A new approach to the analysis of cooperation under the shadow of the future: Theory and experimental evidence*

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Abstract

The theory of infinitely repeated games lacks predictive power due to its insensitivity to, e.g., changes in some game parameters, the timing of players' moves and communication possibilities. We propose a new approach by studying an infinitely repeated prisoner's dilemma game and its variants with heterogeneous preferences for cooperation and defection, and strategic risk arising from incomplete information about opponents' preferences. Our model generates a rich set of comparative static predictions in a variety of settings. We show that, unlike standard theory and other existing models, our approach organizes the findings of a host of experiments including our novel experiments.

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1 Introduction

The theory of repeated games has been subject to criticism as it may not provide sharp predictions, due to a multiplicity of equilibria (see Tirole (1988) and Fudenberg and Maskin (1993)). Another shortcoming of the theory is that its predictions do not account for the effects of specific changes, for instance in some game parameters or the structure of the stage game, in contrast to what mounting experimental evidence indicates. To study behavior in infinitely repeated dilemma games, we develop an intuitive model in which players' preferences for cooperation and defection are heterogeneous and unobservable.[1] Our model generates a rich set of comparative static predictions in a variety of settings that go beyond the standard prisoner's dilemma game. We show that our approach organizes the findings of a host of experiments including our novel experiments, which neither the standard theory nor other existing approaches can.

The difficulty of understanding the determinants of cooperation and of accurately predicting cooperation levels in infinitely repeated prisoner's dilemma games is well-known in the experimental literature. It is also recognized that cooperation levels depend on the "strategic risk" of cooperation—see, e.g., Blonski and Spagnolo (2003, 2015), Blonski et al. (2011) and the related *basin of attraction* of a defective strategy, as discussed in Dal Bó and Fréchette (2011). However, the literature so far fails to provide a formal and widely applicable modeling of the strategic risk that governs the potential costs and benefits of cooperation. This is the gap that we try to fill in this paper.

In our model, cooperation and the associated strategic risk depend not only on the stage-game payoff matrix and other related game parameters implemented by the experimenter, but also on certain characteristics of subjects—in particular, their preferences for cooperation versus defection. We formalize this idea by developing a model that incorporates a private, heterogeneous (positive or negative) preference for cooperation in an infinitely repeated setting. Our approach endogenizes the strategic risk of cooperation: the realized level of cooperation is endogenously determined in equilibrium depending on the preference

[1] A sizeable experimental literature has documented deviations from material self-interest, such as preferences for (conditional) cooperation, fairness, and reciprocity, as well as anti-social preferences. Various specifications have been offered in the literature to model such behavior, e.g., Rabin (1993), Levine (1998), Fehr and Schmidt (1999), Bolton and Ockenfels (2000), and Charness and Rabin (2002).

distribution and the game parameters. This is an important step in formalizing strategic risk, as this richer theory can yield intuitive comparative static predictions in a variety of settings, where other approaches are unresponsive.

We first show how the features of our model interact with the parameter changes in the standard infinitely repeated prisoner's dilemma game. For example, a change in the sucker payoff is associated with a change in the measure of player types that prefer cooperative play over defection. This change is equivalent to a change in the strategic risk of cooperation and hence the equilibrium cooperation rate. Specifically, if the sucker payoff increases, this reduces the strategic risk of cooperation and increases the predicted level of cooperation, consistent with the discussion in Blonski et al. (2011) and Dal Bó and Fréchette (2011), as well as the experimental evidence in Blonski et al. (2011) and Mermer et al. (2020). In addition to the effect of stage-game payoffs and the discount factor, we also show the effect of changes in the preference distribution on comparative static predictions, which is supported by the recent experimental evidence from Kölle et al. (2020).[2]

We then theoretically compare cooperation and coordination rates in the infinitely repeated prisoner's dilemma game to the rates in two of its variants keeping everything else (e.g., the stage game payoffs and the discount factor) identical except one aspect of the stage game. The first variant changes the simultaneous-move stage game to a sequential-move version, and the second variant introduces cheap-talk communication to the simultaneous-move stage game. Standard theory (i.e., the complete-information model with identical preferences) does not differentiate between these variants, and the approaches in Dal Bó and Fréchette (2011) and Blonski et al. (2011) are not applicable for these comparisons. However, our model indicates that both a sequential structure and communication foster cooperation in the infinitely repeated setting relative to the benchmark simultaneous-move game by mitigating the private information problem and the risk of being the sucker. Put differently, these two variants reduce strategic risk by making it easier to recognize a co-operative opponent, and this reduction in strategic risk in turn increases the incentive to

[2] We also extend these comparative static results to the infinitely repeated stag hunt games as well as the infinitely repeated variant where the stage-game moves are sequential (rather than simultaneous) and discuss supporting experimental evidence from Duffy and Fehr (2018) for the former and from Ghidoni and Suetens (in press) for the latter.

cooperate.

To exemplify how our model endogenizes strategic risk, let us explain the intuition behind this result in more detail. We first compare the simultaneous game to the sequential version where we predict the second-mover cooperation rate to be significantly higher than the cooperation rate in the simultaneous game, since there is essentially no strategic risk of cooperation for second movers who observe first-mover cooperation. In turn, the first-mover cooperation rate is strictly higher than the cooperation rate in the simultaneous game, since first movers expect a higher rate of cooperation in return. However, the strategic risk for first movers is still non-negligible, and hence their cooperation rate is lower than that of second movers. Given these insights, the predicted share of players who coordinate on cooperation is strictly higher in the sequential game than in the simultaneous game. Moreover, we predict the communication game to generate an even higher rate of coordination on cooperation, on the assumption that lying is costly to many people and a sufficiently large proportion of communication will therefore be truthful (consistent with the findings of a sizable experimental literature on honesty in communication). Our comparative static predictions are borne out by the existing experimental evidence (Ghidoni and Suetens, in press) and by our novel experiments.

In our experiments, we implement the three aforementioned infinitely repeated settings. Importantly, the standard theory *uniquely* predicts defection in all three experimental settings, in contrast to our theoretical predictions. The experimental results are consistent with our predictions. The communication game and the sequential game generate higher cooperation and coordination on cooperation than the benchmark simultaneous game (with the communication game generating the highest coordination and cooperation rates).

We finally apply our model to more sophisticated infinitely repeated settings; i.e., a setting that allows for costly punishment—as in Dreber et al. (2008)—and a setting that allows for a dynamic transition between different types of prisoner's dilemma stage games—as in Vespa and Wilson (2019). Our model makes comparative static predictions which are, again, borne out by the data of these experimental papers. For example, cooperation significantly increases in infinitely repeated games that involve the costly punishment option, consistent with the experimental findings by Dreber et al. (2008).[3] These authors note that winners in their experiment (i.e., subjects who earn the most money) do not punish. However, the sole focus on monetary payoffs may be misguided because our model indicates that *all* player types that choose cooperation in the infinitely repeated setting without punishment are, in *utility* terms, strictly better off in the presence of a punishment option. Put differently, altruistic punishment has a nontrivial *positive externality* on cooperators (especially, on those who do not punish) by reducing the strategic risk of cooperation and thus the expected utility of a cooperative strategy.

Most of the literature allowing for nonstandard preferences are in one-shot settings or in bargaining-game type of environments. While the one-shot setting is a special case of our model, our results indicate that there can be a significant interaction between the shadow of the future and nonstandard preferences. Hence, theories of cooperation in infinitely repeated games may have more predictive power if they account for private and heterogeneous tastes for cooperation and defection. Our richer setup enables us to endogenize strategic risk and to make comparative static predictions even in infinitely repeated games where cooperation is not an equilibrium according to standard theory, as well as in infinitely repeated games where stage games are more complex than the standard prisoner's dilemma game. We demonstrate that our model organizes experimental findings in a variety of settings. We also note that, to our knowledge, our study is the first to present a thorough and detailed analysis of subject communication in an infinitely repeated setting and document its cooperation boosting features.

The remainder of the paper is organized as follows. In Section 2 we review the related literature. In Section 3 we introduce our model, derive basic results, and discuss the relevant existing evidence. In Section 4 we present further theory on more advanced setups as well as corresponding experimental results. In Section 5 we introduce our own novel experiments, and we present their results in Section 6. Finally, Section 7 offers a summary and some concluding remarks.

[3] To the extent that there are cooperative types who prefer implementing the costly punishment option against defectors, costly punishment is associated with a greater willingness to cooperate (in order to avoid a possible punishment), which decreases the strategic risk of cooperation. This in turn increases the equilibrium cooperation rate.

2 Related Literature

Our paper relates to various strands of the game-theoretic and experimental literature. Firstly, our paper relates to a burgeoning experimental literature on infinitely repeated prisoner's dilemma games (see, for example, Palfrey and Rosenthal, 1994; Engle-Warnick and Slonim, 2004, 2006a, 2006b; Dal Bó, 2005; Aoyagi and Fréchette, 2009; Camera and Casari, 2009; Duffy and Ochs, 2009; Dal Bó and Fréchette, 2011; Blonski et al., 2011; Fudenberg et al., 2012; Embrey et al., 2013; Arechar et al., 2017; and Vespa and Wilson, 2019). Blonski and Spagnolo (2003, 2015), Dal Bó and Fréchette (2011) and Blonski et al. (2011) are particularly related to our paper as they develop approaches showing the importance of strategic risk as a determinant of cooperation. Blonski et al. (2011) take an axiomatic approach to characterize an equilibrium selection criterion for repeated prisoner's dilemma games, whereas Blonski and Spagnolo (2003, 2015) build on Harsanyi and Selten's (1988) concept of risk dominance. Dal Bó and Fréchette (2011) analyze various infinitely repeated simultaneous prisoner's dilemma games in the laboratory. Among other things, they show that cooperation may not prevail in games in which it is a possible equilibrium action and that even if cooperation is supported in equilibrium and is risk dominant, the cooperation rate need not be high.

Our experimental findings go in a different direction showing that even if cooperation is not an equilibrium action under standard assumptions, the cooperation rate may deviate from this prediction. In fact, it can be quite high in certain variants of the benchmark game which keeps all the parameters identical but either adds communication or introduces a sequential-move structure to the game. We show that our findings are consistent with the predictions of our theory, which incorporates heterogeneous, private preferences for cooperation and defection. This theory rationalizes our experimental data as it predicts that some variants of the game utilize tastes for cooperation better and can foster cooperation.[4] Our model assumes a rich set of behavioral types involving not only those intrinsically motivated to cooperate but possibly also anti-social types as well as prudent types averse to cooperation unless they are confident enough that the opponent will cooperate. Thus, our modeling

[4] To our knowledge, there are only two other experimental studies that incorporate private types into their theoretical predictions in an infinitely repeated setting, Bernard et al. (2018) and Kartal et al. (2020).

of preferences for cooperation is closer in spirit to Andreoni and Samuelson (2006), which generalizes the two-type private information model introduced by Kreps, Milgrom, Robert, and Wilson.[5,6]

Our paper also relates to the literature on strategic risk/uncertainty. Various authors developed models of strategic risk/uncertainty and others measured its extent and importance in experiments (see, for example, Van Huyck et al., 1990, 1991; Morris and Shin, 2002; Heinemann et al., 2009; Cabrales et al., 2010; Dal Bó and Fréchette, 2011; Blonski et al., 2015; and Andersson et al., 2014). Note that the models in the papers just mentioned cannot be applied to the analysis of the variants of the prisoner's dilemma game we consider in this paper, while our model can.

The experimental study by Ghidoni and Suetens (in press) is closely related to our study as they implement simultaneous and sequential infinitely-repeated game versions for all six parameter combinations used in Dal Bó and Fréchette (2011).[7] However, they do not provide a comprehensive theoretical model or results for games with communication. Dvorak and Fehrler (2020) report, among many other treatments, the results of an infinitely repeated prisoner's dilemma game with perfect monitoring (where subjects observe both actions and both signals) and either free-form, pre-play communication or free-form communication prior to each period of the repeated game. Note, however, that their continuation probability is such that cooperation can be supported as a subgame perfect Nash equilibrium in their treatment. This is *not* the case in our treatment with communication. To economize on space, we comment on other related experimental literature in the context of our theoretical results right after the statement of each proposition in the next section. Where appropriate, we will also briefly mention results of one-shot prisoner's dilemma games.

[5] Andreoni and Samuelson (2006) analyze theoretically and experimentally a twice-repeated (simultaneous-move) prisoner's dilemma game instead of an infinitely repeated setting.

[6] There is an extensive reputation literature dating back to 1982. For example, Kreps et al. (1982) study a finitely repeated prisoner's dilemma game assuming that each player has a private type that is "committed" to conditional cooperation with some positive probability and self-interested with the remaining probability. They show that reputation concerns in addition to the presence of conditional cooperators can sustain high levels of cooperation in equilibrium. The experimental literature on finitely repeated prisoner's dilemma games is surveyed in Embrey et al. (2018) and Mengel (2018). Oskamp (1974) compares cooperation in finitely repeated simultaneous and sequential prisoner's dilemma games.

[7] Through personal communication, the authors of this paper and Ghidoni and Suetens (in press) became aware of each other's work during the time of simultaneous data collection.

3 A Model of Endogenous Strategic Risk in Infinitely Repeated Games

We analyze infinitely repeated prisoner's dilemma games assuming that (i) players have heterogeneous preferences for cooperation and defection, and (ii) players' preferences are their private information. Consider the following monetary payoff matrix for a symmetric prisoner's dilemma stage game:

	C	D
C	c, c	a, b
D	b, a	d, d

The monetary payoff parameters of the stage game a, b, c, and d are such that $b > c > d > a$. The term $\Gamma(\delta)$ denotes an arbitrary symmetric infinitely repeated prisoner's dilemma game with discount factor δ, and $\Gamma(a, b, c, d, \delta)$ denotes a symmetric infinitely repeated game with discount factor δ and monetary stage game payoffs a, b, c, and d as in the table above.

At the beginning of each period $t = 0, 1, \ldots$, two players make a choice between C and D. We model preferences and specify stage-game utilities in game $\Gamma(a, b, c, d, \delta)$ as follows. Player i receives a utility of $u(a_i, a_j, m(a_i, a_j), \gamma_i)$ from choosing $a_i \in \{C, D\}$, where $a_j \in \{C, D\}$ denotes player j's choice in the stage game, $m(a_i, a_j)$ denotes the resulting monetary stage-game payoff from (a_i, a_j), and γ_i represents player i's preferences, which is i's private information. We interpret γ as a measure of taste for cooperation in a sense that will become clear below (in particular, the higher the value of γ_i for player i, the stronger the taste of i for cooperation).

The stage-game utility $u(a_i, a_j, m(a_i, a_j), \gamma_i)$ is continuous in $m(a_i, a_j)$ and γ_i, and γ_i is an i.i.d. draw from a commonly known distribution $F(\gamma)$ with a continuous density on $[\underline{\gamma}, \bar{\gamma}]$. As in the standard prisoner's dilemma game, $u(a_i, C, m(a_i, C), \gamma_i) > u(a_i, D, m(a_i, D), \gamma_i)$ for $a_i \in \{C, D\}$. That is, i prefers j to cooperate regardless of i's choice and γ_i. Moreover, $u(D, D, d, \gamma_i) > u(C, D, a, \gamma_i)$ as in the standard game.[8] Finally,

[8]However, note that comparative static results are unaffected if $u(D, D, d, \gamma_i) \leq u(C, D, a, \gamma_i)$ for large γ_i. Such an assumption would be consistent with, for example, the presence of some unconditional cooperators among players. This would require us to consider a third strategy below, namely the "always cooperate" strategy, but it would not affect our main conclusions.

$\partial u(a_i, a_j, m(a_i, a_j), \gamma_i)/\partial m(a_i, a_j) > 0$. That is, all else equal an increase in $m(a_i, a_j)$ increases i's stage-game utility from the choice pair (a_i, a_j). Hereafter, to reduce notation in the text we will suppress $m(a_i, a_j)$ in the stage-game utility and use $u(a_i, a_j, \gamma_i)$ unless $m(a_i, a_j)$ is directly relevant.

To make the analysis tractable, we focus on perfect Bayesian Equilibria in which—adopting and extending the approach in Blonski et al. (2003, 2015)—subjects play either a conditionally cooperative strategy, such as grim (hereafter, CS) or the "always defect" strategy (hereafter, AD). Put differently, a perfect Bayesian Equilibrium (PBE) consists of the strategies CS and AD. Despite this restriction on the set of strategies, our model generates interesting and novel comparative statics predictions regarding cooperative behavior, which is borne out by the data. In Section 4, where we analyze richer games, we will allow for additional strategies in our PBE analysis.

For the analysis of PBE in the infinitely repeated game, let

$$\begin{aligned}\Pi(\delta, p, \gamma) \quad = \quad & \left[p\frac{u(C,C,\gamma)}{1-\delta} + (1-p)\left(u(C,D,\gamma) + \delta\frac{u(D,D,\gamma)}{1-\delta}\right)\right] - \\ & \left[p\left(u(D,C,\gamma) + \delta\frac{u(D,D,\gamma)}{1-\delta}\right) + (1-p)\frac{u(D,D,\gamma)}{1-\delta}\right].\end{aligned}$$

$\Pi(\delta, p, \gamma)$ denotes the *net* expected benefit of choosing CS (rather than AD) for a type-γ player assuming that the opponent chooses CS with probability p and AD with probability $1-p$. The terms p and $\Pi(\delta, p, \gamma)$ relate to the equilibrium selection approach in Blonski and Spagnolo (2003, 2015) who emphasize the importance of the "sucker payoff" as a determinant of cooperation in repeated games and the "basin of attraction" of AD elaborated on in Dal Bó and Fréchette (2011). In our model, an increase in the sucker payoff increases $\Pi(\delta, p, \gamma)$, and a decrease in the value of p that makes $\Pi(\delta, p, \gamma)$ equal to zero implies the basin of attraction of AD decreases. Thus, an increase in the sucker payoff decreases the basin of attraction of AD. We extend the literature by endogenizing p, which represents the strategic risk of cooperation, because the fraction of conditional cooperators is endogenously determined in equilibrium and pins down the value of p. Moreover, we go beyond the typical games studied in the experimental literature to show the predictive power of our approach.

Throughout, we assume that $u(C, C, \gamma_i) + u(C, C, \gamma_j) > u(C, D, \gamma_i) + u(D, C, \gamma_j)$

for those γ_i values for which $\Pi(\delta, 1, \gamma_i) \geq 0$ to justify our interest in *mutual cooperation*. In addition, we will typically focus on the case where $p < 1$ as we are interested in understanding cooperation in games where a nontrivial measure of γ-types face a dilemma because, e.g., δ is away from one, b is not close to c, or c is not substantially higher than d.[9] However, to build intuition for our approach we first consider a setting where $p = 1$ so that cooperation involves *no* strategic risk. According to Assumption A1 below, the type space is *rich* enough so that in the absence of strategic risk, there exists a γ_1-type player who strictly prefers CS over AD, but there also exists a γ_2-type player who strictly prefers AD.

Assumption A1 *Assume that δ is bounded away from one and fix $\Gamma(a, b, c, d, \delta)$. There exists $\gamma_1 \in (\underline{\gamma}, \bar{\gamma})$ and $\gamma_2 \in [\underline{\gamma}, \gamma_1)$ such that $\Pi(\delta, 1, \gamma_1) > 0$, and $\Pi(\delta, 1, \gamma_2) < 0$.*

Importantly, γ_1 and γ_2 types are *endogenous* to $\Gamma(a, b, c, d, \delta)$, the game under consideration. As an example, it may well be that $\Pi(\delta, 1, \gamma_1) > 0$ in $\Gamma(a, b, c, d, \delta)$, but $\Pi(\delta, 1, \gamma_1) < 0$ in $\Gamma(a, b, c, d', \delta)$ where $d' > d$. To understand A1 better, consider the simple case where $\delta = 0$ so that the game is effectively one shot. If $\Pi(0, 1, \gamma_2) < 0 < \Pi(0, 1, \gamma_1)$, then a γ_1-type player strictly prefers cooperating against an opponent who will certainly cooperate in the one-shot game, whereas a γ_2-type player strictly prefers defecting in the same situation. The interpretation is that γ_1 type has a strong enough taste for mutual cooperation, but there are other types who do not share those preferences, e.g., a selfish type with standard preferences, a spiteful type, or types with a weak preference for cooperation.

Even a γ_1-type player for whom $\Pi(\delta, 1, \gamma_1) > 0$ may have preferences such that $\Pi(\delta, p, \gamma_1) < 0$ and thus prefer defection for some $p < 1$. Put differently, there are presumably many types who strictly prefer cooperating against an opponent who will certainly cooperate but will defect if they are not sufficiently confident that the opponent will cooperate because the risk of obtaining the sucker payoff kicks in as p decreases. As a result, A1 is too weak to ensure that there is (at least some) cooperation in equilibrium, and there are various ways to make it stronger. We choose one such possibility. The following assumption *strengthens* the condition regarding γ_1 in A1 (hence the name A1S).

[9] Indeed, experimental studies suggest that this is the empirically relevant case. As an example, in the six repeated games analyzed by Dal Bó and Fréchette (2011), only one game comes close to generating full cooperation, and in that game, b and c are very close at 50 and 48, respectively, and the discount factor is relatively high at $\delta = 0.75$.

Assumption A1S *Assume that* δ *is bounded away from one and fix* $\Gamma(a,b,c,d,\delta)$*. There exists* $\gamma_1 \in (\underline{\gamma}, \bar{\gamma})$ *and* $\gamma_2 \in [\underline{\gamma}, \gamma_1)$ *such that* $\Pi(\delta, 1-F(\gamma_1), \gamma_1) > 0$ *and* $\Pi(\delta, 1, \gamma_2) < 0$.

The term $\Pi(\delta, 1-F(\gamma_1), \gamma_1)$ above equals the net expected benefit of choosing CS for a γ_1-type player provided that an opponent with type $\gamma > \gamma_1$ chooses CS and AD otherwise. Thus, A1S implies that there exists a γ_1 type that strictly prefers cooperation if every γ type with $\gamma > \gamma_1$ will cooperate (i.e., if the strategic risk of cooperation equals $1 - F(\gamma_1)$). To reiterate, γ_1 and γ_2 are endogenous to the game; e.g., it may well be the case that $\Pi(\delta, 1 - F(\gamma_1), \gamma_1) > 0$ in game Γ, but not in game Γ'.

Assumption A2 below imposes *monotonicity* on $\Pi(\delta, p, \gamma)$ consistent with our definition of the γ parameter: the strength of preferences for cooperation increases in γ. In particular, A2 implies that if a γ_1-type player strictly prefers CS over AD with strategic risk p equal to $1 - F(\gamma_1)$ as postulated in A1S, then any type greater than γ_1 strictly prefers CS as well, which will give rise to a *cutoff* structure in PBE strategies.

Assumption A2 $\Pi(\delta, p, \gamma') > \Pi(\delta, p, \gamma)$ *if* $\gamma' > \gamma$.

In all of our results below, we assume that A1S and A2 hold. Below we provide simple examples that satisfy A1S and A2.

Example 1 Consider a stage game where $a = 12$, $b = 50$, $c = 32$, and $d = 25$, and assume that $\delta = 0.5$ (these are the parameter values we use in our experimental design). Consider preferences that are represented by the following utility specification: $u(C, C, \gamma_i) = c^{\gamma_i}$ where $\gamma_i > 0$, and for every other (a_i, a_j) pair, stage-game utilities equal stage-game monetary payoffs. It can easily be checked that A2 is satisfied. In addition, A1S is satisfied if, e.g., γ_i is drawn from a uniform distribution between 1 and 1.25 with $\gamma_1 = 1.2$ and $\gamma_2 = 1$.

Example 2 Consider the stage game payoffs in Example 1, and assume that $\delta = 0.75$. Consider preferences represented by the following utility specification: $u(C, C, \gamma_i) = c + \gamma_i$, $u(C, D, \gamma_i) = a + \frac{\gamma_i}{4}$, $u(D, C, \gamma_i) = b - \gamma_i$, and $u(D, D, \gamma_i) = d - \frac{\gamma_i}{4}$. Then, A2 is satisfied. In addition, A1S is satisfied if, e.g., γ_i is drawn from a uniform distribution between -4 and 8 with $\gamma_1 = 2$ and $\gamma_2 = -2$.

In every game that satisfies A1S and A2 there are at least some (conditional) cooperators who will optimally choose a cooperative strategy—either because the strategic risk of cooperation is not too high as there are sufficiently many cooperators, or because their taste for (mutual) cooperation is high enough to compensate for the strategic risk of being the sucker. In addition, in every game that satisfies A1S the type space is rich enough so that there are at least some defector types who will optimally choose AD (e.g., because they are selfish, anti-social/spiteful or intensely averse to being a sucker and so will not cooperate unless they are highly confident the opponent will cooperate). Thus, A1S, A2, and our assumptions on $u(a_i, a_j, \gamma_i)$ ensure that the share of types that select into cooperative and defective strategies is an *interior* value and *endogenous* to the game. Put differently, the model endogenizes the strategic risk of cooperation and generates meaningful comparative static results in various dilemma games.

Below we will present our theoretical results together with the relevant experimental evidence. In particular, after the statement of each proposition below, we will discuss the relevant experimental literature in the context of our theoretical result. Where appropriate, the details of the significance levels of statistical tests as reported in the literature will be provided in endnotes (see page 41) which are numbered by small-letter superscripts.

We start by investigating perfect Bayesian Nash equilibria in our benchmark case: the infinitely repeated simultaneous prisoner's dilemma game. As formally stated in Proposition 1, there always exists an equilibrium cutoff type $\gamma^* \in (\underline{\gamma}, \bar{\gamma})$ such that $\Pi(\delta, 1-F(\gamma^*), \gamma^*) = 0$, and a type-$\gamma$ player selects CS if $\gamma > \gamma^*$ and AD otherwise. Moreover, every equilibrium must be symmetric. It is not possible to claim that there is a unique equilibrium cutoff in every setting we study below in the absence of further assumptions. Therefore, our theoretical statements always focus on the most cooperative equilibrium, that is, the lowest equilibrium cutoff of the game. (The proofs of our Propositions can be found in Online Appendix A.)

Strategic risk arises endogenously in our model since the expected fraction of cooperators, which equals $1 - F(\gamma^*)$, is an equilibrium object. As a result, a change in the stage-game payoff matrix, the discount factor δ, the distribution $F(\gamma)$ or the game format directly influences γ^* and the equilibrium cooperation rate as shown in Propositions 1-5 below.

Proposition 1 ***(i)*** *There exists a PBE in $\Gamma(a, b, c, d, \delta)$. Every PBE is symmetric and consists of a cutoff γ^* such that a player with type $\gamma > \gamma^*$ $(\gamma < \gamma^*)$ chooses CS (AD).* ***(ii)***

If $a' < a$ ($b' > b$), then the cooperation rate in game $\Gamma(a', b, c, d, \delta)$ ($\Gamma(a, b', c, d, \delta)$) is strictly lower than the cooperation rate in game $\Gamma(a, b, c, d, \delta)$. ***(iii)*** *If $\delta' < \delta$, then the cooperation rate in game $\Gamma(a, b, c, d, \delta')$ is strictly lower than the cooperation rate in game $\Gamma(a, b, c, d, \delta)$.* ***(iv)*** *If $F'(\gamma) < F(\gamma)$ for all $\gamma \in (\underline{\gamma}, \bar{\gamma})$ (i.e., we have strict first order stochastic dominance of $F'(\gamma)$ over $F(\gamma)$), then $F'(\gamma)$ induces a strictly higher cooperation rate than $F(\gamma)$.*

Proposition 1 implies that—all else equal—an increase in the sucker payoff a or a decrease in the temptation payoff b decreases the equilibrium cutoff and increases the equilibrium cooperation rate, while a decrease in a or an increase in b increases the cutoff and reduces cooperation. Similarly, an increase in δ decreases the equilibrium cutoff type and boosts cooperation. For brevity, in Proposition 1 we focus on changes in a or b, but the results extend to changes in c or d.

Experimental results regarding Proposition 1. Part (ii) of Proposition 1 deals with the effect of *ceteris paribus* changes in the sucker payoff a. The results of two experimental infinitely repeated prisoner's dilemma games reported in Blonski et al. (2011) are in line with our predictions. For a related result, see Mermer et al. (2020). Note that our method enables us to study joint changes that are consistent in their effect as stated in Proposition 1. For example, an increase in a *and* a decrease in b strictly increases the predicted cooperation rate. This prediction is borne out in the study by Vespa and Wilson (2019).[a] There are several studies that vary the gain from mutual cooperation, c, while holding the other parameters fixed. For example, Dal Bó and Fréchette (2011), Romero and Rosokhaz (2018) and Ghidoni and Suetens (in press) report that the cooperation rate increases when c increases (*ceteris paribus*), which Proposition 1 predicts.[10] With respect to part (iii) of Proposition 1, Dal Bó and Fréchette (2011) [henceforth DB&F] summarize the evidence regarding changes in the discount factor δ for both players in their Result 1 as follows: "Cooperation is increasing in the probability of future interactions, and this effect increases with experience." Part (iv) of Proposition 1, which concerns a shift in the distribution of preferences, is relevant for

[10] Apart from Duffy and Fehr (2018) discussed below, we are not aware of studies that report results of infinitely repeated experiments that vary payoff parameters b or d in a *ceteris paribus* manner as assumed in Proposition 1. Mengel (2018) reports one-shot game results (from experiments conducted on Amazon Mechanical Turk) regarding a change in b keeping the other payoffs fixed. In all these games the cooperation rate drops (sometimes mildly) when the payoff parameter increases from b to some b'.

subject-pool effects (see, e.g., Fehr et al., 2006; and Engelmann and Normann, 2010). More direct evidence for this part of Proposition 1 is reported in Kölle et al. (2020) who sort subjects according to their degree of prosociality prior to the play of an infinitely repeated prisoner's dilemma game and inform subjects about the details of this sorting. The authors find that "cooperation is three to four times higher among prosocial players compared to selfish players."[b]

The above theoretical framework and Proposition 1 directly extend to infinitely repeated stag-hunt games. The stage game of a prisoner's dilemma can be modified to a stag hunt game by reducing b in a way that $b \leq c$. Duffy and Fehr (2018) vary b—keeping all else equal—in their infinitely repeated environment so that subjects play both a stag hunt game (i.e., $b < c$) and a prisoner's dilemma game (i.e., $b > c$). They find increased cooperation whenever $b < c$ consistent with Proposition 1. In addition, the magnitude of b matters for the cooperation rate within the stag hunt games, which is in line with Proposition 1.

We can prove an *asymmetric* version of Proposition 1 and show that even if a stage-game payoff or δ changes for only one player, it changes the cutoff type and hence the cooperation rate of *both* players. Let $\Gamma((a, a'), b, c, d, \delta)$ denote the asymmetric version of the game $\Gamma(a, b, c, d, \delta)$ where $a' > a$ and all other parameter values are identical across players and games. In a similar vein, let $\Gamma(\delta, \delta')$ denote the asymmetric version of the game $\Gamma(\delta)$ where $\delta' > \delta$ with other parameters identical across players and games.

Proposition 2 ***(i)*** *There exists a PBE in game* $\Gamma((a, a'), b, c, d, \delta)$ *and* $\Gamma(\delta, \delta')$ *consisting of (asymmetric) cutoffs. In particular, the equilibrium cutoff type for the player with a higher sucker payoff (or discount factor) is strictly lower than the cutoff for the other player.* ***(ii)*** *If* $a' > a$ $(\delta' > \delta)$*, then the cooperation rate of both players is strictly higher in* $\Gamma((a, a'), b, c, d, \delta)$ $(\Gamma(\delta, \delta'))$ *than in* $\Gamma(a, b, c, d, \delta)$ $(\Gamma(\delta))$*.*

Again, for brevity in Proposition 2 we focus on a change in a or δ for one player, but the results extend to *ceteris paribus* changes in b, d, or $F(\gamma)$ for one of the players.[11] We are not aware of studies that report infinitely repeated prisoner's dilemma game experiments

[11] We do not deal with the case of an asymmetric change in c as possible inequality concerns are not formally unaccounted for in our approach.

that vary payoff parameters, the discount factor or $F(\gamma)$ in a way assumed in Proposition 2. Hence, this appears to be a rich and fruitful avenue for future research.

We next analyze how preferences for cooperation influence cooperation and coordination on cooperation under different infinitely repeated institutions. We start with the comparison of the infinitely repeated simultaneous prisoner's dilemma game to the infinitely repeated sequential prisoner's dilemma game. The stage game payoffs and parameters are identical across the two games, but players make choices simultaneously in the stage game of one variant, and sequentially in the other. Standard theory makes identical equilibrium predictions for the two games (and no other existing approach has a different prediction), but our results are different as Proposition 3 indicates.

Proposition 3 ***(i)*** *The first-mover cooperation rate in the sequential game is strictly higher than the cooperation rate in the simultaneous game.* ***(ii)*** *The second-mover cooperation rate conditional on the first-mover cooperation in the first period is strictly higher than the cooperation rate in the simultaneous game and the first-mover cooperation rate in the sequential game.*[12] ***(iii)*** *The rate of coordination on cooperation and the continuation game cooperation rate are strictly higher in the sequential game.*

The intuition of Proposition 3 is based on the simple idea that sequential moves reduce the strategic risk of cooperation for *both* the first mover and the second mover, and the reduction in strategic risk is associated with a boost in the incentive to cooperate. To see this, note first that there is no strategic risk from the viewpoint of a second mover who observes cooperation by the first mover. Thus, a γ-type second mover for whom $\Pi(\delta, 1, \gamma) > 0$ strictly prefers the cooperative strategy if the first mover chooses to cooperate. As a result, the cooperation rate of second movers—conditional on first-mover cooperation—is determined by the cutoff type γ_2^* that satisfies $\Pi(\delta, 1, \gamma_2^*) = 0$. It follows that $\gamma_2^* < \gamma^*$ because cooperation is risky in the simultaneous game, unlike the situation for a second mover who observes first-mover cooperation, and the strategic risk in the simultaneous game reduces the incentive to cooperate. In turn, the first mover in the sequential game expects a strictly higher cooperation rate than the cooperation rate a player can expect in the simultaneous game;

[12] Parts (i) and (ii) of Proposition 3 hold both in the first period and on average.

i.e., $1 - F(\gamma_2^*) > 1 - F(\gamma^*)$. Thus, the strategic risk for the first mover is reduced, and the first-mover cutoff type γ_1^* is such that $\gamma_1^* < \gamma^*$. As the strategic risk in the sequential game is higher for the first mover than the second mover, we have that $\gamma_2^* < \gamma_1^* < \gamma^*$.

It is not possible to show that the average first-period cooperation rate is higher in the sequential game than in the simultaneous game simply because cooperation in the sequential game has a *correlated* structure even in the first period. Thus, even though $\gamma_2^* < \gamma_1^* < \gamma^*$, we cannot know how the unconditional probability that the second mover cooperates in the first period of the sequential game (i.e., $(1 - F(\gamma_1^*))(1 - F(\gamma_2^*))$ compares to the first-period cooperation rate in the simultaneous game (i.e., $1 - F(\gamma^*)$).[13] Still, the rate of coordination on cooperation (i.e., the mutual cooperation rate) is always strictly higher in the sequential game than in the simultaneous game, and therefore, the continuation game cooperation rate is strictly higher in the sequential game.

Note that incorporating preferences for *reciprocity* into the sequential move game would only make our conclusions stronger. That is, one may naturally assume that observing first-mover cooperation may result in a preference distribution $F'(\gamma)$ for second movers such that $F'(\gamma)$ first order stochastically dominates $F(\gamma)$. This reciprocity effect reduces γ_2^*, which in turn reduces γ_1^*.

Experimental results regarding Proposition 3. Experimental evidence for Proposition 3 is reported in Ghidoni and Suetens (in press) and new experiments in this paper. Ghidoni and Suetens (in press) implement simultaneous and sequential infinitely repeated prisoner's dilemma games for all six sets of payoff parameters used in DB&F. These payoff parameters are $(a, b, d) = (12, 50, 25)$ combined with $(c, \delta) \in \{32, 40, 48\}\times \{0.5, 0.75\}$. In our experiments, reported in Sections 5 and 6, we also implement a simultaneous and a sequential infinitely repeated prisoner's dilemma game with payoff parameters $(a, b, c, d, \delta) = (12, 50, 32, 25, 0.5)$. In general, the data of Ghidoni and Suetens (in press) as well as our data are in line with all predictions of Proposition 3. More precisely, for *all six parameter sets* in Ghidoni and Suetens (in press) and in our data,

[13] That is, the unconditional probability that a second mover cooperates in the first period could be relatively low since some second movers who would choose to cooperate in the simultaneous game will meet first movers who choose to defect and will subsequently defect themselves.

• the first-mover cooperation rate in the sequential game is larger than the cooperation rate in the simultaneous game (Part (i) of Proposition 3),[c]

• the second-mover cooperation rate in the sequential game (conditional on first-mover cooperation) is higher than the cooperation rate in the simultaneous game[d] and the first-mover cooperation rate in the sequential game[e] (Part (ii) of Proposition 3),

• the mutual cooperation rate is higher in the sequential game than in the simultaneous game (Part (iii) of Proposition 3).[f,14]

We next investigate the effect of parameter changes in the sequential game.

Proposition 4 ***(i)*** *If $c' > c$ ($\delta' > \delta$), then the first- and the second-mover as well as the average (mutual) cooperation rates are higher in the sequential game with c' (δ') than in the game with c (δ).*[15] ***(ii)*** *If $a' > a$ ($F'(\gamma) < F(\gamma)$ for all $\gamma \in (\underline{\gamma}, \bar{\gamma})$), then the first-mover and the average (mutual) cooperation rates are strictly higher in the sequential game with a' ($F'(\gamma)$) than in the game with a ($F(\gamma)$). The second-mover cooperation rate is unaffected.*

Experimental results regarding Proposition 4. The predictive power of part (i) of Proposition 4 can again be checked using the sequential-game data of Ghidoni and Suetens (in press). Their results are (almost) completely in line with the predictions of Proposition 4. That is, the first- and the second-mover as well as mutual cooperation rates strictly increase when c increases from 32 to 40 to 48 (keeping δ fixed)[g] as well as when δ increases from 0.5 to 0.75 (keeping c fixed, with the exception of some cases depending on the slice of the data one considers).[h] Note that the "basin of attraction" notion employed in their paper (based on DB&F) cannot generally be used to derive the comparative-statics of Proposition 4 (i). Experimental evidence for part (ii) of Proposition 4 does not exist, which suggests another direction for future research.

[14] Hayashi et al. (1999), Ahn et al. (2003, 2007), Khadjavi and Lange (2013) and Healy (2017) run *one-shot* simultaneous and sequential prisoner's dilemma games—the latter also compares behavior of different subject pools (female prisoners versus female university students). While first movers in the sequential game are often reported to cooperate more than subjects in the simultaneous game, this effect is not "universal" and seems to depend on payoff parameters and subject pools.

[15] The same result also obtains if $d' < d$ ($b' < b$); i.e., the first- and the second-mover as well as the average (mutual) cooperation rates increase with b' (d').

We now investigate the effect of communication (i.e., free-form chat) on cooperation. In what follows, "honesty rate" refers to the fraction of players who will choose AD but will nevertheless be honest and signal their intention truthfully (via communication or via refusing to communicate).[16] In particular, it refers to the probability that a player who intends to choose AD is nevertheless honest and will not lie about her intention. Experimental studies on honesty and communication have documented an aversion to lying. Put differently, lying has a psychological cost, and as a result, a sizeable fraction of communication is found to be truthful in numerous experiments (see among others Embrey et al. (2013), Arechar et al. (2017), Bigoni et al. (2019) and Wilson and Vespa (2020) who explore infinitely repeated interactions with communication). This turns out to be true in our experiment as well. Proposition 5 shows how the comparison of the communication game to the sequential game and the simultaneous game depends on the honesty rate.

Proposition 5 ***(i)*** *With any strictly positive honesty rate, the rate of coordination on cooperation and the continuation game cooperation rate are strictly higher in the communication game than in the simultaneous game.* ***(ii)*** *If the honesty rate is sufficiently high, then the rate of coordination on cooperation and the continuation game cooperation rate are strictly higher in the communication game than in the sequential game.*

We construct cooperative PBE in the communication game as follows. Players who intend to use a cooperative strategy in equilibrium always communicate their intention to cooperate—they indeed choose the cooperative strategy upon mutual agreement and the defecting strategy otherwise. To build intuition for the comparative static result, consider the simple case where all players are honest about whether they will choose CS or AD. The cooperative equilibrium has a correlated structure (as in the sequential game) and a type-γ player for whom $\Pi(\delta, 1, \gamma) \geq 0$ will choose to cooperate if and only if this player meets and communicates with a type-γ' player for whom $\Pi(\delta, 1, \gamma') \geq 0$ also holds. Thus, the equilibrium cutoff in the communication game is given by $\Pi(\delta, 1, \gamma_2^*) = 0$, where γ_2^* is precisely the equilibrium cutoff for the second mover conditional on first-mover cooperation in the sequential game. It follows that the coordination rate in the communication game is equal to

[16] We interpret a player's refusal to communicate as a refusal to lie and as an honest signal that the player will choose AD. This interpretation indeed finds support in the data as we discuss in Section 5.2.

$(1-F(\gamma_2^*))^2$, which is also the first-period cooperation rate because the decision to cooperate is perfectly coordinated if all players are honest. As explained before when comparing the sequential game to the simultaneous game, $\gamma_2^* < \gamma_1^* < \gamma^*$. Thus, the coordination rate in the communication game is strictly greater than $(1 - F(\gamma^*))^2$ and $(1 - F(\gamma_1^*))(1 - F(\gamma_2^*))$, the respective coordination rate in the simultaneous game and the sequential game. These arguments extend to the case where the honesty rate in communication is strictly positive (this is relevant for the comparison to the simultaneous game) or sufficiently high (this is relevant for the comparison to the sequential game).[17]

Preferences for reciprocity may also be evoked in this game as in the sequential game. A player may feel reciprocity towards an opponent who proposes mutual cooperation or declares the intention to cooperate. In fact, reciprocity may influence behavior even more in the communication game than in the sequential game, because players likely feel less anonymous in the presence of a chat opportunity. This would then result in a preference distribution $F'(\gamma)$ for recipients of "nice" communication such that $F'(\gamma)$ first order stochastically dominates $F(\gamma)$, further increasing equilibrium cooperation and coordination on cooperation. In addition to a possible reciprocity effect in the communication game, the first-period cooperation rate may be higher in the communication game than in the simultaneous game especially if the simultaneous game is one with high strategic risk similar to the simultaneous game we implement in the experiment. This means that $1 - F(\gamma^*)$ is very low, and thus, it is easier for $(1 - F(\gamma^*))^2$ to exceed $1 - F(\gamma^*)$. Our experimental design choices are guided by this observation: as discussed in Section 5, we choose a simultaneous game which is experimentally shown by DB&F to have high strategic risk and low cooperation.

Experimental results regarding Proposition 5. The effect of communication has been studied in many contexts and games. Most relevant for our purposes is the potentially cooperation enhancing effect of communication studied in variants of infinitely repeated prisoner's dilemma games with perfect or imperfect monitoring by Embrey et al. (2013), Wilson and Vespa (2020), Arechar et al. (2017), Bigoni et al. (2019) and Dvorak and Fehrler

[17] We cannot claim that the first-period cooperation rate is higher in the communication game than in the simultaneous game since the first-period cooperation rate equals $(1 - F(\gamma_2^*))^2$ in the communication game without dishonesty, whereas it equals $1 - F(\gamma^*)$ in the simultaneous game.

(2020).[18] Various communication regimes are implemented in these papers. In Embrey et al. (2013) and Arechar et al. (2017) subjects can only exchange pre-selected messages, while Wilson and Vespa (2020), Bigoni et al. (2019) and Dvorak and Fehrler (2020) allow for free-form chats as in our experiment. Focusing on experimental games with perfect monitoring, note first that the honesty rate of communication seems high. For instance, the honesty rate is typically around 90 percent in the treatments reported in Dvorak and Fehrler (2020). In our own experiments we find a similarly high percentage of honesty. Second, in general, communication is reported to increase cooperation rates, which is consistent with the prediction of our model. Dvorak and Fehrler (2020) report large and significant effects of allowing for communication in their infinitely repeated prisoner's dilemma games with perfect monitoring (where subjects observe both actions and both signals).[i] In our experiments, we implement simultaneous versions with and without free-form communication between players before each period of an infinitely repeated prisoner's dilemma game. Considering all data, we find that the average cooperation rate increases from 16.8 percent in the game without to 74.6 percent in the game with communication, as predicted by Proposition 5.

We conclude this Section with a remark. Most of the literature allowing for non-standard preferences are in one-shot settings or in bargaining-game type of environments. However, combining our results above, we see that there can be a significant interaction between the shadow of the future and nonstandard preferences. The most direct pieces of theoretical evidence for this come from Propositions 1, 2, and 4. For example, an increase in the discount factor from 0 to a strictly positive number (even if for only one player) is predicted to strictly increase the cooperation rate—this stems solely from the interaction between δ and preferences for cooperation. Moreover, Propositions 3 and 5 indicate that the comparison of the average cooperation rates in the three types of games (simultaneous, sequential, and communication) is very sharp in the *continuation game*, but not necessarily in the first period, indicating the importance of $\delta > 0$ for the distribution of γ to assert its

[18] While Embrey et al. (2013), Wilson and Vespa (2020) and Bigoni et al. (2019) consider games that resemble prisoner's dilemma games in expectation, Arechar et al. (2017) and Dvorak and Fehrler (2020) implement prisoner's dilemma games with noise. In Arechar et al. (2017) chosen actions are implemented with errors and in Dvorak and Fehrler (2020) subjects' actions are transformed into signals and a subject's profit in a given round depends on the own action chosen and the *signal* received about the other player's action.

impact on comparative statics.

4 Further Theory and Experimental Evidence

Our framework and analysis can be extended to richer environments, which require considering more than two strategies we allowed so far, AD and CS. Consider the infinitely repeated prisoner's dilemma experiment by Dreber et al. (2008) where the stage game involves a costly punishment option in addition to C and D. A similar environment is analyzed in Wilson and Wu (2017): each player has the option to unilaterally terminate the relationship, and if the relationship is terminated at t, both parties obtain their respective outside options from $t+1$ onward.

For simplicity, we adopt a game structure more similar to that in Wilson and Wu (2017) so that punishment takes place only once and for all. At the beginning of each period $t = 0, 1, \ldots$, two players make a choice between C, D, or P. P refers to costly punishment, and if P is chosen by one of the players at t, then each player receives a fixed per-period monetary payoff of e from $t+1$ onward. For ease of notation, we assume without loss of generality that the outside option is identical for both the punished and the punisher—it is easy to relax this assumption. Thus, $\Gamma(a, b, c, d, e, \delta)$ refers to the *extended* infinitely repeated prisoner's dilemma game with discount factor δ, monetary payoffs a, b, c, and d, as well as the outside option e, where $e < d$. Throughout, we maintain the notation in Section 3, and assume that A1S and A2 are satisfied.

We will now show that the risk of being punished for defection can act as a "discipline device" and increase cooperation provided that there are at least some cooperators who prefer punishing defectors even though it reduces their monetary payoff. To that aim, we extend the stage-game utility specification in Section 3 to incorporate the respective per-period punishment utilities for the "punisher" and the "punished". Let the per-period utility of player i who chooses to punish at $t > 0$ be given by $u(\bar{P}, e, \gamma_i)$ if i's opponent misbehaved at $t-1$, and i received the sucker payoff as a result; i.e., $(a_i, a_j) = (C, D)$ at $t-1$. That is, $u(\bar{P}, e, \gamma_i)$ is the per-period utility of the "punisher" following the opponent's misbehavior.

We define

$$\bar{\pi}(d, e, \gamma) \equiv u(\bar{P}, e, \gamma) - u(D, D, d, \gamma).$$

The term $\bar{\pi}(d, e, \gamma)$ relates to preferences for "altruistic punishment": if a $\tilde{\gamma}$-type player ends up being the sucker, and $\bar{\pi}(d, e, \tilde{\gamma}) > 0$, then this player will punish misbehavior. Next, let the per-period utility of player i who is punished by i's opponent at $t > 0$ be given by $u(\underline{P}, e, \gamma_i)$ if i has misbehaved and received the temptation payoff; i.e., $(a_i, a_j) = (D, C)$ at $t-1$. That is, $u(\underline{P}, e, \gamma_i)$ is the per-period utility of the "punished" due to misbehavior. We define

$$\underline{\pi}(d, e, \gamma) \equiv u(D, D, d, \gamma) - u(\underline{P}, e, \gamma) > 0.$$

The term $\underline{\pi}(d, e, \gamma)$ is the per-period utility cost of punishment due to misbehavior and an important part of the calculus of cooperation if there exist cooperative types for whom $\bar{\pi}(d, e, \gamma) > 0$ holds. In particular, the cutoff equilibrium type in the standard game without punishment may strictly prefer cooperating due to the risk of losing $\underline{\pi}(d, e, \gamma)$ per period. Put differently, since $\underline{\pi}(d, e, \gamma) > 0$, the presence of altruistic punishment increases the net benefit of choosing a cooperative strategy rather than AD. For completeness, $u(P, e, \gamma)$ denotes the per-period utility of each player if one of the players chooses P at some t although neither i nor j has misbehaved before, where $u(P, e, \gamma) < u(D, D, d, \gamma)$ for every γ. Utility functions $u(\bar{P}, e, \gamma)$, $u(P, e, \gamma)$, and $u(\underline{P}, e, \gamma)$ are continuous in γ.[19]

We assume that there exists $\gamma \in (\underline{\gamma}, \bar{\gamma})$ such that $\bar{\pi}(d, e, \gamma) > 0$; otherwise, the game is trivially identical to the one without punishment. Therefore, our analysis includes not only strategies CS and AD as before but also a cooperative strategy that punishes defectors, which we hereafter denote by CPS. To maintain the cutoff structure of a PBE, Assumption A3 below complements A2 imposing an intuitive "monotonic" structure on $\bar{\pi}(d, e, \gamma)$ and $\underline{\pi}(d, e, \gamma)$. Assumption A3 implies that preferences for cooperation and altruistic punishment are positively associated: the higher the magnitude of γ_i, the higher the chances i chooses conditional cooperation and punishes misbehavior by choosing P.[20] Our assump-

[19] If $u(\bar{P}, e, \gamma) > u(P, e, \gamma)$ for some γ, this reflects a tendency to punish misbehavior. Indeed, $\bar{\pi}(d, e, \gamma_i) > 0$ will hold if $u(\bar{P}, e, \gamma_i)$ is high enough. If $u(\underline{P}, e, \gamma) < u(P, e, \gamma)$, this can be interpreted as (an aversion to) shame or guilt.

[20] Assumption A3 also implies that preferences for cooperation and shame/guilt aversion are positively associated.

tions (i.e., A3 and the assumption that $\bar{\pi}(d, e, \gamma) > 0$ for some γ types) are consistent with experimental evidence showing that the use of a punishment option is not rare, and most acts of punishment are executed by cooperative types due to defective play (see among others Fehr and Gächter (2000, 2002) and Fowler (2005), and the references therein). While our assumption that $u(P, e, \gamma) < u(D, D, d, \gamma)$ rules out anti-social punishment, note that our analysis is robust to the presence of some anti-social punishment (see also Footnote 21).

Assumption A3 *The willingness to punish misbehavior (i.e., $\bar{\pi}(d, e, \gamma)$) and the willingness to avoid punishment due to misbehavior (i.e., $\underline{\pi}(d, e, \gamma)$) are weakly increasing in γ.*

We can now show that the option to punish defectors strictly reduces the equilibrium cutoff type that selects into a cooperative strategy (CS or CPS) and boosts the cooperation rate.[21]

Proposition 6 *Assume that $\bar{\pi}(d, e, \gamma) > 0$ for some $\gamma \in (\underline{\gamma}, \bar{\gamma})$, and A1S, A2, and A3 hold. The addition of a punishment option strictly increases the cooperation rate in the infinitely repeated prisoner's dilemma game.*

Consistent with Proposition 6, Dreber et al. (2008) find that cooperation significantly increases in the infinitely repeated games that involve the costly punishment option.[22] In addition, Dreber et al. (2008) deduce from their experimental analysis that winners (i.e., subjects who earn most) do not punish. Naturally, only monetary outcomes (not utilities) can be compared in the data. Still, the sole focus on monetary payoffs may be misguided. In our model, punishment can be rational depending on preferences, and it is altruistic in the sense that it has a nontrivial *positive externality* on conditional cooperators who choose not to punish. Put differently, *all conditional cooperators in the game without punishment are "utility-wise" strictly better off with the addition of the punishment option, and those who choose CS rather than CPS are strictly better off in both monetary and utility terms.*

Vespa and Wilson (2019) study experimentally *dynamic* infinitely repeated environ-

[21] Note that our result is robust to the presence of anti-social punishment as long as it is limited in scope (i.e., relative to the measure of types that choose CPS). Anti-social punishment could be in the form of punishment of cooperators or random punishment irrespective of the history of play. The magnitude of anti-social punishment is observed to be relatively low in experiments.

[22] Wilson and Wu (2017) obtain a similar result; however, in their setting stage-game payoffs are stochastic conditional on player choices, and there is imperfect public monitoring.

ments where the prisoner's dilemma stage game payoffs are variable and compare them to the *static* infinitely repeated environments where the stage game payoffs are fixed over time. Two players play in an infinitely repeated prisoner's dilemma setting with constant discount factor δ and two possible states ($\Theta = \{L(\text{ow}), H(\text{igh})\}$) at every t. The state at t determines the prisoner's dilemma stage game to be played at t. The "static environment" is analogous to the model in Section 3 in the sense that the state (i.e., the stage game) is fixed throughout the game; i.e., $\theta_t = \theta_{t+1}$ at every $t \geq 0$, and either $\theta_0 = L$ or $\theta_0 = H$. In the "dynamic environment," the state may vary, and transitioning between states is endogenously determined by the two players' choices. At $t = 0$, the game starts at the low state ($\theta_0 = L$), and the players face the stage game in Figure 1(A). The next period's state $\theta_{t+1} = \psi((a_{it}, a_{jt}), \theta_t)$ is entirely determined by the actions of the two players, where

$$\psi((a_i, a_j), \theta) = \begin{cases} H & \text{if } ((a_i, a_j), \theta) = ((C, C), L), \\ L & \text{if } ((a_i, a_j), \theta) = ((D, D), H), \\ \theta & \text{otherwise.} \end{cases}$$

Both stage games are prisoner's dilemma games, but the stage game in state H increases the returns to symmetric play; i.e., the stage game in Figure 1(B) is such that $c < c'$, and $d < d'$. The intuition is that coordination on cooperation at $t = 0$ is necessary to shift the game from the L-state to the more productive H-state, and once in H, play will remain there except if mutual defection is the outcome. This is similar to the concept of "starting small" (also called gradualism). As an example, state L can be interpreted as the dating/engagement phase and state H as the marriage phase of a partnership. Indeed, we will show that under certain intuitive assumptions, linking the two static environments as do Vespa and Wilson (2019) not only reduces strategic risk and increases cooperation in state H but also boosts *overall* cooperation.

We now analyze this dynamic environment using our methods, and we will then compare the outcome to those in the static versions.[23] We consider three types of strategies in the dynamic game described above: AD and CS as before, and a "semi-cooperative

[23] The experiment in Vespa and Wilson (2019) also involves a dynamic environment with exogenous transitioning between high and low states, but we omit the analysis of this setting for space considerations.

Figure 1: The two payoff matrics of the dynamic environment

(A) $\theta = L$

	C	D
C	c, c	a, b
D	b, a	d, d

(B) $\theta = H$

	C	D
C	c', c'	a', b'
D	b', a'	d', d'

strategy" that starts with C at $t = 0$ and switches to AD from $t = 1$ onward regardless of the state. We denote this semi-cooperative strategy by SCS. It is particularly important to allow for such a strategy as some spiteful, uncooperative or mildly cooperative types may have an incentive to choose C at $t = 0$ in order to shift the state from L to H and revert to AD when payoffs increase (SCS could also be interpreted as "imitation" in the language of the reputation literature). To analyze the decision whether or not to cooperate at $t = 0$, we extend $\Pi(\delta, p, \gamma)$ in Section 3 to the dynamic game and define

$$\begin{aligned}\Pi_{LH}(\delta,(p_L,p_H),\gamma) \quad = \quad & \left[p_L V_{HL}(p_H,\gamma) + (1-p_L)\left(u(C,D,a,\gamma) + \delta\frac{u(D,D,d,\gamma)}{1-\delta}\right)\right] - \\ & \left[p_L\left(u(D,C,b,\gamma) + \delta\frac{u(D,D,d,\gamma)}{1-\delta}\right) + (1-p_L)\frac{u(D,D,d,\gamma)}{1-\delta}\right],\end{aligned}$$

where p_L is the probability that the opponent chooses C at $t = 0$ (i.e., $\theta_0 = L$), and $V_{HL}(p_H, \gamma)$ is the continuation payoff of a type-γ player at $t = 1$ assuming that $\theta_1 = H$ (i.e., $(a_{i0}, a_{j0}) = (C, C)$) and the opponent chooses a cooperative strategy with probability p_H. V_{HL} depends on not only p_H and γ but also a', b', c', d', d, and δ. In particular, the value of $V_{HL}(p_H, \gamma)$ comes from the payoff of either CS or AD in the continuation game with $\theta_1 = H$ depending on the magnitude of p_H, γ, and the game parameter values.

Throughout, we maintain assumptions A1S and A2 as well as the stage-game utility assumptions in Section 3, and we will make only one addition to A2 in order to expand the method in Section 3 to dynamic games. The "extended" assumption 2 below ("EA2") is an intuitive extension of the monotonicity imposed by A2 in the sense that the likelihood of choosing C at $t = 0$ in the dynamic game increases in γ. This assumption has the benefit of preserving the cutoff structure of the PBE in the dynamic setting and makes the theoretical analysis tractable.

EA2 *All else equal,* $\Pi(\delta, p, \gamma)$ *and* $\Pi_{LH}(\delta, (p, p'), \gamma)$ *are strictly increasing in* γ.

For our main result, let $\tilde{\gamma}_L$ and $\tilde{\gamma}_H$ denote the equilibrium cutoff in the static infinitely repeated game with $\theta_0 = L$ and $\theta_0 = H$, respectively. The PBE of the dynamic infinitely repeated game consists of two cutoffs γ_L^* and $\gamma_H^* \geq \gamma_L^*$, where γ_L^* denotes the equilibrium cutoff type in the low state at $t = 0$, and the cutoff γ_H^* denotes the equilibrium cutoff type at $t = 1$ if $(a_{i0}, a_{j0}) = (C, C)$ so that $\theta_1 = H$ at $t = 1$. The interpretation is as follows. The type set is partitioned into three intervals such that types with $\gamma \leq \gamma_L^*$ choose AD, types with $\gamma \in (\gamma_L^*, \gamma_H^*]$ choose SCS (provided that $\gamma_H^* > \gamma_L^*$), and the highest γ types (i.e., $\gamma > \gamma_H^*$) choose CS.

Proposition 7 *Assume that A1S and EA2 hold in the dynamic game. If* $\tilde{\gamma}_L$ *and* $\tilde{\gamma}_H$ *are not too distant from each other, then there exists a PBE such that* $\gamma_L^* < \tilde{\gamma}_L$ *and* $\gamma_H^* < \tilde{\gamma}_H$. *In particular, the dynamic game is strictly more cooperative than the static infinitely repeated games.*

We restate Proposition 7 and formalize the condition regarding $\tilde{\gamma}_L$ and $\tilde{\gamma}_H$ in Online Appendix A. The condition is equivalent to saying the following: in the static infinitely-repeated environment, the cooperation rate with $\theta_0 = L$ is not too low relative to that with $\theta_0 = H$ or vice versa. The intuition for this condition is as follows. If, for example, L involves a relatively low cooperation rate (i.e., $\tilde{\gamma}_L$ is high relative to $\tilde{\gamma}_H$), then the dynamic setting is likely to curtail cooperation at $t = 1$ with $\theta_1 = H$ and keep it below the levels that can be attained in the static setting with $\theta_0 = H$. If in contrast H is highly defective (i.e., $\tilde{\gamma}_H$ is high relative to $\tilde{\gamma}_L$), then this will likely reduce initial cooperation in L in the dynamic setting as players anticipate the difficulty of coordinating on cooperation in the continuation game.

The findings of two experiments reported in Vespa and Wilson (2019) are consistent with Proposition 7: overall, the dynamic game is more cooperative than the static infinitely repeated games. In addition, the results are in line with our predictions that $\gamma_L^* < \tilde{\gamma}_L$ and $\gamma_H^* < \tilde{\gamma}_H$. There is also experimental evidence for an *imitation* equilibrium (i.e., the use of SCS) in the sense that the first-period (L-state) cooperation rates are relatively high, but the cooperation rate if the game proceeds to H state is well below 100 percent (if SCS is not part of PBE in the dynamic game, then the theoretical cooperation rate in H is 100 percent).

5 Treatments, Hypotheses and Protocols

In this section, we describe our own experiments related to Propositions 1, 3, and 5 presented in Section 3.

5.1 Treatments and Hypotheses

Our experiment consists of three treatments. In all treatments we implemented $\delta = 0.5$ and used the following game matrix (corresponding to the treatment with $c = 32$ and $\delta = 0.5$ in DB&F):

	C	D
C	32, 32	12, 50
D	50, 12	25, 25

That is, in view of the general matrix introduced in Section 3, $a = 12$, $b = 50$, $c = 32$, $d = 25$.

In this game, the standard theory uniquely predicts defection. Indeed, DB&F found that the game gives rise to very low cooperation rates especially after subjects gained experience. We chose this game as our baseline infinitely repeated simultaneous game because there is arguably more room for variation in behavior across our treatments if we implement a baseline which is experimentally shown to have very high strategic risk and a low cooperation rate.

In what follows, we use the terms "match" and "indefinitely repeated game" interchangeably, and we refer to each repetition of the game within a match as a round. In the baseline treatment (denoted by "SIM"), players make their choices simultaneously in every round of a match as in DB&F, whereas in the second treatment (denoted by "SEQ"), players make their choices sequentially; i.e., the stage game is a sequential prisoner's dilemma game, and everything else is the same as in the SIM treatment. In the third treatment (denoted by "CHAT"), everything is as in the SIM treatment with the exception that players have the chance to chat in free form at the beginning of every round of a match. In our theory, whether communication takes place once at the beginning of the first round, or at the beginning of every round does not matter, barring the *reciprocity* effect of communication on cooperation, which we discussed after Proposition 5. We conjectured that such a reciprocity effect is easier to maintain if pairs can repeatedly communicate. Therefore, in our experimental design we chose to allow for communication at the beginning of every round.

We now state our hypotheses based on Propositions 3 and 5, as well as our theoretical discussion that follows Proposition 5. Let λ_{SIM} and λ_{CHAT} denote the cooperation rate in the first round of a match in the SIM and CHAT treatments, respectively. For the SEQ treatment, λ^1_{SEQ} and λ^2_{SEQ} denote the respective first-mover and second-mover cooperation rate in the first round, the latter being conditional on the first mover choosing C. Furthermore, let γ_{SIM} and γ_{CHAT} denote the respective equilibrium cutoff in the SIM treatment and the CHAT treatment. Finally, let γ^1_{SEQ} and γ^2_{SEQ} denote the respective equilibrium cutoff for the first mover and the second mover (conditional on first-mover cooperation) in the SEQ treatment. It follows that $\lambda_{SIM} = 1 - F(\gamma_{SIM})$, $\lambda^1_{SEQ} = 1 - F(\gamma^1_{SEQ})$, and $\lambda^2_{SEQ} = 1 - F(\gamma^2_{SEQ})$. In addition, λ_{CHAT} is such that $\lambda_{CHAT} \in \left((1 - F(\gamma_{CHAT}))^2, 1 - F(\gamma_{CHAT})\right)$ with the precise cooperation rate depending on the honesty rate in communication. If, for example, the honesty rate is 100 percent, then cooperation is perfectly coordinated and λ_{CHAT} equals $(1 - F(\gamma_{CHAT}))^2$, whereas if the honesty rate is 0, then we have a babbling equilibrium, and λ_{CHAT} equals $1 - F(\gamma_{CHAT})$. Note that part (ii) of Hypothesis 1 is based on our discussion following Proposition 5 since the SIM treatment game has very high strategic risk; that is, the equilibrium cutoff type is high and should be close to $\bar{\gamma}$ as DB&F found very low cooperation rates in this game.

Hypothesis 1 $\lambda^2_{SEQ} > \lambda^1_{SEQ} > \lambda_{SIM}$: *The first-mover cooperation rate in the first round of a match in SEQ is strictly higher than the cooperation rate of a player in the first period in SIM and strictly lower than the second-mover cooperation rate in the first round in SEQ (conditional on first-mover cooperation). These statements also hold on average across all rounds.*[24] **(ii)** $\lambda_{CHAT} > \lambda_{SIM}$: *Since strategic risk is high in the SIM treatment, the first-round cooperation rate in CHAT is strictly higher than the rate in SIM. The analogous*

[24]That is, the average first-mover cooperation rate in SEQ is strictly higher than the average cooperation rate of a player in SIM and is strictly lower than the average second-mover cooperation rate in SEQ (conditional on first-mover cooperation).

statement also holds on average across all rounds.

The next hypothesis concerns coordination on cooperation and follows from Proposition 5.

Hypothesis 2 *The rate of coordination on cooperation (and the continuation game cooperation rate) is highest in the CHAT treatment, followed by the SEQ treatment and lowest in the SIM treatment.*

5.2 Experimental Protocol

Our design is between-subject; i.e., each subject participated in only one treatment. For each treatment, we have six independent matching groups. In each treatment, each subject participated in a sequence of infinitely repeated games.

The implementation of the SIM treatment was very similar to that in DB&F for comparability. At the beginning of each session in the SEQ treatment, each subject was randomly assigned to be a first mover or a second mover. Subjects remained in the same role throughout the session. Each session of the experiment ended after the first match that was completed after 75 minutes had passed or after 60 matches had been completed, whichever happened sooner. Subjects were informed about this.

We implemented an infinitely repeated game in the lab by using a random continuation rule. The probability of continuation after each round was equal to $\delta = 0.5$ in each treatment. The experiment was conducted at the experimental laboratory of the Vienna Center for Experimental Economics (VCEE) at the University of Vienna. Subjects were recruited from the subject pool maintained at the VCEE via ORSEE (Greiner, 2015). A total of 280 subjects participated in our experiment. All sessions were conducted through computer terminals, using a program written in z-Tree (Fischbacher, 2007).[25] At the end of each session, the total number of points earned by each subject was converted to Euros at the exchange rate of €0.007 for every point scored, and paid privately in cash. The average payoff per subject was €19.43. The instructions for the treatments can be found in Online Appendix G.

[25] We used adapted versions of a z-Tree program developed by Sevgi Yuksel and Emanuel Vespa for the papers Fréchette and Yuksel (2017) and Vespa (2020).

In all matching groups of treatment SIM, 60 repeated games were played (see Table 5 in Online Appendix B). However, the sequential version of the prisoner's dilemma game and especially the version combined with chat took, as expected, longer to complete than a simple prisoner's dilemma game. Hence, fewer than the maximum number of 60 repeated games were played in treatment SEQ and CHAT. The results mentioned in Footnote 26 and elaborated on in Online Appendix C suggest that our main results would not have changed had more repeated games been played.

6 Experimental results

We report the results of our experiment in two parts. First, we analyze cooperation and coordination on cooperation across the three treatments and test for statistical differences. Second, we analyze the nature and the content of the chat messages in treatment CHAT and relate them to the choices subjects made.

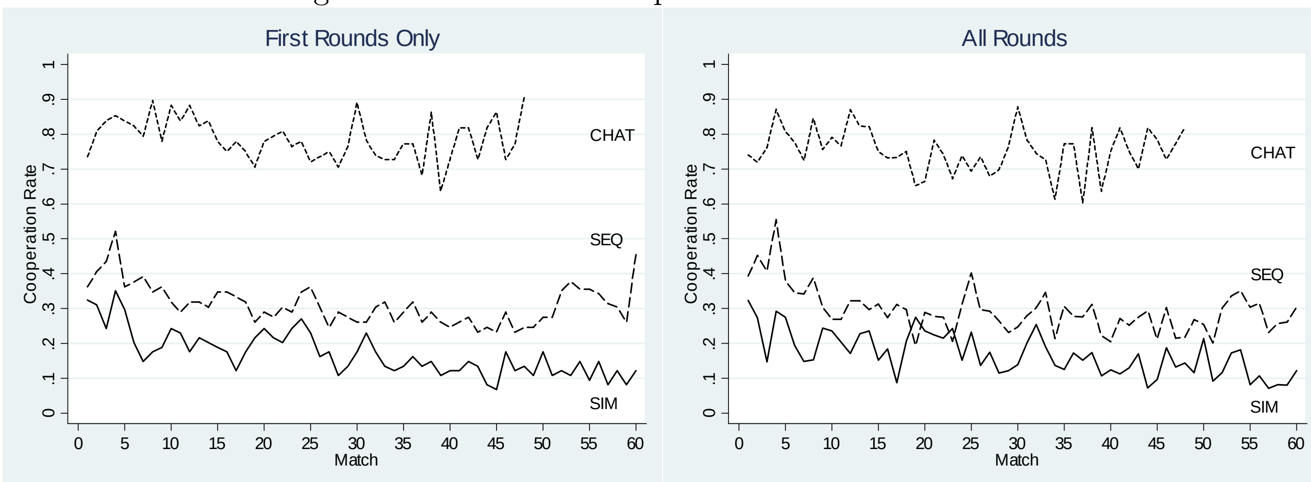
6.1 Cooperation and mutual cooperation rates

Figure 2 shows the evolution of the average cooperation rate in treatments SIM and CHAT and the first-mover cooperation rate in treatment SEQ. In particular, we show the averages of only first rounds of all matches on the left and the averages of all rounds of all matches on the right in Figure 2. We observe a clearly higher cooperation rate in SEQ in comparison to SIM, and a much higher cooperation rate in CHAT than in SIM and SEQ (first movers only). Furthermore, average cooperation rates do not appear to differ much depending on whether only first rounds or all rounds of matches are considered.

Figure 2 shows only the first-mover behavior in SEQ. To also account for second-mover behavior in SEQ, Figure 3 shows the evolution of average mutual-cooperation rates, where mutual cooperation is the outcome in which both players coordinate on cooperation. The differences in average cooperation rates shown in Figure 2, carry over to mutual-cooperation rates shown in Figure 3, with these rates being clearly higher in SEQ than in SIM, and again much higher in CHAT than in SIM and SEQ.

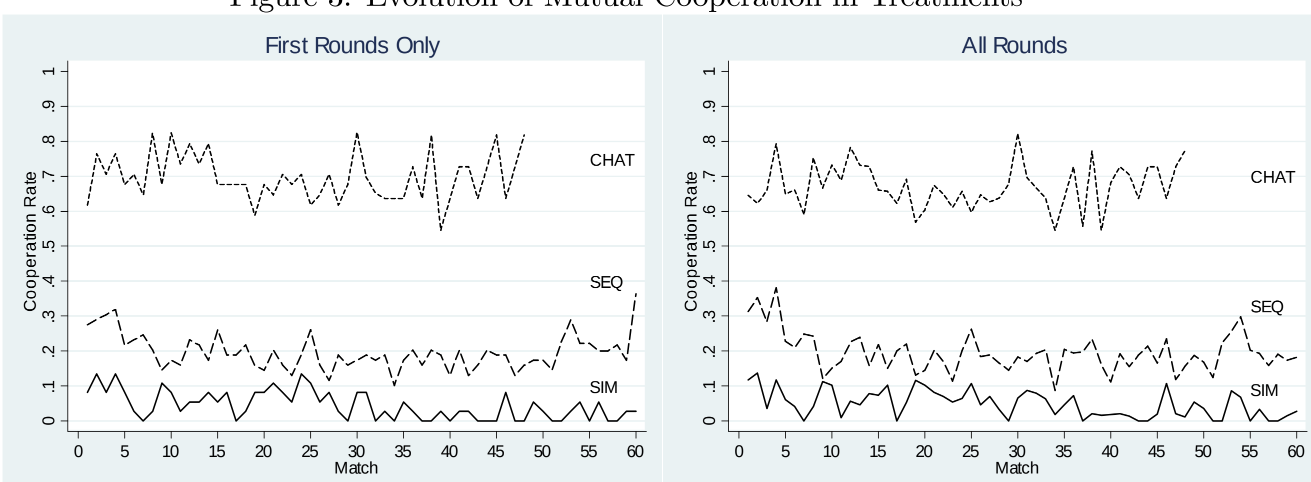
Table 1 shows the summary statistics of cooperation rates in all three treatments

Figure 2: Evolution of Cooperation in Treatments



Notes: Only first-mover data for treatment SEQ. The left (right) panel uses data from first (all) rounds of all matches.

Figure 3: Evolution of Mutual Cooperation in Treatments



Notes: The left (right) panel uses data from first (all) rounds of all matches.

along with the results of statistical tests (indicated by “<”, “>”, and star signs). To formally assess across-treatment differences in our data, we run probit regressions of cooperation and mutual-cooperation rates on a treatment dummy and include data from pairs of treatments, clustering observations at the matching group level. For the results, please refer to Table 1.

The differences in cooperation rates between SEQ (first movers) and SIM are statistically significant at the 5 percent level (regardless of whether data comes from only first rounds or all rounds of all matches). Moreover, the across-treatment differences in treatments CHAT and SIM are highly significantly different—we observe the same when we compare CHAT and SEQ (first movers).

Table 1 also shows the average second-mover cooperation rate in SEQ after the first mover chooses C or D. Using similar probit regressions as above, we tested second-mover behavior in SEQ after observing first-mover cooperation against (a) second-mover behavior after observing first-mover defection, (b) first-mover behavior in SEQ, (c) behavior in SIM, and (d) behavior in CHAT. The test results are indicated in Table 1, and results for (b), (c) and (d) use the notation λ_{SIM}, λ_{CHAT}, λ^1_{SEQ}, and λ^2_{SEQ}, as introduced on page 28 in Section 5.1. Taking all matches into account, and for both first and all rounds, the second-mover cooperation rate in SEQ after observing first-mover cooperation is significantly higher than the first-mover cooperation rate in SEQ and the cooperation rate in SIM as predicted.

Table 2 shows summary statistics and test results regarding coordination on cooperation. To illustrate, the average mutual-cooperation rate in all rounds of all matches in SIM, SEQ and CHAT is 4.99, 19.92, and 66.37 percent, respectively. The test results shown in Table 2 indicate that all pairwise comparisons of mutual-cooperation rates are statistically significant at the 1 percent level, and the signs are as predicted.[26]

The test results indicated in Tables 1 and 2 confirm Hypotheses 1 and 2. To be more precise, we state the following experimental results, which hold for behavior in first rounds as well as all rounds of all matches.

[26] One might wonder what levels the cooperation and the mutual cooperation rates reported in Tables 1 and 2 would have converged to had the experiment been conducted over a very long time horizon. In Online Appendix C we present an analysis that uses techniques proposed in Noussair et al. (1995) or Barut et al. (2002) that suggest that none of the reported (mutual) cooperation rates would have converged to zero in the long run. Moreover, and more important for our purposes, the (mutual) cooperation rates in both treatments SEQ and CHAT would have stayed significantly higher than in those in treatment SIM.

Table 1: Summary statistics and test results: Cooperation rates

All repeated games									
First rounds					**All rounds**				
SEQ		**SIM**		**CHAT**	**SEQ**		**SIM**		**CHAT**
1st Mover					1st Mover				
30.90	$>^{**}$	17.05	$<^{***}$	79.08	29.63	$>^{**}$	16.79	$<^{***}$	74.59
SEQ					**SEQ**				
2nd Mover					2nd Mover				
After					After				
C D					C D				
62.31 $>^{***}$ 3.32					67.21 $>^{***}$ 7.38				
$\lambda^2_{SEQ} >^{***} \lambda_{SIM}$,		$\lambda^2_{SEQ} <^{***} \lambda_{CHAT}$			$\lambda^2_{SEQ} >^{***} \lambda_{SIM}$,		$\lambda^2_{SEQ} < \lambda_{CHAT}$		
$\lambda^2_{SEQ} >^{***} \lambda^1_{SEQ}$,		$\lambda^1_{SEQ} <^{***} \lambda_{CHAT}$			$\lambda^2_{SEQ} >^{***} \lambda^1_{SEQ}$,		$\lambda^1_{SEQ} <^{***} \lambda_{CHAT}$		

Notes: The "<" and ">" signs indicate the direction of comparisons. *** and ** indicate significance at the 1% and 5% level, respectively.

Table 2: Summary statistics and test results: Mutual cooperation rates

All repeated games									
First rounds					**All rounds**				
SEQ		**SIM**		**CHAT**	**SEQ**		**SIM**		**CHAT**
19.25	$>^{***}$	4.41	$<^{***}$	69.86	19.92	$>^{***}$	4.99	$<^{***}$	66.37
19.25		$<^{***}$		69.86	19.92		$<^{***}$		66.37

Notes: The "<" and ">" signs indicate the direction of comparisons. *** indicates significance at the 1% level.

Experimental Result 1: *The first-mover cooperation rate in SEQ is strictly higher than the cooperation rate in SIM, and strictly lower than the second-mover cooperation rate in SEQ (conditional on first-mover cooperation). The cooperation rate in CHAT is strictly higher than the cooperation rate in SIM.*

Experimental Result 2: *The rate of coordination on cooperation is the highest in CHAT, followed by SEQ and the lowest in SIM.*

6.2 Detailed analysis of treatment CHAT

Recall that in each round of a match in treatment CHAT, subjects could exchange free-form chat messages with their opponent prior to making their choices. To find out about the content of messages subjects sent, we hired two student assistants. Their first task was to carefully read the chats of each subject in each round of each match and assign one of various pre-selected verbal codes to each of them so that the assigned verbal code would best summarize the content of each individual chat. The coders had knowledge of the instructions of treatment CHAT, but no access to the actual data of this treatment. Online Appendix D and Table 7 provide a detailed overview of the content of chats as categorized by the two assistants.

As discussed in Section 3, the possibility to exchange messages via chat has the potential of greatly reducing strategic risk regarding the intended action of the other player, *especially* in the first round of a match. According to (a nuanced interpretation of) our theory, a player is more likely to cooperate, the stronger the statement of her partner that she wants to cooperate. Likewise, a subject is more likely to cooperate, the stronger the statement of the subject herself that she wants to cooperate.

To see whether these basic mechanisms are borne out by the data, we assigned a second task to the external coders. We asked them to assess each round's chat of a subject according to a five-point scale, such that a higher code corresponds to a stronger signal for the subject's willingness to cooperate. More precisely, if a subject sent a weak or a strong signal indicating willingness to defect, this was coded as 1 for strong and 2 for weak. If a subject did not communicate a clear signal about intended play, this was coded as 3. Finally, if a subject sent a weak or a strong signal indicating willingness to cooperate, this was coded as 4 for weak and 5 for strong.[27] Clearly, whether or not the content of a message could be categorized as a weak or strong signal indicating willingness to cooperate or defect is a subjective matter for the two coders.[28]

It turned out that for this task the coders only agreed in about 68 percent of the cases. To a substantial extent, the disagreement concerned those messages that were classified as either a weak or a strong signal indicating willingness to cooperate. In our analysis, we want to relate pairs of messages (i.e., their codes) to the probability of cooperation and coordination on cooperation. However, the relatively high disagreement rate in the coding of individual chats would mean a substantial loss of data. Therefore, we decided to use a three-code system instead. We assigned code 1 to a chat that was originally coded as either 1 or 2 (weak or strong "defective" signal), code 2 to a chat that was coded as 3 ("neutral" signal), and code 3 to a chat that was originally coded as either 4 or 5 (weak or strong "cooperative" signal). In what follows we only use data for which the coders agree using this three-code system, which occurred in 90.24 percent of all valid individual assessments.

In Table 3, we show summary statistics of the relationship between pairs of messages exchanged and cooperation rates (top panels) and mutual cooperation rates (bottom panels). In this table, we distinguish between results in the first rounds of all matches (left) and all rounds of all matches (right), as communication has a particularly important role in reducing strategic risk in the first round of a match but may not be essential after the first round.

We first comment on the summary statistics that relate pairs of signals exchanged to individual cooperation rates. These results are shown in the top (left and right) panels of Table 3. Note that these top panels are not symmetric, as cooperation rates might (and do) differ for "asymmetric" pairs of signals. Table 3 shows that the cooperation rate in the first round of each match was 0, 0.3, and 0.91 if *both* players sent defective, neutral, or cooperative

[27] A sixth coding option was when a subject's chat content was classified as saying "same" (see Table 7 in Online Appendix D). In this case, a coder would not know whether 1, 2, 4, or 5 was the appropriate code as the chosen actions were unknown to coders. In this case, coders were asked whether they could again say whether this was a weak or a strong suggestion to play the same action again. Using the action chosen in the previous round, this information was then used by us to assign 1, 2, 4, or 5 to those chats.

[28] The two coders had to code 5,180 individual chats (for all subjects, matches and rounds). While all of these chats were coded verbally (see above), we had to discard 75 data points due to mistakes made by the coders regarding the categorization just described.

Table 3: Summary statistics: Cooperation and mutual cooperation rates

Cooperation rate depending on pairs of messages sent

	First Rounds					**All rounds**			
Own Signal ↓	Other Signal: Defect	Neutral	Cooperate	Total	Own Signal ↓	Other Signal: Defect	Neutral	Cooperate	Total
Defect	0.00	0.15	0.06	0.07	Defect	0.03	0.09	0.13	0.09
	(12)	(13)	(18)	(43)		(30)	(47)	(39)	(116)
Neutral	0.08	0.30	0.43	0.36	Neutral	0.17	0.53	0.56	0.53
	(13)	(100)	(147)	(260)		(47)	(898)	(367)	(1,312)
Cooperate	0.33	0.53	0.91	0.88	Cooperate	0.49	0.63	0.92	0.88
	(18)	(147)	(1,768)	(1,933)		(39)	(367)	(2,773)	(3,179)
Total	0.16	0.42	0.87	0.80	Total	0.24	0.54	0.87	0.76
	(43)	(260)	(1,933)	(2,236)		(116)	(1,312)	(3,179)	(4,607)

Mutual cooperation rate depending on pairs of messages sent

Own Signal ↓	Other Signal: Defect	Neutral	Cooperate	Own Signal ↓	Other Signal: Defect	Neutral	Cooperate
Defect	0.00			Defect	0.00		
	(12)				(30)		
Neutral	0.08	0.18		Neutral	0.02	0.47	
	(26)	(100)			(94)	(898)	
Cooperate	0.00	0.29	0.85	Cooperate	0.10	0.46	0.86
	(36)	(294)	(1,768)		(78)	(734)	(2,773)

Notes: Relationship between pairs of messages exchanged and the shares of cooperative choices (top) and shares of mutual cooperation outcomes (bottom). Results in first rounds of matches (left) and all rounds of matches (right). Numbers of observations in parentheses.

messages, respectively. Hence, the mutual promise of cooperation boosts actual cooperation in first rounds dramatically. The first-round cooperation rate is pretty stable across matches if both players send cooperative signals. However, it decreases to 0 across matches if both players send neutral signals (starting from about 0.5 during the first 5 matches). So over time, first-round cooperation *crucially* relies on cooperative signals. Taking all rounds into account, we observe that the cooperation rate was 0.03, 0.53, and 0.92 if *both* players sent defective, neutral, or cooperative signals, respectively. Thus, the cooperation-boosting effect of both players sending cooperative signals appears to be maintained throughout a match. When all rounds of a match are considered, the average cooperation rate remains relatively high across matches even if both players sent neutral messages (in contrast to the evolution of cooperation in first rounds if both players sent neutral messages). To understand this pattern, note the following two observations which are also consistent with our theory. First, the share of "neutral" messages summarized as, e.g., "none" and "trivial" by the two coders (see Table 7) increases substantially across rounds of a match. Second, the regression analysis reported below will show that "actions speak louder than words," in the sense that once (mutual) cooperation has been observed, this is more predictive of (mutual) cooperation in the next round than promises of cooperation.[29] These two observations together suggest that the relatively high share of cooperation following the mutual exchange of neutral messages is driven by the early establishment of cooperation, which is maintained within matches even if only "neutral" messages are exchanged from then onwards. Finally, note that by holding the subject's own (partner's) message constant and then moving horizontally (vertically) in the top panels in Table 3, the cooperation rate increases monotonically with the message received (sent) with only one exception.

How does coordination on cooperation relate to observed pairs of messages? This is shown in the bottom (left and right) panels in Table 3. Here we show the mutual cooperation rates for each possible pair of signals. Note that these panels are triangular matrices, as data stemming from asymmetric pairs of signals (e.g., cooperate-defect and defect-cooperate) are pooled. Focusing on the first rounds of all matches only, the mutual cooperation rate was 0,

[29] The crucial elements of our theory are: first-round cooperation relies on exchanging cooperative messages, and cooperation is chosen in the continuation game only if cooperation is chosen by both partners in the first and the subsequent rounds.

0.18, and 0.85 after *mutually* defective, neutral or cooperative signals, respectively (however, recall that the first-round cooperation rate, and thus, also the first-round mutual cooperation rate, falls to 0 with experience if neutral signals are exchanged). Considering all rounds of all matches, the mutual cooperation rate was 0, 0.47, and 0.86 after *mutually* defective, neutral or cooperative messages, respectively. The increase in the mutual cooperation rate given a pair of neutral messages when moving from first-round to all-rounds statistics is not surprising given the increased cooperation rate for this message pair when moving from first-round to all-rounds statistics, the reasons of which we discussed above.

To formally test for the results presented in the top panels of Table 3, we will proceed by reporting the results of regressions, for which we cluster all observations at the matching-group level and report marginal effects.

Table 4 presents the relationship between pairs of signals exchanged and the likelihood of a cooperative choice. For this purpose, we ran probit regressions with the dependent variable being whether or not cooperation was chosen in a round (coded as 1 or 0, respectively). The independent variables are binary variables coding the various pairwise combinations of signals. Note that in these signal pairs the order of signals has significance, because we want to assess how players react to combinations of their partner's and own messages, consistent with the statistics presented in the top panels of Table 4. In our regression, we choose the behavior following the mutual exchange of neutral signals as the reference group and measure the effect of all independent variables with reference to this group. Note that if only the first-round data of all matches are considered, subject behavior for the defect-defect signal pair was constant (i.e., all-defect choices). This implies that these observations are dropped from the probit regressions. We indicate this in Table 4 by the entry "All-Defect." To save space, we focus on the most important features in Table 4.

In column (1) of Table 4, we measure the relationship between signal pairs and the likelihood of cooperation in the first round of each match. Consistent with the numbers shown in Table 3, signal pairs that involve at least one defective signal do not foster cooperation. However, mutual exchange of cooperative signals significantly improves cooperation relative to the reference group of neutral-neutral message pairs.[30] In column (2) of Table 4

[30] The estimated coefficient of "Cooperate-Cooperate" in column (1) of Table 4 is highly significantly larger

Table 4: Regressing actions on both players' communicated signals

	(1)	(2)	(3)	(4)
	Rd = 1	Rd $\geq$ 1	Rd > 1	Rd > 1
Own Signal-Other Signal	Match $\geq$ 1	Match $\geq$ 1	Match $\geq$ 1	Match $\geq$ 1
Defect-Defect	All-Defect	-0.661^{***}	-0.613^{***}	-0.711^{***}
		(0.078)	(0.093)	(0.066)
Defect-Neutral	-0.145	-0.530^{***}	-0.607^{***}	-0.608^{***}
	(0.117)	(0.067)	(0.105)	(0.137)
Defect-Cooperate	-0.363	-0.446^{***}	-0.390^{**}	-0.235
	(0.225)	(0.152)	(0.173)	(0.190)
Neutral-Defect	-0.297^{**}	-0.376^{**}	-0.368^{**}	-0.276
	(0.139)	(0.160)	(0.173)	(0.214)
Neutral-Cooperate	0.069^{*}	0.018	0.066	0.071
	(0.036)	(0.051)	(0.075)	(0.050)
Cooperate-Defect	0.021	-0.035	0.042	0.105^{**}
	(0.049)	(0.092)	(0.083)	(0.048)
Cooperate-Neutral	0.106^{***}	0.062	0.098	0.056
	(0.021)	(0.061)	(0.082)	(0.063)
Cooperate-Cooperate	0.605^{***}	0.390^{***}	0.363^{***}	0.275^{***}
	(0.021)	(0.114)	(0.130)	(0.079)
Other action in previous				0.634^{***}
round of current match				(0.060)
N	2,224	4,607	2,371	2,371

Notes: The dependent variable is Pr(cooperate). Marginal effects reported. The entry "All-Defect" indicates that for the corresponding pair of messages and slice of the data only defect choices were observed. ***, **, and * indicates significance at the 1%, 5%, and 10% level, respectively.

we include all rounds and observe, for instance, that various signal pairs involving defective signals significantly reduce cooperative choices relative to the reference group. In column (4) we drop all data stemming from the first rounds of matches. As an additional regressor, we include the current partner's choice in the previous round of the current match. (For a clean comparison, column (3) reports the results for the same selection of data without this additional regressor.) We observe that if the partner cooperated in the previous round, this boosts the likelihood of cooperation by about 63 percent. This coefficient is also significantly larger (pairwise Wald tests) than any other estimated coefficient in column (4), which suggests the interpretation that "actions speak louder than words" after the first round, consistent with our theory. We also observe that "own-defect" signal pairs (significantly) reduce cooperative choices, while the exchange of cooperative signals significantly improves cooperation relative to the reference group.[31,32]

7 Summary

The theory of infinitely repeated dilemma games is so far largely based on the assumption that player preferences are identical and hence complete information. Although this theory correctly predicts an increased tendency of players to cooperate in specific infinitely repeated games, the multiplicity of predicted equilibrium outcomes has been the subject of criticism by various authors. An additional shortcoming of this theory is that it does not predict changes in behavior when specific aspects of the game change, such as the timing of players' moves or the possibility of players communicating with each other. In this paper we propose to mitigate such shortcomings by incorporating privately observed, heterogeneous preferences for cooperation into the context of infinitely repeated dilemma games. Our model captures an important component of strategic risk even in those games in which cooperation is not an equilibrium or a risk-dominant action. Additionally, it allows us to make intuitive comparative static predictions regarding changes in (a) the payoff parameters of a game for

than any other estimated coefficient in column (1) (pairwise Wald tests).

[31] We also formally analyze the relationship between signal pairs and the likelihood of mutual cooperation as shown in the bottom panels of Table 3. The results are presented in Online Appendix E.

[32] In Online Appendix F, we present estimated shares of several repeated-game strategies used in our three treatments using the "structural frequency estimation method" developed in DB&F.

both or one of the players, (b) the distribution of players' preferences, (c) the timing of players' moves (d) the mode of communication, (e) the introduction of a punishment option, and (f) the transition between stage games. While standard theory is unresponsive to most of these changes, we show that our model sensitively reacts to these changes. In particular, we show that variations of a standard simultaneous-move stage game reduce strategic risk by making it easier for players to recognize a cooperative opponent. Moreover, we provide new experimental evidence that is in line with these theoretical predictions.

There is ample room for future research. First, we plan to further demonstrate the usefulness of our theory by applying it to other infinitely repeated games and variants thereof. Second, we plan to make our approach operational for wider application by structurally estimating the main moments of the distribution of subjects' taste for cooperation and eliciting utility functions of stage-game outcomes. To do this, new experiments will be needed. Third, in Section 3 we pointed out that experimental evidence for some of the setups considered in the paper is lacking, especially for prisoner's dilemma games with asymmetric payoffs.

Endnotes

[a]While Vespa and Wilson (2019) do not report a significance level for the difference, the increase in a coupled with a decrease in b increases the cooperation rate from 21.3 percent to 56.3 percent.

[b]More precisely, Kölle et al (2020) have one set of treatments with a discount factor of $\delta = 0.6$ (so that cooperation is not an equilibrium according to standard theory) and another set of treatments with a discount factor of $\delta = 0.8$ (so that cooperation is an equilibrium according to standard theory). In both sets of treatments, the cooperation rate of prosocial players is highly significantly larger than the one of selfish players for first periods and all periods of all repeated games.

[c]In Ghidoni and Suetens (in press), henceforth referred to as G&S, these differences are statistically significant for $(c, \delta) = (32, 0.75)$ and $(c, \delta) \in \{40, 48\} \times \{0.5\}$ (first periods of supergames only, which is what G&S concentrate on). In our experiment—that is, for $(c, \delta) = (32, 0.5)$—the difference is statistically significantly for first and all periods of all supergames.

[d]In G&S, these differences are signifiacnt for the cases mentioned in endnote c and in case of $(c, \delta) = (32, 0.5)$. In our experiment, the difference is statistically significantly for first and all periods of all supergames.

[e]In G&S these differences are statistically significant for $(c, \delta) \in \{32, 40\} \times 0, 5$ and $(c, \delta) = (32, 0.75)$. In our experiment, the difference is statistically significantly for first and all periods of all supergames.

[f]In G&S these differences are statistically significant for $(c, \delta) \in \{40, 48\} \times 0.5$ and $(c, \delta) = (32, 0.75)$, (all periods). In our experiment, the difference is statistically significantly for first and all periods of all supergames.

[g]G&S provide test results for these *ceteris paribus* changes regarding first- and second-mover behavior for various slices of the data. Focusing for instance on all periods of all repeated games, the differences regarding

first- and second-mover cooperation rates are significant with the exception of second-mover behavior for the comparison $c = 40$ and $c = 48$ (when $\delta = 0.75$). G&S do not report test results regarding mutual cooperation rates.

[h] Focusing again on all periods of repeated games 31 to 50 in the G&S data, the differences regarding first- and second-mover data are significant, except for the case $\delta = 0.5$ and $\delta = 0.75$ (when $c = 48$). G&S do not report test results regarding mutual cooperation rates.

[i] Dvorak and Fehrler (2020) implement their perfect monitoring game variant with (a) no communication, (b) free-form, pre-play communication and (c) repeated communication (before each round) of the infinitely repeated prisoner's game. Considering all rounds of all games, they find that the average cooperation rate is 53 percentage points higher with pre-play communication when compared to no communication. Furthermore, the average cooperation rate is about 10 percentage points higher with repeated communication when compared to pre-play communication, suggesting the possibility of (increased) reciprocity via repeated communication. Both effects are statistically significant at the 1 percent level.

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A Proofs of Propositions

We first present and prove the following claim, which we repeatedly invoke in the proofs of our propositions below.

Claim 1 *If* $\Pi(\delta, p, \gamma) \geq 0$ *then* $\Pi(\delta, p', \gamma) > 0$ *for all* $p' > p$ *and if* $\Pi(\delta, p, \gamma) \leq 0$*, then* $\Pi(\delta, p', \gamma) < 0$ *for all* $p' < p$*.*

Proof: $\Pi(\delta, p, \gamma)$ can be written as

$$p\left(\frac{u(C,C,\gamma)}{1-\delta} - u(D,C,\gamma) - \delta\frac{u(D,D,\gamma)}{1-\delta}\right) + (1-p)(u(C,D,\gamma) - u(D,D,\gamma)).$$

If $\Pi(\delta, p, \gamma) \geq 0$, then the first term inside parentheses must be strictly positive (because the term $u(C,D,\gamma) - u(D,D,\gamma)$ is negative); *i.e.*,

$$\frac{u(C,C,\gamma)}{1-\delta} > u(D,C,\gamma) + \delta\frac{u(D,D,\gamma)}{1-\delta}.$$

Hence, increasing p strictly increases $\Pi(\delta, p, \gamma)$. If $\Pi(\delta, p, \gamma) \leq 0$, then $\Pi(\delta, p', \gamma) < 0$ for $p' < p$ because a decrease in p increases the weight of the term $u(C,D,\gamma) - u(D,D,\gamma)$, which is negative. Thus, $\Pi(\delta, p', \gamma)$ cannot be nonnegative if $\Pi(\delta, p, \gamma) \leq 0$ and $p' < p$.

Proof of Proposition 1 (i). First note that equilibrium must have a cutoff form by A2. Next, we show that there always exists a $\gamma^* \in (\underline{\gamma}, \bar{\gamma})$ such that $\Pi(\delta, 1-F(\gamma^*), \gamma^*) = 0$. By A1S, there exist γ_1 and γ_2 such that $\gamma_2 < \gamma_1$, $\Pi(\delta, 1-F(\gamma_1), \gamma_1) > 0$ and $\Pi(\delta, 1-F(\gamma_2), \gamma_2) < 0$. The latter inequality holds because $\Pi(\delta, 1, \gamma_2) < 0$ implies that $\Pi(\delta, 1-F(\gamma_2), \gamma_2) < 0$ by Claim 1. Thus, by continuity of $\Pi(\delta, 1-F(\gamma), \gamma)$ in γ, there must exist a $\gamma^* \in (\underline{\gamma}, \bar{\gamma})$ such that $\Pi(\delta, 1-F(\gamma^*), \gamma^*) = 0$. Next, we show that an asymmetric equilibrium is not possible. Suppose towards a contradiction that there exist asymmetric equilibrium cutoffs γ_1^* and γ_2^* for Players 1 and 2, and assume without loss of generality that $\gamma_1^* > \gamma_2^*$. Then, in equilibrium we must have $\Pi(\delta, 1-F(\gamma_2^*), \gamma_1^*) \leq 0$, and $\Pi(\delta, 1-F(\gamma_1^*), \gamma_2^*) \geq 0$ (we allow for the possibility that $\gamma_1^* = \bar{\gamma}$ or $\gamma_2^* = \underline{\gamma}$). From $\Pi(\delta, 1-F(\gamma_2^*), \gamma_1^*) \leq 0$, $\gamma_1^* > \gamma_2^*$, and A2, it follows that

$$\Pi(\delta, 1-F(\gamma_2^*), \gamma_2^*) < 0. \tag{1}$$

Since $\Pi(\delta, 1-F(\gamma_1^*), \gamma_2^*) \geq 0$ and $\Pi(\delta, p, \gamma_2^*)$ is continuous in p, there must exist a $\gamma \in (\gamma_2^*, \gamma_1^*]$ such that $\Pi(\delta, 1-F(\gamma), \gamma_2^*) = 0$. However, by Claim 1, $\Pi(\delta, 1-F(\gamma), \gamma_2^*) = 0$ implies that $\Pi(\delta, 1-F(\gamma_2^*), \gamma_2^*) > 0$ as $\gamma > \gamma_2^*$ and $1-F(\gamma_2^*) > 1-F(\gamma)$, a contradiction to (1) above. Finally, it can easily be checked that no type $\gamma > \gamma^*$ has an incentive to deviate from CS to

AD, and likewise no type $\gamma < \gamma^*$ benefits from deviating from AD, for example choosing C in the first period (or in the first few periods) and then reverting to AD.

Proof of Proposition 1 (ii). Let $\gamma(a)$ denote the minimum equilibrium cutoff in game $\Gamma(a,b,c,d,\delta)$ and assume that $a' < a$. We will show that any equilibrium cutoff in game $\Gamma(a',b,c,d,\delta)$ must be strictly higher than $\gamma(a)$.[33] Let $\Pi_a(\delta,p,\gamma)$ and $\Pi_{a'}(\delta,p,\gamma)$ denote $\Pi(\delta,p,\gamma)$ in games $\Gamma(a,b,c,d,\delta)$ and $\Gamma(a',b,c,d,\delta)$, respectively. Suppose towards a contradiction that there exists an equilibrium cutoff γ' in game $\Gamma(a',b,c,d,\delta)$ such that $\gamma' \leq \gamma(a)$. As $a > a'$ and $\Pi_{a'}(\delta, 1-F(\gamma'),\gamma') = 0$, it follows that $\Pi_a(\delta,1-F(\gamma'),\gamma') > 0$. Moreover, there must exist a type $\hat{\gamma} < \gamma'$ such that $\Pi_a(\delta,1-F(\hat{\gamma}),\hat{\gamma}) < 0$. To see why, note that by A1S there exists a type $\gamma_2 > \underline{\gamma}$ such that $\Pi_a(\delta,1,\gamma_2) < 0$. By A2, $\Pi_a(\delta,1,\gamma) < 0$ must hold for every $\gamma < \gamma_2$. By Claim 1, $\Pi_a(\delta,1,\gamma) < 0$ implies that $\Pi_a(\delta,1-F(\gamma),\gamma) < 0$. In particular, $\Pi_a(\delta,1-F(\gamma),\gamma) < 0$ holds for every $\gamma < \gamma_2$. As a result, there must exist a type $\hat{\gamma} < \gamma'$ such that $\Pi_a(\delta,1-F(\hat{\gamma}),\hat{\gamma}) < 0$. Then by continuity, there exists a $\gamma \in (\hat{\gamma},\gamma')$ such that $\Pi_a(\delta,1-F(\gamma),\gamma) = 0$ and $\gamma < \gamma(a)$, in contradiction to $\gamma(a)$ being the minimum equilibrium cutoff in $\Gamma(a,b,c,d,\delta)$. The proof for the case in which $b < b'$ is very similar, and therefore omitted.

Proof of Proposition 1 (iii). Note that if $\Pi(\delta,p,\gamma) = 0$ for fixed γ and δ, then $\Pi(\delta',p,\gamma) > 0$ must hold for $\delta' > \delta$ by the assumptions on utilities in Section 3. After noting this fact, the proof of the claim is very similar to the proof of part (ii) and therefore omitted.

Proof of Proposition 1 (iv). Let γ^* denote the minimum equilibrium cutoff in game $\Gamma(a,b,c,d,\delta)$ with preferences characterized by $F(\gamma)$. We now show that the minimum equilibrium cutoff induced by $F'(\gamma)$ is strictly lower than γ^*. Since $1-F(\gamma^*) < 1-F'(\gamma^*)$ (by strict first order stochastic dominance) and $\Pi(\delta,1-F(\gamma^*),\gamma^*) = 0$, it follows from Claim 1 that $\Pi(\delta,1-F'(\gamma^*),\gamma^*) > 0$. By A1S and A2, there exists a type $\gamma_2 > \underline{\gamma}$ such that $\Pi(\delta,1,\gamma) < 0$ for every $\gamma < \gamma_2$. In particular, $\Pi(\delta,1-F'(\gamma),\gamma) < 0$ for every $\gamma < \gamma_2$ by Claim 1. Hence by continuity there exists $\hat{\gamma} \in (\gamma_2,\gamma^*)$ such that $\Pi(\delta,1-F'(\hat{\gamma}),\hat{\gamma}) = 0$. Since $\hat{\gamma} < \gamma^*$, the desired result follows.

Proof of Proposition 2 (i). As in the previous proposition, equilibrium must have a cutoff form by A2. We now show that if $a' > a$, then $\gamma(a) > \gamma(a')$, where $\gamma(a)$ denotes the equilibrium cutoff for player with sucker payoff equal to a. Assume towards a contradiction that $a' > a$, but $\gamma(a) \leq \gamma(a')$. It follows that

$$\begin{aligned}
\Pi^{a'}(\delta,1-F(\gamma(a)),\gamma(a')) &= 0 \\
\Pi^{a}(\delta,1-F(\gamma(a')),\gamma(a)) &= 0
\end{aligned}$$

[33] Let $\gamma(a) = \inf\{\gamma|\Pi_a(\delta,p,\gamma) = 0\}$. By continuity, $\Pi_a(\delta,p,\gamma(a)) = 0$ must hold. Thus, $\gamma(a) = \min\{\gamma|\Pi_a(\delta,p,\gamma) = 0\}$.

where the superscript in Π refers to the player's own sucker payoff. Since $\gamma(a) \leq \gamma(a')$ by hypothesis, $1 - F(\gamma(a)) \geq 1 - F(\gamma(a'))$. Thus, $\Pi^{a'}(\delta, 1 - F(\gamma(a)), \gamma(a')) = 0$ implies that $\Pi^{a'}(\delta, 1 - F(\gamma(a')), \gamma(a)) \leq 0$ by Claim 1 and A2. Finally, $\partial u(a_i, a_j, m(a_i, a_j), \gamma_i)/\partial m(a_i, a_j) > 0$ and $a' > a$ together imply that $\Pi^{a}(\delta, 1 - F(\gamma(a')), \gamma(a)) < 0$ in contradiction to the equilibrium condition above. Thus, $\gamma(a) > \gamma(a')$ if $a > a'$. The proof for the case where $\delta' > \delta$ is similar.

Proof of Proposition 2 (ii) Let $\gamma_S(a)$ denote the minimum equilibrium cutoff in the symmetric game $\Gamma(a, b, c, d, \delta)$. As before, $\Gamma((a, a'), b, c, d, \delta)$ denotes the asymmetric version where $a' > a$. We will now show that there always exists an equilibrium in $\Gamma((a, a'), b, c, d, \delta)$ such that the cooperation rate of both players is higher than that in the symmetric version with sucker payoff equal to a; i.e., there exist $\gamma_{AS}(a)$ and $\gamma_{AS}(a')$ such that $\gamma_{AS}(a') < \gamma_{AS}(a) < \gamma_S(a)$, where $\gamma_{AS}(a)$ and $\gamma_{AS}(a')$ are the respective equilibrium cutoffs for players with a and a' in the asymmetric game. The first inequality is straightforward by what we have already shown above. We now show that the asymmetric game has an equilibrium such that $\gamma_{AS}(a) < \gamma_S(a)$. First, note that in the symmetric game $\Pi^a(\delta, 1 - F(\gamma_S(a)), \gamma_S(a)) = 0$. It follows that in the asymmetric game

$$\begin{aligned} \Pi^{a}(\delta, 1 - F(\gamma_S(a)), \gamma_S(a)) &= 0 \\ \Pi^{a'}(\delta, 1 - F(\gamma_S(a)), \gamma_S(a)) &> 0 \end{aligned}$$

since $a' > a$ and $\partial u(a_i, a_j, m(a_i, a_j), \gamma_i)/\partial m(a_i, a_j) > 0$ by assumption. Let γ' solve the following: $\Pi^{a'}(\delta, 1 - F(\gamma_S(a)), \gamma') = 0$. Obviously, γ' exists, it is unique, and $\gamma' < \gamma_S(a)$. These follow from A2, continuity, and the inequalities $\Pi^{a'}(\delta, 1 - F(\gamma_S(a)), \gamma_S(a)) > 0$, and $\Pi^{a'}(\delta, 1 - F(\gamma_S(a)), \underline{\gamma}) < 0$ by A1S and Claim 1. More generally, let $g(\gamma)$ solve

$$\Pi^{a'}(\delta, 1 - F(\gamma), g(\gamma)) = 0$$

for every $\gamma \leq \gamma_S(a)$. Similar to what we showed above, $g(\gamma)$ exists and is unique for $\gamma \leq \gamma_S(a)$. In addition, $g(\gamma_S(a)) = \gamma' < \gamma_S(a)$, and $g(\underline{\gamma}) > \underline{\gamma}$ by A1S. Furthermore, $g(\gamma)$ is strictly increasing and continuous in γ given A2, Claim 1, and the continuity of the utility function and F. Next, note that

$$\begin{aligned} \Pi^{a}(\delta, 1 - F(g(\gamma_S(a))), \gamma_S(a)) &> 0 \\ \Pi^{a}(\delta, 1 - F(g(\underline{\gamma})), \underline{\gamma}) &< 0. \end{aligned}$$

Thus, there exists a $\gamma \in (\underline{\gamma}, \gamma_S(a))$ such that $\Pi^a(\delta, 1 - F(g(\gamma)), \gamma) = 0$ by continuity. Using the definition of $g(\gamma)$, it follows that $\Pi^{a'}(\delta, 1 - F(\gamma), g(\gamma)) = 0$, and hence, we found an equilibrium: $g(\gamma)$ and γ are the respective cutoff types for the player with a' payoff and the player with a payoff; i.e., $\gamma_{AS}(a') = g(\gamma)$ and $\gamma_{AS}(a) = \gamma$. Combining these findings, it follows that $g(\gamma) < \gamma < \gamma_S(a)$. The proof with $\delta' > \delta$ is very similar and therefore omitted.

Proof of Proposition 3. Let γ^* denote the minimum equilibrium cutoff type in the infinitely repeated *simultaneous* prisoners' dilemma game. Let γ_1^* and γ_2^* denote the repeated sequential prisoner's dilemma game equilibrium cutoff for the first mover and the second mover respectively. In our PBE construction, γ_2^* satisfies $\Pi(\delta, 1, \gamma_2^*) = 0$ because A1S and Claim 1 hold, and because, there is no strategic risk for the second mover in equilibrium, a first-mover choice of C implies a commitment to CS, which is optimal; *i.e.*, choosing C and switching to D in a later period although the second mover always reciprocates cooperation by the first mover is strictly dominated for all first movers for whom $\Pi(\delta, 1 - F(\gamma_2^*), \gamma) \neq 0$. In particular, it is dominated by CS for those for whom $\Pi(\delta, 1 - F(\gamma_2^*), \gamma) > 0$ and by AD for those for whom $\Pi(\delta, 1 - F(\gamma_2^*), \gamma) < 0$. A similar argument is also true for second movers; choosing C and then switching to D later against a cooperating first mover is dominated. Thus, in our PBE construction, players optimally sort into CS or AD according to their type. To prove (i), we first show that $\gamma_2^* < \gamma^*$, which is part of the statement in (ii). Assume towards a contradiction that $\gamma_2^* \geq \gamma^*$. Since $\Pi(\delta, 1, \gamma_2^*) = 0$, it follows that $\Pi(\delta, 1, \gamma^*) \leq 0$ by A2. However, this implies that $\Pi(\delta, p, \gamma^*) < 0$ for all $p < 1$. In particular, $\Pi(\delta, 1 - F(\gamma^*), \gamma^*) < 0$, a contradiction. Hence, we have shown that $\gamma_2^* < \gamma^*$. Next, we show that $\gamma_1^* < \gamma^*$. Suppose towards a contradiction that $\gamma_1^* \geq \gamma^*$. Note that γ_1^* must be interior by A1S and Claim 1; *i.e.*, $\Pi(\delta, 1 - F(\gamma_2^*), \gamma_1^*) = 0$. By A2, it follows that $\Pi(\delta, 1 - F(\gamma_2^*), \gamma^*) \leq 0$. But then $\Pi(\delta, p, \gamma^*) < 0$ for all $p < 1 - F(\gamma_2^*)$ by Claim 1. In particular, $\Pi(\delta, 1 - F(\gamma^*), \gamma^*) < 0$ since $1 - F(\gamma^*) < 1 - F(\gamma_2^*)$, which is a contradiction. Hence, $\gamma_1^* < \gamma^*$ holds as well. As a result, the first-mover cooperation rate in the first period as well as the continuation game is strictly higher in the sequential game than the corresponding cooperation rates in the simultaneous game, and part (i) is proved. To prove part (ii), we will show, in addition to what we have already shown, that $\gamma_2^* < \gamma_1^*$. Suppose towards a contradiction that $\gamma_2^* \geq \gamma_1^*$. Since we must have $\Pi(\delta, 1, \gamma_2^*) = 0$, and $\Pi(\delta, 1 - F(\gamma_2^*), \gamma_1^*) = 0$ in equilibrium, and $\gamma_2^* \geq \gamma_1^*$ by hypothesis, it follows that $\Pi(\delta, 1 - F(\gamma_2^*), \gamma_2^*) \geq 0$ by A2 and $\Pi(\delta, 1, \gamma_2^*) > 0$ by Claim 1, which is a contradiction. Finally, the proof of part (iii) follows from the fact that $(1 - F(\gamma_1^*))(1 - F(\gamma_2^*)) > (1 - F(\gamma^*))^2$ as $\gamma_1^* < \gamma^*$ and $\gamma_2^* < \gamma^*$. Hence the proposition is proved.

We will now argue that the "reasonable" equilibrium is unique. To see why, recall that $\Pi(\delta, 1, \gamma_2^*) = 0$ must hold for the second mover (and the second mover's expectation that the first mover will continue cooperating is correct) since only those first movers who find CS better than AD will choose C in the first period as argued above. As a result, for those first-mover types who prefer CS over AD, $\Pi(\delta, 1 - F(\gamma_2^*), \gamma_1^*) = 0$ must hold. Since γ_2^* is interior and unique, γ_1^* is also interior and unique. The only other possibility is the case where $\gamma_1^* = \bar{\gamma}$ is an equilibrium. If no cooperation outcome is an equilibrium, then the first-mover choice of C in the first round is an off-the-equilibrium path move and is not reciprocated because the second mover assumes that C is a mistake and will not be chosen again. First, note that the case where $\gamma_1^* = \bar{\gamma}$ cannot be an equilibrium if there exists a sufficiently cooperative type γ such that $\Pi(\delta, \mu, \gamma) = 0$, where μ denotes the measure of γ-types such that $u(C, C, \gamma) > u(D, C, \gamma)$ holds. Even if there is no such type, we still argue that a no-cooperation equilibrium is "unreasonable" in the spirit of the Intuitive Criterion of Cho and Kreps (1987). The sketch of the proof of this claim proceeds by integrating the expectations of first movers and second movers regarding their partners actions' into the type space. In a reasonable equilibrium, a first mover who chooses C must be assigned the belief that the first mover is highly cooperative *and* sufficiently optimistic regarding the chances that the second mover will reciprocate. This is because only a first mover with such preferences and optimistic beliefs benefits from choosing C in the first period relative to the outcome in the equilibrium with $\gamma_1^* = \bar{\gamma}$ along the lines of a dynamic version of the Intuitive Criterion (see Kartal (2018) for a formal dynamic application of the Intuitive Criterion). In a similar vein, a first mover who chooses C and is reciprocated must believe that the second mover is highly cooperative and sufficiently optimistic that the first mover will continue cooperating because otherwise reciprocating the first-mover's cooperation is dominated by defection. Given this construction, it is a best response for a cooperative second mover to be optimistic and reciprocate the first mover's cooperation choice in the first period, and thus, a highly cooperative first mover must deviate and choose to cooperate in the first round. Hence, under assumption A1S, an equilibrium in which there is no cooperation in the sequential game is unreasonable.

Proof of Proposition 4 (i). We already showed the existence of a PBE such that $\gamma_2^* < \gamma_1^* < \bar{\gamma}$. Let $\gamma_2(c)$ and $\gamma_2(c')$ denote the respective second-mover equilibrium cutoff in the sequential games $\Gamma(a, b, c, d, \delta)$ and $\Gamma(a, b, c', d, \delta)$, where $c > c'$. Also, let $\Pi_c(\delta, p, \gamma)$ and $\Pi_{c'}(\delta, p, \gamma)$ denote $\Pi(\delta, p, \gamma)$ in the sequential games $\Gamma(a, b, c, d, \delta)$ and $\Gamma(a, b, c', d, \delta)$, respectively. Thus, $\Pi_c(\delta, 1, \gamma_2(c)) = 0$, and $\Pi_{c'}(\delta, 1, \gamma_2(c')) = 0$. We will now show that $\gamma_2(c) < \gamma_2(c')$. Suppose towards a contradiction that $\gamma_2(c) \geq \gamma_2(c')$. Then, A2 implies that $\Pi_c(\delta, 1, \gamma_2(c')) \leq 0$. However, since $u(C, C, c, \gamma) > u(C, C, c', \gamma)$ for every γ, $\Pi_{c'}(\delta, 1, \gamma_2(c')) < \Pi_c(\delta, 1, \gamma_2(c')) \leq 0$ contradicting $\Pi_{c'}(\delta, 1, \gamma_2(c')) = 0$. Thus, $\gamma_2(c) < \gamma_2(c')$. Next, we show that if $c > c'$, then $\gamma_1(c) < \gamma_1(c')$ also holds, where $\gamma_1(c)$ denotes the first-mover equilibrium cutoff in the sequential game with mutual cooperation payoff equal to c. We have that $\Pi_c(\delta, 1 - F(\gamma_2(c)), \gamma_1(c)) = 0$, and $\Pi_{c'}(\delta, 1 - F(\gamma_2(c')), \gamma_1(c')) = 0$ with $c > c'$ and $1 - F(\gamma_2(c)) > 1 - F(\gamma_2(c'))$. Thus, in the sequential game with cooperation payoff c, the first mover not only benefits from $c > c'$ but also expects a strictly higher second-mover cooperation rate. We will show that this results in $\gamma_1(c) < \gamma_1(c')$. Suppose not. Then, we obtain

$\Pi_c(\delta, 1 - F(\gamma_2(c')), \gamma_1(c)) > \Pi_{c'}(\delta, 1 - F(\gamma_2(c')), \gamma_1(c)) \geq 0$. Moreover, $1 - F(\gamma_2(c)) > 1 - F(\gamma_2(c'))$, and thus, it follows from Claim 1 that $\Pi_c(\delta, 1 - F(\gamma_2(c)), \gamma_1(c)) > 0$, a contradiction. The proof is analogous for two sequential games that differ only in δ.

Proof of Proposition 4 (ii) Since γ_2^* is given by $\Pi(\delta, 1, \gamma_2^*) = 0$ in PBE (i.e., there is no strategic risk for a second mover who observes first-mover cooperation), the change in a does not affect the second mover. Let $\gamma_1(a)$ and $\gamma_1(a')$ denote the respective first-mover equilibrium cutoff in the sequential games $\Gamma(a, b, c, d, \delta)$ and $\Gamma(a', b, c, d, \delta)$, where $a' > a$. Also, let $\Pi_a(\delta, p, \gamma)$ and $\Pi_{a'}(\delta, p, \gamma)$ denote $\Pi(\delta, p, \gamma)$ in the sequential games $\Gamma(a, b, c, d, \delta)$ and $\Gamma(a', b, c, d, \delta)$, respectively. Thus, $\Pi_a(\delta, 1, \gamma_1(a)) = 0$, and $\Pi_{a'}(\delta, 1, \gamma_a(a')) = 0$. We will now show that $\gamma_1(a) > \gamma_1(a')$. Suppose towards a contradiction that $\gamma_1(a) \leq \gamma_1(a')$. However, since $u(C, D, a', \gamma) > u(C, D, a, \gamma)$ for every γ, it follows that $\Pi_{a'}(\delta, 1 - F(\gamma_2^*)), \gamma_1(a')) > \Pi_a(\delta, 1 - F(\gamma_2^*), \gamma_1(a)) \geq 0$, a contradiction. Hence, $\gamma_1(a) > \gamma_1(a')$, and the the average cooperation rate is strictly higher in the game with a'. The proof is analogous for two sequential games that differ only in $F(\gamma)$.

Proof of Proposition 5. We start with the benchmark case in which lying is costly enough so that no type misrepresents her incentive to cooperate. Let γ^* be such that $\Pi(\delta, 1, \gamma^*) = 0$ holds. We construct an equilibrium with a cutoff of γ^* as follows. Every type $\gamma > \gamma^*$ communicates either suggesting mutual cooperation or agreeing after the other party suggests it (depending on who starts the communication). After a type-γ player with $\gamma > \gamma^*$ suggests mutual cooperation, type-γ player indeed cooperates if the matched player agrees (so there is mutual agreement on cooperation), and chooses to defect otherwise. If the matched player suggests mutual cooperation, then every type $\gamma > \gamma^*$ agrees and cooperates, whereas every other type disagrees. No type $\gamma < \gamma^*$ suggests (mutual) cooperation and defects afterwards as lying is costly. It is easy to show that there is no incentive to deviate from this for any type. No type $\gamma > \gamma^*$ has an incentive to defect and deviate from the mutual agreement on cooperation since $\Pi(\delta, 1, \gamma) > 0$ and lying is costly. No type $\gamma < \gamma^*$ has an incentive to misrepresent her intentions and defect since lying is sufficiently costly.

Next, we consider the case in which a positive fraction of types is dishonest. Throughout, we will assume that every type who will or intends to choose the cooperative strategy communicates her intention truthfully. Thus, dishonesty refers to an intention to choose AD but pretending to be a cooperative type in the communication. Let $\rho(\gamma')$ denote the fraction of dishonest γ types such that $\gamma < \gamma'$. Note that by Bayesian updating, a type above the equilibrium cutoff γ^* will know that upon mutual agreement on cooperation the other player will cooperate with probability $\frac{1-F(\gamma^*)}{1-F(\gamma^*)+F(\gamma^*)\rho(\gamma^*)}$. This is because $\rho(\gamma^*)$ fraction of types below the cutoff will imitate a cooperator and pretend to agree on mutual cooperation. Thus, the cutoff in the most cooperative equilibrium of the communication games is such that $\Pi(\delta, \frac{1-F(\gamma^*)}{1-F(\gamma^*)+F(\gamma^*)\rho(\gamma^*)}, \gamma^*) = 0$. The full honesty scenario boils down to the case in which $\rho(\gamma^*) = 0$ and $\Pi(\delta, 1, \gamma^*) = 0$ holds. At the other extreme, we have $\rho(\gamma^*) = 1$ and $\Pi(\delta, 1 - F(\gamma^*), \gamma^*) = 0$. In this case, communication is entirely uninformative (babbling), and the most cooperative equilibrium is identical in the games with and without communication. For any $\rho(\gamma) < 1$, the equilibrium cutoff with communication is strictly lower than that in the simultaneous game. To show this, let $\hat{\gamma}$ denote the minimum equilibrium cutoff in the simultaneous game. Since $\Pi(\delta, 1 - F(\hat{\gamma}), \hat{\gamma}) = 0$ and $\rho(\hat{\gamma}) < 1$, it follows that $\Pi(\delta, \frac{1-F(\hat{\gamma})}{1-F(\hat{\gamma})+F(\hat{\gamma})\rho(\hat{\gamma})}, \hat{\gamma}) > 0$ from Claim 1. Moreover, by A1S and A2, there exists a type $\gamma_2 > \underline{\gamma}$ such that $\Pi(\delta, 1, \gamma) < 0$ for every $\gamma < \gamma_2$. In particular, $\Pi(\delta, \frac{1-F(\gamma)}{1-F(\gamma)+F(\gamma)\rho(\gamma)}, \gamma) < 0$ for every $\gamma < \gamma_2$ by Claim 1. Thus, $\gamma_2 < \hat{\gamma}$ and there exists a $\gamma \in (\gamma_2, \hat{\gamma})$ such that $\Pi(\delta, \frac{1-F(\gamma)}{1-F(\gamma)+F(\gamma)\rho(\gamma)}, \gamma) = 0$. As a result, the minimum equilibrium cutoff in the communication game is strictly lower than that in the simultaneous game for any strictly positive honesty rate. This also implies that the rate of coordination on cooperation and the continuation game cooperation rate in the communication game are strictly higher than the corresponding rates in the simultaneous game.

We will now derive an upper bound on the dishonesty rate so that the statement in Proposition 3 regarding the comparison between the communication game and the sequential game holds. Let γ_1^* and γ_2^* denote the sequential game equilibrium cutoff for the first mover and the second mover, respectively as in the proof of Proposition 2 above. Let $\hat{\gamma}$ solve $(1 - F(\hat{\gamma}))^2 = (1 - F(\gamma_1^*))(1 - F(\gamma_2^*))$. As $\gamma_2^* < \gamma_1^*$, $\hat{\gamma} \in (\gamma_2^*, \gamma_1^*)$ must hold. Next note that there exists a number $\hat{\rho} \in (0, 1)$ such that $\Pi(\delta, \frac{1-F(\hat{\gamma})}{1-F(\hat{\gamma})+F(\hat{\gamma})\hat{\rho}}, \hat{\gamma}) = 0$ because if $\hat{\rho} = 0$, then $\Pi(\delta, 1, \hat{\gamma}) > 0$ (as $\hat{\gamma} > \gamma_2^*$) and if $\hat{\rho} = 1$, then $\Pi(\delta, 1 - F(\hat{\gamma}), \hat{\gamma}) < 0$ (as $\hat{\gamma} < \gamma_1^*$, and $\Pi(\delta, 1 - F(\gamma), \gamma) < 0$ for every $\gamma < \gamma_1^*$ due to A2, Claim 1 and the fact that γ_1^* is strictly lower than the minimum equilibrium cutoff in the simultaneous game γ^* which solves $\Pi(\delta, 1 - F(\gamma^*), \gamma^*) = 0$). Thus, for every honesty function $\rho(\gamma)$ such that $\rho(\gamma) < \hat{\rho}$, the statement in Proposition 3 regarding the comparison between the communication game and the sequential game holds because there exists a $\tilde{\gamma}$ such that $\tilde{\gamma} < \hat{\gamma}$ and $\Pi(\delta, 1 - F(\tilde{\gamma})\rho(\tilde{\gamma}), \tilde{\gamma}) = 0$. Such $\tilde{\gamma}$ exists because (i) $\Pi(\delta, \frac{1-F(\hat{\gamma})}{1-F(\hat{\gamma})+F(\hat{\gamma})\rho(\hat{\gamma})}, \hat{\gamma}) > 0$ given Claim 1 and $\rho(\hat{\gamma}) < \hat{\rho}$, and (ii) there must exist $\gamma < \hat{\gamma}$ such that $\Pi(\delta, \frac{1-F(\gamma)}{1-F(\gamma)+F(\gamma)\rho(\gamma)}, \gamma) < 0$ by A2 and Claim 1. As a result, there exists $\tilde{\gamma} < \hat{\gamma}$ such that $\Pi(\delta, \frac{1-F(\tilde{\gamma})}{1-F(\tilde{\gamma})+F(\tilde{\gamma})\rho(\tilde{\gamma})}, \tilde{\gamma}) = 0$, and $\tilde{\gamma}$ is an equilibrium cutoff of the communication game. It follows that $(1 - F(\tilde{\gamma}))^2 > (1 - F(\gamma_1^*))(1 - F(\gamma_2^*))$.

Proof of Proposition 6. Let $\Pi^P(\delta, p, \gamma)$ denote the *net* expected benefit of choosing a cooperative strategy CS or CPS (rather than AD) for a type-γ player assuming that the opponent chooses a cooperative strategy with probability p and AD with probability $1 - p$. In particular, $\Pi^P(\delta, 1 - F(\gamma'), \gamma)$ denotes the *net* expected benefit of choosing a cooperative strategy (CS or CPS, whichever is optimal) for a type-γ player assuming that the opponent chooses a cooperative strategy if his type is higher than γ' and AD otherwise. Thus, we can write

$$\Pi^P(\delta, 1-F(\gamma'), \gamma) = \Pi(\delta, 1-F(\gamma'), \gamma) + \max\{F(\gamma')\frac{\delta}{1-\delta}\bar{\pi}(d, e, \gamma), 0\} + (1-\tilde{F}(\gamma'))\underline{\pi}(d, e, \gamma),$$

where $\Pi(\delta, p, \gamma)$ is defined as before in the main text in Section 3, and by A3, $1-\tilde{F}(\gamma')$ the measure of types $\tilde{\gamma} > \gamma'$ such that $\bar{\pi}(d, e, \gamma) > 0$ so that they prefer CPS over than CS. Note that the second term is relevant only if $\bar{\pi}(d, e, \gamma) > 0$, and in that case CPS is preferred over CS. Otherwise, CS is (weakly) preferred over CPS (but not necessarily over AD).

It follows from A2 and A3 that $\Pi^P(\delta, 1-F(\gamma), \gamma') > \Pi^P(\delta, 1-F(\gamma), \gamma)$ if $\gamma' > \gamma$. In particular, if $\Pi^P(\delta, 1-F(\gamma^P), \gamma^P) = 0$, it follows that $\Pi^P(\delta, 1-F(\gamma^P), \gamma) < 0$ for $\gamma < \gamma^P$ and $\Pi^P(\delta, 1-F(\gamma^P), \gamma) > 0$ for $\gamma > \gamma^P$. Hence, a PBE has a cutoff structure as before. Hereafter, we assume without loss of generality that $\Pi^P(\delta, 1-F(\underline{\gamma}), \underline{\gamma}) = \Pi^P(\delta, 1, \underline{\gamma}) < 0$; otherwise, the case where everyone cooperates is trivially an equilibrium in the punishment game, and we obtain the desired result.

First, assume that the equilibrium cutoff γ^* in the standard repeated game without punishment is such that $\bar{\pi}(d, e, \gamma^*) > 0$. This implies that $\Pi^P(\delta, 1-F(\gamma^*), \gamma^*) > 0$. We will now show that there exists a $\gamma^P \in (\underline{\gamma}, \gamma^*)$ such that $\Pi^P(\delta, 1-F(\gamma^P), \gamma^P) = 0$ with γ^P constituting the equilibrium cutoff such that γ types lower than γ^P choose AD, intermediate γ types greater than γ^P choose CS, and the highest γ types choose CPS.

Given the result above that $\Pi^P(\delta, 1-F(\gamma'), \gamma)$ is strictly increasing in γ, the continuity of $\Pi^P(\delta, 1-F(\gamma), \gamma)$ in γ, and the fact that $\Pi^P(\delta, 1-F(\gamma^*), \gamma^*) > 0$, it will be enough to show that $\Pi^P(\delta, 1-F(\hat{\gamma}), \hat{\gamma}) < 0$ for some $\hat{\gamma} \in (\underline{\gamma}, \gamma^*)$. Suppose towards a contradiction that $\Pi^P(\delta, 1-F(\gamma), \gamma) \geq 0$ for all $\gamma \in (\underline{\gamma}, \gamma^*)$. However, this is a contradiction because $\Pi^P(\delta, 1-F(\gamma), \gamma)$ is a strictly negative number for small enough $\gamma > \underline{\gamma}$. Thus, there exists $\hat{\gamma} \in (\underline{\gamma}, \gamma^*)$ such that $\Pi^P(\delta, 1-F(\hat{\gamma}), \hat{\gamma}) < 0$. As a result, there exists $\gamma^P \in (\hat{\gamma}, \gamma^*)$ such that $\Pi^P(\delta, 1-F(\gamma^P), \gamma^P) = 0$. Next, assume that the equilibrium cutoff γ^* in the original game without punishment is such that $\bar{\pi}(d, e, \gamma^*) \leq 0$. Note that $\Pi^P(\delta, 1-F(\gamma^*), \gamma^*) > 0$ still holds, since $\underline{\pi}(d, e, \gamma^*) > 0$, and γ^* type is no longer indifferent between CS and AD because anyone who chooses AD is punished with a positive probability. The rest of the proof is then identical to the proof in the case where $\bar{\pi}(d, e, \gamma^*) > 0$.

For the statement of Proposition 7 below, let $\gamma_1(\gamma)$ solve $\Pi_{HL}(\delta, \frac{1-F(\gamma)}{1-F(\gamma_1(\gamma))}, \gamma) = 0$. For $\gamma \in [\gamma_{HL}(1), \tilde{\gamma}_{HL}]$, $\gamma_1(\gamma)$ is well-defined and unique as explained in the Proof of Proposition 7.

Proposition 7. *Assume that A1S and EA2 hold in the dynamic game. Under the following conditions, there exists a PBE such that $\gamma_L^* < \tilde{\gamma}_L$ and $\gamma_H^* < \tilde{\gamma}_H$. In particular, the dynamic setting is strictly more cooperative than the static versions.*
(i) $\tilde{\gamma}_{HL} < \tilde{\gamma}_L < \tilde{\gamma}_H$.

(ii) $\tilde{\gamma}_H \leq \tilde{\gamma}_L$ and $\Pi_{LH}(\delta, (1-F(\tilde{\gamma}_H), 1), \tilde{\gamma}_H) > 0$.
(iii) $\gamma_{HL}(1) < \tilde{\gamma}_L < \tilde{\gamma}_{HL}$ and $\Pi_{LH}(\delta, (1-F(\gamma_1(\tilde{\gamma}_L)), \frac{1-F(\tilde{\gamma}_L)}{1-F(\gamma_1(\tilde{\gamma}_L))}), \gamma_1(\tilde{\gamma}_L)) < 0$.

Proof. First, let $\Gamma((a,b,c,d),(a',b',c',d'),\delta)$ denote the dynamic game outlined in the main text with payoffs in Figure 1(A) and 1(B). Also, let $\Gamma_{HL}(a',b',c',d',d,\delta)$ denote the (hypothetical) dynamic game that begins at H (i.e., $\theta_0 = H$) but will switch to L at $t+1$ and remain there if $(a_{it}, a_{jt}) = (D, D)$.

Recall that $V_{HL}(p_H, \gamma)$ is defined in the main text as the continuation payoff for a type-γ player at $t = 1$ if $\theta_1 = H$. V_{HL} depends on p_H and γ (in addition to a', b', c', d', d, and δ), and equals the payoff of CS if $\Pi_{HL}(\delta, p_H, \gamma) > 0$ and the payoff of AD otherwise, where $\Pi_{HL}(\delta, p, \gamma)$ refers to the net expected benefit of choosing CS (rather than AD) in H at $t = 1$ for a type-γ player assuming that the opponent chooses CS with probability p and AD with probability $1-p$. Note that the term $\Pi_{HL}(\delta, p, \gamma)$ applies to not only the continuation game of the dynamic game that starts at $\theta_1 = H$ but also the game $\Gamma_{HL}(a',b',c',d',d,\delta)$ and is a convex combination of $\Pi_{d'}(\delta,p,\gamma)$ for the game $\Gamma(a',b',c',d',\delta)$ and $\Pi_d(\delta,p,\gamma)$ for the game $\Gamma(a',b',c',d,\delta)$ where $d' > d$. In particular, it can be checked that $\Pi_{HL}(\delta,p,\gamma) = \delta\Pi_d(\delta,p,\gamma) + (1-\delta)\Pi_{d'}(\delta,p,\gamma)$. By A2, $\Pi_d(\delta,p,\gamma)$ and $\Pi_{d'}(\delta,p,\gamma)$ are strictly increasing in γ. Thus, $\Pi_{HL}(\delta,p,\gamma)$ is strictly increasing in γ as desired. As a result, by A1S and A2, and the stage-game utility assumptions, there exists an equilibrium cutoff type in $\Gamma_{HL}(a',b',c',d',d,\delta)$, denoted by $\tilde{\gamma}_{HL}$, such that a type-γ player selects CS at $t = 0$ if $\gamma > \tilde{\gamma}_{HL}$ and AD otherwise. Obviously, $\tilde{\gamma}_{HL} < \tilde{\gamma}_H$ because a failure to coordinate on cooperation in H is followed by mutual defection, which then strictly reduces the defection payoff to the level in L.

Let $\gamma_{HL}(1)$ denote the type such that $\Pi_{HL}(\delta, 1, \gamma_{HL}(1)) = 0$. It follows that $\gamma_{HL}(1) < \tilde{\gamma}_{HL}$ by A2 and since Claim 1 also holds for $\Pi_{HL}(\delta,p,\gamma)$ (i.e., $\Pi_{HL}(\delta, 1-F(\tilde{\gamma}_{HL}), \gamma_{HL}(1)) < 0$ by Claim 1). Throughout, we will assume that there exists $\gamma \in [\underline{\gamma}, \bar{\gamma})$ in $\Gamma((a,b,c,d),(a',b',c',d'),\delta)$ such that $\Pi_{LH}(\delta,(1,p),\gamma) < 0$ where p is the highest equilibrium cooperation rate that can be sustained in $\Gamma_{HL}(a,b,c,d,d',\delta)$. This assumption is without loss of generality, as otherwise the result in Proposition 7 trivially obtains with $\gamma_L^* = \underline{\gamma} < \tilde{\gamma}_L$ *and* $\gamma_H^* = \tilde{\gamma}_{HL} < \tilde{\gamma}_H$.

(i) $\tilde{\gamma}_{HL} < \tilde{\gamma}_L < \tilde{\gamma}_H$. Note that given $c' > c$, $\Pi_{LH}(\delta, (1-F(\tilde{\gamma}_L), 1), \tilde{\gamma}_L) > 0$ must hold; i.e., in the dynamic game $\tilde{\gamma}_L$ type strictly prefers CS at $t = 0$ if every type-γ player selects CS for $\gamma > \tilde{\gamma}_L$ and AD for $\gamma \leq \tilde{\gamma}_L$. If there exists a $\gamma \in (\gamma_{HL}(1), \tilde{\gamma}_L)$ such that $\Pi_{LH}(\delta, (1-F(\gamma),1),\gamma) \leq 0$, this means there exists a type $\gamma^* \in (\gamma, \tilde{\gamma}_L)$ such that $\Pi_{LH}(\delta,(1-F(\gamma^*),1),\gamma^*) = 0$; i.e., we obtain a PBE such that a type-γ player selects CS if $\gamma > \gamma^*$ and AD otherwise at $t = 0$ (there is no type that selects into SCS in such an equilibrium). This cutoff structure of PBE is due to EA2. Next, assume that for every $\gamma \in (\gamma_{HL}(1), \tilde{\gamma}_L)$, $\Pi_{LH}(\delta,(1-F(\gamma),1),\gamma) > 0$. Consider $\Pi_{LH}(\delta, (1-F(\gamma_1(\gamma_2)), \frac{1-F(\gamma_2)}{1-F(\gamma_1(\gamma_2))}), \gamma_1(\gamma_2))$ for $\gamma_2 \in [\gamma_{HL}(1), \tilde{\gamma}_{HL}]$, where $\gamma_1(\gamma_2)$ is such that $\Pi_{HL}(\delta, \frac{1-F(\gamma_2)}{1-F(\gamma_1(\gamma_2))}, \gamma_2) = 0$. For fixed γ_2, there is a unique value of $\gamma_1 \leq \gamma_2$ that satisfies this, and $\gamma_1(\gamma_2)$ is continuous. Note that $\gamma_1(\gamma_2) = \gamma_{HL}(1)$ for $\gamma_2 = \gamma_{HL}(1)$, whereas $\gamma_1(\gamma_2) = \underline{\gamma}$ for $\gamma_2 = \tilde{\gamma}_{HL}$. In addition, by hypothesis $\Pi_{LH}(\delta, (1 - F(\gamma_{HL}(1)), 1), \gamma_{HL}(1)) > 0$ with $\Pi_{HL}(\delta, 1, \gamma_{HL}(1)) = 0$, and also, $\Pi_{LH}(\delta, (1, 1 - F(\tilde{\gamma}_{HL})), \tilde{\gamma}_{HL}) < 0$ with $\Pi_{HL}(\delta, 1 - F(\tilde{\gamma}_{HL}), \tilde{\gamma}_{HL}) = 0$ since there exists $\gamma \in [\underline{\gamma}, \bar{\gamma})$ in $\Gamma((a, b, c, d), (a', b', c', d'), \delta)$ such that $\Pi_{LH}(\delta, (1, p), \gamma) < 0$ where p is the highest equilibrium cooperation rate that can be sustained in $\Gamma_{HL}(a, b, c, d, d', \delta)$. Thus, by continuity, there exist (γ_L^*, γ_H^*) such that $\gamma_L^* < \tilde{\gamma}_{HL}$ and $\gamma_H^* < \tilde{\gamma}_{HL}$, where γ_L^* and γ_H^* satisfy $\Pi_{LH}(\delta, (1-F(\gamma_L^*), \frac{1-F(\gamma_H^*)}{1-F(\gamma_L^*)}), \gamma_L^*) = 0$ and $\Pi_{HL}(\delta, \frac{1-F(\gamma_H^*)}{1-F(\gamma_L^*)}, \gamma_H^*) = 0$.

(ii) $\tilde{\gamma}_{HL} < \tilde{\gamma}_H \leq \tilde{\gamma}_L$ and $\Pi_{LH}(\delta, (1 - F(\tilde{\gamma}_H), 1), \tilde{\gamma}_H) > 0$. The proof in this case is similar to the proof of the case above. If there exists a $\gamma \in (\gamma_{HL}(1), \tilde{\gamma}_H)$ such that $\Pi_{LH}(\delta, (1-F(\gamma), 1), \gamma) \leq 0$, this means there exists a type $\gamma^* \in (\gamma, \tilde{\gamma}_H)$ such that $\Pi_{LH}(\delta, (1-F(\gamma^*), 1), \gamma^*) = 0$; i.e., we obtain a PBE such that a type-γ player selects CS if $\gamma > \gamma^*$ and AD otherwise at $t = 0$ (there is no type that selects into SCS in such an equilibrium). Next, assume that for every $\gamma \in (\gamma_{HL}(1), \tilde{\gamma}_H)$, $\Pi_{LH}(\delta, (1 - F(\gamma), 1), \gamma) > 0$. Now, consider $\Pi_{LH}(\delta, (1 - F(\gamma_1(\gamma_2)), \frac{1-F(\gamma_2)}{1-F(\gamma_1(\gamma_2))}), \gamma_1(\gamma_2))$ for $\gamma_2 \in [\gamma_{HL}(1), \tilde{\gamma}_{HL}]$, where $\gamma_1(\gamma_2)$ is such that $\Pi_{HL}(\delta, \frac{1-F(\gamma_2)}{1-F(\gamma_1(\gamma_2))}, \gamma_2) = 0$. For fixed γ_2, there is a unique value of $\gamma_1(\gamma_2) \leq \gamma_2$ that satisfies this. Note that $\gamma_1(\gamma_2) = \gamma_{HL}(1)$ for $\gamma_2 = \gamma_{HL}(1)$, whereas $\gamma_1(\gamma_2) = \underline{\gamma}$ for $\gamma_2 = \tilde{\gamma}_{HL}$. In addition, we have that $\Pi_{LH}(\delta, (1 - F(\gamma_{HL}(1)), 1), \gamma_{HL}(1)) > 0$ with $\Pi_{HL}(\delta, 1, \gamma_{HL}(1)) = 0$, and $\Pi_{LH}(\delta, (1, 1-F(\tilde{\gamma}_{HL})), \underline{\gamma}) < 0$ with $\Pi_{HL}(\delta, 1-F(\tilde{\gamma}_{HL}), \tilde{\gamma}_{HL}) = 0$. Thus, there exist (γ_L^*, γ_H^*) such that $\gamma_L^* < \tilde{\gamma}_{HL}$ and $\gamma_H^* < \tilde{\gamma}_{HL}$, where γ_L^* and γ_H^* satisfy $\Pi_{LH}(\delta, (1 - F(\gamma_L^*), \frac{1-F(\gamma_H^*)}{1-F(\gamma_L^*)}), \gamma_L^*) = 0$ and $\Pi_{HL}(\delta, \frac{1-F(\gamma_H^*)}{1-F(\gamma_L^*)}, \gamma_H^*) = 0$.

(iii) $\gamma_{HL}(1) < \tilde{\gamma}_L < \tilde{\gamma}_{HL}$ and that $\Pi_{LH}(\delta, (1 - F(\gamma_1(\tilde{\gamma}_L)), \frac{1-F(\tilde{\gamma}_L)}{1-F(\gamma_1(\tilde{\gamma}_L))}), \gamma_1(\tilde{\gamma}_L)) < 0$. The proof is similar to the proofs above. If there exists a $\gamma \in (\gamma_{HL}(1), \tilde{\gamma}_L)$ such that $\Pi_{LH}(\delta, (1 - F(\gamma), 1), \gamma) \leq 0$, there exists a type $\gamma^* \in (\gamma, \tilde{\gamma}_L)$ such that $\Pi_{LH}(\delta, (1 - F(\gamma^*), 1), \gamma^*) = 0$; i.e., $\gamma^* = \gamma_L^* = \gamma_H^* < \tilde{\gamma}_L$ in equilibrium. Otherwise, there exist (γ_L^*, γ_H^*) such that $\gamma_L^* < \tilde{\gamma}_L$ and $\gamma_H^* < \tilde{\gamma}_{HL}$ where γ_L^* and γ_H^* satisfy $\Pi_{LH}(\delta, (1 - F(\gamma_L^*), \frac{1-F(\gamma_H^*)}{1-F(\gamma_L^*)}), \gamma_L^*) = 0$ and $\Pi_{HL}(\delta, \frac{1-F(\gamma_H^*)}{1-F(\gamma_L^*)}, \gamma_H^*) = 0$.

Finally, note that in (i) and (ii), the overall cooperation rate in the dynamic game certainly exceeds those in the static versions with $\theta_0 = L$ and $\theta_0 = H$. The same also holds in part (iii) provided that $\tilde{\gamma}_L < \tilde{\gamma}_{HL}$ is sufficiently close to $\tilde{\gamma}_{HL}$ so that not only $\gamma_L^* < \tilde{\gamma}_L$ but also $\gamma_H^* < \tilde{\gamma}_L$ must hold.

B Treatment and session information

Table 5: Treament and session information

Treatment	Matching Group	# Subjects	# of games played	Avg. percentage of mutual cooperation rate
SIM	1	12	60	3.26
SIM	2	12	60	3.26
SIM	3	14	60	8.43
SIM	4	12	60	0.14
SIM	5	12	60	11.53
SIM	6	12	60	1.36
SEQ	1	24	57	24.31
SEQ	2	24	52	26.94
SEQ	3	20	55	18.48
SEQ	4	24	51	4.17
SEQ	5	24	59	17.74
SEQ	6	22	60	27.51
CHAT	1	12	29	46.77
CHAT	2	10	29	74.52
CHAT	3	12	48	64.06
CHAT	4	10	48	72.71
CHAT	5	12	32	89.91
CHAT	6	12	32	50.00

Notes: In treatment SEQ, subjects are assigned to one of two player roles (first mover or second mover). Therefore, matching groups for Treatment SEQ had to be larger for reasons of comparability.

C Projection of mutual cooperation levels over a long time horizon

In this Appendix we assess to what levels cooperation and mutual cooperation rates might have converged to had the experiment been conducted over a very long time horizon. For this purpose, we employ an approach similar to the one suggested in Noussair et al. (1995) and Barut et al. (2002). For instance, to estimate and statistically compare asymptotes of cooperation rates in treatments SIM (all data) and SEQ (first-mover data) we run the following two OLS regressions:

$$\text{Coop}_{ijt} = \sum_{j=1}^{6} \alpha_j^{SIM} \times \frac{D_j^{SIM}}{t} + \beta^{SIM} \times \frac{(t-1)}{t} + \varepsilon \tag{2}$$

and

$$\text{Coop}_{ijt} = \sum_{j=1}^{6} \alpha_j^{SEQ} \times \frac{D_j^{SEQ}}{t} + \beta^{SEQ} \times \frac{(t-1)}{t} + \varepsilon, \tag{3}$$

where Coop_{ijt} denotes the observed average cooperation rate in group i, of matching group j in match t; D_j^{SIM} (D_j^{SEQ}) is a dummy for matching group j of treatment SIM (SEQ). The regressions were run with all data and with observations clustered at the matching group level.

Following the interpretation in Barut et al. (2002), the coefficient α_j^{SIM} (α_j^{SEQ}) is an estimate of the average cooperation rate in match 1 of matching group j in treatment SIM (SEQ), whereas β^{SIM} (β^{SEQ}) is the estimated average cooperation rate to which the time series converge if $t \to \infty$. Hence, this model allows the starting cooperation rates to be different across the individual matching groups of a treatment but assumes the cooperation rates in all matching groups of a treatment to converge to a common asymptote. (Similar regressions were run to estimates asymptotes for mutual cooperation rates.)

We are interested in whether in the very long run the cooperation rates across treatments would have converged to the same level. To test the hypothesis H_0: $\beta^{SIM} = \beta^{SEQ}$, we compute the statistic

$$z = \frac{\widehat{\beta}^{SIM} - \widehat{\beta}^{SEQ}}{\sqrt{se(\widehat{\beta}^{SIM})^2 + se(\widehat{\beta}^{SEQ})^2}}, \tag{4}$$

where $\widehat{\beta}^{SIM}$ and $\widehat{\beta}^{SEQ}$ are the estimated coefficients and $se(\widehat{\beta}^{SIM})$ and $se(\widehat{\beta}^{SEQ})$ the standard errors from equations (2) and (3), respectively. Table 6 shows the results. The "<" and ">" signs in Table 6 summarize the results of statistical tests based on the z-statistic defined in (4). The superscripts indicate the level of significance. We find that all asymptotes are

Table 6: Estimated asymptotes and test results

Cooperation Rates

SEQ		**SIM**		**CHAT**
0.269	$>^{***}$	0.169	$<^{***}$	0.744
(0.005)		(0.013)		(0.031)

Mutual Cooperation Rates

SEQ		**SIM**		**CHAT**
0.176	$>^{***}$	0.045	$<^{***}$	0.666
(0.006)		(0.006)		(0.039)

Notes: The table shows the estimated asymptotes from equations of the form (2) and (3). Standard errors in parentheses. The “$>$” and “$<$” signs summarize the results of statistical tests based on the z-statistic defined in equation (4). The superscripts indicate the level of significance, where *** indicates significance at the 1% level.

precisely estimated to be significantly larger than 0. Furthermore, the estimated asymptotes for treatments SEQ and CHAT, respectively, are significantly larger than the estimated asymptotes for treatment SIM. To the extent that the above projection technique is justified, these results mean that the treatment effects reported in Tables 1 and 2 would have prevailed in case the experiments had consisted of many more matches.

D Summary of chat contents

Table 7 only contains subjects' chats of rounds for which both coders assigned the same verbal code listed in the first column of this table. The rate of agreement was 75.71 percent of all individual chats (per subject, round, and match). The most common chat content (32.8 percent of all cases considered in Table 7) was the suggestion that both players choose to cooperate. The second most common chat content (15.8 percent) was that a player agreed to a proposal made. In roughly two thirds of the cases in which a subject's chat was classified as "agree" the other player had made the suggestion that both choose to cooperate (verbal code "both1"). In 13 percent of the cases, a subject chose not to communicate in a round. In another 10.8 percent of the cases, a subject sent messages with trivial content. These four categories summarize 72.5 of all chats considered in Table 7.

Table 7: Summary of chat contents

Verbal Code	Explanation	N	%	Cum %
both1	Subject suggests that both play 1	1,278	32.80	32.80
agree	Subject agrees to a proposal	617	15.84	48.64
none	Subject does not communicate	506	12.99	61.63
trivial	Small talk, off topic	422	10.83	72.46
same	Subject suggests/announces to play as before	282	7.24	79.70
both1 always	Subject suggests that both always play 1	158	4.06	83.75
self1	Subject announces to play 1	158	4.06	87.81
both1 again	Subject suggests that both play 1 again	114	2.93	90.73
complain	Subject complains about behavior of other	86	2.21	92.94
both2	Subject suggests that both play 1	57	1.46	94.40
greeting	Subject greets the other	47	1.21	95.61
self2	Subject announces to play 2	29	0.74	96.36
what to do?	Subject asks what to do	28	0.72	97.07
sorry	Subject apologizes for own behavior	21	0.54	97.61
unclear	Subject answers but it is not clear if she (dis)agrees	21	0.54	98.15
me1 you2	Subject suggests that she plays 1, the other 2	18	0.46	98.61
other1	Subject asks the other player to choose 1	18	0.46	99.08
disagree	Subject disagrees with a proposal or statement	10	0.26	99.33
me2 you1	Subject suggests that she plays 2, the other 1	9	0.23	99.56
weak agree	Subject weakly agrees to a proposal	8	0.21	99.77
alternating me1 you2	Subject suggests to alternate in choices	4	0.10	99.87
same always	Subject suggests that both play always the same action	3	0.08	99.95
question	Subject asks a question	1	0.03	99.97
risk	Subject mentions riskiness w.r.t. own or other action	1	0.03	100.00
Total		3,896	100.00	

Notes: Data from all rounds of all matches for which the verbal codes assigned to chats by both coders coincided. Note that in the instructions the cooperative (defective) action was labeled 1 (2).

E Relationship between signal pairs and the likelihood of mutual cooperation

We also analyze the relationship between signal pairs and the likelihood of coordination on cooperation (as shown in the bottom panels of 3). For this purpose, we ran probit regressions with the dependent variable being whether or not a pair of subjects coordinated on cooperation (coded as 1 or 0, respectively). The independent variables are again binary variables coding the various pairwise combinations of signals. The results are presented in Table 8. Note that here the order of signal pairs listed in the first column of Table 8 are inconsequential, as in the middle panels of Table 3. We again choose the behavior following the exchange of a pair of neutral messages as the reference group and measure the effect of all independent variables with reference to this group. For some slices of the data and signal pairs, mutual cooperation was never achieved. This implies again that these observations are dropped from the probit regressions. We indicate this in Table 8 by the entry "All-Zero." Again, to save space we focus on the most important results of the regressions shown in Table 8.

In column (1) of Table 8, we consider the first round of each match. The main finding is that first-round coordination on cooperation is significantly more likely relative to the reference group *only if* a pair of players exchanged cooperative messages. This holds true (albeit to a less strong extent) when, in column (2), we include all rounds in the data. In column (4) we include a variable that indicates whether a pair of players managed to achieve mutual cooperation in the previous round of the current match. (For a clean comparison, column (3) reports the results for the same selection of data without this additional regressor.) The estimated effect of this new variable is at 0.758 "big" and highly significantly larger than both 0 and the estimated coefficient of the "Cooperate-Cooperate" signal pair (Wald test). This, again, suggests the interpretation that "actions speak louder than words." Once mutual cooperation was successfully achieved in the previous round of a match, this is more predictive of mutual cooperation in the current round than mutual promises of cooperation.

Table 8: Regressing mutual cooperation outcome both players' communicated intents

	(1)	(2)	(3)	(4)
	Rd = 1	Rd ≥ 1	Rd > 1	Rd > 1
	Match ≥ 1	Match ≥ 1	Match ≥ 1	Match ≥ 1
Defect-Defect	All-Zero	All-Zero	All-Zero	All-Zero
Neutral-Defect	−0.183	−0.638***	All-Zero	All-Zero
	(0.154)	(0.084)		
Cooperate-Defect	All-Zero	−0.452***	−0.347*	−0.125
		(0.137)	(0.185)	(0.145)
Cooperate-Neutral	0.101	−0.018	0.045	−0.011
	(0.070)	(0.065)	(0.081)	(0.046)
Cooperate-Cooperate	0.665***	0.394***	0.363***	0.210***
	(0.061)	(0.098)	(0.129)	(0.081)
Coordination in previous round of current match				0.758***
				(0.053)
N	1,095	2,289	1,142	1,142

Notes: The dependent variable is Pr(mutual cooperation outcome). Marginal effects reported. Reference group: "Neutral- Neutral." The entry "All-Zero" indicates that for the corresponding pair of messages and slice of the data mutual cooperation was never achieved. ***, **, and * indicates significance at the 1%, 5%, and 10% level, respectively.

F Strategies used

We use the structural frequency estimation method (SFEM) developed in DB&F to estimate the shares of several strategies used in the three treatments. To use this method, a set of repeated-game strategies needs to be specified and the incidence of each strategy is estimated via maximum likelihood. DB&F assume that subjects possibly make errors in executing a strategy; a parameter γ captures the amount of noise in the data, with choices becoming purely random as γ approaches infinity. We assume that subjects use five of the six strategies suggested in DB&F: Always Defect (AD), Always Cooperate (AC), Grim (G), Tit for Tat (TFT), Win Stay Loose Shift (WSLS) (start cooperating, and cooperate if both or neither player cooperated in the previous round, otherwise defect).[34] We disregard a sixth (trigger) strategy (called T2) as it works with a two-period memory, which is unlikely to play a role in

[34] Recall that our theory in Section 3 is based on cooperative strategies ("CS") that include G and TFT.

Table 9: Shares of estimated strategies (All data)

	SEQ		SIM	CHAT
	1st Mover	2nd Mover		
Always Defect	0.720***	0.379***	0.902***	0.064
	(0.116)	(0.108)	(0.106)	(0.054)
Always Cooperate	0.020	0.000	0.000	0.117
	(0.038)	(0.0000)	(0.000)	(0.138)
Grim Trigger	0.000	0.078	0.043	0.300**
	(0.080)	(0.073)	(0.072)	(0.126)
Tit-for-Tat	0.217*	0.543***	0.055	0.492***
	(0.127)	(0.115)	(0.067)	(0.144)
Win-Stay-Lose-Shift	0.043	0.000	0.000	0.031
γ	0.555***	0.385***	0.537***	0.552***
	(0.088)	(0.044)	(0.115)	(0.091)

Notes: Data from all matches and rounds. ***, **, and * indicates significance at the 1%, 5%, and 10% level, respectively.

our experiment as the average duration of a repeated game is just 2. Moreover, its share was estimated to be 0 in the corresponding treatment of DB&F. The five strategies were assumed to be used by players in SIM, CHAT, and SEQ (first movers only). For second movers in SEQ, strategies G, TFT and WSLS were adjusted: Strategies G and WSLS condition on the first mover's current-period and the second mover's previous period choice; TFT conditions on the first mover's current-period choice. Table 9 shows the results using all data of the experiment. Note that the coefficient for WSLS is implied by the requirement that the proportions of strategies included must sum to one. As will become clear, most estimation results are in line with the theory in Section 3.

Let us start by comparing the estimated shares of strategies in SIM with those in the corresponding treatment in DB&F. The latter only find positive shares for strategies AD (0.92) and TFT (0.08). Our estimates for these strategies are very similar with AD at 0.902 and TFT at 0.055. Additionally, we find the share of strategy G to be positive at 0.043. Note that the shares of strategy TFT in DB&F and G and TFT in our data are not significantly different from 0. We conclude that both in DB&F and in our treatment SIM subjects predominantly use the always-defect strategy.

Moving from SIM to CHAT, we see drastic changes in estimated shares of strategies.

First, the share of AD decreases drastically from 0.902 in SIM to 0.064 in CHAT. Second, the shares of the cooperative strategies AC, G, and TFT, respectively, increase from 0, 0.043, and 0.055 in SIM to 0.117, 0.300, and 0.492 in CHAT. However, in CHAT only the shares of strategies G and TFT are statistically different from 0. Hence, the substantial increase of cooperative choices in CHAT in comparison to SIM is driven by the drastic drop in the always-defect and the significant increase in the (conditionally) cooperative strategies G and TFT.

Moving from SIM to first movers in SEQ, we note that the estimated share of strategy AD decreases from 0.902 in SIM to 0.702 in SEQ and the estimated share of strategy TFT increases from 0.055 in SIM to 0.217 in SEQ. Both changes are not significantly different. However, while the share of TFT in SIM is not significantly different from 0, the share of TFT for first movers in SEQ is (albeit only at the 10 percent level). These observations are consistent with the higher share of cooperative choices by first movers in SEQ compared with those in SIM. Finally, comparing the estimated shares of strategies by first and second movers in SEQ, we observe that the share of AD decreases from 0.720 for first movers to 0.379 for second movers. Moreover, the share of strategy TFT increases from 0.217 for first movers to 0.543 for second movers. Based on the z-statistic defined in (4) in the Online Appendix C, both changes are significant at the 5 percent level. Hence, compared to first movers, second movers make less use of strategy AD and more use of strategy TFT.

G Experimental Instructions

On the next pages, we reproduce the experimental instructions used in treatment SIM, SEQ, and CHAT, respectively.

Instructions (SIM)

Welcome to this experiment!

You are about to participate in an experiment on decision-making, and you will be paid for your participation in cash, privately at the end of the experiment. What you earn depends partly on your decisions, partly on the decisions of others, and partly on chance.

Please turn off your cellular phone now.

The entire experiment will take place through computer terminals, and all interaction between you will take place through the computers. Please do not talk or in any way try to communicate with other participants during the experiment. If you have any questions, or need assistance of any kind, please raise your hand and an experimenter will come to you.

General Instructions

1. In this experiment you will be asked to make decisions in several rounds. You will be randomly paired with another participant for a sequence of rounds. Each sequence of rounds is referred to as a match.

2. The length of a match is randomly determined. After each round of a match, there is a 50% chance that the match will continue for at least another round. For this purpose, at the end of each round of a match the computer will roll a fair 100-sided die and the match will continue if the die shows a number between 1 and 50 and the match will end if the die shows a number between 51 and 100. So, for instance, if you are in round 1 of a match, the chance that there will be a 2nd round is 50%, and if you are in round 2 of a match, the chance that there will be a 3rd round is also 50%, and so on.

3. Once a match ends, you will be randomly paired with another participant for a new match.

4. The choices and the payoffs associated with each choice in each round are as follows:

	the other's choice	
your choice	1	2
1	32, 32	12, 50
2	50, 12	25, 25

The first entry in each cell represents your payoff, while the second entry represents the payoff of the participant you are matched with.

Once you and the participant you are paired with have made your choices, those choices will be highlighted and your payoff for the round will appear.

Payoffs are as indicated in the table above. That is, if:

You select 1 and the other selects 1, you each make 32.

You select 1 and the other selects 2, you make 12 while the other makes 50.
You select 2 and the other selects 1, you make 50 while the other makes 12.

You select 2 and the other selects 2, you each make 25.

The experiment will end after the first match that is completed after 75 minutes have passed, or after 60 matches have been completed, whichever is the sooner.

At the end of the experiment you will be paid € 0.007 for every point scored.

Before the start of the experiment, let us remind you that:

- The length of a match is randomly determined. After each round, there is a 50% chance that the match will continue for at least another round. You will interact with the same participant for the entire match.
- After a match is finished, you will be randomly paired with another participant for a new match.

Instructions (SEQ)

Welcome to this experiment!

You are about to participate in an experiment on decision-making, and you will be paid for your participation in cash, privately at the end of the experiment. What you earn depends partly on your decisions, partly on the decisions of others, and partly on chance.

Please turn off your cellular phone now.

The entire experiment will take place through computer terminals, and all interaction between you will take place through the computers. Please do not talk or in any way try to communicate with other participants during the experiment. If you have any questions, or need assistance of any kind, please raise your hand and an experimenter will come to you.

General Instructions

1. In this experiment you will be asked to make decisions in several rounds. You will be randomly paired with another participant for a sequence of rounds. Each sequence of rounds is referred to as a match.

2. The length of a match is randomly determined. After each round of a match, there is a 50% chance that the match will continue for at least another round. For this purpose, at the end of each round of a match the computer will roll a fair 100-sided die and the match will continue if the die shows a number between 1 and 50 and the match will end if the die shows a number between 51 and 100. So, for instance, if you are in round 1 of a match, the chance that there will be a 2^{nd} round is 50%, and if you are in round 2 of a match, the chance that there will be a 3^{rd} round is also 50%, and so on.

3. Once a match ends, you will be randomly paired with another participant for a new match.

4. The choices and the payoffs associated with each choice in each round are as follows:

	the other's choice	
your choice	1	2
1	32, 32	12, 50
2	50, 12	25, 25

The first entry in each cell represents your payoff, while the second entry represents the payoff of the participant you are matched with.

Once you and the participant you are paired with have made your choices, those choices will be highlighted and your payoff for the round will appear.

At the beginning of the experiment each participant will be randomly assigned the role of participant A or participant B. You will be informed about your role when the experiment starts. You will keep this role for the entire experiment.

In each round of a match, participant A makes his/her decision first. Then, after observing the decision of participant A, participant B makes his/her decision. (The decision of A will be highlighted on the screen of B when B makes his/her decision.)

Payoffs are as indicated in the table above. First, assume that you are participant A. Then, you make the first decision. If:
You select 1 and participant B selects 1, you each make 32.
You select 1 and participant B selects 2, you make 12 while participant B makes 50.
You select 2 and participant B selects 1, you make 50 while participant B makes 12.
You select 2 and participant B selects 2, you each make 25.

Next, assume that you are participant B. Then, you make a decision after observing the decision of participant A. If:
Participant A selects 1 and you select 1, you each make 32.
Participant A selects 1 and you select 2, you make 50 while participant A makes 12.
Participant A selects 2 and you select 1, you make 12 while participant A makes 50.
Participant A selects 2 and you select 2, you each make 25.

The experiment will end after the first match that is completed after 75 minutes have passed, or after 60 matches have been completed, whichever is the sooner.

At the end of the experiment you will be paid € 0.007 for every point scored.

Before the start of the experiment, let us remind you that:

- The length of a match is randomly determined. After each round, there is a 50% chance that the match will continue for at least another round. You will interact with the same participant for the entire match.
- After a match is finished, you will be randomly paired with another participant for a new match.
- In each round of a match, participant A makes his/her decision first. Then, after observing the decision of participant A, participant B makes his/her decision.

Instructions (CHAT)

Welcome to this experiment!

You are about to participate in an experiment on decision-making, and you will be paid for your participation in cash, privately at the end of the experiment. What you earn depends partly on your decisions, partly on the decisions of others, and partly on chance.

Please turn off your cellular phone now.

The entire experiment will take place through computer terminals, and all interaction between you will take place through the computers. Please do not talk or in any way try to communicate with other participants during the experiment. If you have any questions, or need assistance of any kind, please raise your hand and an experimenter will come to you.

General Instructions

1. In this experiment you will be asked to make decisions in several rounds. You will be randomly paired with another participant for a sequence of rounds. Each sequence of rounds is referred to as a match.

2. The length of a match is randomly determined. After each round of a match, there is a 50% chance that the match will continue for at least another round. For this purpose, at the end of each round of a match the computer will roll a fair 100-sided die and the match will continue if the die shows a number between 1 and 50 and the match will end if the die shows a number between 51 and 100. So, for instance, if you are in round 1 of a match, the chance that there will be a 2^{nd} round is 50%, and if you are in round 2 of a match, the chance that there will be a 3^{rd} round is also 50%, and so on.

3. Once a match ends, you will be randomly paired with another participant for a new match.

4. The choices and the payoffs associated with each choice in each round are as follows:

	the other's choice	
your choice	1	2
1	32, 32	12, 50
2	50, 12	25, 25

The first entry in each cell represents your payoff, while the second entry represents the payoff of the participant you are matched with.

Once you and the participant you are paired with have made your choices, those choices will be highlighted and your payoff for the round will appear.

Payoffs are as indicated in the table above. That is, if:

You select 1 and the other selects 1, you each make 32.

You select 1 and the other selects 2, you make 12 while the other makes 50.
You select 2 and the other selects 1, you make 50 while the other makes 12.

You select 2 and the other selects 2, you each make 25.

During a match a dialogue box is available in which you can exchange messages with the participant you are paired with. Although we will record these messages, only you and the participant you are paired with in a match will see them. Think of the dialogue box as your own private dialogue system to help you decide what to do. Note, in sending messages back and forth between you and the participant you are paired with in a match we request you follow three simple rules: (1) Discussion must be in English. No other language is allowed. (2) Be civil to each other, don't use bad language, and don't make any threats to each other. (3) Do not identify yourself, your seat number or anything that might reveal your identity. The dialogue box is intended for you to use to discuss your choices and should be used that way. During the first 5 matches you are able to exchange messages for 30 seconds per round; as of match 6 for 15 seconds per round.

The experiment will end after the first match that is completed after 75 minutes have passed, or after 60 matches have been completed, whichever is the sooner.

At the end of the experiment you will be paid € 0.007 for every point scored.

Before the start of the experiment, let us remind you that:

- The length of a match is randomly determined. After each round, there is a 50% chance that the match will continue for at least another round. You will interact with the same participant for the entire match.
- After a match is finished, you will be randomly paired with another participant for a new match.