, as in most game theory, the only concern of each individual player (prisoner) is maximizing his or her own payoff, without any concern for the other player's payoff. The unique equilibrium for this game is a Pareto-suboptimal solution, that is, rational choice leads the two players to both play defect, even though each player's individual reward would be greater if they both played cooperatively.

In the classic form of this game, cooperating is strictly dominated by defecting, so that the only possible equilibrium for the game is for all players to defect. No matter what the other player does, one player will always gain a greater payoff by playing defect. Since in any situation playing defect is more beneficial than cooperating, all rational players will play defect, all things being equal.

In the iterated prisoner's dilemma, the game is played repeatedly. Thus each player has an opportunity to punish the other player for previous non-cooperative play. If the number of steps is known by both players in advance, economic theory says that the two players should defect again and again, no matter how many times the game is played. However, this analysis fails to predict the behavior of human players in a real iterated prisoners dilemma situation, and it also fails to predict the optimum algorithm when computer programs play in a tournament. Only when the players play an indefinite or random number of times can cooperation be an equilibrium, technically a subgame perfect equilibrium meaning that both players defecting always remains an equilibrium and there are many other equilibrium outcomes. In this case, the incentive to defect can be overcome by the threat of punishment.

In casual usage, the label "prisoner's dilemma" may be applied to situations not strictly matching the formal criteria of the classic or iterative games, for instance, those in which two entities could gain important benefits from cooperating or suffer from the failure to do so, but find it merely difficult or expensive, not necessarily impossible, to coordinate their activities to achieve cooperation.

Strategy for the classic prisoner's dilemma

The classical prisoner's dilemma can be summarized thus:
Prisoner's dilemma

<table>
<thead>
<tr>
<th>Prisoner B Stays Silent</th>
<th>Prisoner B Betrays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Each serves 6 months</td>
<td>Prisoner A: 10 years</td>
</tr>
<tr>
<td></td>
<td>Prisoner B: goes free</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prisoner A Stays Silent</th>
<th>Each serves 6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prisoner A: 10 years</td>
</tr>
</tbody>
</table>

In this game, regardless of what the opponent chooses, each player always receives a higher payoff (lesser sentence) by betraying; that is to say that betraying is the strictly dominant strategy. For instance, Prisoner A can accurately say, "No matter what Prisoner B does, I personally am better off betraying than staying silent. Therefore, for my own sake, I should betray." However, if the other player acts similarly, then they both betray and both get a lower payoff than they would get by staying silent. Rational self-interested decisions result in each prisoner being worse off than if each chose to lessen the sentence of the accomplice at the cost of staying a little longer in jail himself (hence the seeming dilemma). In game theory, this demonstrates very elegantly that in a non-zero-sum game a Nash equilibrium need not be a Pareto optimum.

**Generalized form**

We can expose the skeleton of the game by stripping it of the prisoner framing device. The generalized form of the game has been used frequently in experimental economics. The following rules give a typical realization of the game.

There are two players and a banker. Each player holds a set of two cards, one printed with the word "Cooperate" (as in, with each other), the other printed with "Defect" (the standard terminology for the game).

Each player puts one card face-down in front of the banker. By laying them face down, the possibility of a player knowing the other player's selection in advance is eliminated (although revealing one's move does not affect the dominance analysis [1]). At the end of the turn, the banker turns over both cards and gives out the payments accordingly.

Given two players, "red" and "blue": if the red player defects and the blue player cooperates, the red player gets the Temptation to Defect payoff of 5 points while the blue player receives the Sucker's payoff of 0 points. If both cooperate they get the Reward for Mutual Cooperation payoff of 3 points each, while if they both defect they get the Punishment for Mutual Defection payoff of 1 point. The checker board payoff matrix showing the payoffs is given below.

**Example PD payoff matrix**

<table>
<thead>
<tr>
<th></th>
<th>Cooperate</th>
<th>Defect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperate</td>
<td>3, 3</td>
<td>0, 5</td>
</tr>
<tr>
<td>Defect</td>
<td>5, 0</td>
<td>1, 1</td>
</tr>
</tbody>
</table>

In "win-lose" terminology the table looks like this:
Prisoner's dilemma

<table>
<thead>
<tr>
<th></th>
<th>Cooperate</th>
<th>Defect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperate</td>
<td>win-win</td>
<td>lose more-win more</td>
</tr>
<tr>
<td>Defect</td>
<td>win more-lose more</td>
<td>lose-lose</td>
</tr>
</tbody>
</table>

These point assignments are given arbitrarily for illustration. It is possible to generalize them, as follows:

**Canonical PD payoff matrix**

<table>
<thead>
<tr>
<th></th>
<th>Cooperate</th>
<th>Defect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperate</td>
<td>R, R</td>
<td>S, T</td>
</tr>
<tr>
<td>Defect</td>
<td>T, S</td>
<td>P, P</td>
</tr>
</tbody>
</table>

Where $T$ stands for Temptation to defect, $R$ for Reward for mutual cooperation, $P$ for Punishment for mutual defection and $S$ for Sucker's payoff. To be defined as prisoner's dilemma, the following inequalities must hold:

$T > R > P > S$

This condition ensures that the equilibrium outcome is defection, but that cooperation Pareto dominates equilibrium play. In addition to the above condition, if the game is repeatedly played by two players, the following condition should be added:[2]

$2 R > T + S$

If that condition does not hold, then full cooperation is not necessarily Pareto optimal, as the players are collectively better off by having each player alternate between Cooperate and Defect.

These rules were established by cognitive scientist Douglas Hofstadter and form the formal canonical description of a typical game of prisoner's dilemma.

A simple special case occurs when the advantage of defection over cooperation is independent of what the co-player does and cost of the co-player's defection is independent of one's own action, i.e. $T+S = P+R$.

**Human behavior in the prisoner's dilemma**

One experiment based on the simple dilemma found that approximately 40% of participants played "cooperate" (i.e., stayed silent).[3]

**The iterated prisoner's dilemma**

If two players play prisoner's dilemma more than once in succession and they remember previous actions of their opponent and change their strategy accordingly, the game is called iterated prisoner's dilemma.

The iterated prisoner's dilemma game is fundamental to certain theories of human cooperation and trust. On the assumption that the game can model transactions between two people requiring trust, cooperative behaviour in populations may be modelled by a multi-player, iterated, version of the game. It has, consequently, fascinated many scholars over the years. In 1975, Grofman and Pool estimated the count of scholarly articles devoted to it at over 2,000. The iterated prisoner's dilemma has also been referred to as the "Peace-War game".[4]

If the game is played exactly $N$ times and both players know this, then it is always game theoretically optimal to defect in all rounds. The only possible Nash equilibrium is to always defect. The proof is inductive: one might as well defect on the last turn, since the opponent will not have a chance to punish the player. Therefore, both will defect on the last turn. Thus, the player might as well defect on the second-to-last turn, since the opponent will defect on the last no matter what is done, and so on. The same applies if the game length is unknown but has a known upper limit.
Unlike the standard prisoner's dilemma, in the iterated prisoner's dilemma the defection strategy is counterintuitive and fails badly to predict the behavior of human players. Within standard economic theory, though, this is the only correct answer. The superrational strategy in the iterated prisoners dilemma with fixed N is to cooperate against a superrational opponent, and in the limit of large N, experimental results on strategies agree with the superrational version, not the game-theoretic rational one.

For cooperation to emerge between game theoretical rational players, the total number of rounds N must be random, or at least unknown to the players. In this case always defect may no longer be a strictly dominant strategy, only a Nash equilibrium. Amongst results shown by Nobel Prize winner Robert Aumann in his 1959 paper, rational players repeatedly interacting for indefinitely long games can sustain the cooperative outcome.

**Iterated prisoners dilemma experiments**

Interest in the iterated prisoners dilemma (IPD) was kindled by Robert Axelrod in his book *The Evolution of Cooperation* (1984). In it he reports on a tournament he organized of the N step prisoner dilemma (with N fixed) in which participants have to choose their mutual strategy again and again, and have memory of their previous encounters. Axelrod invited academic colleagues all over the world to devise computer strategies to compete in an IPD tournament. The programs that were entered varied widely in algorithmic complexity, initial hostility, capacity for forgiveness, and so forth.

Axelrod discovered that when these encounters were repeated over a long period of time with many players, each with different strategies, greedy strategies tended to do very poorly in the long run while more altruistic strategies did better, as judged purely by self-interest. He used this to show a possible mechanism for the evolution of altruistic behaviour from mechanisms that are initially purely selfish, by natural selection.

The best deterministic strategy was found to be tit for tat, which Anatol Rapoport developed and entered into the tournament. It was the simplest of any program entered, containing only four lines of BASIC, and won the contest. The strategy is simply to cooperate on the first iteration of the game; after that, the player does what his or her opponent did on the previous move. Depending on the situation, a slightly better strategy can be "tit for tat with forgiveness." When the opponent defects, on the next move, the player sometimes cooperates anyway, with a small probability (around 1–5%). This allows for occasional recovery from getting trapped in a cycle of defections. The exact probability depends on the line-up of opponents.

By analysing the top-scoring strategies, Axelrod stated several conditions necessary for a strategy to be successful.

**Nice**

The most important condition is that the strategy must be "nice", that is, it will not defect before its opponent does (this is sometimes referred to as an "optimistic" algorithm). Almost all of the top-scoring strategies were nice; therefore a purely selfish strategy will not "cheat" on its opponent, for purely utilitarian reasons first.

**Retaliating**

However, Axelrod contended, the successful strategy must not be a blind optimist. It must sometimes retaliate. An example of a non-retaliating strategy is Always Cooperate. This is a very bad choice, as "nasty" strategies will ruthlessly exploit such players.

**Forgiving**

Successful strategies must also be forgiving. Though players will retaliate, they will once again fall back to cooperating if the opponent does not continue to defect. This stops long runs of revenge and counter-revenge, maximizing points.

**Non-envious**

The last quality is being non-envious, that is not striving to score more than the opponent (impossible for a 'nice' strategy, i.e., a 'nice' strategy can never score more than the opponent).
The optimal (points-maximizing) strategy for the one-time PD game is simply defection; as explained above, this is true whatever the composition of opponents may be. However, in the iterated-PD game the optimal strategy depends upon the strategies of likely opponents, and how they will react to defections and cooperations. For example, consider a population where everyone defects every time, except for a single individual following the tit for tat strategy. That individual is at a slight disadvantage because of the loss on the first turn. In such a population, the optimal strategy for that individual is to defect every time. In a population with a certain percentage of always-defectors and the rest being tit for tat players, the optimal strategy for an individual depends on the percentage, and on the length of the game.

A strategy called Pavlov (an example of Win-Stay, Lose-Switch) cooperates at the first iteration and whenever the player and co-player did the same thing at the previous iteration; Pavlov defects when the player and co-player did different things at the previous iteration. For a certain range of parameters, Pavlov beats all other strategies by giving preferential treatment to co-players which resemble Pavlov.

Deriving the optimal strategy is generally done in two ways:

1. Bayesian Nash Equilibrium: If the statistical distribution of opposing strategies can be determined (e.g. 50% tit for tat, 50% always cooperate) an optimal counter-strategy can be derived analytically.
2. Monte Carlo simulations of populations have been made, where individuals with low scores die off, and those with high scores reproduce (a genetic algorithm for finding an optimal strategy). The mix of algorithms in the final population generally depends on the mix in the initial population. The introduction of mutation (random variation during reproduction) lessens the dependency on the initial population; empirical experiments with such systems tend to produce tit for tat players (see for instance Chess 1988), but there is no analytic proof that this will always occur.

Although tit for tat is considered to be the most robust basic strategy, a team from Southampton University in England (led by Professor Nicholas Jennings and consisting of Rajdeep Dash, Sarvapali Ramchurn, Alex Rogers, Perukrishnen Vytelingum) introduced a new strategy at the 20th-anniversary iterated prisoner's dilemma competition, which proved to be more successful than tit for tat. This strategy relied on cooperation between programs to achieve the highest number of points for a single program. The University submitted 60 programs to the competition, which were designed to recognize each other through a series of five to ten moves at the start. Once this recognition was made, one program would always cooperate and the other would always defect, assuring the maximum number of points for the defector. If the program realized that it was playing a non-Southampton player, it would continuously defect in an attempt to minimize the score of the competing program. As a result, this strategy ended up taking the top three positions in the competition, as well as a number of positions towards the bottom.

This strategy takes advantage of the fact that multiple entries were allowed in this particular competition, and that the performance of a team was measured by that of the highest-scoring player (meaning that the use of self-sacrificing players was a form of minmaxing). In a competition where one has control of only a single player, tit for tat is certainly a better strategy. Because of this new rule, this competition also has little theoretical significance when analysing single agent strategies as compared to Axelrod's seminal tournament. However, it provided the framework for analysing how to achieve cooperative strategies in multi-agent frameworks, especially in the presence of noise. In fact, long before this new-rules tournament was played, Richard Dawkins in his book *The Selfish Gene* pointed out the possibility of such strategies winning if multiple entries were allowed, but remarked that most probably Axelrod would not have allowed them if they had been submitted. It also relies on circumventing rules about the prisoner's dilemma in that there is no communication allowed between the two players. When the Southampton programs engage in an opening "ten move dance" to recognize one another, this only reinforces just how valuable communication can be in shifting the balance of the game.

Another odd case is "play forever" prisoner's dilemma. The game is repeated infinitely many times and the player's score is the average (suitably computed).
Continuous iterated prisoner's dilemma

Most work on the iterated prisoner's dilemma has focused on the discrete case, in which players either cooperate or defect, because this model is relatively simple to analyze. However, some researchers have looked at models of the continuous iterated prisoner's dilemma, in which players are able to make a variable contribution to the other player. Le and Boyd\cite{8} found that in such situations, cooperation is much harder to evolve than in the discrete iterated prisoner's dilemma. The basic intuition for this result is straightforward: in a continuous prisoner's dilemma, if a population starts off in a non-cooperative equilibrium, players who are only marginally more cooperative than non-cooperators get little benefit from assorting with one another. By contrast, in a discrete prisoner's dilemma, tit for tat cooperators get a big payoff boost from assorting with one another in a non-cooperative equilibrium, relative to non-cooperators. Since nature arguably offers more opportunities for variable cooperation rather than a strict dichotomy of cooperation or defection, the continuous prisoner's dilemma may help explain why real-life examples of tit for tat-like cooperation are extremely rare in nature (ex. Hammerstein\cite{9}) even though tit for tat seems robust in theoretical models.

Learning psychology and game theory

Where game players can learn to estimate the likelihood of other players defecting, their own behaviour is influenced by their experience of the others' behaviour. Simple statistics show that inexperienced players are more likely to have had, overall, atypically good or bad interactions with other players. If they act on the basis of these experiences (by defecting or cooperating more than they would otherwise) they are likely to suffer in future transactions. As more experience is accrued a truer impression of the likelihood of defection is gained and game playing becomes more successful. The early transactions experienced by immature players are likely to have a greater effect on their future playing than would such transactions have upon mature players. This principle goes part way towards explaining why the formative experiences of young people are so influential and why, for example, those who are particularly vulnerable to bullying sometimes become bullies themselves.

The likelihood of defection in a population may be reduced by the experience of cooperation in earlier games allowing trust to build up.\cite{10} Hence self-sacrificing behaviour may, in some instances, strengthen the moral fibre of a group. If the group is small the positive behaviour is more likely to feed back in a mutually affirming way, encouraging individuals within that group to continue to cooperate. This is allied to the twin dilemma of encouraging those people whom one would aid to indulge in behaviour that might put them at risk. Such processes are major concerns within the study of reciprocal altruism, group selection, kin selection and moral philosophy.

Douglas Hofstadter's Superrationality

Douglas Hofstadter in his Metamagical Themas proposed that the conception of rationality that led "rational" players to defect is faulty. He proposed that there is another type of rational behavior, which he called "superrational", where players take into account that the other person is presumably superrational, like them. Superrational players behave identically and know that they will behave identically. They take that into account before they maximize their payoffs, and they therefore cooperate with each other.

This view of the one-shot PD leads to cooperation as follows:

• Any superrational strategy will be the same for both superrational players, since both players will think of it.
• Therefore the superrational answer will lie on the diagonal of the payoff matrix
• When you maximize return from solutions on the diagonal, you cooperate

If a superrational player plays against a known rational opponent, he or she will defect. A superrational player only cooperates with other superrational players, whose thinking is correlated with his or hers. If a superrational player plays against an opponent of unknown superrationality in a symmetric situation, the result can be either to cooperate or to defect depending on the odds that the opponent is superrational (Pavlov strategy).
Superrationality is not studied by academic economists, because the economic definition of rationality excludes any superrational behavior by definition. Nevertheless, analogs of one-shot cooperation are observed in human culture, wherever religious or ethical codes exist. Hofstadter discusses the example of an economic transaction between strangers passing through a town—where either party stands to gain by cheating the other, with little hope of retaliation. Still, cheating is the exception rather than the rule.

Morality
While it is sometimes thought that morality must involve the constraint of self-interest, David Gauthier famously argues that co-operating in the prisoners dilemma on moral principles is consistent with self-interest and the axioms of game theory. In his opinion, it is most prudent to give up straight-forward maximizing and instead adopt a disposition of constrained maximization, according to which one resolves to cooperate in the belief that the opponent will respond with the same choice, while in the classical PD it is explicitly stipulated that the response of the opponent does not depend on the player's choice. This form of contractarianism claims that good moral thinking is just an elevated and subtly strategic version of basic means-end reasoning.

Douglas Hofstadter expresses a strong personal belief that the mathematical symmetry is reinforced by a moral symmetry, along the lines of the Kantian categorical imperative: defecting in the hope that the other player cooperates is morally indefensible. If players treat each other as they would treat themselves, then they will cooperate.

Real-life examples
These particular examples, involving prisoners and bag switching and so forth, may seem contrived, but there are in fact many examples in human interaction as well as interactions in nature that have the same payoff matrix. The prisoner's dilemma is therefore of interest to the social sciences such as economics, politics and sociology, as well as to the biological sciences such as ethology and evolutionary biology. Many natural processes have been abstracted into models in which living beings are engaged in endless games of prisoner's dilemma. This wide applicability of the PD gives the game its substantial importance.

In politics
In political science, for instance, the PD scenario is often used to illustrate the problem of two states engaged in an arms race. Both will reason that they have two options, either to increase military expenditure or to make an agreement to reduce weapons. Either state will benefit from military expansion regardless of what the other state does; therefore, they both incline towards military expansion. The paradox is that both states are acting rationally, but producing an apparently irrational result. This could be considered a corollary to deterrence theory.

In science
In environmental studies, the PD is evident in crises such as global climate change. All countries will benefit from a stable climate, but any single country is often hesitant to curb CO₂ emissions. The immediate benefit to an individual country to maintain current behavior is perceived to be greater than the eventual benefit to all countries if behavior was changed, therefore explaining the current impasse concerning climate change. In program management and technology development, the PD applies to the relationship between the customer and the developer. Capt Dan Ward, an officer in the US Air Force, examined The Program Manager's Dilemma in an article published in Defense AT&L, a defense technology journal.
**In social science**

In sociology or criminology, the PD may be applied to an actual dilemma facing two inmates. The game theorist Marek Kaminski, a former political prisoner, analysed the factors contributing to payoffs in the game set up by a prosecutor for arrested defendants (see references below). He concluded that while the PD is the ideal game of a prosecutor, numerous factors may strongly affect the payoffs and potentially change the properties of the game.

**Steroid use**

The prisoner’s dilemma applies to the decision whether or not to use performance enhancing drugs in athletics. Given that the drugs have an approximately equal impact on each athlete, it is to all athletes’ advantage that no athlete take the drugs (because of the side effects). However, if any one athlete takes the drugs, they will gain an advantage unless all the other athletes do the same. In that case, the advantage of taking the drugs is removed, but the disadvantages (side effects) remain.[14]

**In economics**

Advertising is sometimes cited as a real life example of the prisoner’s dilemma. When cigarette advertising was legal in the United States, competing cigarette manufacturers had to decide how much money to spend on advertising. The effectiveness of Firm A’s advertising was partially determined by the advertising conducted by Firm B. Likewise, the profit derived from advertising for Firm B is affected by the advertising conducted by Firm A. If both Firm A and Firm B chose to advertise during a given period the advertising cancels out, receipts remain constant, and expenses increase due to the cost of advertising. Both firms would benefit from a reduction in advertising. However, should Firm B choose not to advertise, Firm A could benefit greatly by advertising. Nevertheless, the optimal amount of advertising by one firm depends on how much advertising the other undertakes. As the best strategy is dependent on what the other firm chooses there is no dominant strategy and this is not a prisoner's dilemma but rather is an example of a stag hunt. The outcome is similar, though, in that both firms would be better off were they to advertise less than in the equilibrium. Sometimes cooperative behaviors do emerge in business situations. For instance, cigarette manufacturers endorsed the creation of laws banning cigarette advertising, understanding that this would reduce costs and increase profits across the industry.[10] This analysis is likely to be pertinent in many other business situations involving advertising.

Without enforceable agreements, members of a cartel are also involved in a (multi-player) prisoners’ dilemma.[15] 'Cooperating' typically means keeping prices at a pre-agreed minimum level. 'Defecting' means selling under this minimum level, instantly stealing business (and profits) from other cartel members. Anti-trust authorities want potential cartel members to mutually defect, ensuring the lowest possible prices for consumers.

**In law**

The theoretical conclusion of PD is one reason why, in many countries, plea bargaining is forbidden. Often, precisely the PD scenario applies: it is in the interest of both suspects to confess and testify against the other prisoner/suspect, even if each is innocent of the alleged crime. Arguably, the worst case is when only one party is guilty — here, the innocent one is unlikely to confess, while the guilty one is likely to confess and testify against the innocent.

**Multiplayer dilemmas**

Many real-life dilemmas involve multiple players. Although metaphorical, Hardin's tragedy of the commons may be viewed as an example of a multi-player generalization of the PD: Each villager makes a choice for personal gain or restraint. The collective reward for unanimous (or even frequent) defection is very low payoffs (representing the destruction of the "commons"). Such multi-player PDs are not formal as they can always be decomposed into a set of classical two-player games. The commons are not always exploited: William Poundstone, in a book about the prisoner's dilemma (see References below), describes a situation in New Zealand where newspaper boxes are left...
unlocked. It is possible for people to take a paper without paying (defecting) but very few do, feeling that if they do not pay then neither will others, destroying the system.

Related games

Closed-bag exchange

Hofstadter[16] once suggested that people often find problems such as the PD problem easier to understand when it is illustrated in the form of a simple game, or trade-off. One of several examples he used was "closed bag exchange":

Two people meet and exchange closed bags, with the understanding that one of them contains money, and the other contains a purchase. Either player can choose to honor the deal by putting into his or her bag what he or she agreed, or he or she can defect by handing over an empty bag.

In this game, defection is always the best course, implying that rational agents will never play. However, in this case both players cooperating and both players defecting actually give the same result, assuming there are no gains from trade, so chances of mutual cooperation, even in repeated games, are few.

Friend or Foe?

Friend or Foe? is a game show that aired from 2002 to 2005 on the Game Show Network in the United States. It is an example of the prisoner's dilemma game tested by real people, but in an artificial setting. On the game show, three pairs of people compete. As each pair is eliminated, it plays a game similar to the prisoner's dilemma to determine how the winnings are split. If they both cooperate (Friend), they share the winnings 50-50. If one cooperates and the other defects (Foe), the defector gets all the winnings and the cooperator gets nothing. If both defect, both leave with nothing. Notice that the payoff matrix is slightly different from the standard one given above, as the payouts for the "both defect" and the "cooperate while the opponent defects" cases are identical. This makes the "both defect" case a weak equilibrium, compared with being a strict equilibrium in the standard prisoner's dilemma. If you know your opponent is going to vote Foe, then your choice does not affect your winnings. In a certain sense, Friend or Foe has a payoff model between prisoner's dilemma and the game of Chicken.

The payoff matrix is

<table>
<thead>
<tr>
<th></th>
<th>Cooperate</th>
<th>Defect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperate</td>
<td>1, 1</td>
<td>0, 2</td>
</tr>
<tr>
<td>Defect</td>
<td>2, 0</td>
<td>0, 0</td>
</tr>
</tbody>
</table>

This payoff matrix was later used on the British television programmes Shafted and Golden Balls. The latter show has been analyzed by a team of economists. See: Split or Steal? Cooperative Behavior When the Stakes are Large. [17]

It was also used earlier in the UK Channel 4 gameshow Trust Me, hosted by Nick Bateman, in 2000.

Notes

[1] A simple tell that partially or wholly reveals one player's choice — such as the Red player playing his Cooperate card face-up — does not change the fact that Defect is the dominant strategy. When one is considering the game itself, communication has no effect whatsoever. When the game is being played in real life, communication may matter due to considerations outside of the game itself; however, when external considerations are not taken into account, communications do not affect the single-instance prisoner's dilemma. Even in the single-instance prisoner's dilemma, meaningful prior communication about issues external to the game could alter the play environment by raising the possibility of enforceable side contracts or credible threats. For example, if the Red player plays their Cooperate card face-up and simultaneously reveals a binding commitment to blow the jail up if and only if Blue Defects (with additional payoff -11,-10), then Blue's Cooperation becomes dominant. As a result, players are screened from each other and prevented from communicating outside of the game.


Prisoner's dilemma

References

- Kenneth Binmore, Fun and Games.

[5] For example see the 2003 study "Bayesian Nash equilibrium; a statistical test of the hypothesis" (http://econ.hvra.haifa.ac.il/~mbengad/seminars/whole1.pdf) for discussion of the concept and whether it can apply in real economic or strategic situations (from Tel Aviv University).
[7] The 2004 Prisoner's Dilemma Tournament Results (http://www.prisoners-dilemma.com/results/cec04/ipd_cec04_full_run.html) show University of Southampton's strategies in the first three places, despite having fewer wins and many more losses than the GRIM strategy. (Note that in a PD tournament, the aim of the game is not to "win" matches — that can easily be achieved by frequent defection). It should also be pointed out that even without implicit collusion between software strategies (exploited by the Southampton team) tit for tat is not always the absolute winner of any given tournament; it would be more precise to say that its long run results over a series of tournaments outperform its rivals. (In any one event a given strategy can be slightly better adjusted to the competition than tit for tat, but tit for tat is more robust). The same applies for the tit for tat with forgiveness variant, and other optimal strategies: on any given day they might not 'win' against a specific mix of counter-strategies. An alternative way of putting it is using the Darwinian ESS simulation. In such a simulation tit for tat will almost always come to dominate, though nasty strategies will drift in and out of the population because a tit for tat population is penetratable by non-retaliating nice strategies, which in turn are easy prey for the nasty strategies. Richard Dawkins showed that here no static mix of strategies form a stable equilibrium and the system will always oscillate between bounds.
[10] This argument for the development of cooperation through trust is given in The Wisdom of Crowds, where it is argued that long-distance capitalism was able to form around a nucleus of Quakers, who always dealt honourably with their business partners. (Rather than defecting and reneging on promises — a phenomenon that had discouraged earlier long-term unenforceable overseas contracts). It is argued that dealings with reliable merchants allowed the meme for cooperation to spread to other traders, who spread it further until a high degree of cooperation became a profitable strategy in general commerce.


**Further reading**


**External links**

• Video Lecture of the Prisoner's Dilemma (http://www.youtube.com/watch?v=aRZ_oH9Sxm4)

• Prisoner's Dilemma (Stanford Encyclopedia of Philosophy) (http://plato.stanford.edu/entries/prisoner-dilemma/)

• Effects of Tryptophan Depletion on the Performance of an Iterated Prisoner's Dilemma Game in Healthy Adults (http://www.nature.com/npp/journal/v31/n5/full/1300932a.html) - Nature Neuropsychopharmacology

• Is there a "dilemma" in Prisoner's Dilemma (http://www.egwald.ca/operationsresearch/prisonersdilemma.php) by Elmer G. Wiens

• "Games Prisoners Play" (http://webfiles.uci.edu/mkaminsk/www/book.html) - game-theoretic analysis of interactions among actual prisoners, including PD.

• Iterated prisoner's dilemma game (http://www.iterated-prisoners-dilemma.net/)

• Another version of the iterated prisoner's dilemma game (http://kane.me.uk/ipd/)

• Another version of the iterated prisoner's dilemma game (http://www.gametheory.net/Web/PDilemma/)

• Iterated prisoner's dilemma game (http://www.paulspages.co.uk/hmd/) applied to Big Brother TV show situation.


• Examples of Prisoners' dilemma (http://www.economics.li/downloads/egefdile.pdf)

• Multiplayer game based on prisoner dilemma (http://www.gohfgl.com/) Play prisoner's dilemma over IRC — by Axiologic Research.

• The Edge cites Robert Axelrod's book and discusses the success of U2 following the principles of IPD. (http://www.rte.ie/tv/thetview/archive/20080331.html)

• Classical and Quantum Contents of Solvable Game Theory on Hilbert Space (http://arxiv.org/abs/quant-ph/0503233v2)
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