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Prisoner's Dilemma, Chicken, and Mixed-strategy Evolutionary Equilibria

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In an article of exceptional scholarship and originality, Mealey has put forward an interesting new interpretation of sociopathy. Given the vast range of material covered by the article and the limited space available for my reply, I shall confine my comments to the specific game-theoretic model that underpins Mealey's interpretation. I shall argue that it cannot do what is required of it, and I shall suggest an alternative.

Like most earlier theorists who have used game theory to explain the evolution of social behavior, starting with Maynard Smith (1974; Maynard Smith & Price, 1973), Mealey relied on a two-person game, specifically the Prisoner's Dilemma game. A generalized payoff matrix for any two-person, two-choice game can be represented as follows:

	<i>C</i>	<i>D</i>
<i>C</i>	<i>R</i>	<i>S</i>
<i>D</i>	<i>T</i>	<i>P</i>

The row and column players each choose between two pure strategies, *C* and *D*, and the payoffs shown in the matrix are those to the row player. Thus the payoff to the row player following a *C* choice is *R* or *S* depending on whether the column player chooses *C* or *D* respectively, and following a *D* choice it is *T* or *P* depending on whether the column player chooses *C* or *D* respectively. In the Prisoner's Dilemma game, *C* represents *cooperation* and *D* *defection*, and by definition $T > R > P > S$, so that the row player receives the best payoff by choosing *D* (defect) while the column player chooses *C* (cooperate), the second-best payoff by choosing *C* while the column player chooses *C*, and so on. Although it is customary to show only the row player's payoffs, the game is the same from the column player's point of view, so that the column player also gets the best payoff by choosing *D* while the row player chooses *C*, and so on.

The standard two-person model is of limited value in determining evolutionary processes. We need to establish what will happen in an entire population in which individuals interact with one another in pairwise games with this strategic structure, assuming that the payoffs

represent units of *Darwinian fitness* (the lifetime reproductive success of the individual players) and that the propensity to choose *C* or *D* is heritable. For this purpose, we need to construct a multi-person *compound game* (Colman, 1982, pp. 163-166, 243-249) in which it is assumed that every player plays the same average number of two-person games either with each of the others with a random sample of the others.

Considering the situation from a single player's viewpoint, suppose that the number of other players is n and the number of other players choosing *C* is c . The total payoff to a player choosing *C*, denoted by $P(C)$, and the total payoff to a player choosing *D*, denoted by $P(D)$, are then defined by the following payoff functions:

$$P(C) = Rc + S(n - c),$$

$$P(D) = Tc + P(n - c).$$

The total payoff to a player adopting a mixed strategy is just a weighted average of $P(C)$ and $P(D)$.

The values of the $P(C)$ and $P(D)$ payoff functions at their end-points are found by setting $c = 0$ and $c = n$. Thus if none of the other players chooses *C* (i.e., $c = 0$), the payoff to a solitary *C* chooser is Sn and the payoff to a *D* chooser is Pn . If all of the other players choose *C* (i.e., $c = n$), then a *C* chooser gets Rn and a solitary *D* chooser is Tn . It is clear that, in the case of the Prisoner's Dilemma game, Tn can be interpreted as the *temptation* to be the sole *D* chooser, Rn the *reward* for collective cooperation, Pn the *punishment* for collective defection, and Sn the *sucker's payoff* for being the sole *C* chooser.

Figure 1 about here

Figure 1(a) shows clearly that, in the case of the Prisoner's Dilemma game (with $T > R > P > S$), the $P(D)$ payoff function *strictly dominates* the $P(C)$ payoff function, which means that a *D* choice pays better than a *C* choice irrespective of the number of others choosing *C*.

The evolutionarily optimal strategy is therefore not frequency-dependent, and the population will (regrettably) evolve to a stable equilibrium in which every player chooses D in every two-person encounter. This means that the Prisoner's Dilemma game cannot provide a basis for Mealey's interpretation of sociopathy, in which the "cheater strategy" (the D choice) corresponds to various criminal, delinquent, and generally antisocial or predatory forms of behavior that she claims exist at a low frequency in every society and are maintained through frequency-dependent Darwinian selection.

A more appropriate game-theoretic model might be a compound version of the game of Chicken, which Maynard Smith (1976, 1978) and Maynard Smith and Price (1973) call the Hawk-Dove game. This game is defined by the inequalities $T > R > S > P$, and the $P(C)$ and $P(D)$ payoff functions are shown graphically in Figure 1(b). In this case, the population will evolve to a mixed-strategy equilibrium point where the two payoff functions intersect. To the left of the intersection, when relatively few of the others choose C (c is small), the C function lies above the D function, which means that the fitness payoff from a C choice is higher than from a D choice, so the number of C choosers will increase relative to D choosers and the outcome will move to the right as c increases. To the right of the intersection, exactly the reverse holds: D choosers will increase relative to C choosers and the outcome will move to the left as c decreases. At the intersection, and only there, the strategies are best against each other and are in equilibrium, and any deviation from the mixture at that point will tend to be self-correcting. By setting the parameters (values of the payoffs T , R , S , and P) appropriately, the intersection point, and thus the proportion of "predatory" D -choices, can be made as small as required.

It appears, therefore, that the Prisoner's Dilemma game cannot underpin an evolutionary explanation of sociopathic behavior, but that a multi-person compound game version of Chicken, in which cheating is at least frequency-dependent, might be more promising. Chicken is the archetypal *dangerous* game, because a player can outdo a co-player only by

cheating (choosing D) while the co-player behaves cautiously (by choosing C), and any such attempt to get the best payoff (T in the payoff matrix above) involves a necessary risk of the worst possible payoff (P). The interpretation of criminal, delinquent, and generally antisocial behavior in terms of strategic choices seems more natural in the game of Chicken. For a more detailed discussion of the strategic properties of Chicken and some observations on its application to antisocial and criminal behavior, see Colman (1982, pp. 98-104; in press, chap. 6).

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Figure Caption

Figure 1. Multi-person compound games based on 2×2 matrices. Panel (a) on the left is multi-person Prisoner's Dilemma; (b) on the right is multi-person Chicken. The $P(C)$ and $P(D)$ functions indicate the payoffs to a player choosing C or D when c of the other players choose C . Dashed circles indicate stable equilibria.