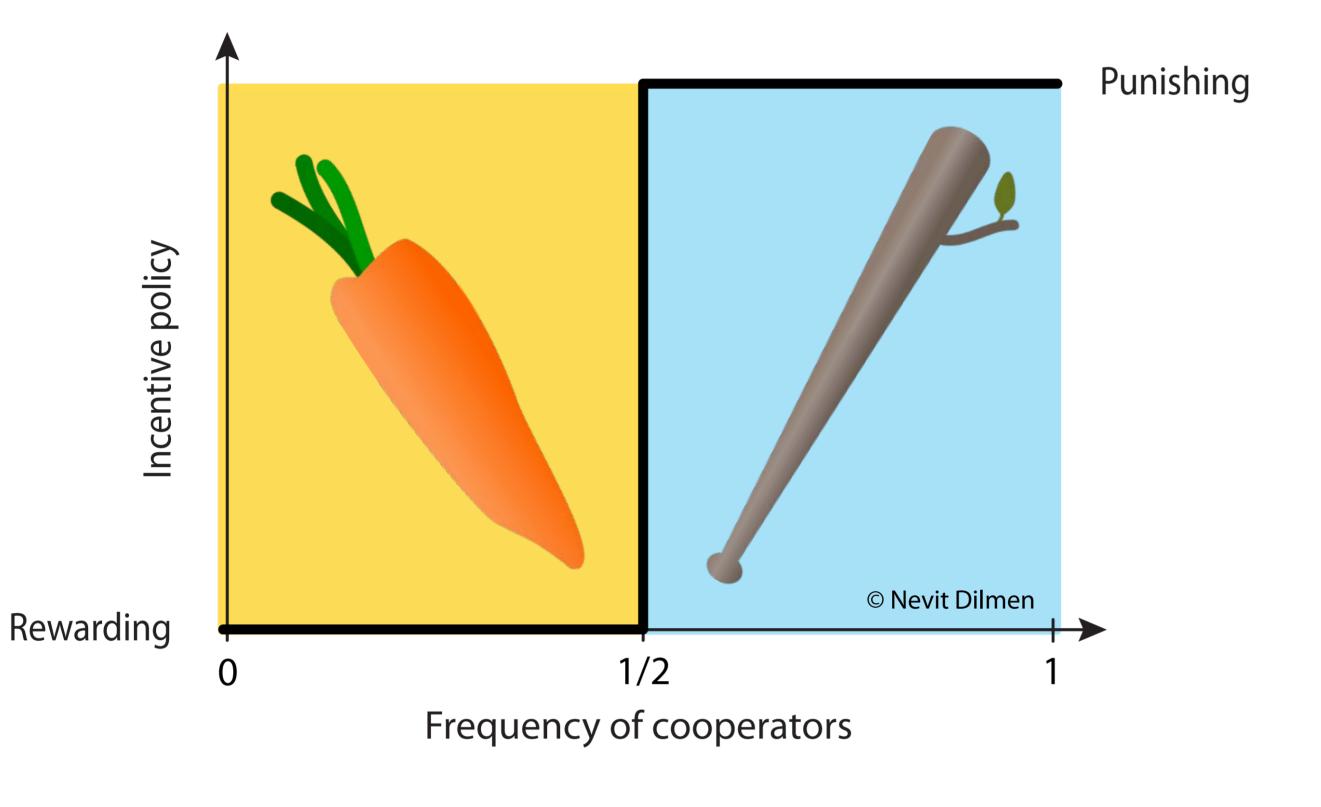# How 'First Carrot, Then Stick' Incentives Promote Cooperation

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Carrots or sticks?

Social institutions often use rewards ('carrots') and penalties ('sticks') to promote cooperation. Providing incentives tends to be costly, so it is important to find efficient strategies for the combined use and synthesis of rewards and penalties. Most studies of cooperation have, however, addressed rewarding and punishing in isolation and have focused on peer-to-peer sanctioning as opposed to institutional sanctioning. Here, we demonstrate that an institutional sanctioning policy we call 'first carrot, then stick' is unexpectedly successful in promoting cooperation in the standard public good game. Our results show that this hybrid policy of rewards and penalties is a surprisingly inexpensive and widely applicable method, compared to either rewards or penalties alone.
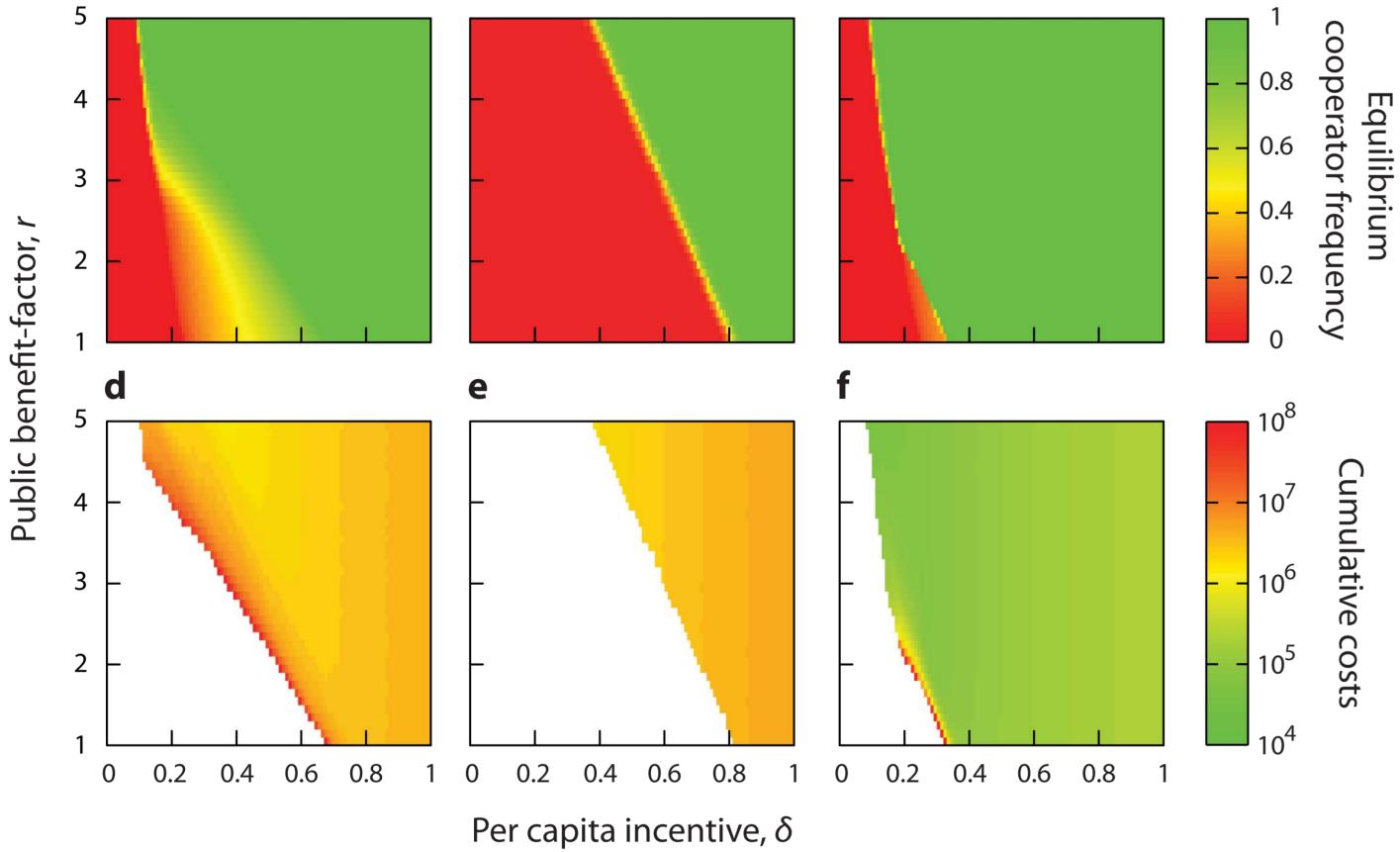
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Adaptive hybridization of carrots and sticks

We assume the existence of institutions that can provide incentives on a limited budget. The policy switches the incentive from rewarding to punishing when the frequency of cooperators exceeds a threshold. The amount of rewards (or penalties) per target is equal to the incentive budget divided by the number of cooperators (or defectors). We find that this policy establishes and maintains full cooperation at lower cost and under a wider range of conditions than either rewarding or punishing alone, in infinitely large, well-mixed populations, as well as in spatially structured populations.
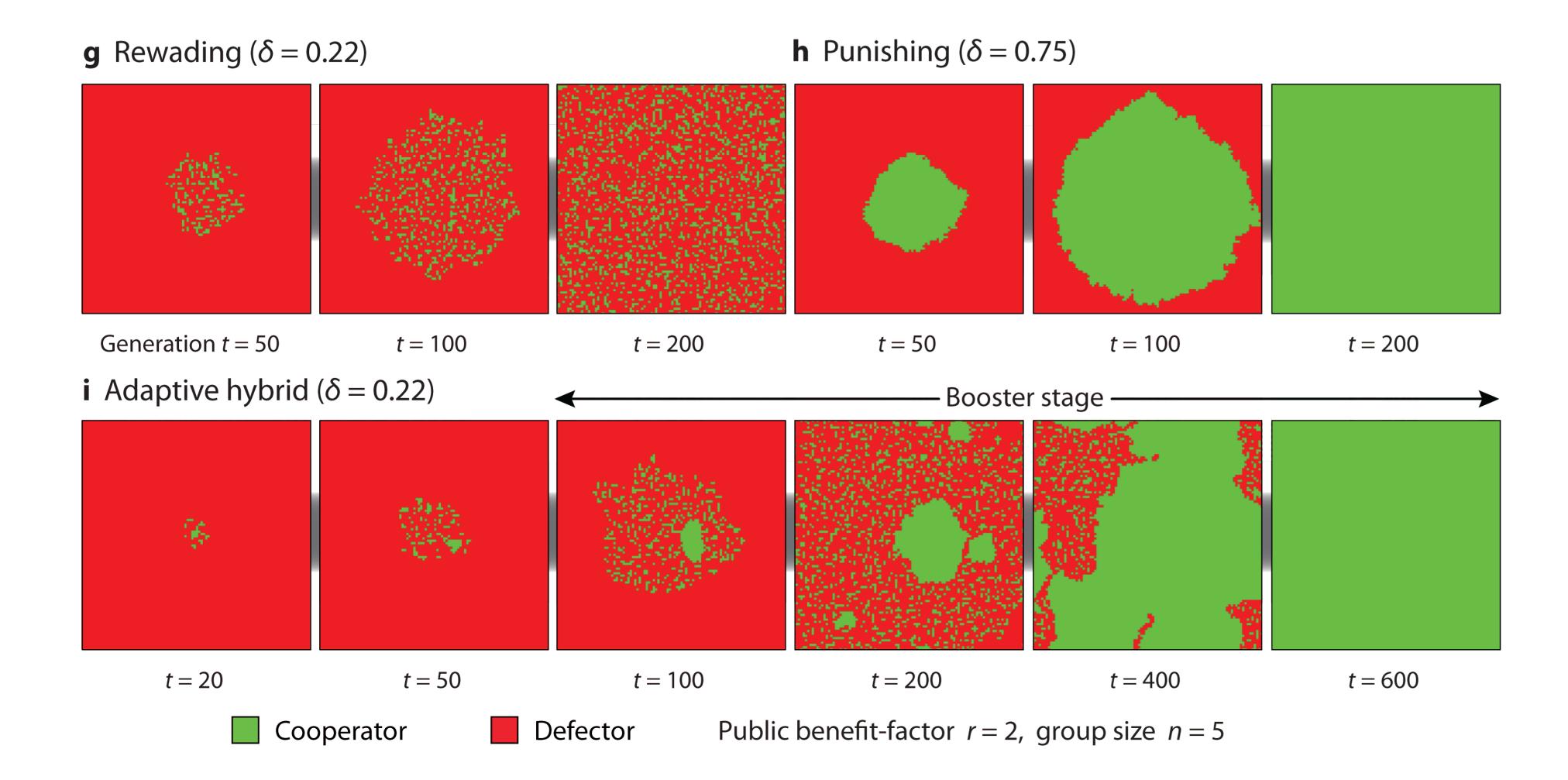
Widely applicable and surprisingly inexpensive

Individuals play the game with the nearest four neighbors on the 100×100 square lattice, in which a single cooperator is initially given among a defector population. Specifically, the domain of applicability of the adaptive hybrid policy is the widest among the three incentive strategies (**a**–**c**). Once full cooperation has been established, the adaptive hybrid policy and pure punishing are equally successful in preventing the emergence of defectors. The adaptive hybrid policy is also the least expensive method of establishing cooperation among the three incentive strategies (**d**–**f**). Once a state of full cooperation has been reached, the adaptive hybrid policy, as well as pure punishment, is cheaper as a means of maintaining cooperation since it needs to be used only occasionally.

Best of both worlds

In the structured population, cooperators thrive under a policy of pure rewarding (**g**), forming local mixtures with defectors, but ultimately fail to establish a cooperative norm for the incentive strength considered. With pure punishing (**h**), an invasion which begins with a single cooperator always results in a cluster of cooperators that grows and eventually displaces all defectors. The adaptive hybrid policy (**i**), on the other hand, exhibits an intriguing phase transition. Punishment acts as a 'booster stage' that capitalizes on and amplifies the pro-social effects of rewarding.

g Rewading ($\delta = 0.22$)   **h** Punishing ($\delta = 0.75$)
Generation $t = 50$ $t = 100$ $t = 200$ $t = 50$ $t = 100$ $t = 200$
i Adaptive hybrid ($\delta = 0.22$)   Booster stage
$t = 20$ $t = 50$ $t = 100$ $t = 200$ $t = 400$ $t = 600$
Cooperator   Defector   Public benefit-factor $r = 2$, group size $n = 5$