Supporting Information for: Institutional Incentives for the Evolution of Committed Cooperation: Ensuring Participation is as Important as Enhancing Compliance *

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Contents

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1 Analytical results: risk dominance analysis

1.1 In absence of errors

In case of reward: For ACD to be risk dominant against all other strategies (except for ACC to which it is neutral)

$$\alpha < 1 - (T + P - R - S)/(2u); \quad \epsilon < 2(u + u\alpha + min\{T - S, R - P\}).$$

In case of punishment: For ACD to be risk dominant against all other strategies (except for ACC to which it is neutral)

$$\alpha < 1 - (T + P - R - S)/(2u); \quad \epsilon < 2(2u\alpha + min\{T - S, R - P\}).$$

When $\alpha = 0$, they are equivalent to

$$u > (T + P - R - S)/2; \quad \epsilon < 2(u + min\{T - S, R - P\}),$$

$$u > (T + P - R - S)/2; \quad \epsilon < 2min\{T - S, R - P\}.$$

Also, for Donation game, i.e., $T = b, R = b - c, P = 0, S = -c$, the equations are simplified to, respectively,

$$\alpha < 1 - c/u; \quad \epsilon < 2(u + u\alpha + b - c),$$

$$\alpha < 1 - c/u; \quad \epsilon < 2(2u\alpha + b - c).$$

First equation (for both reward and punishment) suggests that a larger α makes it more difficult for ACD to be risk dominant against commitment accepting players. A larger reward for participation provides a greater advantage to defective committers (e.g., ADD, ADC) as a smaller budget available for incentivising commitment compliance. ADD is increasingly more successful as such. Also from this equation, as $\alpha \geq 0$, the necessary condition is that the budget size u must be at least equal to $(T + P - R - S)/2$ (or c in case of the Donation game).

On the other hand, a larger reward (i.e., greater value of α) for participation provides advantage to all committers against non-participating players (see second inequality). It's equivalent to reducing the cost of participation ϵ by $2u\alpha$ for reward and $4u\alpha$ for punishment, respectively, compared to when no participation rewarding is present. Thus, the advantage of increasing α is greater for punishment than reward. Thus, one might expect that there is an optimal value of α that leads to highest frequency of ACD. This analytical observations are in line with the numerical results reported in the main text.

1.2 In presence of errors (at pre-commitment state)

Differently from the scenario without noise, ACD can be risk dominant against ACC if, for both types of incentive,

$$2c(2-\chi)\omega > 0.$$

which always holds given that $\chi > 0$.

Now, for ACD to be risk dominant against all other strategies, including ACC, it must hold that

$$\alpha < 1 - c/u \min\left\{1, \frac{1-4\chi+2\chi^2}{(1-\chi)^2}\right\} = 1 - c/u,$$

for both types of incentive, plus the following condition, differently for (pure) reward and punishment. For reward,

$$\epsilon < 2(b+u+u\alpha) - 2\min\left\{b\chi - \frac{c(1+\chi)}{1-2\chi}, c, 2b\chi + \frac{u-u\alpha}{2} - \frac{2c+u-u\alpha}{2(1-2\chi)}, \frac{c+u-u\alpha}{2} + b\chi + \frac{c-u+u\alpha}{2(1-2\chi)}\right\},$$

For punishment,

$$\epsilon < 2(b+2u\alpha) - 2\min\left\{\frac{c}{2} + b\chi - \frac{3c}{2(1-2\chi)}, c, 2b\chi - \frac{u+u\alpha}{2} + \frac{2c+u-u\alpha}{2(1-2\chi)}, \frac{c+u-u\alpha}{2} + b\chi + \frac{c-u+u\alpha}{2(1-2\chi)}\right\}.$$

2 Errors during the games

In the main text, we focused on errors a the pre-commitment stage. Here we consider that with a small probability χ an error occurs when an intended action is carried out during the interaction (i.e. PD game). We assume that this probability is the same regardless of the presence of an agreement. All the payoff matrices described in Methods (main text) can be re-written as follows.

Namely, for a payoff matrix $\Pi \in \{\Pi_0, \Pi_R, \Pi_P\}$, and for $P_j \in \{A, N\}$ and $X_j, Y_j \in \{C, D\}$, and denote $\bar{C} = D$ and $\bar{D} = C$, the payoff a player $P_1X_1Y_1$ received when playing against another player $P_2X_2Y_2$, i.e., $\Pi_{P_1X_1Y_1,P_2X_2Y_2}$, is given by

$$(1-\chi)^2\Pi_{P_1X_1Y_1,P_2X_2Y_2} + \chi(1-\chi)\left(\Pi_{P_1\bar{X}_1Y_1,P_2X_2Y_2} + \Pi_{P_1X_1Y_1,P_2\bar{X}_2Y_2}\right) + \chi^2\Pi_{P_1\bar{X}_1Y_1,P_2\bar{X}_2Y_2},$$

when a commitment is formed, i.e. when $P_1 = P_2 = A$. Otherwise ($P_1 = P_2 = N$), it is given by

$$(1-\chi)^2\Pi_{P_1X_1Y_1,P_2X_2Y_2} + \chi(1-\chi)\left(\Pi_{P_1X_1\bar{Y}_1,P_2X_2Y_2} + \Pi_{P_1X_1Y_1,P_2X_2\bar{Y}_2}\right) + \chi^2\Pi_{P_1X_1\bar{Y}_1,P_2X_2\bar{Y}_2}.$$

We have analysed the payoff matrices and shown that this type of error during the interactions, unlike errors at the pre-commitment stage, does not change the equivalence of NCC - NDC, NCD - NDD nor the neutrality between ACC - ACD, ADC - ADD. Thus, as in the case of no errors, none of the strategies can be ESS. Also, ACD cannot be risk-dominant against all other strategies. Given this, we have focused in this paper on the errors in a decision whether to participate in a prior commitment.

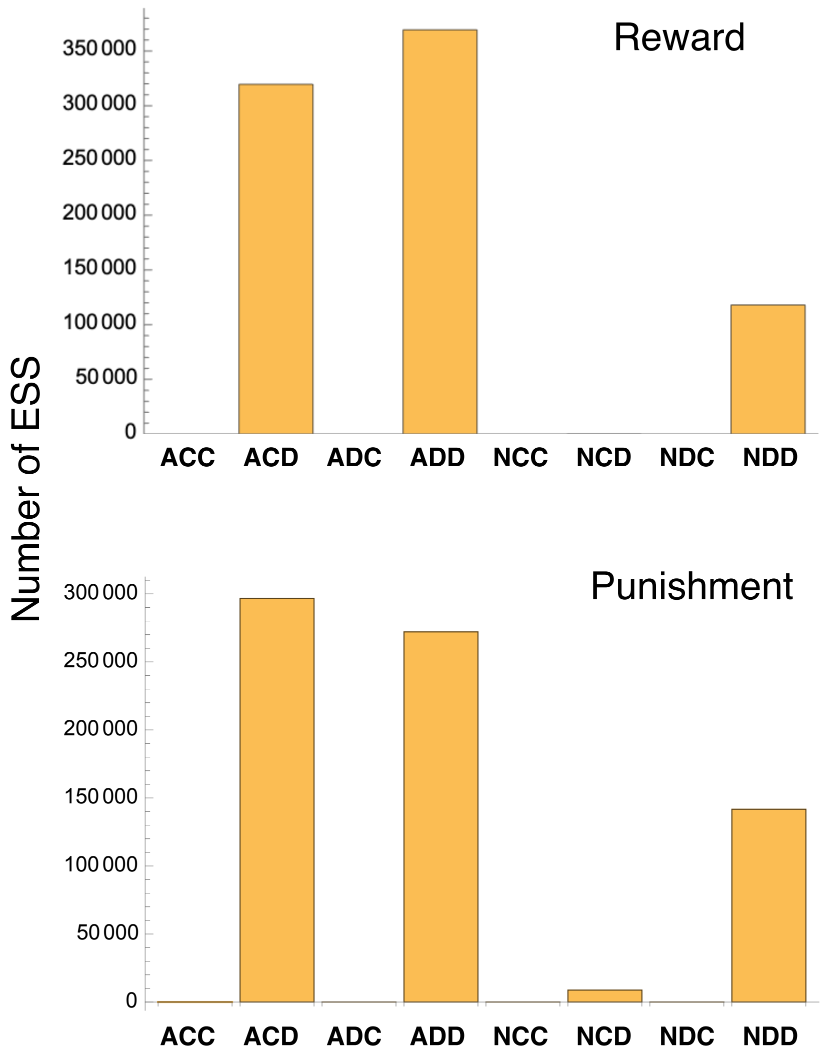

Figure S1. ESS analysis - similar to the main text but now b also varies (fixing $c = 1$). We show which strategies can be ESS and their frequencies across the parameters space: $u \in [0, 3]$ (increment 0.1), $\epsilon \in [0, 3]$ (increment 0.1), $\alpha \in [0, 1]$ (increment 0.1), $\chi \in [0, 0.2]$ (increment 0.02), $b \in [1, 10]$ (increment 1.0). Similarly to the results in the main text, we observe that for reward, three strategies ACD, ADD and NDD can be ESS, while in case of punishment, NCD can also be an ESS.

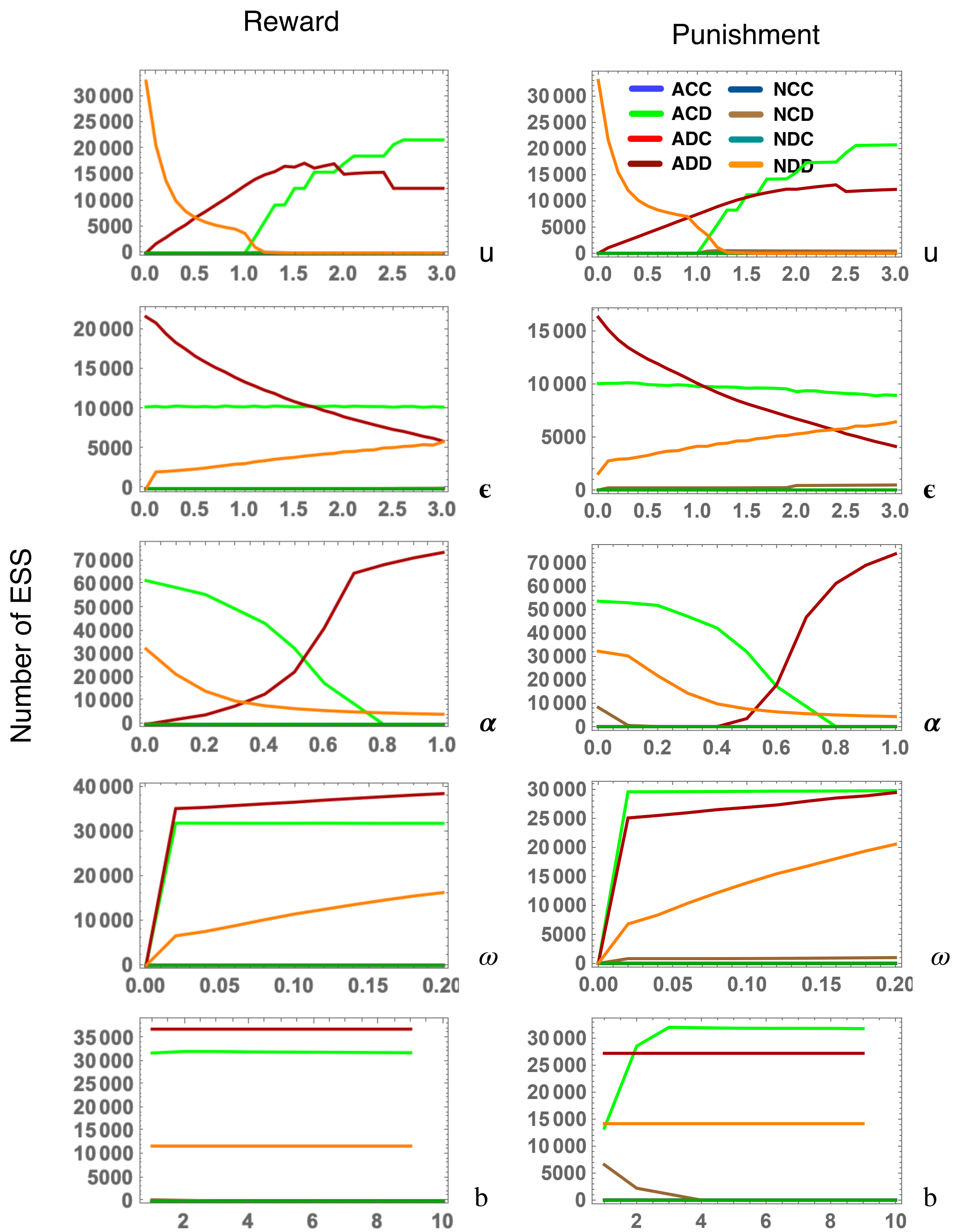

Figure S2. ESS analysis - similar to the main text but now b also varies (in $[1, 10]$, where we fix $c = 1$). Depicted are the frequency of ESS strategies for varying u, ϵ, α, χ, and b. We observe that for reward, three strategies ACD, ADD and NDD can be ESS, and their chance of being ESS does not depend on b. While in case of punishment, NCD can also be an ESS when b is small (approximately less than 4). The frequency of ACD to be ESS increases with b/c.

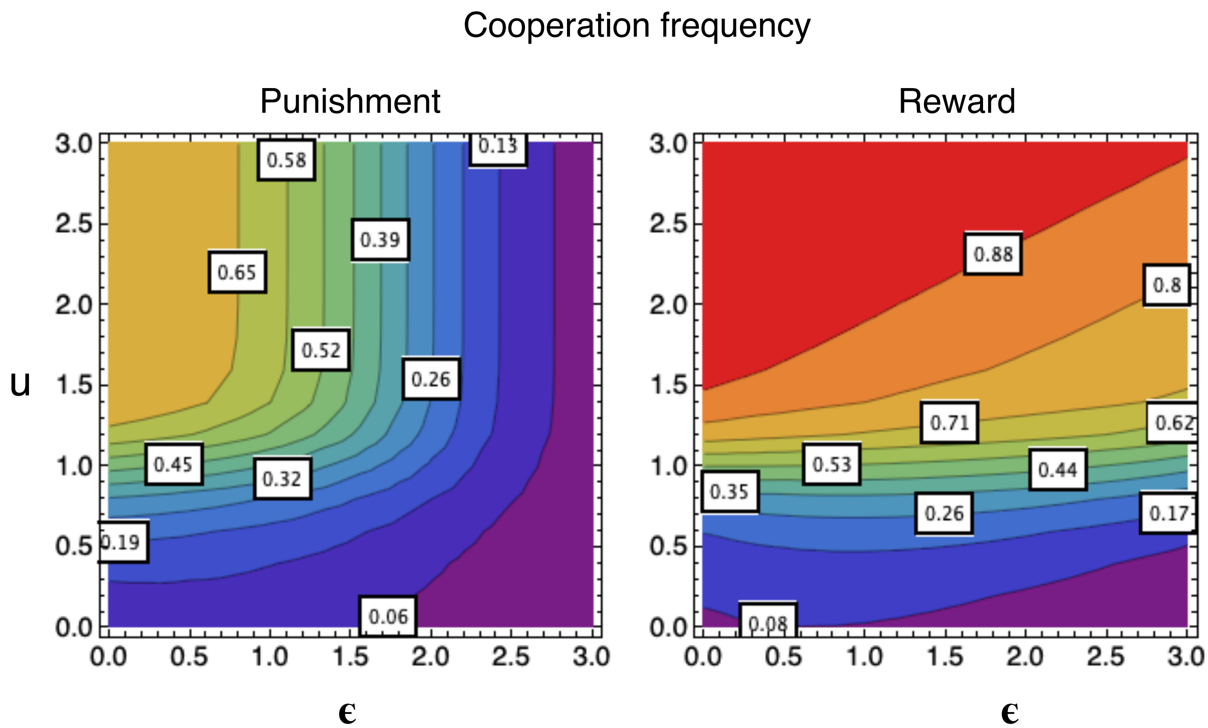

Figure S3. (Pure) Reward and punishment in promoting cooperation. Frequency of cooperation when either reward or punishment is applied to those who honour (i.e. ACC and ACD) or dishonour (i.e. ADC and ADD) an adopted commitment, for varying ϵ (cost of commitment) and per-interaction budget for incentives (u). When $u = 0$, it is equivalent to when no policy is applied, providing a baseline reference. To ensure a high frequency of cooperation, a sufficient budget for providing incentives (u) is required. However, cooperation always reduces when ϵ increases, both both reward and punishment. Reward ensures a similarly high frequency of cooperation for a larger range of these parameters. Other parameters: population size $N = 100$, $R = 1,\ S = -1,\ T = 2,\ P = 0$.

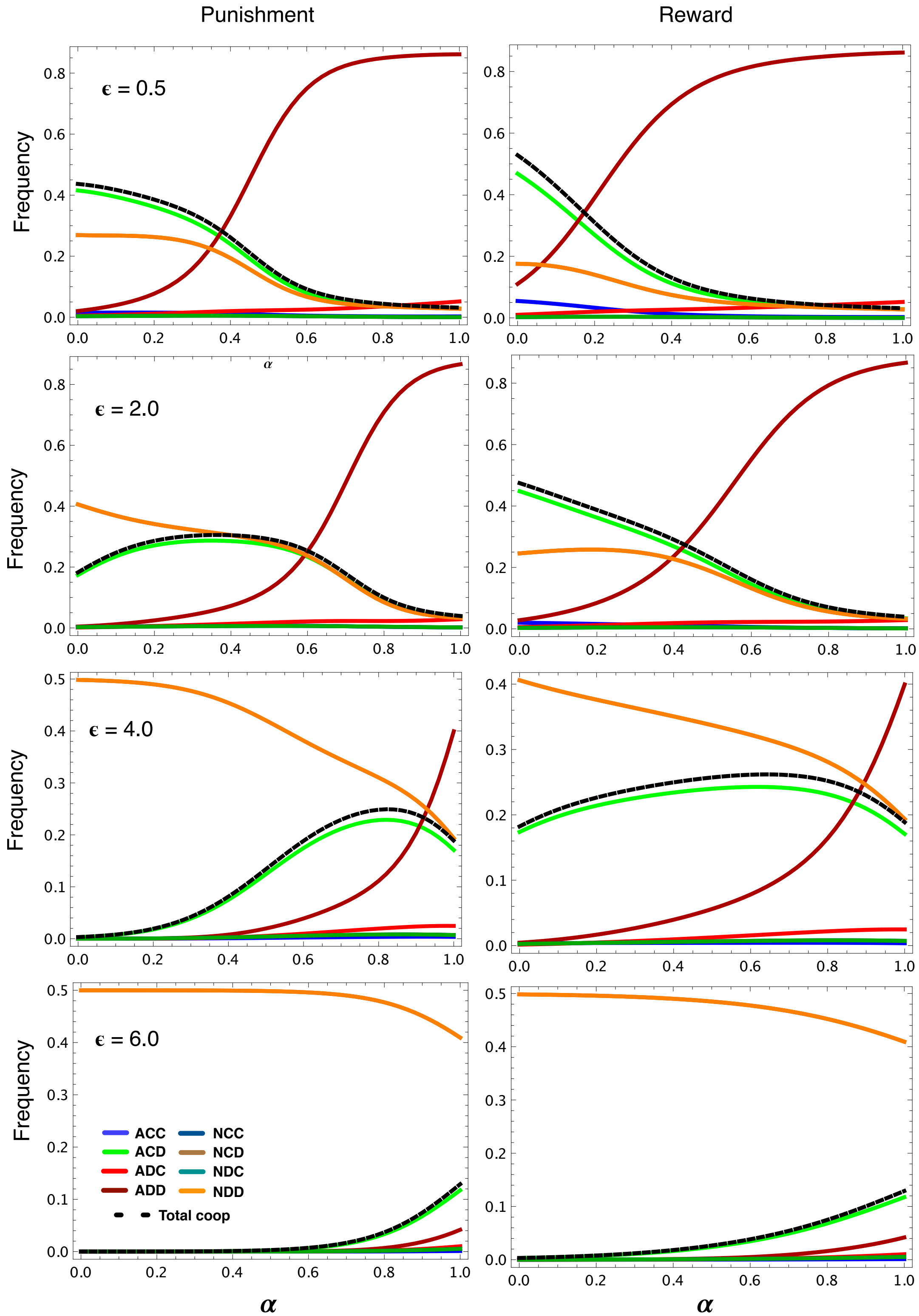

Figure S4. Frequency of strategies as a function of α, when rewarding of participation is applied, besides either punishment or reward as before (Small budget, $u = 1$). We show results for different values of ϵ. Other parameters: population size $N = 100$, $R = 1,\ S = -1,\ T = 2,\ P = 0$.

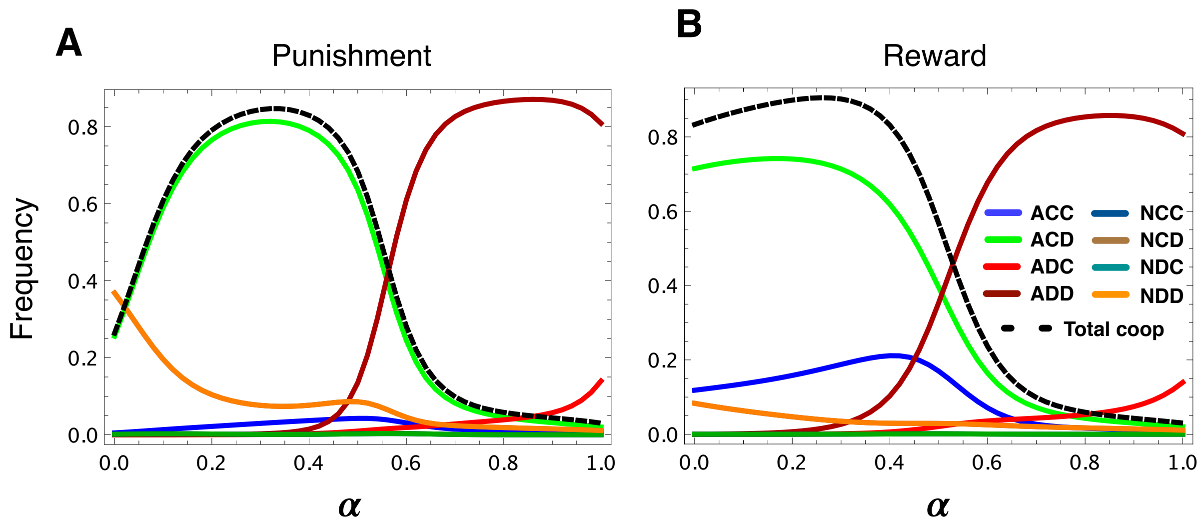

Figure S5. Rewarding participation. Frequency of strategies as a function of α, when rewarding of participation is applied, besides either punishment (A) or reward (B). For small α (smaller than $\alpha^{\star}$), the frequency of NDD decreases and those of ACD and ACC increase. This increase is more significant for punishment than for reward. When $\alpha > \alpha^{\star}$, ADD frequency starts to increase quickly and become dominant in the population since the remaining budget for incentivising behaviours in the game becomes insufficient. Other parameters: population size $N = 100$, $u = 2.0$, $\epsilon = 2.0$, $R = 1,\ S = -1,\ T = 2,\ P = 0$.

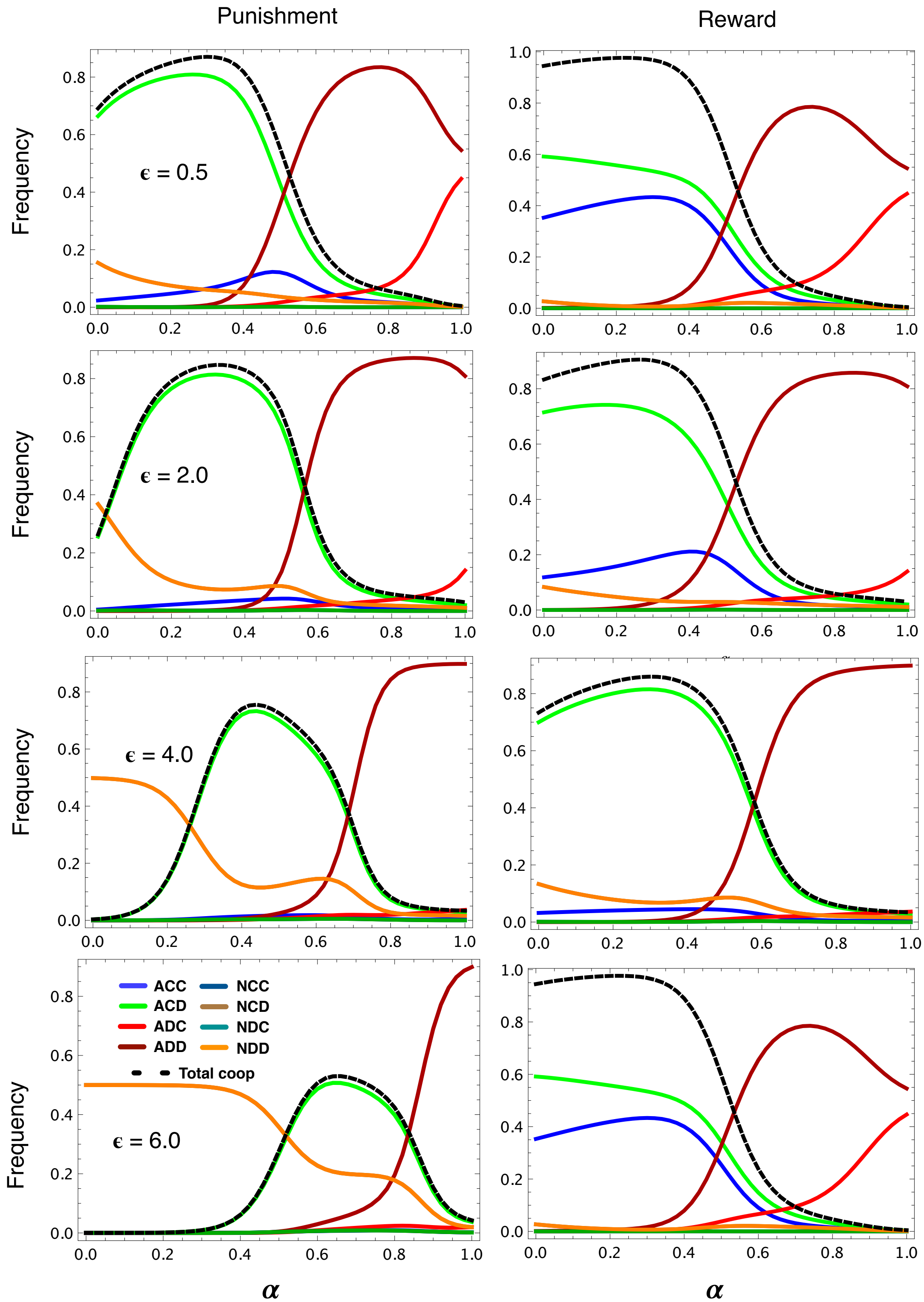

Figure S6. Frequency of strategies as a function of α, when rewarding of participation is applied, besides either punishment or reward as before (Large budget, $u = 2$). We show results for different values of ϵ. Other parameters: population size $N = 100$,
$R = 1,\ S = -1,\ T = 2,\ P = 0$.

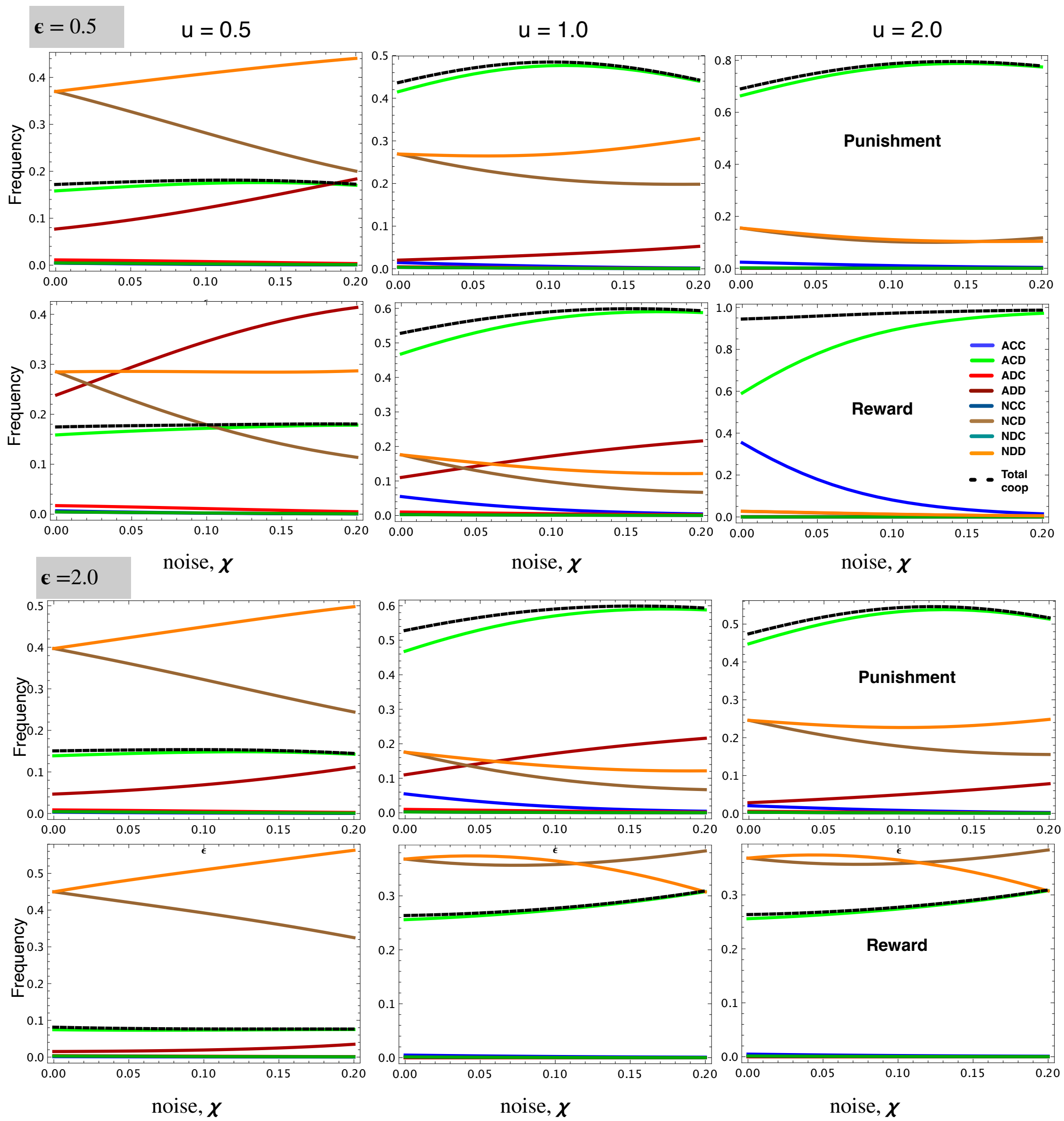

Figure S7. Frequency of strategies for varying error/noise probability χ (at the pre-commitment decision stage), for pure punishment and reward ($\alpha = 0$). We consider scenarios with a small cost of commitment ($\epsilon = 0.5$, top two rows) and with a large one ($\epsilon = 2.0$, bottom two rows). When the budget is large $u = 1, 2$, ACD benefits significantly from having some noise (since it can dominates ACC, see risk dom analysis). Other parameters: population size $N = 100$, $R = 1$, $S = -1$, $T = 2$, $P = 0$.

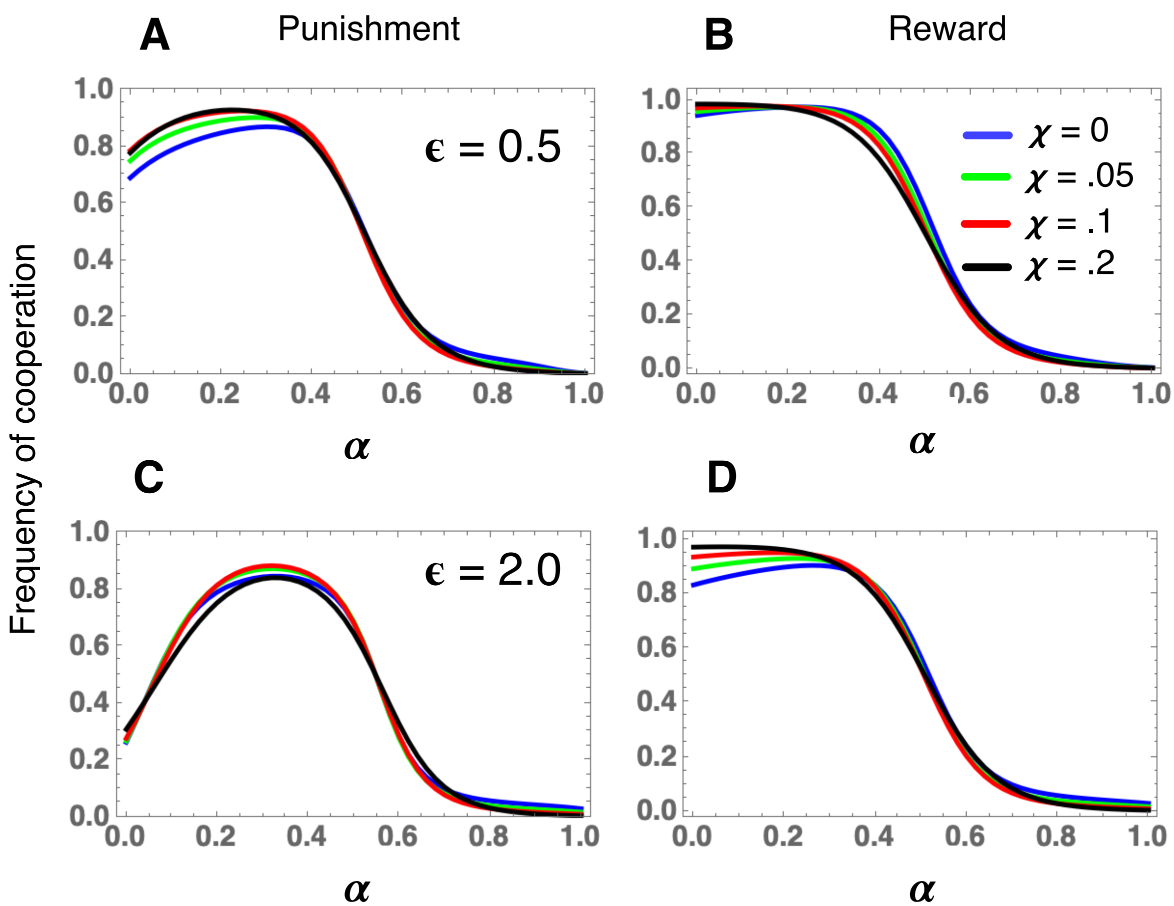

Figure S8. Rewarding participation can improve cooperation in the presence of noise. Depicted are the frequency of cooperation as a function of the fraction of the budget for rewarding participation (α), for different noise probabilities, for punishment (left column) and reward (right column). We consider different values of ϵ: top row ($\epsilon = 0.5$) and bottom row ($\epsilon = 2.0$). A lower optimal value of α is observed given a smaller value of χ. Other parameters: population size $N = 100$, $\alpha = 0$, $u = 2$, $R = 1,\ S = -1,\ T = 2,\ P = 0$.

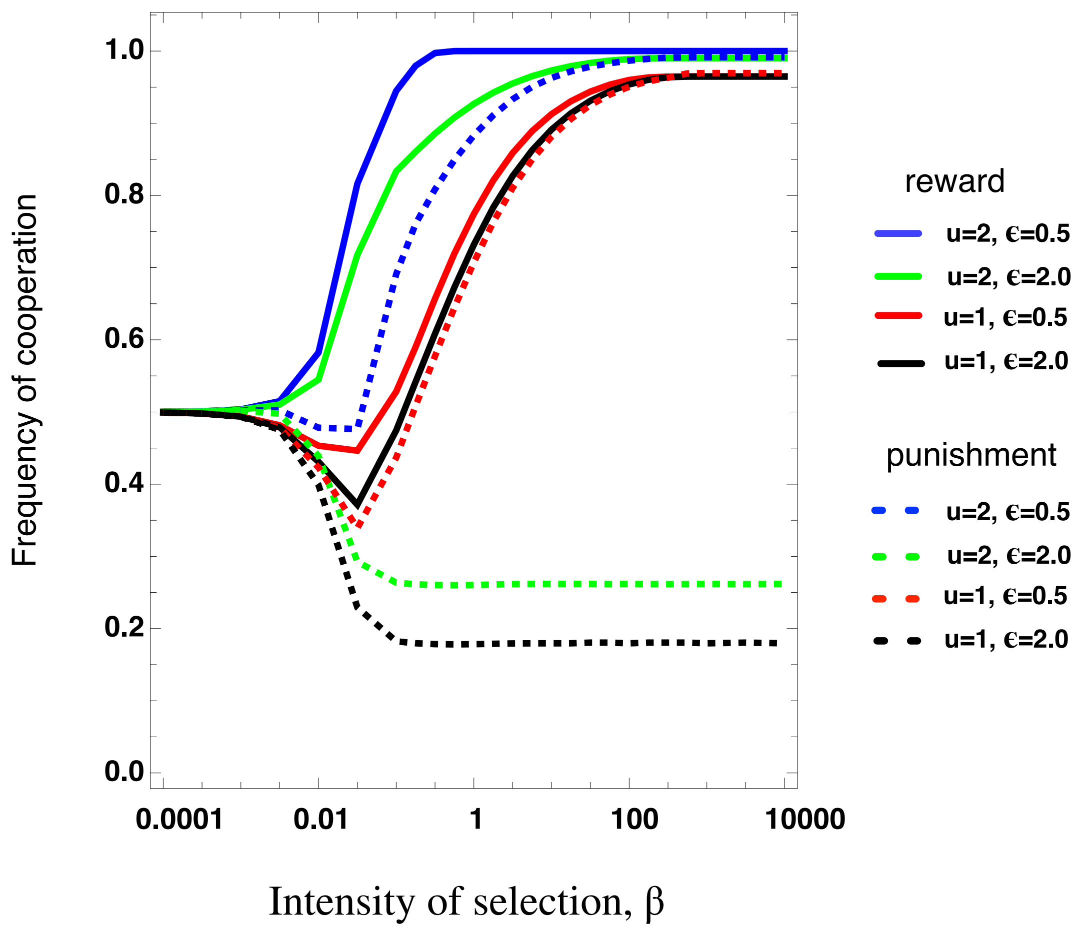

Figure S9. Reward promotes higher levels of cooperation than punishment for increasing the intensity of selection β. Depicted are the frequency of the overall population cooperation for different combinations of u and ϵ. Similar to results in the main text, we observe that reward leads to higher levels of cooperation than punishment. Other parameters: $\alpha = 0$, $\chi = 0$, $R = 1,\ S = -1,\ T = 2,\ P = 0$.

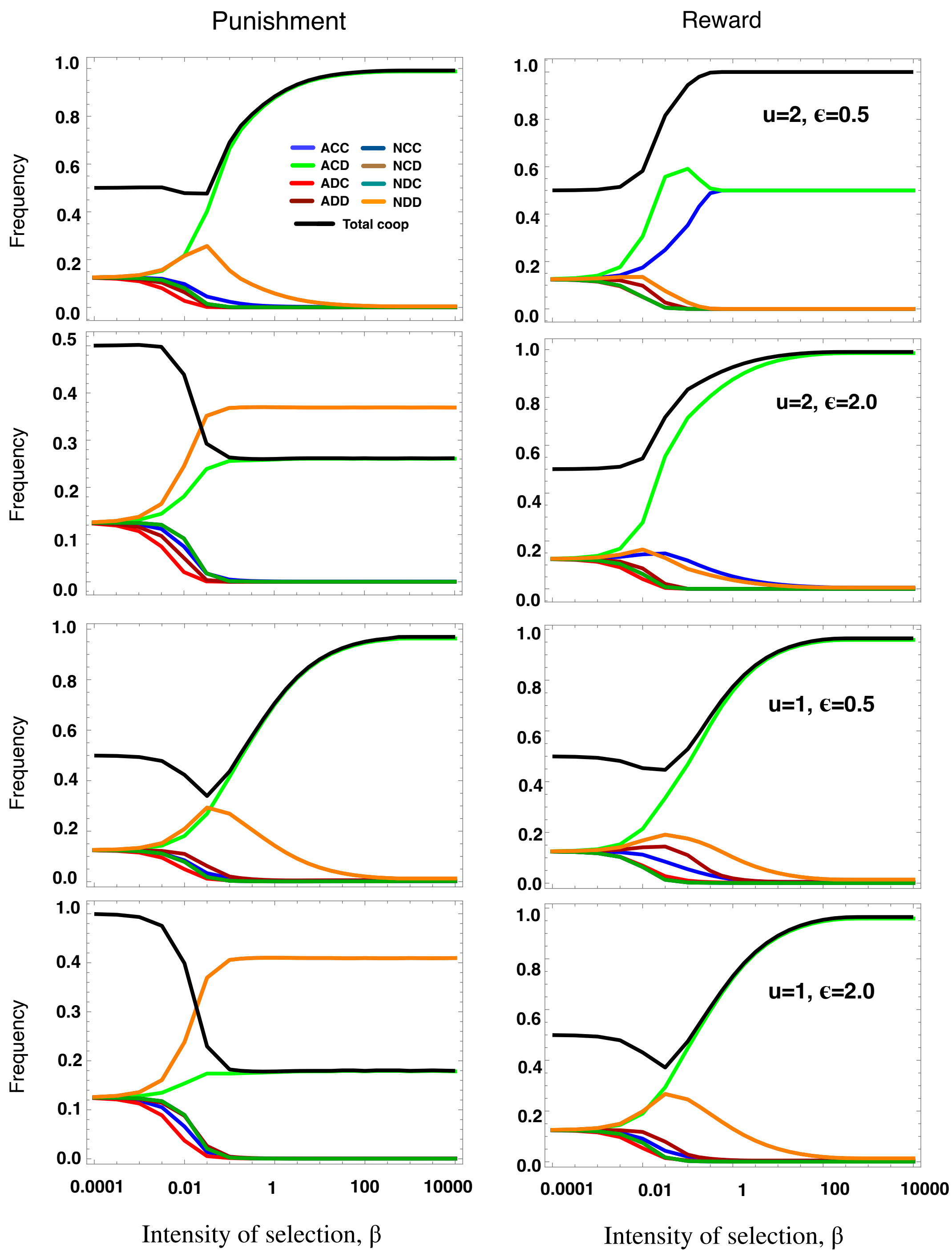

Figure S10. Reward promotes higher levels of cooperation than punishment for increasing the intensity of selection β. Depicted are the frequency of the eight strategies in the population for different combinations of u and ϵ. Similar to results in the main text, we observe that commitment compliance (ACD) is more frequent in case of reward than in case of punishment, leading to higher levels of cooperation than punishment. Other parameters: $\alpha = 0$, $\chi = 0$, $R = 1$, $S = -1$, $T = 2$, $P = 0$.