Negotiating Cooperation under Uncertainty: Communication in Noisy, Indefinitely Repeated Interactions*

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Abstract

Case studies of cartels and recent theory suggest that communication is a key factor for cooperation under imperfect monitoring, where actions can only be observed with noise. We conduct a laboratory experiment to study how communication affects cooperation under different monitoring structures. Pre-play communication reduces strategic uncertainty and facilitates very high cooperation rates at the beginning of an interaction. Under perfect monitoring, this is sufficient to reach a high and stable cooperation rate. However, repeated communication is important to maintain a high level of cooperation under imperfect monitoring, where players face additional uncertainty about the history of play.

Keywords: infinitely repeated games, monitoring, communication, cooperation, strategic uncertainty, prisoner's dilemma

JEL Classification: C72, C73, C92, D83

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1 Introduction

Many social and economic relationships are characterized by repeated interactions in which the behavior of partners is observable only with noise. Two examples are teamwork arrangements in which workers repeatedly produce goods for each other, and cartels with repeated price-setting by its members. How much effort a worker exerts in the production of the good cannot be observed directly but only inferred from the good itself – a noisy signal (Sekiguchi, 1997; Compte and Postlewaite, 2015). Likewise, whether or not other cartel members stick to a collusive agreement cannot be observed directly but only inferred from noisy signals like own sales in Stigler's (1964) or the market price in Green and Porter's (1984) seminal treatments of oligopolies. The former is the classic example for imperfect private monitoring – own sales can be observed only by the firm itself; the latter is the classic example for imperfect public monitoring, the market price being publicly observable.

Sustaining cooperation under imperfect monitoring has been the central topic in the theory of infinitely repeated games for the last three decades. This literature identifies communication as a key factor (see, e.g., Matsushima, 1991; Compte, 1998; Obara, 2009; Awaya and Krishna, 2016). However, empirical evidence that allows to answer the question if communication is particularly important under imperfect monitoring compared to perfect monitoring is so far missing in the literature. This is unfortunate not only from a scientific but also from a policy perspective as evidence of cartel communication is an important source of evidence for antitrust authorities. Hence, it is important to know if communication is necessary and, if so, how much of it is needed to sustain a collusive agreement. Several experimental studies with perfect monitoring have demonstrated that the mere existence of cooperative equilibria is by no means sufficient for the emergence of cooperation (see, e.g., Dal Bó, 2005; Blonski et al., 2011; Breitmoser, 2015; Dal Bó and Fréchette, 2018). Therefore, it is important to learn from data and not only from theory how communication affects cooperation and how this depends on the monitoring structure. As many important variables, such as private signals and communications, cannot be observed in the field, we design a laboratory experiment, which allows us to study this interaction in a tightly controlled setting.[1]

Our laboratory experiment follows a (3×3) design varying both the communication and the monitoring structure of the game. We study the following communication structures: (i) no communication; (ii) pre-play communication,

[1]Most cartel communication is not documented as such documents could be used as evidence in legal cases. See Genesove and Mullin (2001), Andersson and Wengström (2007), and Cooper and Kühn (2014) for further discussion and examples of cartel cases.

where subjects can chat with their partner before the first round of an interaction; and (iii) repeated communication, where subjects can chat with their partner before every round of the interaction. The second treatment variable is the monitoring structure. We study (i) perfect monitoring, (ii) imperfect public montoring, and (iii) imperfect private monitoring. The game that we ask subjects to play is an indefinitely repeated noisy prisoner's dilemma, similar to that studied theoretically by Sekiguchi (1997) and Compte and Postlewaite (2015), and experimentally, but without communication, by Aoyagi et al. (2018). In this variant of the prisoner's dilemma, signals are independent conditional on actions. Payoffs depend on own actions and received signals, which are noisy reflections of the other player's actions. Under perfect monitoring, signals and actions are observed; under imperfect public monitoring, sent and received signals are observed; and under private monitoring, only the received signals are observed.

In their comprehensive review of experimental studies of repeated games without communication, Dal Bó and Fréchette (2018) show that the robustness of cooperation to strategic uncertainty is a good predictor for cooperation under perfect monitoring (see also Blonski et al., 2011; Breitmoser, 2015). We extend their measure of robustness to strategic uncertainty – the basin of attraction for playing a defective strategy – to the imperfect monitoring cases. According to this measure, robustness to strategic uncertainty is low in all of our treatments and lower in the treatments with imperfect monitoring than in those with perfect monitoring. Pre-play communication might reduce strategic uncertainty and thus increase cooperation rates. Under imperfect monitoring, full cooperation is not possible in equilibrium and simple grim-trigger strategies lead to lower efficiency than more lenient and forgiving strategies. Bad signals can also occur after a history of full cooperation, which adds another type of uncertainty, as the history of play becomes becomes uncertain. If communication makes subjects' strategies more lenient and forgiving, this could boost cooperation rates. As we will see, the opportunity to communicate after the occurrence of a bad signal is important in this respect.

Our main results are the following: Cooperation rates are much higher in all pre-play communication treatments than in the no-communication treatments (Result 1). With repeated communication, cooperation rates are high and stable under all monitoring conditions, whereas they start high but decline rapidly over rounds with pre-play communication when monitoring is imperfect (Result 2). As bad signals occur with positive probability even after mutual cooperation under both imperfect monitoring structures, subjects need to coordinate their behavior for more contingencies than under perfect monitoring. While subjects do use pre-play communication to coordinate behavior (Result 3a), we also find for all three monitoring structures that most subjects merely coordinate on mutual cooperation in the first round. If successful, they continue to cooperate. While this is enough to lead to stable coordination under perfect monitoring, it is not when signals are noisy. To reduce uncertainty about the history of the game under imperfect monitoring, subjects use repeated communication phases to exchange private information (Result 3b), and to revisit their incomplete pre-play agreements. Our subjects' behavior becomes more lenient and forgiving with pre-play communication, and even more so with repeated communication, than in the absence of communication opportunities (Result 4). These results corroborate the importance of communication for high cooperation rates and of repeated communication for the stability of cooperation in noisy environments.

In summary, our results suggest that communication promotes cooperation by reducing two types of uncertainty. First, communication before the first round of the game reduces *strategic uncertainty*, or more precisely, the risk of meeting another player who follows a non-cooperative strategy in the game. Second, communication between rounds reduces *uncertainty about the history of play*, which stems from the noisy signals. Participants' play becomes more lenient and forgiving after bad signals, which facilitates relationships with high and stable cooperation rates.

Several laboratory experiments have been conducted to explore the effects of communication and test predictions from renegotiation-proofness refinements (Pearce, 1987; Farrell and Maskin, 1989) in experiments without noise (Andersson and Wengström, 2012; Fonseca and Normann, 2012; Cooper and Kühn, 2014) or imperfect public monitoring (Embrey et al., 2013; Arechar et al., 2017). While they offer important insights, these experiments do not allow for a comparison of the use and the effects of communication across monitoring structures.[2] Moreover, we are not aware of any previous empirical study of communication under private monitoring. Given the important role that communication plays for this monitoring structure in the theoretical literature, this is quite surprising. Our study makes a first step to fill these gaps, and provides novel insights into how communication reduces uncertainty

[2]Camera et al. (2013) study communication in a setting with random re-matching within groups after every round of the repeated game. Kamei and Nesterov (2020) study endogenous reports of opponents' choices after a supergame to their next interactions partners. Wilson and Vespa (2020) study an indefinitely repeated version of a sender-receiver game (Crawford and Sobel, 1982). Another string of recent studies focus on communication and cooperation in various one-shot or finitely repeated games (Charness and Dufwenberg, 2006, 2010; Utikal, 2012; Fischbacher and Utikal, 2013; Camera et al., 2013; Cooper and Kühn, 2014; Cason and Mui, 2014, 2015; Landeo and Spier, 2015; Wang and Houser, 2019). The experimental literature on indefinitely repeated games with imperfect monitoring but without communication further includes the papers by Aoyagi and Fréchette (2009) and Fudenberg et al. (2012), who study public monitoring.

under all three monitoring structures.

The rest of the paper is structured as follows. In the next section, we present the game, the experimental design, the theoretical background and our research questions. We turn to the experimental results in Section 3. In Section 4, we discuss our key findings, before we state our conclusions in Section 5.

2 Theoretical Background and Experimental Design

2.1 Set-up

In the indefinitely repeated noisy prisoner's dilemma, two players interact with each other in indefinitely many rounds of an interaction, henceforth called a supergame. Let δ denote the fixed continuation probability after any given round. In every round, each of the two players can choose between two actions, C or D. After both players have chosen an action $a \in \{C, D\}$, a noisy process translates both actions into conditionally independent signals. Each signal $\omega \in \{c, d\}$ corresponds to the chosen action with probability $(1 - \epsilon)$. With probability ϵ an error occurs and the action is translated into the wrong signal (C to d and D to c). All aspects of this process, the conditional independence of signals as well as the probability of an error are common knowledge. The payoff π_i of player i from the current round is defined by player i's own action a_i and the signal of the other player's action ω_{-i}.[3] The left panel of Figure 1 shows the normalized expected stage-game payoffs of action profiles which take the noise into account. The upper right panel of Figure 1 shows the payoff in experimental currency units that a subject receives in a round of a supergame as a function of the action and the signal received about the other player's action. We use the same payoff structure, the same continuation probability of $\delta = 0.8$ and the same error probability of $\epsilon = 0.1$ in all treatments. These values translate into expected stage-game payoffs for actions depicted in the lower right panel, which can be normalized by substracting 19 from all payoffs and then dividing them by 8. Hence, $g = 1$ and $l = 2$ in the experiment.

With $g > 0$ and $l > 0$ the stage game has the form of a prisoner's dilemma. The restriction $1 + l > g$ prevents that coordinated switching between cooperation and defection yields a greater expected payoff than mutual cooperation. Both conditions are fulfilled with our parameters. We consider three different monitoring structures.

[3]This might reflect the interaction of two workers where each worker exerts low or high effort on the production of a good for the other worker, and where whether the good is useful for the partner or not is a noisy signal of effort (Sekiguchi, 1997). For an alternative but similar interpretation, see Compte and Postlewaite (2015).

Under perfect monitoring, each player i is informed about the actions $\{a_i, a_{-i}\}$ and the signals $\{\omega_i, \omega_{-i}\}$. Under imperfect *public* monitoring (Green and Porter, 1984), players cannot observe the action of the other player and the information set reduces to $\{a_i, \omega_i, \omega_{-i}\}$. Under imperfect *private* monitoring (Stigler, 1964), players also remain uninformed about ω_i, the signal the other player receives, as the information set reduces to $\{a_i, \omega_{-i}\}$. In addition to the three different monitoring conditions, we consider three different communication conditions. The benchmark case is that of *no communication.* In the *pre-play communication* condition, players can communicate before the first round of a supergame. In the *repeated communication* condition, players additionally enter a communication stage before each of the following rounds.

Figure 1: The Stage-Game

	C	D
C	1,1	$-l$,1+g
D	1+g,$-l$	0,0

	c	d
C	30	0
D	37	17

	C	D
C	27,27	3,35
D	35,3	19,19

Notes: The payoffs depicted in the right panel are in experimental currency units. The exchange rate was 50 ECU = EUR 1. Subjects saw both representations of the stage-game at all times when making their decisions.

We choose open chat as the mode of communication to avoid reducing the potential roles that communication might play. Free-form communication is also the most natural type and allows us to study its use and content.

2.2 Procedural Details

To keep the length of the supergames constant between treatments, we generate two sequences of supergames beforehand using a series of random numbers to determine the length of each supergame.[4] Both sequences are implemented for all treatments in

[4] We use the Stata random number generator with seeds 1 and 2 to create two series of uniformly distributed random numbers between 0 and 1. The first supergame had x rounds if the xth random

different sessions. At the end of every round of a supergame, subjects receive feedback about their earnings and additional information which allows them to (imperfectly) monitor the other player's decisions. The realized random number, which determines whether the supergame continues or not, is also displayed at the end of each round, and could thus be used as a public randomization device. To allow for learning, each participant in our experiment plays seven supergames with different partners. The matching proceeds as follows: we divide the subjects of an experimental session into matching groups of 8–12 subjects. For the first supergame, each subject is then randomly matched with another participant from their matching group. After the termination of a supergame, participants are re-matched with a new partner from their matching group who they did not interact with before. Subjects were informed about this matching procedure. In the communication treatments, subjects can exchange messages via a chat box. In the *pre-play communication* condition, the chat can be used by both players of the current match to exchange messages for 120 seconds. In the *repeated communication* condition, players additionally enter a communication stage before each of the following rounds where they can exchange messages for 40 seconds. Before the start of all treatments, participants had to answer control questions to check their understanding of the instructions (see Appendix D).

We collected data from three matching groups per sequence-treatment combination, that is from six matching groups per treatment. A total of 458 participants (average age 22, 60% female) participated between January and April of 2016 in the 24 sessions of our experiment at the LakeLab of the University of Konstanz.[5] The average earning was EUR 18, and the session length 75–90 minutes. Table 1 summarizes the distribution of sessions, subjects, and matching groups across experimental treatments and depicts the average size of a matching group as well as the average length of the supergames.

number was less than or equal to 0.2 and all previous numbers were greater than 0.2. Then the first x random numbers were deleted and the following numbers determined the length of the second supergame, and so forth. We used the two series to determine the lengths of seven supergames each. The length of the two resulting sequences of supergames are: SQ1 (11 3 5 1 5 2 11) and SQ2 (2 5 5 7 13 4 4). Average supergame lengths were moderately longer than the expected length of five of the underlying geometric distribution (SQ1: 5.4; SQ2: 5.7). Random termination is the most widely used way of implementing infinitely repeated games in the lab. See Fréchette and Yuksel (2017) for a study of other implementation methods.

[5]The experiment was programmed in z-Tree (Fischbacher, 2007) and subjects were recruited via ORSEE (Greiner, 2015).

Table 1: Summary Statistics for the Experimental Treatments

	Perfect			Public			Private		
	No	Pre	Rep	No	Pre	Rep	No	Pre	Rep
Sessions	2	2	2	3	3	4	2	3	3
Matching groups	6	6	6	6	6	6	6	6	6
Subjects	52	54	54	48	52	50	48	50	50
Mean group size	8.7	9.0	9.0	8.0	8.7	8.3	8.0	8.3	8.3
Mean supergame length	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6

Notes: Mean group size indicates the average number of subjects who formed a matching group. The modal size of a matching group was eight (44 groups). Seven groups were of size 10 and three of size 12. Subjects did not know the exact size of their matching group. Mean supergame length indicates the average number of rounds of all supergames played in a treatment.

2.3 Equilibria and Strategic Uncertainty

Equilibria Table 2 gives an overview of the types of cooperative equilibria that have been described in the literature and that exist for our experimental parameters.[6]

Table 2: Cooperative Equilibria and Stability

	repeated	pre-play	no
private	**TT**,BB,T1BF	BB,T1BF	BB,T1BF
public	**PS-SPE**,BB,T1BF	**PS-SPE**,BB,T1BF	**PS-SPE**,BB,T1BF
perfect	**PS-SPE**,BB,M1BF	**PS-SPE**,BB,M1BF	**PS-SPE**,BB,M1BF

Notes: PS-SPE: pure-strategy SPE, BB: belief-based (mixed-strategy) equilibria, M1BF: memory-one belief-free equilibria (in behavior strategies), T1BF: threshold memory-one belief-free equilibria, TT: truth-telling equilibria. The equilibria in boldface are evolutionarily-stable equilibria (Heller, 2017).

The conditions for the existence of cooperative pure-strategy subgame-perfect equilibria (PS-SPE) under perfect and imperfect public monitoring are well-known results of the theoretical literature (see, e.g., Mailath and Samuelson, 2006). With perfect monitoring, players can condition on the intended actions and support full cooperation using pure strategies, such as the grim-trigger strategy, if the continuation probability δ is greater or equal to $\delta^{SPE} = \frac{g}{1+g}$. With public monitoring and strategies condi-

[6]Trivially, mutual defection in every round of the repeated game is an equilibrium under all three monitoring conditions.

tioning only on the public signals, the stricter condition $\delta^{SPE} = \frac{g}{1-\epsilon+(1-\epsilon)^2 g}$ applies. Both conditions are fulfilled in our experiment, as $\delta = 0.8 > \frac{1}{1-0.1+(1-0.1)^2} > \frac{1}{1+1}$. The second condition implies reduced efficiency under imperfect public monitoring since defection occurs with positive probability on the equilibrium path. Lenient and (or) forgiving strategies, which do not start punishment immediately after the first bad signal or punish for fewer rounds as compared to the grim-trigger strategy, counteract the efficiency loss caused by the monitoring imperfections.

With private monitoring, cooperation cannot be supported by a subgame-perfect equilibrium based on pure strategies and players have to rely on mixed (Bhaskar and Obara, 2002; Sekiguchi, 1997) or behavior strategies (Ely and Välimäki, 2002; Ely et al., 2005; Piccione, 2002), giving rise to belief-based (BB) or belief-free equilibria (BF).[7] Players, who follow a behavior strategy, randomize between actions (C and D) in each round. The probabilities with which actions are chosen depend on the history. A strategy that only considers the latest observed signals and actions is called a memory-one belief-free (M1BF) strategy. The theoretical literature has largely focused on this type of behavior strategy (Ely and Välimäki, 2002; Piccione, 2002; Heller, 2017). An M1BF strategy under perfect monitoring would, for example, specify the five probabilities to cooperate (i) at the beginning of the supergame (after the empty history), (ii) after mutual cooperation CC in the previous round, (iii) after mutual defection DD, (iv) after CD and (v) after DC.[8,9] For the existence of M1BF equilibria, the continuation probability δ has to be greater or equal to a threshold δ^{BF}. If $\delta > \delta^{BF}$ a continuum of equilibria exist. The cooperation probabilities (ii)-(v) are exactly pinned down if $\delta = \delta^{BF}$. The cooperation probability (i) at the start of the game is always a free parameter. We call the equilibria with the cooperation pattern at the threshold T1BF equilibria. The resulting T1BF equilibrium strategies are a lenient version of tit-for-tat with cooperation probabilities $\sigma = (\sigma_\emptyset, 1, 0.5, 1, 0)$ conditional on the memory-one action-signal histories $(\sigma_\emptyset, Cc, Cd, Dc, Dd)$.

[7]Under private monitoring, players lack a public history of play to coordinate behavior in such a way that defection is the mutual best-response after a defection signal. Instead, a player who believes that the other player is still in the cooperative state and obtains a defection signal would want to ignore the defection signal to keep the partner in the cooperative state. The incentive to ignore defection signals undermines the necessary responsiveness of the cooperative strategy to defection.

[8]Under imperfect monitoring, the five states upon which the cooperation probabilities depend would be the first round and the four different possible signal–action combinations of the previous round. Under public-monitoring, M1BF could condition either on the public signals or the private signal, whereas under private monitoring only the latter is possible.

[9]Semi-grim strategies are a sub-class of M1BF strategies with the property that the probabilities of cooperation after CD and DC are the same. Breitmoser (2015) provides empirical evidence that under perfect monitoring, behavior on both the aggregate, and the individual level is well summarized by semi-grim strategies.

With our experimental parameters, cooperative mixed-strategy and belief-free equilibria exist under all three monitoring conditions. The parameters rule out that the set of M1BF equilibria is different between public and private monitoring since no M1BF equilibria exists in which strategies condition on the public signals, and so only M1BF which condition on the private signal (and the player's own action) can be played in equilibrium. To pinpoint the behavior of M1BF strategies, we set $\delta = \delta^{BF}$.

When players can communicate repeatedly under private monitoring, private signals can be reported, which creates a quasi-public history and thereby allows for simpler and more stable equilibria (Heller, 2017). Such *truth-telling* equilibria (TT) can exist if certain revelation constraints are fulfilled (Compte, 1998). The punishment stage is constructed in a way that makes every player indifferent between truthfully reporting the private signal and misreporting or staying silent. This requires that no player benefits or suffers from entering the punishment phase in which the other player is punished. The stability of these equilibria stems from the fact that they provide strict incentives for cooperation, whereas the other equilibrium constructions by Sekiguchi (1997), Piccione (2002), or Ely and Välimäki (2002) do not (see Heller, 2017).[10] In the experiment, we are interested in whether subjects use communication to transform the game with private monitoring into one with quasi-public signals. Our parameters assure that such truth-telling equilibria exist. They also assure the existence of renegotiation-proof cooperative equilibria under perfect and public monitoring.[11]

The equilibria in boldface Table 2 are evolutionarily-stable equilibria (Heller, 2017). Note that there are no stable cooperative equilibria without repeated communication under private monitoring. This is different for the other two monitoring conditions and the reason for the special role that communication plays under private monitoring in the theoretical literature.

Strategic Uncertainty Experimental evidence suggests that the SPE-existence conditions are necessary but insufficient to observe high levels of cooperation in the indefinitely repeated prisoner's dilemma with perfect monitoring (see Dal Bó

[10] If signals are correlated, which is not the case in our set-up, *truthful communication* equilibria with strict revelation constraints can be constructed (Kandori and Matsushima, 1998), and higher levels of efficiency might be achievable by exploiting the informational content of the correlation (Awaya and Krishna, 2016). Awaya and Krishna (2016) study a set-up with a fixed discount rate, whereas other studies have focused on proving Folk theorems (Ben-Porath and Kahneman, 1996; Compte, 1998; Kandori and Matsushima, 1998; Obara, 2009).

[11] In Appendix A, we provide the technical details behind the results in this section. We derive the δ^{BF} threshold and present a truth-telling equilibrium for the private monitoring as well as renegotiation-proof equilibria for the perfect and public monitoring conditions.

and Fréchette, 2018). An obstacle for the emergence of cooperation is that mutual defection remains an equilibrium of the repeated game when cooperative equilibria exist. Without the possibility to coordinate strategies, the uncertainty about the strategy choice of the other player makes cooperation risky. Dal Bó and Fréchette (2011) propose the basin of attraction of defection (BAD) as a predictor for cooperation. In a mixed population of grim-trigger (GRIM) and always-defect (ALLD) players, the BAD is defined as the share of GRIM which makes players indifferent between the two strategies.

In contrast to the SPE condition, the BAD also takes the *sucker* payoff $-l$ into account. The BAD is inversely related to the frequency of cooperation observed in laboratory experiments with perfect monitoring (Dal Bó and Fréchette, 2018).[12]

The role of strategic uncertainty for the emergence of cooperation under imperfect monitoring is not well understood. We derive BADs under public and private monitoring. For this purpose, we use variants of GRIM that are very robust to strategic uncertainty as they defect forever after a bad signal (see Subsection A.1 in the appendix). Lenient or forgiving versions of GRIM are more vulnerable to defection and result in higher values of the BAD. This highlights the trade-off between the efficiency of cooperative strategies and their robustness to strategic uncertainty under imperfect monitoring. The BADs under public and private monitoring suggest that, in the frequently studied cases $g = l$ and $1 + g = l$ (as in the experiment), the negative impact of strategic uncertainty on cooperation is amplified under imperfect monitoring. With our experimental parameters, the BAD is 0.4 under perfect monitoring 0.76 under imperfect public and 0.77 under imperfect private monitoring.

We expect low levels of cooperation under imperfect monitoring and a slightly higher but still low level under perfect monitoring. These expectations are formed on the basis of our analysis of the BAD and the cooperation rates in other studies with different levels of BAD as reviewed by Dal Bó and Fréchette (2018). This leaves scope for higher cooperation levels in the communication treatments.[13]

[12] Blonski et al. (2011) use an axiomatic approach to derive a critical value of δ for the emergence of cooperation which is also related to strategic uncertainty. This δ-threshold turns out to be the value of δ that makes cooperation risk-dominant in the sense of Harsanyi and Selten (1988).

[13] Our no-communication treatments complement the treatments of Aoyagi et al. (2018) where the BAD takes lower values of 0.03 (0.06), 0.15 (0.53), 0.13 (0.43) for perfect, public, private monitoring, in their low (high) noise treatment, respectively.

2.4 Research Questions and Predictions

We state three main research questions. As we explain below, we expect different answers to them for the three monitoring regimes based on the different existing sets of equilibria and their complexity.

Question 1: *Does pre-play communication increase cooperation rates?*

Prediction 1: *We expect a positive effect for perfect and imperfect public monitoring, while the absence of stable cooperative equilibria under private monitoring suggests no such effect for this monitoring condition.*

According to our measure, robustness to strategic uncertainty is low in our parametrization in all three monitoring structures. However, while strategic uncertainty has been shown to matter, at least under perfect monitoring without communication, it has also long been recognized that communication can help coordination (e.g., Cooper et al., 1992; Rabin, 1994; Ellingsen and Östling, 2010) and that coordination on a cooperative equilibrium would decrease strategic uncertainty (Kartal and Müller, 2018). Therefore, we expect pre-play communication to facilitate coordination and thereby to lower strategic uncertainty. However, while efficient equilibria are easy to find in the perfect monitoring case, this task becomes a lot more difficult under imperfect public monitoring. Even if players cooperate, bad signals occur with positive probability and thus players will likely have to enter a phase of punishment at some point. For this reason, simple punishments, such as "defect forever" after a bad signal, are inefficient and players have to coordinate on lenient or forgiving strategy profiles to reap a greater share of the potential gains of cooperation. With private monitoring it becomes even more complicated. The equilibria that have been found and analyzed in the literature are all mixed (or behavior) strategy profiles, which are extremely hard to find, and coordination on these equilibria seems highly unlikely (Compte and Postlewaite, 2015).

So, while we expect a positive effect of pre-play communication on cooperation rates for perfect and public monitoring, compared to the no communication treatments, the effect might be more pronounced under perfect monitoring than under public monitoring. Under private monitoring, there might be no effect at all, given the absence of stable cooperative equilibria without repeated communication (Heller, 2017).

Question 2: *Is repeated communication important for stable cooperation over rounds?*

Prediction 2: *As stable cooperative (truth-telling) equilibria under private monitoring only exist with repeated communication, the positive effect should be largest in this condition. We expect pre-play communication to be sufficient for high cooperation under perfect monitoring and hence no additional benefit from repeated communication. For imperfect public monitoring, the additional uncertainty about the history of play as compared to perfect monitoring lets us expect higher and more stable cooperation with repeated communication.*

For the case of private monitoring, Heller (2017) shows that only defection can be sustained, by any of the mechanisms discussed in the literature, as an equilibrium that survives the evolutionary-stability criterion. He further shows that if players can communicate repeatedly, there typically are cooperative *truthful communication equilibria*, which are evolutionarily stable. In our parametrization, this is the case. Moreover, stable cooperative equilibria also exist without communication under public and perfect monitoring. We would thus expect a large positive effect of repeated communication on cooperation under private monitoring, whereas high cooperation is already achievable in stable equilibria without communication under public and perfect monitoring. However, repeated communication might have an additional benefit also under imperfect public monitoring where coordination on an efficient equilibrium is more difficult than under perfect monitoring, too, and players might need to revisit incomplete agreements after round one, in particular when a bad signal occurs for the first time.

Question 3: *What are the mechanisms through which communication affects behavior?*

Prediction 3: *We expect attempts to coordinate behavior through communication in order to reduce strategic uncertainty. For private monitoring, truthful sharing of private information is part of any stable cooperative equilibrium; hence, we also expect to find it in our data.*

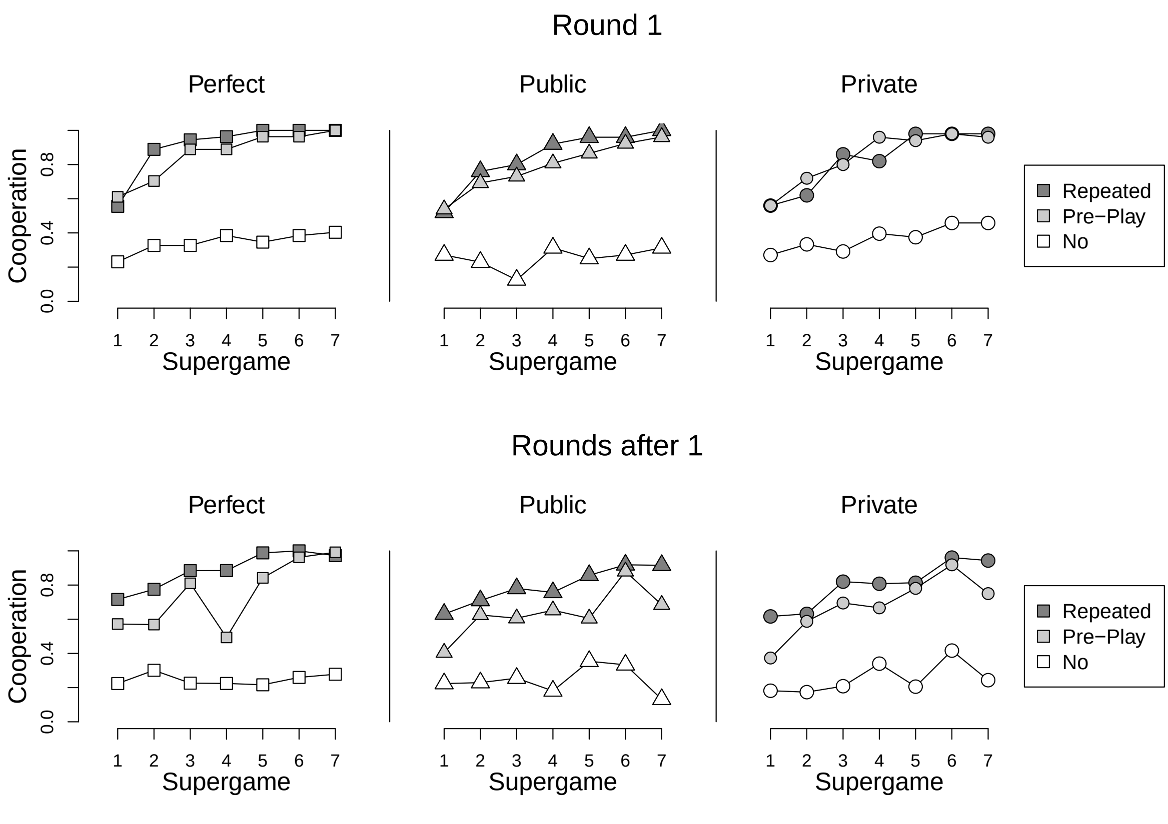
We expect pre-play communication to be used for coordination to reduce strategic uncertainty. Under imperfect private monitoring, we expect a very specific and important role for repeated communication. The sharing of private information is the key role ascribed to communication under private monitoring in the recent theoretical literature (e.g., Compte, 1998; Kandori and Matsushima, 1998; Awaya and Krishna, 2016; Heller, 2017). The reduction of uncertainty regarding the history of play is important in this context, which could also play a role under imperfect public monitoring.

3 Experimental Results

A common result in the experimental literature is that participants need a few supergames to adapt their behavior to the experimental environment (e.g., Dal Bó, 2005). Figure 2 shows that participants generally become more cooperative over the course of the experiment. With communication, most participants eventually manage to coordinate on cooperation in round one under every monitoring condition.

For cooperation after round one, we observe differences in the effect of pre-play and repeated communication that persist until the very last supergame in the treatments with imperfect monitoring. To acknowledge learning over supergames, we will report the main results for all supergames as well as the last three supergames, when participants' behavior has largely stabilized.

Figure 2: Evolution of Cooperation over Supergames



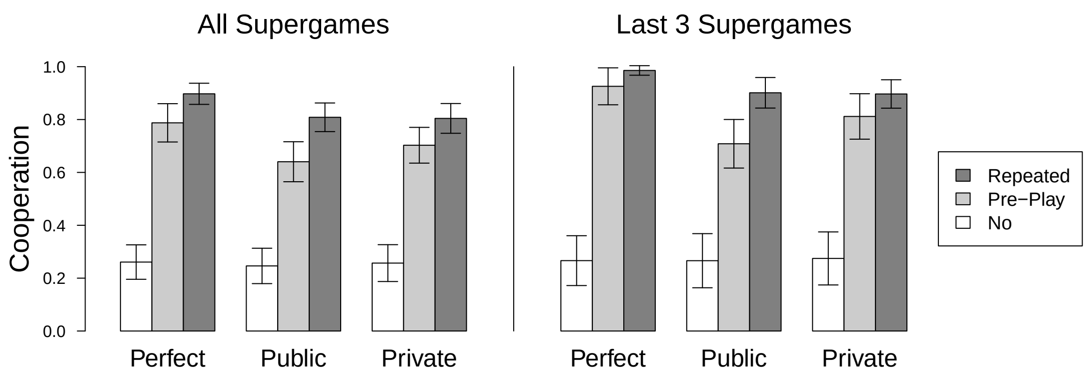
Notes: The upper three panels display average cooperation rates in round one over the seven supergames. The lower three panels display average cooperation rates after round one over the seven supergames.

3.1 Cooperation

Figures 3 and 4 present two measures of cooperation: the average frequency of cooperation, and the average stability of cooperation over rounds. We provide answers to Questions 1 and 2 based on these two figures. The reported p-values, p_{all} (p_{l3}), result from one-sided t-tests of regression coefficients with two-way clustered standard errors at the participant-match level (Cameron et al., 2011), including all (the last three) supergames.

Question 1: *Does pre-play communication increase cooperation rates?*

Figure 3: Average Frequency of Cooperation Across Treatments



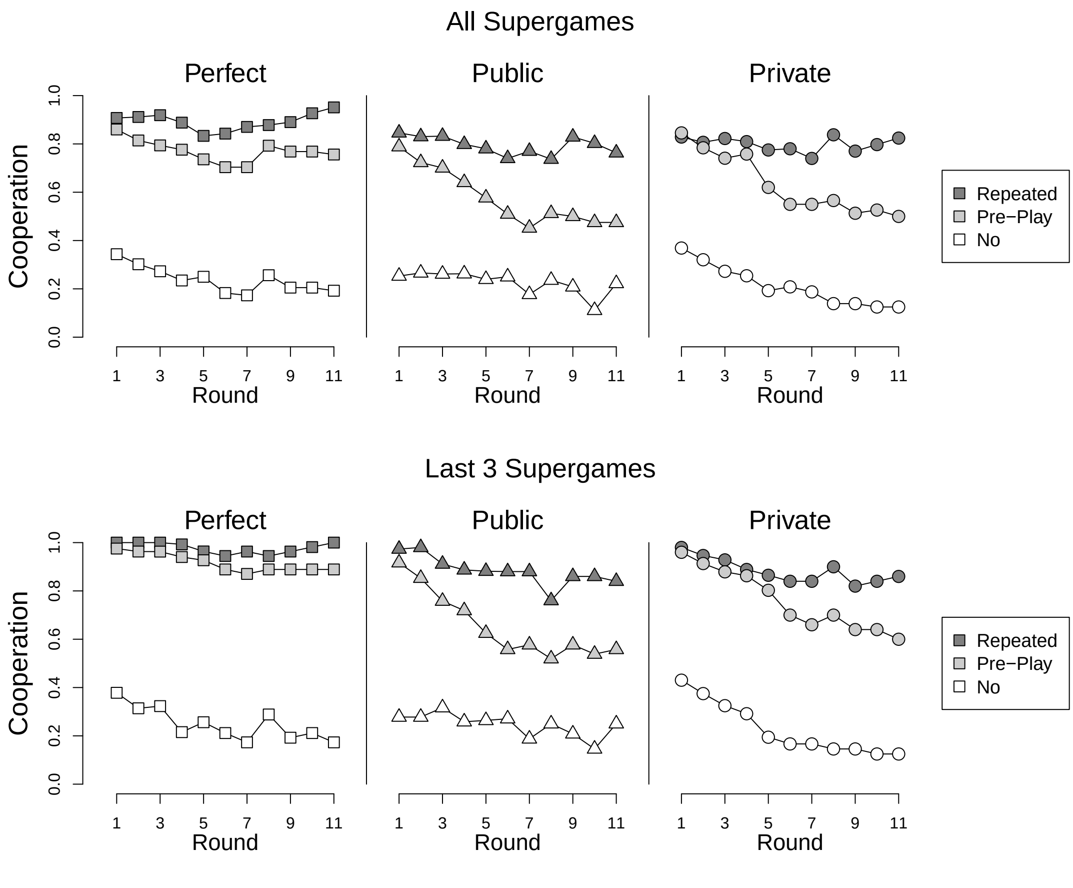
Notes: Bars show the relative frequency of cooperation. Whiskers depict 95% confidence intervals based on clustered standard errors of the mean (clustered on subject and match).

Figure 3 shows the average frequency of cooperation across the nine experimental treatments. The depicted levels of cooperation mostly reflect the amount of cooperation observed in the first four rounds, where each participant contributes two or three observations depending on the length of the supergames played. The bars indicate that the mean cooperation level in the treatments with pre-play communication is substantially higher compared to the treatments without communication ($p_{all} < 0.01$, $p_{l3} < 0.01$). The effect of pre-play communication on the average cooperation rate is largest under perfect monitoring. Under perfect monitoring, the average cooperation rate is 53 percentage points higher with pre-play communication (66 ppt, last three sg). Under imperfect public monitoring, the average cooperation rate is 39 percentage points higher with pre-play communication (44 ppt, last three sg). Under imperfect private monitoring, the average cooperation rate is 44 percentage points higher with pre-play communication (54 ppt, last three sg). Difference-in-differences tests indicate that the effect of pre-play communication is larger under perfect compared to imperfect public monitoring (perfect vs. public: $p_{all} = 0.04$, $p_{l3} < 0.01$; perfect vs. private: $p_{all} < 0.12$, $p_{l3} = 0.06$).

Result 1: *Pre-play communication leads to a large increase in cooperation rates under all three monitoring structures. The effect is largest under perfect monitoring.*

Question 2: *Is repeated communication important for stable cooperation over rounds?*

Figure 4: Stability of Cooperation over Rounds



Notes: The graph depicts the frequency of cooperation over rounds averaged over all supergames (top) and the last three supergames (bottom). The average number of observations per treatment decreases from 355 (153) in round one to 77 (51) in round eleven because of the different lengths of the supergames (see footnote 16).

Figure 3 also shows that the mean cooperation level in treatments with repeated communication is higher compared to the treatments with pre-play communication (perfect: $p_{all} < 0.01$, $p_{l3} = 0.02$; public: $p_{all} < 0.01$, $p_{l3} < 0.01$; private: $p_{all} = 0.01$,

$p_{l3} = 0.04$). The size of the effect is largest under public monitoring where the mean cooperation level is 17 percentage points higher (19 ppt in the last three sg) with repeated communication. Difference in differences tests indicate that the effect of repeated communication is not significantly different under public monitoring (public vs. perfect: $p_{all} = 0.49$, $p_{l3} = 0.34$; public vs. private: $p_{all} = 0.18$, $p_{l3} = 0.14$).

Figure 4 shows the mean cooperation level over rounds. The mean cooperation level is depicted up to round 11 to assure that each participant contributes at least one observation to every round. The slopes of the lines indicate that the decline of cooperation over rounds varies between treatments. With communication, the cooperation rate in round one is around 85% (95% in the last three supergames) and does not differ much between the monitoring structures. In the treatments with repeated communication, the cooperation rate is generally more stable over rounds compared to the treatments with only pre-play communication. The differences in the stability of cooperation between the repeated and the pre-play communication treatments are more pronounced under imperfect monitoring. Under imperfect monitoring with pre-play communication, the average cooperation rate is around 30 percentage points lower after 10 rounds without communication opportunities, but at most 13 percentage points lower with repeated communication. In contrast, if monitoring is perfect, the average cooperation rate only reduces by around 10 percentage points with pre-play communication, and does not decline at all with repeated communication. Without communication, cooperation declines over the rounds of a supergame at a similar rate under all three monitoring structures.

To test whether the stability of cooperation over rounds differs between the pre-play and repeated communication treatments, we use the data of both treatments and regress cooperation on a dummy for the repeated communication treatment, the round number, and the interaction of the two variables. We test whether the coefficient of the interaction term is positive and significantly different from zero using two-way clustered standard errors for participant and match. The results indicate that cooperation is more stable with repeated communication if monitoring is imperfect (perfect: $p_{all} = 0.10$, $p_{l3} = 0.17$; public: $p_{all} < 0.01$, $p_{l3} = 0.01$; private: $p_{all} < 0.01$, $p_{l3} = 0.02$). If we compare the treatments with pre-play communication, we find that the decline of cooperation over rounds is significantly stronger under imperfect monitoring (perfect vs. public: $p_{all} < 0.01$, $p_{l3} < 0.01$; perfect vs. private: $p_{all} < 0.01$, $p_{l3} < 0.01$).[14] Finally, Figure 4 shows no differences in the stability of

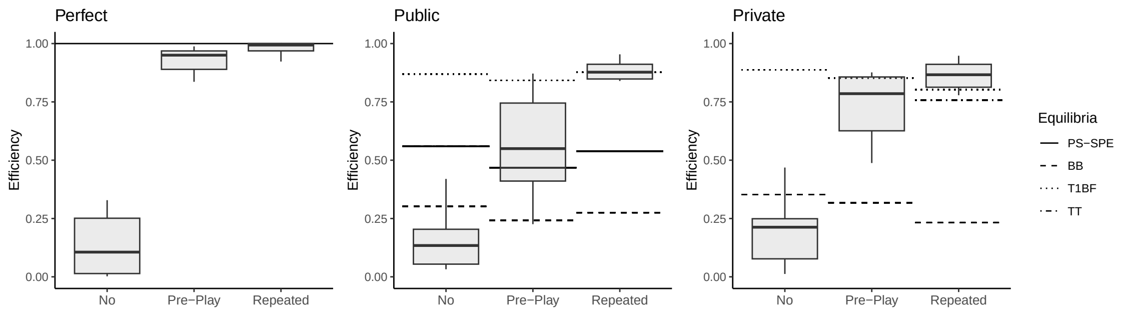
[14]The results are robust if we additionally include fixed effects for the supergame length in the regressions. Cooperation is more stable with repeated communication if monitoring is imperfect (perfect: $p_{all} = 0.10$, $p_{l3} = 0.16$; public: $p_{all} < 0.01$, $p_{l3} = 0.01$; private: $p_{all} < 0.01$, $p_{l3} = 0.02$) and the decline of cooperation over rounds is significantly stronger under imperfect monitoring

cooperation between the perfect and the imperfect monitoring structures without communication.

Result 2: *While pre-play communication is sufficient for reaching a high and stable cooperation rate under perfect monitoring, repeated communication is important for stable cooperation under both imperfect monitoring structures.*

Efficiency In Figure 5, we relate the observed cooperation rates in the experiment to the equilibria discussed in Section 2.3. For this purpose we compute a measure of efficiency relative to simulated mutual cooperation in all rounds. We simulate cooperation rates in different cooperative equilibria using the noise realization in the experiment and compare their efficiency to the efficiency of the observed rates in our matching groups.[15]

Figure 5: Efficiency (last 3 supergames)



Notes: Boxplots show the distribution of relative efficiency (matching group averages) over the last three supergames. The efficiency of the payoffs is depicted relative to simulated symmetric play of ALLD (0 on y-axis) and simulated symmetric play of ALLC (1 on y-axis). The horizontal line within each box indicates the median, the boxes the interquartile range, and the whiskers the minimum and maximum efficiencies. The efficiency of the equilibria is computed based on 1000 simulation runs using the actual implementation of the noise in each treatment (that is, whether the correct or the incorrect signal is transmitted in a certain round). Note that the larger differences between the matching groups in the imperfect monitoring treatments, as compared to the perfect monitoring treatments, is partly due to this noise.

The comparison reveals that efficiency under imperfect monitoring is far lower without communication, and also with pre-play communication, than what is theoretically possible in cooperative equilibria. The same holds for perfect monitoring without communication. With pre-play communication under perfect monitoring, and with repeated communication under all three monitoring conditions, efficiency is close to the most efficient equilibria in the last three supergames.

(perfect vs. public: $p_{all} < 0.01$, $p_{l3} < 0.01$; perfect vs. private: $p_{all} < 0.01$, $p_{l3} < 0.01$).

[15]We simulate cooperation rates for the most efficient pure-strategy-SPEs, for the most efficient M1BF equilibrium (the most efficient T1BF equilibrium), belief-based equilibria (mixing GRIM and ALLD), and the truth-telling equilibrium described in Appendix A.3.3.

Conditional Cooperation Rates Table 3 offers a detailed picture of when players cooperate in the nine different treatments. The upper part shows the frequency of cooperation conditional on five different histories of play - focusing on information about the previous round. The first history is the empty information set ($\emptyset$) in round one of a supergame. For perfect monitoring, the four remaining histories are the possible action combinations $\{a_i, a_{-i}\}$ of the previous round. For imperfect monitoring, we focus on the four possible action-signal combinations $\{a_i, \omega_{-i}\}$.[16] To test for significant differences between treatments, we use one-sided t-tests of logistic regression coefficients with standard errors clustered on participant and match.

Table 3: Conditional Cooperation Rates

	Perfect			Public			Private		
history	No	Pre	Rep	No	Pre	Rep	No	Pre	Rep
cooperation rate									
$\emptyset$	0.34	0.86	0.91	0.25	0.79	0.85	0.37	0.85	0.83
CC/Cc	0.94	0.98	0.98	0.86	0.88	0.94	0.91	0.94	0.94
CD/Cd	0.29	0.29	0.43	0.42	0.58	0.69	0.36	0.51	0.61
DC/Dc	0.28	0.33	0.43	0.17	0.35	0.46	0.16	0.42	0.56
DD/Dd	0.09	0.07	0.32	0.11	0.18	0.33	0.07	0.13	0.38
absolute frequency									
$\emptyset$	364	378	378	336	364	350	336	350	350
CC/Cc	192	1290	1496	162	807	1085	210	889	1063
CD/Cd	244	70	47	225	273	208	184	238	223
DC/Dc	244	70	47	309	221	129	264	171	131
DD/Dd	984	296	136	840	359	176	878	300	185

Notes: The upper part of the table shows the frequency of cooperation after five different histories of the last round. The first history is the empty history ($\emptyset$) in round one of a supergame. For perfect monitoring, the remaining four histories represent four possible combinations of last round actions $\{a_i, a_{-i}\}$. For imperfect monitoring, the remaining four histories are the action-signal combinations $\{a_i, \omega_{-i}\}$ of the last round. The lower part of the table shows the absolute frequency of the histories in each treatment. Data of all supergames is presented.

The first row of Table 3 shows that pre-play communication facilitates coordination on cooperation in the first round. Repeated communication opportunities further increase the frequency of cooperation by at most 6 percentage points (under public

[16]For perfect and public monitoring, the reported histories only represent a subset of the available information about the last round. Analyses of participants' strategies suggest that the behavior in these treatments is explained best by assuming that participants condition on the action profile under perfect monitoring, and the action-signal profile under public monitoring.

monitoring). The additional benefit of repeated communication is even smaller in the last three supergames (not reported here).

The frequencies reported in the second row of Table 3 can be interpreted as a measure for unjustified defection since most cooperative strategies cooperate after CC (Cc). The frequency of unjustified defection is one minus the frequency reported in the second row. Unjustified defection is generally rare across all treatments and does not substantially decrease when communication opportunities are available. An exception is public monitoring where unjustified defection is more frequent and does significantly decrease with repeated communication (6 ppt difference, $p < 0.01$).

The largest effect of communication on the probability to cooperate is observed after histories that indicate defection (rows 3-5). A comparison of the reported cooperation frequencies across the communication treatments shows that leniency towards defection (signals) shown in row three and forgivingness - the probability to return to cooperation after defection shown in row four and five - increase in the number of communication opportunities. In the treatments with imperfect monitoring, the additional increase of leniency and forgivingness with repeated communication is significant (all comparisons $p < 0.1$). With repeated communication opportunities, participants are 10-11 percentage points more lenient towards defection signals (11-14 ppt in the last three supergames), and 11-25 percentage points more likely to return to cooperation after defection (7-30 ppt in the last three supergames). We also find more mutual cooperation after wrong defection signals with repeated communication under imperfect monitoring by looking only at rounds in which both players jointly cooperated in the previous round and one player received a defection signal (public: 9 ppt, $p = 0.06$; private 11 ppt, $p = 0.07$).

3.2 Mechanisms

Question 3: *What are the mechanisms through which communication affects behavior?*

Communication Content We analyze the content of communication based on a classification of two independent raters. Our two raters made an average of 2.65 classifications into 72 sub-categories per participant-round observation, resulting in 18,678 and 18,984 classifications in total. To make the interpretation of the communication content easier, we collapse the 72 sub-categories into five main categories: *Coordination, Deliberation, Relationship, Information* and *Trivia*.[17] The

[17]See Tables B1 and B2 in Appendix B for the mapping of sub-categories to main categories, the frequency of occurrence of messages in the (sub-)categories and the average Cohen's κ (across

category *Coordination* includes all attempts by participants to coordinate behavior in future rounds. The category also includes implicit or explicit announcements of choices since such announcements could also be used to coordinate behavior. The category *Deliberation* includes all instances in which participants discuss choices or strategies. All content that concerns the relationship of a matched pair of participants is included in the category *Relationship*. The category also covers motivational talk and positive feedback that we find to be quite common. The category *Information* includes all statements that contain reports of actions, signals or payoffs from the current supergame, which cannot occur before round one. Our last main category, *Trivia*, contains content that is off-topic or classified as small talk by our raters. In contrast to the *Relationship* category, the content does not have an obvious relation to the game.

Table 4 reports the relative frequency of the five main categories in the last three supergames.[18] The frequencies are very similar when all supergames are considered (see Table B1, Appendix B). Overall, we observe that the frequencies of the categories in round one of the repeated communication treatments (column Rep-f) are similar to those of pre-play communication. This indicates that the communication phase before the first round is used similarly by the participants of the pre-play and repeated communication treatments.

Table 4: Frequency of Codings per Individual-Round Observation

	Perfect			Public			Private		
	Pre	Rep-f	Rep-l	Pre	Rep-f	Rep-l	Pre	Rep-f	Rep-l
Coordination	0.98	0.96	0.11	0.97	0.97	0.21	0.97	0.97	0.28
Deliberation	0.54	0.51	0.08	0.65	0.60	0.09	0.58	0.71	0.09
Relationship	0.12	0.19	0.21	0.24	0.15	0.33	0.29	0.17	0.31
Information	–	–	0.21	–	–	0.38	–	–	0.40
Trivia	0.96	0.99	0.68	0.91	0.93	0.58	0.83	0.99	0.60

Notes: Level of the analysis are individual-round observations. "Rep-f" (Rep-l) indicates the first (later) rounds in the repeated communication treatments. The data is from the last three supergames. A coding is considered as valid if both raters indicated the same category for a participant-round observation.

The category *Coordination* occurs in the vast majority of participant-round observations of the pre-play phase. Its relative frequency in the later rounds of the repeated

treatments) of all categories and sub-categories.

[18]The average Cohen's κ across treatments is above 0.7 for all five main categories, which indicates a high level of agreement between the two raters.

communication treatments is lower, which suggests that coordination predominantly occurs before the first round. The frequencies of the sub-categories of the *Coordination* category reveal that an initial suggestion to play CC is made by roughly half of all participants, and in almost all pairs of participants in the communication treatments.

Our raters indicate content related to *Deliberation* in roughly every second participant-round observation with pre-play communication. In the repeated communication treatments, content related to deliberation becomes less frequent after round one. Content related to the category *Relationship* is more frequent under imperfect monitoring. In contrast to the categories *Coordination* and *Deliberation*, the category *Relationship* does not become less frequent after round one. Content falling in the *Information* category is most frequent with repeated communication under imperfect monitoring. In order to assess whether participants report private information, we will look at data from sub-category level in the following. The *Trivia* category is always among the most frequent in all treatments.

Strategic Uncertainty The probability of facing a non-cooperative player is much lower in the communication treatments than in the no-communication treatments. Most likely, communication also reduces subjective strategic uncertainty, that is, the players' beliefs in their opponents' cooperativeness. To understand how this is achieved, we relate the content of communication to the behavior observed in the experiment. It is important to stress that, since the content of communication is endogenous, the results presented in the following reflect correlations between the content of communication and behavior.

We find that agreements to cooperate are associated with a higher frequency of mutual cooperation in round one. If participants agree to cooperate, the frequency of mutual cooperation in round one is 35 percentage points higher under perfect monitoring, 49 ppt higher under public monitoring, and 38 ppt higher under private monitoring (data of all supergames). The differences are smaller in the last three supergames, in which nearly all pairs start with cooperation. Participants who agree to cooperate in round one actually cooperate in 95% of all cases. This appears to be the key channel to reduce strategic uncertainty. Some participants also suggest DD but this occurs at a frequency below 10% in all treatments. More complex suggestions than CC or DD for coordinated play or explicit or implicit threats of punishment in the case of defection occur at very lower frequencies (even lower than DD).

Uncertainty about the History of Play The mere coordination on behavior in the first round means that most pairs of participants enter the game without an agreed-upon plan for how to deal with defections or bad signals in the imperfect monitoring treatments. It seems plausible that this incomplete coordination on an efficient equilibrium explains the decline in cooperation in the pre-play communication treatments under imperfect monitoring.

To shed more light on this, we exploit the randomness of the signals to investigate what happens under imperfect monitoring when participants have the opportunity to talk repeatedly after a wrong defection signal. We compare the communication after a random interruption of a perfectly cooperative history (crisis) to the communication after an uninterrupted perfectly cooperative history (when things go well) in Table 5 (see Table B4, Appendix B for all supergames). Participants make more proposals regarding future play (mostly CC) in the crisis situations than when things go well, suggesting that the first defection signal generates some demand for (re)coordination. The frequency of communication related to deliberation and the relationship of the matched participants does not change in crisis situations. However, an analysis of the subcategory level reveals that the tone of the communication about the relationship of the matched participants is negatively affected by the first defection signal. We see an increase in the frequency of expressions of disappointment, and an increase in the frequency of accusations of cheating (see Tables B5 and B6 in Appendix B). At the same time, we see a drop in off-topic talk in crisis situations and a substantial increase in information exchange about signals and payoffs. Table 5 also reveals that communication about signals increases after the first defection signal. Moreover, participants frequently respond to the uncertainty triggered by the first defection signal by reporting that their previous action was C, which is a truthful exchange of private information. In many cases, this appears to be sufficient to decrease the uncertainty triggered by the defection signal to a level that prevents participants from switching to defection.

Table 6 takes a closer look at the exchange of private information under imperfect public and imperfect private monitoring. It depicts the frequency and the truthfulness of the exchange of private information in all communication opportunities of the last three supergames (see Table B7, Appendix B for all supergames). Under public monitoring, this concerns the actions which cannot be observed by the other player. The left columns show that an action is reported in only 10% of all participant-round observations after round one. The vast majority of reports indicate cooperation in the last round, which is true in 93% of all cases.

The right columns of Table 6 show a similar pattern of reports for private

Table 5: Message-content comparison: cooperative history vs. first defection signal

	Public Repeated				Private Repeated			
Category	d signal	c signals	diff	p-value	d signal	c signal	diff	p-value
Coordination	0.32	0.17	0.15	0.05	0.49	0.24	0.25	0.00
Deliberation	0.11	0.10	0.01	0.89	0.02	0.08	-0.06	0.22
Relationship	0.33	0.35	-0.02	0.79	0.30	0.37	-0.06	0.46
Information	0.68	0.32	0.36	0.00	0.70	0.40	0.30	0.00
Trivia	0.51	0.61	-0.10	0.17	0.47	0.66	-0.20	0.04
Report of action	0.46	0.01	0.45	0.00	0.47	0.11	0.36	0.00
Report of C	0.46	0.01	0.45	0.00	0.47	0.11	0.36	0.00
Report of D	-	-	-	-	-	-	-	-
Report of signal	0.56	0.32	0.23	0.00	0.70	0.37	0.33	0.00
Report of c	0.08	0.32	-0.24	0.00	0.00	0.37	-0.37	0.00
Report of d	0.46	-	-	-	0.70	0.00	0.69	0.00

Notes: Frequency of communication categories for subject-round observations with cooperative history of both players up to round t. A participant has a cooperative history if all her previous actions were C and all signals she observed in rounds $< t$ were c. Columns compare the communication in round $t+1$ conditional on the signals received in round t. Frequencies indicate the probability that both raters indicated the category for a text unit. P-values derived from logit models with standard errors clustered on participant and match. Zero frequencies omitted (-).

Table 6: Frequency and Truthfulness of Private Information Exchange

	Public		Private	
	p(report)	p(true)	p(report)	p(true)
Actions				
Report of action	0.10	0.93	0.17	0.93
Report of C	0.09	0.93	0.16	0.93
Report of D	0.01	0.86	0.00	1.00
Report of C if $\omega_i = d$	0.22	0.82	0.24	0.75
Report of C if $\omega_i = d$ and $a_i = C$	0.38	1.00	0.35	1.00
Report of C if $\omega_i = d$ and $a_i = D$	0.07	0.00	0.12	0.00
Report of D if $\omega_i = d$ and $a_i = D$	0.09	1.00	0.03	1.00
Signals				
Report of signal	-	-	0.38	0.96
Report of c	-	-	0.27	0.99
Report of d	-	-	0.10	0.87
Report of d if $\omega_{-i} = d$	-	-	0.48	-

Notes: Frequencies of coding in all participant-round observations after round one of the last three supergames for the repeated communication treatments with public monitoring (columns 2 and 3) and private monitoring (columns 4 and 5). A coding is considered valid if both raters indicated the same sub-category for a participant-round observation. Values might not add up as expected due to rounding.

monitoring. Reports of C occur in 24% of all cases when the partner has received a defection signal in the last round. As under public monitoring, this strategy is not systematically used by defectors (only in 12% of all cases, 9 absolute cases). One important difference concerns the interpretation of reporting C when the signal is d. Under private monitoring, the difference compared to the baseline frequency of C reports suggests that their partners reported the d signal in the first place. This indirect evidence is supported by the values in the lower part of the table. A signal is reported in 38% of all participant-round interaction after round one. Most of the reports reveal a c signal truthfully. In 10% of all participant-round interactions participants report a d signal. To put this value into perspective, remember that d signals occur very seldom because of the high level of cooperation. The last line shows the frequency of d reports when a d signal actually occurred: it is 48%.

Approximately half of the defection signals observed stem from defection (54% under public, 48% under private monitoring), while the other half is due to noise. Honest revelation of defection in the communication phase after the partner observed a defection signal is rare and only happens in 9% of all cases under public, and 3% of all cases under private monitoring. Table 6 also lists the frequency of C reports if the signal was d. In 22% of the cases where a d signal occurs, it is followed by a report of C (truthful in 82% of cases). The next two rows indicate that deceptive reports of C are not systematically used by defectors. While participants who defected in the last round report C in response to a d signal in only 7% of all cases (5 absolute cases), cooperators did so in 38% of all cases. Together with the high frequency of cooperation, this explains why reports of C after a defection signal are generally credible (even though defectors self-select into this state).

Summarizing the results reported in Table 6, we can say that participants make ample use of repeated communication to exchange private information. Actions are communicated less often than signals and both types of reports are generally credible. As a result, it seems highly likely that uncertainty about the history of play is substantially reduced with repeated communication.

Table 7 shows that the exchange of private information is correlated with the frequency of mutual cooperation after a defection signal. We consider all cases where a defection signal was obtained by one of the participants in the last round. If the player for whom the last signal indicated defection reports cooperation (denying the accuracy of the signal), the frequency of mutual cooperation is higher under public monitoring. The difference in the frequency of mutual cooperation after reporting C is larger under private monitoring when the reporting player is not aware of the d signal. The interaction term indicates that, when a report of C occurs together with a report of d, the frequency of mutual cooperation after reporting C is smaller but still substantial. Truthfully reporting a defection signal under private monitoring is also associated with a higher frequency of mutual cooperation. For data of all supergames, the differences in the frequency of mutual cooperation after private information exchange are similar (Table B8).

Table 7: Private Information Exchange and Mutual Cooperation after a bad Signal

	Public			Private		
	estimate	std. error	p-value	estimate	std. error	p-value
Intercept	0.00	0.38	1.00	-0.32	0.52	0.54
Report of C	0.79	0.41	0.05	16.84	0.81	0.00
Report of d	-	-	-	1.02	0.69	0.14
Report of C $\times$ Report of d	-	-	-	-16.29	1.25	0.00
Trivia	1.00	0.40	0.01	0.13	0.40	0.75

Notes: Coefficients of logit models with standard errors clustered on participant and match. Report of C is a dummy that indicates if C is reported by the player for whom the signal indicated d in the last round. Report of d is a dummy that indicates whether the defection signal was reported by the player who received the defection signal. Data of the last three supergames. A coding is considered valid if both raters indicated the same sub-category for a participant-round observation.

Result 3: *Communication opportunities are mainly used to* ***(a)*** *coordinate behavior before the start of the interaction, which appears to reduce strategic uncertainty, and* ***(b)*** *to exchange information about the history of play in later rounds under imperfect monitoring, which appears to reduce uncertainty about what has happened.*

Strategies One limitation of conditional cooperation rates, as reported in the Section 3.1, is that they can only partially reflect more complex strategies that participants might use. To assess the robustness of the finding that communication opportunities make participants' play more lenient and forgiving, we perform a treatment-wise strategy frequency estimation (Dal Bó and Fréchette, 2011) (see Appendix C for details). We use a candidate set of pure strategies for imperfect monitoring (Fudenberg et al., 2012), augmented by four memory-one belief free strategies - including T1BF, the unique memory-one belief-free equilibrium strategy under imperfect monitoring (see Appendix A).[19] We assume that all strategies of the

[19]The other three belief-free strategies are: SGRIM, M1BF, and RAND. SGRIM is a semi-grim strategy (Breitmoser, 2015) which starts with cooperation, cooperates after CC (Cc), defects after DD (Dd), and cooperates with probability 0.35 in the remaining states, CD (Cd) and DC (Dc). The probability 0.35 is the average cooperation probability that Backhaus and Breitmoser (2021)

treatment condition on the same information. The strategies fitted to the data of the perfect monitoring treatments condition on the action profile $\{a_i, a_{-i}\}$ observed in the previous round. The strategies fitted to the data of the imperfect monitoring treatments condition on the action-signal profile $\{a_i, \omega_{-i}\}$ observed in the previous round.

Table 8 depicts strategy estimation results. It show the estimated strategy shares of "always-defect" (ALLD), an alternating strategy (DC) that starts with D and subsequently alternates between C and D, the false-cooperator (FC) that cooperates only in the first period and subsequently defects, the grim-trigger strategy (GRIM), and a strategy that randomly plays either C or D (RAND). To facilitate the interpretation of the strategy estimation results, the shares of all remaining lenient or forgiving strategies are pooled into a single category (Table C1 in Appendix C shows the strategy shares of the pooled strategies together with standard errors). The proportion of participants that use lenient or forgiving strategies increases substantially with pre-play communication under all three monitoring structures. Repeated communication further increases the use of lenient or forgiving strategies.

Table 8: Strategy Frequency Estimation

	Perfect			Public			Private		
	No	Pre	Rep	No	Pre	Rep	No	Pre	Rep
ALLD	0.42	-	-	0.61	0.02	-	0.50	0.02	-
DC	-	-	-	-	-	-	-	-	-
FC	-	-	-	-	0.08	0.01	-	-	-
GRIM	0.08	0.23	-	-	0.02	-	0.03	-	-
RAND	0.03	-	-	0.05	0.08	0.05	0.03	0.11	0.03
lenient/forgiving	0.46	0.77	1.00	0.34	0.79	0.94	0.45	0.87	0.97
γ	0.06	0.01	0.01	0.07	0.06	0.03	0.05	0.02	0.04

Notes: Treatment-wise strategy estimation for 24 strategies listed in Tables C2-C5 assuming constant strategy use over the last three supergames. Strategies condition on the observed actions in perfect treatments, and on action-signal profiles in public and private treatments. The parameter γ reflects the probability of a tremble. Zero shares are omitted (-). The sum of strategy shares in a treatment might differ from one due to rounding.

report for these states. M1BF refers to the unique belief-free strategy under perfect monitoring with $\delta = 0.8$ that starts with cooperation, cooperates after CC (Cc) and defects after DD (Dd) (see Appendix A for the derivation of these strategies). RAND cooperates with 50% probability after all histories.

Result 4: *With more communication opportunities, subjects' play becomes more lenient and forgiving.*

4 Discussion

In the theoretical literature, communication has played a particularly prominent role in combination with private monitoring. For this monitoring structure, it has been shown that repeated communication opportunities can enlarge the set of achievable equilibria (Matsushima, 1991; Ben-Porath and Kahneman, 1996; Compte, 1998; Kandori and Matsushima, 1998; Obara, 2009; Awaya and Krishna, 2016). *Truth-telling equilibria*, in which players reveal their private signals, are stable, while the cooperative equilibria without repeated communication that have been analyzed in the literature are not (Heller, 2017). Moreover, any cooperative equilibrium without repeated communication requires complicated mixing, which makes coordination with or without pre-play communication extremely difficult; this led Compte and Postlewaite (2015) to characterize them as "*unrealistically complex and fragile*" (p. 45). These considerations suggest low cooperation rates in the private monitoring treatment without communication; this is, indeed, what we observe. They also suggests low cooperation rates with pre-play communication (Prediction 1); instead, we observe high cooperation rates (Result 1). This suggests that pre-play communication is effective in reducing strategic uncertainty through improved coordination on cooperation, even in the absence of stable equilibria. However, subjects' mere coordination on mutual cooperation in the beginning of the interaction is insufficient to maintain a high and stable cooperation level both under imperfect private monitoring and under imperfect public monitoring, where efficient equilibria require the use of complex strategies as well. In our experiment, subjects fail to identify and communicate these strategies, which further increases the uncertainty about the history of play when bad signals occur for the first time.

Our key finding that repeated communication is important for stable cooperation in noisy environments (Result 2), which confirms Prediction 2, is consistent with evidence from a number of case studies of cartels, which point to different roles for repeated communication. Genesove and Mullin (2001) note in their account of the sugar-refining cartel that its weekly *"[m]eetings were used to interpret and adapt the agreement, coordinate on jointly profitable actions, and determine whether cheating had occurred"* (p. 379); put differently: meetings were used to reduce strategic uncertainty and uncertainty about the history of play. Levenstein and Suslow (2006) review the empirical literature on cartels and identify repeated communication as a key ingredient of successful cartel organizations – *“not only to provide flexibility in the details of the agreement, but to build trust as well”* (p. 67). Finally, Harrington and Skrzypacz (2011), who study various cartel agreements, conclude that repeated truthful communication of sales is an important property of all of them. These accounts are consistent with our findings of more lenient and forgiving behavior with communication (Result 4), and of the use of communication to coordinate behavior and to share private information (Result 3), which confirms Prediction 3.

It is long known that the mere existence of cooperative equilibria is an insufficient condition for reaching high cooperation rates in indefinitley repeated interactions (e.g., Dal Bó and Fréchette, 2019). Our results show how powerful communication is to achieve high cooperation rates. However, while pre-play communication boosts cooperation, it does not increase it all the way up to the theoretically possible efficiency levels under imperfect monitoring. Repeated communication opportunities are important in these environments. We observe that repeated communication is mainly used to share information about the history of play, which is the key role ascribed to communication in the theoretical literature.

5 Conclusion

We set out to answer the central question how communication affects the level and stability of cooperation in long-term interactions with different monitoring structures, such as cartels, teams or friendships. Our results give a comprehensive overview of how communication is used and affects cooperation and strategy choices. They demonstrate that communication can have an enormous impact on cooperation and its stability. The controlled laboratory environment allows us not only to cleanly identify and separate the effect of communication, but also to understand the mechanisms through which communication affect cooperation. Our results suggest that communication fosters cooperation by reducing two types of uncertainty, strategic uncertainty and uncertainty about the history of play, and thereby reveal an important interplay between communication opportunities and the quality of monitoring. Most importantly, we find that repeated communication opportunities are important for sustaining cooperation under imperfect monitoring where uncertainty about the history of play becomes important. This finding is consistent with case study evidence on cartels and corroborates that cracking down on communication is a reasonable strategy for antitrust authorities. Without repeated communication opportunities, it becomes very difficult to sustain cooperation even in the relatively simple setting of our laboratory experiment.

We would finally like to point to some interesting avenues for future research. Communication affects choices and vice-versa. Ideally, we would thus like to estimate strategies that treat communication content as a choice and condition behavior not only on past actions and signals but also on past communication. To have a chance to recover such strategies from the data, one would have to strongly limit the message space, as do Arechar et al. (2017), who allow for communication only about intended actions. To gain more insights into the role of information exchange under private monitoring, it could be useful to limit communication to the reporting of private signals in future studies. However, while that would help to gain insights into this important role of communication, our results, and those from other recent studies of communication in repeated games, clearly suggest that thinking about communication as a mere exchange of information is insufficient. Kartal and Müller (2018) make a first step in broadening this narrow theoretical view of communication by modeling how communication reduces strategic uncertainty. Taking further steps in this direction, for example, by combining the two key roles that communication appears to play under imperfect monitoring – the reduction of strategic uncertainty and the reduction of uncertainty about the history of play – in one framework, promises to be a fruitful agenda for future research.

References

Andersson, O. and E. Wengström (2007): "Do Antitrust Laws Facilitate Collusion? Experimental Evidence on Costly Communication in Duopolies," *Scandinavian Journal of Economics*, 109, 321–339.

——— (2012): "Credible communication and cooperation: Experimental evidence from multi-stage Games," *Journal of Economic Behavior and Organization*, 81, 207–219.

Aoyagi, M., V. Bhaskar, and G. R. Fréchette (2018): "The Impact of Monitoring in Infinitely Repeated Games: Perfect, Public, and Private," *American Economic Journal: Microeconomics*, forthc.

Aoyagi, M. and G. R. Fréchette (2009): "Collusion as public monitoring becomes noisy: Experimental evidence," *Journal of Economic Theory*, 144, 1135–1165.

Arechar, A. A., A. Dreber, D. Fudenberg, and D. G. Rand (2017): "I'm just a soul whose intentions are good: The role of communication in noisy repeated games," *Games and Economic Behavior*, 104, 726–743.

Awaya, Y. and V. Krishna (2016): "On Communication and Collusion," *American Economic Review*, 106, 285–315.

Backhaus, T. and Y. Breitmoser (2021): "Inequity aversion and limited foresight in the repeated prisoner's dilemma," *Center for Mathematical Economics Working Papers*, 652.

Ben-Porath, E. and M. Kahneman (1996): "Communication in Repeated Games with Private Monitoring," *Journal of Economic Theory*, 70, 281–297.

Bhaskar, V., G. J. Mailath, and S. Morris (2008): "Purification in the infinitely-repeated prisoners' dilemma," *Review of Economic Dynamics*, 11, 515–528.

Bhaskar, V. and I. Obara (2002): "Belief-based equilibria in the repeated prisoners' dilemma with private monitoring," *Journal of Economic Theory*, 102, 40–69.

Bland, J. R. (2020): "Heterogeneous trembles and model selection in the strategy frequency estimation method," *Journal of the Economic Science Association*, 6, 113–124.

Blonski, M., P. Ockenfels, and G. Spagnolo (2011): "Equilibrium Selection in the Repeated Prisoner's Dilemma: Axiomatic Approach and Experimental Evidence," *American Economic Journal: Microeconomics*, 3, 164–192.

Breitmoser, Y. (2015): "Cooperation, but no reciprocity: Individual strategies in the repeated prisoner's dilemma," *American Economic Review*, 105, 2882–2910.

Camera, G., M. Casari, and M. Bigoni (2013): "Experimental markets with frictions," *Journal of Economic Surveys*, 27, 536–553.

Cameron, a. C., J. B. Gelbach, and D. L. Miller (2011): "Robust Inference With Multiway Clustering," *Journal of Business & Economic Statistics*, 29, 238–249.

Cason, T. N. and V. L. Mui (2014): "Coordinating resistance through communication and repeated interaction," *Economic Journal*, 124, 226–256.

——— (2015): "Individual versus Group Play in the Repeated Coordinated Resistance Game," *Journal of Experimental Political Science*, 2, 94–106.

Charness, G. and M. Dufwenberg (2006): "Promises and partnership," *Econometrica*, 74, 1579–1601.

——— (2010): "Bare promises: An experiment," *Economics Letters*, 107, 281–283.

Compte, O. (1998): "Communication in Repeated Games with Imperfect Private Monitoring," *Econometrica*, 66, 587–626.

Compte, O. and A. Postlewaite (2015): "Plausible cooperation," *Games and Economic Behavior*, 91, 45–59.

Cooper, D. J. and K.-U. Kühn (2014): "Communication, renegotiation, and the scope for collusion," *American Economic Journal: Microeconomics*, 6, 247–278.

Cooper, R. W., D. V. DeJong, R. Forsythe, and T. W. Ross (1992): "Communication in Coordination Games," *Quarterly Journal of Economics*, 107, 739–771.

Crawford, V. and J. Sobel (1982): "Strategic information transmission," *Econometrica*, 50, 1431–1451.

Dal Bó, P. (2005): "Cooperation under the Shadow of the Future: Experimental Evidence from Infinitely Repeated Games," *American Economic Review*, 95, 1591–1604.

Dal Bó, P. and G. R. Fréchette (2011): "The evolution of cooperation in infinitely repeated games: Experimental evidence," *American Economic Review*, 101, 411–429.

——— (2018): "On the Determinants of Cooperation in Infinitely Repeated Games: A Survey," *Journal of Economic Literature*, 56, 60–114.

——— (2019): "Strategy choice in the infinitely repeated prisoner's dilemma," *American Economic Review*, 109, 3929–3952.

Dempster, A., N. Laird, and D. B. Rubin (1977): "Maximum likelihood from incomplete data via the EM algorithm," *Journal of the Royal Statistical Society Series B*, 39, 1–38.

Dvorak, F. (2020): "stratEst: An R Package for Strategy Estimation," *TWI Working Paper Series*, 119.

——— (2021): *stratEst: Strategy Estimation*, r package version 1.1.4.

Ellingsen, T. and R. Östling (2010): "When Does Communication Improve Coordination?" *American Economic Review*, 100, 1695–1724.

Ely, J. C., J. Hörner, and W. Olszewski (2005): "Belief-Free Equilibria in Repeated Games," *Econometrica*, 73, 377–415.

Ely, J. C. and J. Välimäki (2002): "A Robust Folk Theorem for the Prisoner's Dilemma," *Journal of Economic Theory*, 102, 84–105.

Embrey, M., G. Fréchette, and E. Stacchetti (2013): "An Experimental Study of Imperfect Public Monitoring: Efficiency Versus Renegotiation-Proofness," *Mimeo.*

Farrell, J. and E. Maskin (1989): "Renegotiation in repeated games," *Games and Economic Behavior*, 1, 327–360.

Fischbacher, U. (2007): "Z-Tree: Zurich toolbox for ready-made economic experiments," *Experimental Economics*, 10, 171–178.

Fischbacher, U. and V. Utikal (2013): "On the acceptance of apologies," *Games and Economic Behavior*, 82, 592–608.

Fonseca, M. a. and H. T. Normann (2012): "Explicit vs. tacit collusion-The impact of communication in oligopoly experiments," *European Economic Review*, 56, 1759–1772.

Fréchette, G. R. and S. Yuksel (2017): "Infinitely repeated games in the laboratory: four perspectives on discounting and random termination," *Experimental Economics*, 20, 279–308.

Fudenberg, D., D. G. Rand, and A. Dreber (2012): "Slow to Anger and Fast to Forgive: Cooperation in an Uncertain World," *American Economic Review*, 102, 720–749.

Genesove, D. and W. P. Mullin (2001): "Rules, communication, and collusion: Narrative evidence from the sugar institute case," *American Economic Review*, 91, 379–398.

Green, E. J. and R. H. Porter (1984): "Noncooperative Collusion under Imperfect Price Information," *Econometrica*, 52, 87.

Greiner, B. (2015): "Subject pool recruitment procedures: organizing experiments with ORSEE," *Journal of the Economic Science Association*, 1, 114–125.

Harrington, J. E. and A. Skrzypacz (2011): "Private Monitoring and Communication in Cartels: Explaining Recent Collusive Practices," *American Economic Review*, 101, 2425–2449.

Harsanyi, J. C. and R. Selten (1988): *A General Theory of Equilibrium Selection in Games*, Cambridge, MA: MIT Press.

Heller, Y. (2017): "Instability of belief-free equilibria," *Journal of Economic Theory*, 168, 261–286.

Kalai, E., D. Samet, and W. Stanford (1988): "A note on reactive equilibria in the discounted prisoner's dilemma and associated games," *International Journal of Game Theory*, 17, 177–186.

Kamei, K. and A. Nesterov (2020): "Endogenous Monitoring Through Gossiping in an Infinitely Repeated Prisoner's Dilemma Game: Experimental Evidence," *Working Paper.*

Kandori, M. and H. Matsushima (1998): "Private Observation, Communication and Collusion," *Econometrica*, 66, 627–652.

Kartal, M. and W. Müller (2018): "A New Approach to the Analysis of Cooperation Under the Shadow of the Future: Theory and Experimental Evidence," *SSRN Working Paper.*

Landeo, C. M. and K. E. Spier (2015): "Incentive contracts for teams: Experimental evidence," *Journal of Economic Behavior and Organization*, 119, 496–511.

Levenstein, M. C. and V. Y. Suslow (2006): "What Determines Cartel Success?" *Journal of Economic Literature*, 44, 43–95.

Mailath, G. J. and L. Samuelson (2006): *Repeated Games and Reputations*, Oxford University Press: Oxford.

Matsushima, H. (1991): "On the theory of repeated games with private information. Part II: revelation through communication," *Economics Letters*, 35, 257–261.

Obara, I. (2009): "Folk Theorem with Communication," *Journal of Economic Theory*, 144, 120–134.

Pearce, D. G. (1987): "Renegotiation-Proof Equilibria: Collective Rationality and Intertemporal Cooperation," *Cowles Foundation Discussion Paper*.

Piccione, M. (2002): "The Repeated Prisoner's Dilemma with Imperfect Private Monitoring," *Journal of Economic Theory*, 102, 70–83.

Rabin, M. (1994): "A Model of Pre-game Communication," *Journal of Economic Theory*, 63, 370–391.

Sekiguchi, T. (1997): "Efficiency in repeated prisoner's dilemma with private monitoring," *Journal of Economic Theory*, 76, 345–361.

Stigler, G. J. (1964): "A Theory of Oligopoly," *Journal of Political Economy*, 72, 44–61.

Utikal, V. (2012): "A fault confessed is half redressed - Confessions and punishment," *Journal of Economic Behavior & Organization*, 81, 314–327.

Wang, S. and D. Houser (2019): "Demanding or deferring? An experimental analysis of the economic value of communication with attitude," *Games and Economic Behavior*, 115, 381–395.

Wilson, A. J. and E. Vespa (2020): "Information Transmission under the Shadow of the Future: An Experiment," *American Economic Journal: Microeconomics*, 12, 75–98.

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Appendix A Theoretical Appendix

In A.1, we present an extensions of the BAD to the two imperfect monitoring structures. In A.2, we derive existence conditions for equilibria in memory-one belief-free strategies in general, and for the subset of semi-grim memory-one belief-free equilibria. The latter give us the SG-thresholds. Further, we provide a characterization of these equilibria. In A.3, we construct renegotiation-proof equilibria for perfect and imperfect public monitoring and a truthful communication equilibrium for the case of imperfect private monitoring. It will be useful to recall the normalized stage game parameters:

	C	D
C	1,1	$-l$,1+g
D	1+g,$-l$	0,0

A.1 BAD under imperfect monitoring

Extending the BAD to imperfect monitoring requires to adapt the GRIM strategy to the imperfect monitoring structures. To derive lower bounds of the BAD, we use the adaptation of GRIM which is most robust to strategic uncertainty. This adaptation prescribes that players play D if they already played D in the previous round or when the last signal was not cc (c) under public (private) monitoring.

A.1.1 Public Monitoring

With public monitoring, indifference between GRIM and ALLD requires

$$\pi\frac{1}{1-\delta(1-\epsilon)^2}-(1-\pi)\frac{l}{1-\delta\epsilon(1-\epsilon)}=\pi\frac{(1+g)}{1-\delta\epsilon(1-\epsilon)}.$$

Hence, the BAD is

$$\pi^{DF}=\frac{l}{l-g+\frac{\delta((1-\epsilon)^2-\epsilon(1-\epsilon))}{1-\delta(1-\epsilon)^2}}. \tag{1}$$

If $g = l$, the lower bound is

$$\pi^{DF} = \frac{1-\delta(1-\epsilon)^2}{\delta((1-\epsilon)^2-\epsilon(1-\epsilon))}l,$$

and $\partial\pi^{DF}/\partial\epsilon = l\delta(3-4\epsilon-\delta(1-\epsilon)^2)/(\delta(1-2\epsilon)^2(\epsilon-1)^2) > 0$ for $\delta < 1$ and $\epsilon \leq 0.5$.
If $1+g = l$, the lower bound is

$$\pi^{DF} = \frac{1-\delta(1-\epsilon)^2}{1-\delta\epsilon(1-\epsilon)}l,$$

and $\partial\pi^{DF}/\partial\epsilon = l\delta(3-4\epsilon-\delta(1-\epsilon)^2)/(1-\delta\epsilon(1-\epsilon)^2 > 0$ for $\delta < 1$ and $\epsilon \leq 0.5$. Note that for $\epsilon = 0$ the equations above yield the BAD of perfect monitoring.

A.1.1 Private Monitoring

With private monitoring, indifference requires

$$\pi\frac{1+\delta\epsilon(1-\epsilon)(1+g-l)/(1-\delta\epsilon)}{1-\delta(1-\epsilon)^2} - (1-\pi)\frac{l}{1-\delta\epsilon} = \pi\frac{(1+g)}{1-\delta\epsilon},$$

and the BAD is given by

$$\pi^{DF} = \frac{l}{l-g+\frac{\delta((1-2\epsilon)-\epsilon(1-\epsilon)(l-g))}{1-\delta(1-\epsilon)^2}}. \tag{2}$$

If $g = l$, the lower bound is

$$\pi^{DF} = \frac{1-\delta(1-\epsilon)^2}{\delta(1-2\epsilon)}l,$$

and $\partial\pi^{DF}/\partial\epsilon = 2l(1-\delta(\epsilon(1-\epsilon))/(\delta(1-2\epsilon)^2) > 0$ for $\delta < 1$ and $\epsilon \leq 0.5$.
If $1+g = l$, the lower bound is

$$\pi^{DF} = \frac{1-\delta(1-\epsilon)^2}{1-\delta\epsilon(1-\epsilon)}l,$$

and $\partial\pi^{DF}/\partial\epsilon = l\delta(3-2\epsilon-\delta(1-\epsilon)^2)/(1-\delta\epsilon)^2 > 0$ for $\delta < 1$ and $\epsilon \leq 0.5$. For $\epsilon = 0$, the equations above yield the BAD of perfect monitoring. Note that under private monitoring (GRIM, GRIM) is not an equilibrium in pure strategies but π^{DF} equals the mixing probability in Sekiguchi's (1997) construction of a belief-based equilibrium.

A.2 Belief-Free Equilibria

Depending on the monitoring structure, different versions of memory-one belief-free strategies exist. We consider three cases: (1) M1BF strategies which condition on (a_i, a_{-i}), (2) M1BF strategies which condition on (ω_i, ω_{-i}), and (3) M1BF strategies which condition on (a_i, ω_{-i}). Under perfect monitoring, all three cases are possible. Under public monitoring, only cases 2 and 3 are possible while case 3 is the only possible case under private monitoring. The existence conditions of semi-grim strategies which condition on public signals and action-signal combinations are defined in Propositions 1.1.2, 1.2.2 and 1.3.2.

A.2.1 Actions (Perfect Monitoring)

Proposition 2.1.1 [Memory-One Belief-Free Equilibria Conditioning on Actions]

(i) *If strategies condition on actions, the existence condition for symmetric memory-one belief-free equilibria depends on the larger of the two values g and l. Let ϕ denote the larger of the two values. The existence condition is:*

$$\delta \geq \delta_{aa}^{BF} = \frac{\phi}{1+\phi} \tag{3}$$

(ii) *Above the threshold, a two-dimensional manifold of memory-one belief-free equilibria exists given by*

$$\sigma_{cd} = \sigma_{cc} + \left(\sigma_{cc} - \sigma_{dd} - \frac{1}{\delta}\right) g \tag{4}$$

and

$$\sigma_{dc} = \sigma_{dd} - \left(\sigma_{cc} - \sigma_{dd} - \frac{1}{\delta}\right) l \tag{5}$$

(iii) *For $\delta = \delta_{aa}^{BF}$ all memory-one belief-free equilibrium strategies have the same cooperation probabilities after nonempty memory-one histories and are $\sigma = (\sigma_\emptyset, 1, (1-g/l), 1, 0)$ if $l > g$, $\sigma = (\sigma_\emptyset, 1, 0, (l/g), 0)$ if $g > l$ and $\sigma = (\sigma_\emptyset, 1, 0, 1, 0)$ if $g = l$. We call this the threshold memory-one belief-free equilibrium T1BF.*

Since g and l are both positive values these equilibria exist for high enough values of δ. Note that if $g \geq l$ the δ threshold corresponds to the one for cooperative subgame-perfect equilibria of the repeated game with perfect monitoring. However, if $l > g$ as in our case, the conditions differ with $\delta_{aa}^{BF} > \delta^{SPE}$. The condition applies for belief-free equilibria in reactive strategies

(Kalai et al., 1988) which condition on the other player's action and require $g = l$ which yields $\delta_{aa}^{BF} = \delta^{SPE}$.

Proof of Proposition 1.1.1. Let $V_{a_j a_i}^{a_i}$ denote player i's expected payoff for playing a_i if player j observed the action profile $\{a_j, a_i\}$ in the previous round (we say player j is in state $a_j a_i$). If $\sigma_{a_i a_j}$ denotes the probability to play c for any player i after $\{a_i, a_j\}$, we have:

$$V_{aa}^{c} = (1-\delta)(\sigma_{aa} - (1-\sigma_{aa})l) + \delta(\sigma_{aa} V_{cc} + (1-\sigma_{aa})V_{dc}) \tag{6}$$

$$V_{aa}^{d} = (1-\delta)(\sigma_{aa}(1+g) + (1-\sigma_{aa})0) + \delta(\sigma_{aa} V_{cd} + (1-\sigma_{aa})V_{dd}) \tag{7}$$

Following Bhaskar et al. (2008), we derive conditions for V_{cd} and V_{cc} which assure the strategies are belief-free, that is, for any $\sigma_{aa} \in (0,1)$, player i is indifferent between playing c or d independent of player j's state. Subtracting (7) from (6) gives:

$$0 = \sigma_{aa}\left\{(1-\delta)(l-g) + \delta\left(V_{cc} - V_{cd} - V_{dc} + V_{dd}\right)\right\} - (1-\delta)l + \delta\left(V_{dc} - V_{dd}\right)$$

The equation holds independent of σ_{aa} if the terms in curly brackets and the last part are both zero. Solving the the condition resulting from the last part for $V_{dc} - V_{dd}$ and inserting the solution into the condition derived from the terms in curly brackets gives

$$V_{cc} = V_{cd} + \frac{(1-\delta)g}{\delta}$$

and

$$V_{dc} = V_{dd} + \frac{(1-\delta)l}{\delta}$$

Solving (6) for σ_{cc} using the condition on V_{dc} above and rearranging for V_{cc} yields

$$V_{cc} = \frac{(1-\delta)\sigma_{cc} + \delta(1-\sigma_{cc})V_{dd}}{1-\delta\sigma_{cc}}$$

Solving (6) for σ_{dd} using the condition on V_{cd} and V_{cc} above gives

$$V_{dd} = \frac{\sigma_{dd}}{1+\delta\sigma_{dd} - \delta\sigma_{cc}}$$

Now, all V_{aa} can be eliminated from (6) solved for σ_{dd} and σ_{dc} this yields (4) and (5) which proofs (ii). Note that $\partial\sigma_{cd}/\partial\delta > 0$, $\partial\sigma_{cd}/\partial\sigma_{cc} > 0$ and $\partial\sigma_{cd}/\partial\sigma_{dd} < 0$. The question is, how big δ must be at least in order to assure that $\sigma_{cd} \geq 0$ if $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$. Inserting these values into (4) and rearranging gives $\delta > \delta_{aa}^{BF}$ with $\phi = g$. Note that $\sigma_{cd} \leq 1$ is true even if $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$ for all feasible values of δ, g and l. At the same time $\partial\sigma_{dc}/\partial\delta < 0$,

$\partial\sigma_{dc}/\partial\sigma_{cc} < 0$ and $\partial\sigma_{dc}/\partial\sigma_{dd} > 0$. The question here is, how big δ must be at least in order to assure that $\sigma_{dc} \leq 1$ if $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$. Inserting these values into (5) and rearranging gives $\delta > \delta_{aa}^{BF}$ with $\phi = l$. At the same time, $\sigma_{dc} \geq 0$ true even if $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$ for all feasible values of δ, g and l. Hence, the larger of the values g and l imposes the stricter condition on δ which proofs (i). To complete the proof, insert (3) together with $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$ into (4) and (5) to obtain the structure of the T1BF response defined by g and l. $\square$

Next, we derive the δ threshold, above which semi-GRIM equilibria exist. See Breitmoser (2015) for an alternative derivation.

Proposition 1.1.2 [Semi-Grim M1BF Equilibria Conditioning on Actions]

(i) *If strategies condition on actions, the existence condition for symmetric semi-grim memory-one belief-free equilibria is:*

$$\delta \geq \delta_{aa}^{SG} = \frac{g+l}{1+g+l} \tag{8}$$

(ii) *Above the threshold a continuum* $\sigma_{cc} \in (\frac{g+l}{\delta(1+g+l)}, 1)$ *of memory one belief-free equilibria in semi-grim strategies exists, given by:*

$$\sigma_{dd} = \sigma_{cc} - \frac{g+l}{\delta(1+g+l)} \tag{9}$$

and

$$\sigma_{cd} = \sigma_{dc} = \sigma_{cc} - \frac{g}{\delta(1+g+l)} \tag{10}$$

(iii) *For* $\delta = \delta_{aa}^{SG}$ *all semi-grim memory-one belief-free equilibrium strategies have the same cooperation probabilities after nonempty memory-one histories and are* $\sigma = (\sigma_\emptyset, 1, 1 - g/(g+l), , 0)$. *If* $l = g$, *then* $\sigma = (\sigma_\emptyset, 1, 0.5, 0.5, 0)$.

Proof of Proposition 1.1.2. Using (4) and (5) yields (9) and (10). Note that $\sigma_{dd} < \sigma_{cd} < 1$ for $\sigma_{cc} \in (0,1)$ and any $\delta \in (0,1)$. For existence σ_{dd} must be positive. Rearranging yields the SG-threshold. Note that the condition on δ is always stricter than the condition on δ, which results from $\sigma_{cd} = \sigma_{dc} \geq 0$, and is $\delta \geq g/(1+g+l)$. $\square$

Note that the condition for semi grim equilibria is a mixture of the two possible conditions based on the different values of ϕ with equal weight on g and l as required by axiom 5 in Blonski et al. (2011) while (3) gives full weight on the larger of the two values.

A.2.2 Public Signals (Perfect and Public Monitoring)

Proposition 2.2.1 [M1BF Equilibria Conditioning on Public Signals]

(i) *If strategies condition on the ϵ-noisy public signals, the existence condition for symmetric memory-one belief-free equilibria depends on the larger of the two values g and l. Let ϕ denote the larger and ψ the smaller of the two values. The existence condition is:*

$$\delta \geq \delta_{ss}^{BF} = \frac{(1-\epsilon)\phi - \epsilon\psi}{(1-2\epsilon)(1-2\epsilon+(1-\epsilon)\phi-\epsilon\psi)} \tag{11}$$

(ii) *Above the threshold, a two-dimensional manifold of memory-one belief-free equilibria exists given by*

$$\sigma_{cd} = \sigma_{cc} + \frac{\sigma_{cc} - \sigma_{dd} - \frac{1}{\delta(1-2\epsilon)}}{1-2\epsilon}((1-\epsilon)g - \epsilon l) \tag{12}$$

and

$$\sigma_{dc} = \sigma_{dd} - \frac{\sigma_{cc} - \sigma_{dd} - \frac{1}{\delta(1-2\epsilon)}}{1-2\epsilon}((1-\epsilon)l - \epsilon g) \tag{13}$$

(iii) *For $\delta = \delta_{ss}^{BF}$ all memory-one belief-free equilibrium strategies have the same cooperation probabilities after nonempty memory-one histories and are $\sigma = (\sigma_\emptyset, 1, (1-g/l), 1, 0)$ if $l > g$, $\sigma = (\sigma_\emptyset, 1, 0, (l/g), 0)$ if $g > l$ and $\sigma = (\sigma_\emptyset, 1, 0, 1, 0)$ if $g = l$. We call this the threshold memory-one belief-free equilibrium T1BF.*

In contrast to result for actions, combinations of the parameters g, l and ϵ exists for which $\delta_{ss}^{BF} > 1$.

Proof of Proposition 2.2.1. The proof follows the same steps as for actions. Let $V_{s_j s_i}^{a_i}$ denote player i's expected payoff for playing a_i if player j observed $\{s_j, s_i\}$ in the previous round (which means player j is in state $s_j s_i$). If $\sigma_{s_i s_j}$ denotes the (universal) probability of player i

to play c after $\{s_i, s_j\}$, we get:

$$\begin{aligned}
V_{ss}^{c} = (1-\delta)(\sigma_{ss}-(1-\sigma_{ss})l) + \delta[(1-\epsilon)(\sigma_{ss}(1-\epsilon)+(1-\sigma_{ss})\epsilon)V_{cc} \\
+\epsilon(\sigma_{ss}(1-\epsilon)+(1-\sigma_{ss})\epsilon)V_{cd} \\
+(1-\epsilon)(\sigma_{ss}\epsilon+(1-\sigma_{ss})(1-\epsilon))V_{dc} \\
+\epsilon(\sigma_{ss}\epsilon+(1-\sigma_{ss})(1-\epsilon))V_{dd}] \qquad (14) \\
V_{ss}^{d} = (1-\delta)(\sigma_{ss}(1+g)+(1-\sigma_{ss})0) + \delta[\epsilon(\sigma_{ss}(1-\epsilon)+(1-\sigma_{ss})\epsilon)V_{cc} \\
+(1-\epsilon)(\sigma_{ss}(1-\epsilon)+(1-\sigma_{ss})\epsilon)V_{cd} \\
+\epsilon(\sigma_{ss}\epsilon+(1-\sigma_{ss})(1-\epsilon))V_{dc} \\
+(1-\epsilon)(\sigma_{ss}\epsilon+(1-\sigma_{ss})(1-\epsilon))V_{dd}] \qquad (15)
\end{aligned}$$

Again we derive conditions for V_{cd} and V_{cc} which together assure the belief-free property following Following Bhaskar et al. (2008), that is, for any $\sigma_{ss} \in (0,1)$, player i is indifferent between playing c or d independent of player j's state. First, subtracting (15) from (14) gives:

$$\begin{aligned}
0 = \sigma_{ss}\left\{(1-\delta)(l-g)+\delta\left((1-2\epsilon)^2V_{cc}-(1-2\epsilon)^2V_{cd}-(1-2\epsilon)^2V_{dc}+(1-2\epsilon)^2V_{dd}\right)\right\} \\
-(1-\delta)l+\delta\left((1-2\epsilon)\epsilon V_{cc}-(1-2\epsilon)\epsilon V_{cd}+(1-2\epsilon)(1-\epsilon)V_{dc}-(1-2\epsilon)(1-\epsilon)V_{dd}\right)
\end{aligned}$$

Note that he expression holds independent of σ_{ss} if the terms in curly brackets and the terms in the second line are both zero. Solving the the condition on the second line for $V_{dc} - V_{dd}$ and inserting into the other condition gives

$$V_{cc} = V_{cd} + \frac{(1-\delta)((1-\epsilon)g-\epsilon l)}{\delta(1-2\epsilon)^2}$$

and

$$V_{dc} = V_{dd} + \frac{(1-\delta)((1-\epsilon)l-\epsilon g)}{\delta(1-2\epsilon)^2}$$

Solving (14) for σ_{cc} and rearranging for V_{cc} yields

$$V_{cc} = \frac{(1-\delta)(\sigma_{cc}-l)+\delta(1-\epsilon-\sigma_{cc}(1-2\epsilon))V_{dd}+\frac{(1-\delta)(1-\epsilon)((1-\epsilon)l-\epsilon g)}{(1-2\epsilon)^2}-\frac{(1-\delta)\epsilon l}{1-2\epsilon}}{1-\delta(\sigma_{cc}(1-2\epsilon)+\epsilon)}.$$

Solving (14) for σ_{dd} and inserting V_{cc} yields an expression for V_{dd} (omitted here) that does not depend on any other V_{ss}. Now, all V_{ss} can be eliminated from (14) and we can solve for σ_{cd} and σ_{dc} which leads to (ii). For existence we need to assure that $\sigma_{cd} \in (0,1)$ and $\sigma_{dc} \in (0,1)$

for a feasible combination of values σ_{cc}, σ_{dd} and δ. First assume $(1-\epsilon)\psi - \epsilon\phi > 0$ and consider σ_{cd} (note that $(1-\epsilon)\phi - \epsilon\psi > 0$ always holds for $\epsilon < 0.5$). In this case $\partial\sigma_{cd}/\partial\sigma_{cc} > 0$ and $\partial\sigma_{cd}/\partial\sigma_{dd} < 0$. Note that $\sigma_{cd} \leq 1$ for any $\delta \in (0,1)$ even if $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$. To establish $\sigma_{cd} \geq 0$ we use $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$. Solving for δ shows gives the condition $\delta > \delta_{ss}^{BF}$ with $\phi = g$. Next, we consider σ_{dc} still assuming $(1-\epsilon)\psi - \epsilon\phi > 0$. Hence $\partial\sigma_{dc}/\partial\sigma_{cc} < 0$ and $\partial\sigma_{dc}/\partial\sigma_{dd} > 0$. Again $\sigma_{dc} \geq 0$ for any $\delta \in (0,1)$ even if $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$. To establish $\sigma_{dc} \leq 1$ we use $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$ which gives $\delta > \delta_{ss}^{BF}$ with $\phi = l$. Therefore, if $(1-\epsilon)\psi - \epsilon\phi > 0$ the stricter condition on δ results from the larger of the two values g or l as in (11). Note that $(1-\epsilon)\psi - \epsilon\phi < 0$ also requires $\delta > \delta_{ss}^{BF}$ to make the probabilities interior. On the other hand, it implies $\phi > \frac{1-\epsilon}{\epsilon}\psi$ and $\delta_{ss}^{BF} > 1$. To see this we can rearrange $\delta_{ss}^{BF} < 1$ to $\phi < \frac{(1-2\epsilon)^2 + 2\epsilon^2\psi}{2\epsilon - 2\epsilon^2}$ and show that this contradicts $\phi > \frac{1-\epsilon}{\epsilon}\psi$ for $\epsilon \in (0, 0.5)$. This proofs (i). To complete the proof, insert (11) together with $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$ into (12) and (13) to obtain the structure of the T1BF response defined by g and l. □

Proposition 2.2.2 [Semi-Grim M1BF Equilibria Conditioning on Public Signals]

(i) *If players condition on the ϵ-noisy public signals, the existence condition for semi-GRIM equilibria is:*

$$\delta \geq \delta_{ss}^{SG} = \frac{g+l}{(1-2\epsilon)(1+g+l)} \tag{16}$$

(ii) *Above this threshold, a continuum $\sigma_{cc} \in (\frac{g+l}{\delta(1-2\epsilon)(1+g+l)}, 1)$ of semi-grim equilibria exists given by:*

$$\sigma_{dd} = \sigma_{cc} - \frac{g+l}{\delta(1-2\epsilon)(1+g+l)} \tag{17}$$

and

$$\sigma_{cd} = \sigma_{dc} = \sigma_{cc} - \frac{g}{\delta(1-2\epsilon)(1+g+l)} \tag{18}$$

(iii) *For $\delta = \delta_{ss}^{SG}$ all semi-grim memory-one belief-free equilibrium strategies have the same cooperation probabilities after nonempty memory-one histories and are $\sigma = (\sigma_\emptyset, 1, 1 - g/(g+l), 1 - g/(g+l), 0)$. If $l = g$, then $\sigma = (\sigma_\emptyset, 1, 0.5, 0.5, 0)$.*

Proof of Proposition 2.2.2. Using the semi-grim property $\sigma_{cd} = \sigma_{dc}$ for (12) and (13) yields (17) and (18). Observe that $\sigma_{dd} < \sigma_{cd} < 1$ for $\sigma_{cc} \in (0,1)$ and for existence σ_{dd} must be positive which can be rearranged to yield (16). □

A.2.3 Action-Signal Combinations (All Monitoring Structures)

Proposition 2.3.1 [M1BF Equilibria Conditioning on Action-Signal Combinations]

(i) *If players condition on their own action and the ϵ-noisy signal of the other player's action, the existence condition for symmetric memory-one belief-free equilibria also depends on the larger of the two values g and l. Let ϕ denote the larger of the two values and ψ the smaller of the two. The existence condition is:*

$$\delta \geq \delta_{as}^{BF} = \frac{\phi}{1-2\epsilon+(1-\epsilon)\phi-\epsilon\psi} \tag{19}$$

If $g = l$ the condition is the same as for private signals.

(ii) *Above the threshold, a two-dimensional manifold of memory-one belief-free equilibria exists given by*

$$\sigma_{cd} = \sigma_{cc} + \frac{\sigma_{cc}-\sigma_{dd}-\frac{1}{\delta}}{1-2\epsilon-\epsilon(g+l)} g \tag{20}$$

and

$$\sigma_{dc} = \sigma_{dd} - \frac{\sigma_{cc}-\sigma_{dd}-\frac{1}{\delta}}{1-2\epsilon-\epsilon(g+l)} l \tag{21}$$

(iii) *For $\delta = \delta_{as}^{BF}$ all memory-one belief-free equilibrium strategies have the same cooperation probabilities after nonempty memory-one histories and are $\sigma = (\sigma_\emptyset, 1, (1-g/l), 1, 0)$ if $l > g$, $\sigma = (\sigma_\emptyset, 1, 0, (l/g), 0)$ if $g > l$ and $\sigma = (\sigma_\emptyset, 1, 0, 1, 0)$ if $g = l$. We call this the threshold memory-one belief-free equilibrium T1BF.*

Proof of Proposition 2.3.1. Again the proof follows the same steps as for actions. Let $V_{a_j s_i}^{a_i}$ denote player i's expected payoff for playing a_i if player j played a_j and observed s_i in the previous round (which means player j is in state $a_j s_i$). If $\sigma_{a_i s_j}$ denotes the (universal) probability of player i to play c after $\{a_i, s_j\}$, we get:

$$\begin{aligned} V_{as}^{c} &= (1-\delta)(\sigma_{as} - (1-\sigma_{as})l) + \\ \delta\left((1-\epsilon)\sigma_{as}V_{cc} + \epsilon\sigma_{as}V_{cd} + (1-\epsilon)(1-\sigma_{as})V_{dc} + \epsilon(1-\sigma_{as})V_{dd}\right) & \end{aligned} \tag{22}$$

$$\begin{aligned} V_{as}^{d} &= (1-\delta)\sigma_{as}(1+g) + \\ \delta\left((1-\epsilon)\sigma_{as}V_{cc} + \epsilon\sigma_{as}V_{cd} + (1-\epsilon)(1-\sigma_{as})V_{dc} + \epsilon(1-\sigma_{as})V_{dd}\right) & \end{aligned} \tag{23}$$

Subtracting (23) from (22) gives:

$$0 = \sigma_{as}\left\{(1-\delta)(l-g) + \delta\left((1-2\epsilon)V_{cc} - (1-2\epsilon)V_{cd} - (1-2\epsilon)V_{dc} + (1-2\epsilon)V_{dd}\right)\right\}$$
$$-(1-\delta)l + \delta\left((1-2\epsilon)V_{dc} - (1-2\epsilon)V_{dd}\right)$$

The conditions on V_{cd} and V_{cc} based on the belief-free property are now:

$$V_{dc} = V_{dd} + \frac{(1-\delta)l}{\delta(1-2\epsilon)}$$

$$V_{cc} = V_{cd} + \frac{(1-\delta)g}{\delta(1-2\epsilon)}$$

Solving (22) for σ_{cc} and rearranging for V_{cc} yields

$$V_{cc} = \frac{(1-\delta)(\sigma_{cc} - (1-\sigma_{cc})l) + \delta(1-\sigma_{cc})V_{dd} - \delta\sigma_{cc}\frac{(1-\delta)((1-\epsilon)l+\epsilon g)}{\delta(1-2\epsilon)} + \delta(1-\epsilon)\frac{(1-\delta)l}{\delta(1-2\epsilon)}}{1-\delta\sigma_{cc}}$$

Solving (22) for σ_{dd} and inserting the solution for V_{cc} gives

$$V_{dd} = \frac{\sigma_{dd}\left(1 - \frac{(1-\delta)\epsilon l + \epsilon g}{1-2\epsilon}\right) + (1-\delta\sigma_{cc})\frac{\epsilon l}{1-2\epsilon}}{1+\delta\sigma_{dd} - \delta\sigma_{cc}}$$

Next, all V_{as} can be eliminated from (22) solved for σ_{dd} and σ_{dc} proofs (ii). For existence we need to assure that $\sigma_{cd} \in (0,1)$ and $\sigma_{dc} \in (0,1)$ for a feasible combination of values σ_{cc}, σ_{dd} and δ. First assume $1-2\epsilon-\epsilon(g+l) > 0$ and consider σ_{cd}. In this case $\partial\sigma_{cd}/\partial\sigma_{cc} > 0$ and $\partial\sigma_{cd}/\partial\sigma_{dd} < 0$. Note that $\sigma_{cd} \leq 1$ for any $\delta \in (0,1)$ even if $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$. To establish $\sigma_{cd} \geq 0$ we use $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$. Solving for δ shows gives the condition $\delta > \delta_{as}^{BF}$ with $\phi = g$. Next, we consider σ_{dc} still assuming $1-2\epsilon-\epsilon(g+l) > 0$. Hence $\partial\sigma_{dc}/\partial\sigma_{cc} < 0$ and $\partial\sigma_{dc}/\partial\sigma_{dd} > 0$. Again $\sigma_{dc} \geq 0$ for any $\delta \in (0,1)$ even if $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$. To establish $\sigma_{dc} \leq 1$ we use $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$ which gives $\delta > \delta_{as}^{BF}$ with $\phi = l$. Therefore, if $1-2\epsilon-\epsilon(g+l) > 0$ the stricter condition on δ results from the larger of the two values g or l as in (19).

If $1-2\epsilon-\epsilon(g+l) < 0$, $\partial\sigma_{cd}/\partial\sigma_{cc} < 0$ and $\partial\sigma_{cd}/\partial\sigma_{dd} > 0$. Using $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$ we establish that $\sigma_{cd} \leq 1$ only if $\delta \geq 1$ (and the same can be shown for $\sigma_{dc} \geq 0$ when using $\sigma_{cc} = 0$ and $\sigma_{dd} = 1$). Note that (19) also requires $\delta \geq 1$ in this case. For the last case $1-2\epsilon-\epsilon(g+l) = 0$, σ_{cd} and σ_{dc} are not defined and (19) also requires $\delta \geq 1$. This proofs (i). To complete the proof, insert (19) together with $\sigma_{cc} = 1$ and $\sigma_{dd} = 0$ into (20) and (21) to obtain the structure of the T1BF response defined by g and l. □

Proposition 2.3.2 [Semi-Grim M1BF Equilibria Conditioning on Action-Signal Combinations]

(i) *If players condition on their own action and the ϵ-noisy signal of the other player's action, the existence condition for symmetric memory one belief-free equilibria in semi grim strategies is:*

$$\delta \geq \delta_{as}^{SG} = \frac{g+l}{1-2\epsilon+(1-\epsilon)(g+l)} \tag{24}$$

(ii) *Above this threshold, a continuum $\sigma_{cc} \in (\frac{g+l}{\delta(1-2\epsilon+(1-\epsilon)(g+l))}, 1)$ of semi-grim equilibria exists given by:*

$$\sigma_{dd} = \sigma_{cc} - \frac{g+l}{\delta(1-2\epsilon+(1-\epsilon)(g+l))} \tag{25}$$

and

$$\sigma_{cd} = \sigma_{dc} = \sigma_{cc} - \frac{g}{\delta(1-2\epsilon+(1-\epsilon)(g+l))} \tag{26}$$

(iii) *For $\delta = \delta_{as}^{SG}$ all semi-grim memory-one belief-free equilibrium strategies have the same cooperation probabilities after nonempty memory-one histories and are $\sigma = (\sigma_\emptyset, 1, 1-g/(g+l), 1-g/(g+l), 0)$. If $l = g$, then $\sigma = (\sigma_\emptyset, 1, 0.5, 0.5, 0)$.*

Proof of Proposition 2.3.2. Using the semi-grim property $\sigma_{cd} = \sigma_{dc}$ for (20) and (21) yields (25) and (26). Observe that $\sigma_{dd} < \sigma_{cd} < 1$ for $\sigma_{cc} \in (0,1)$ and for existence σ_{dd} must be positive which can be rearranged to yield (24). □

A.3 Renegotiation-Proof and Truthful Communication Equilibria

We give examples for the construction of renegotiation-proof equilibria for the perfect and imperfect monitoring cases and for a truthful communication equilibrium under imperfect private monitoring. These equilibria can be described by two states each: (1) a reward stage, in which both players cooperate, and (2) a punishment stage; and transition rules between the states. Unlike in equilibria in strongly symmetric strategies, the punisher and the punished player have to play differently in the punishment stage to assure that this state is not Pareto-dominated by the reward state. Hence, the continuation values of the two players will be different once we enter the punishment state. We will use the following notation: V_r

for the continuation value of the reward state, and V_{pp} (V_{pd}) for the continuation value of the punisher (the punished player) in the punishment state. The following condition has to hold in any renegotiation-proof equilibrium:

$$V_{pp} \geq V_r \tag{27}$$

The following condition has to hold in any truthful communication equilibrium, where the revelation constraints require that the punisher must be indifferent between staying in the reward state or entering the punishment state as punisher:

$$V_{pp} = V_r \tag{28}$$

A.3.1 Perfect Monitoring

The most simple candidate equilibrium is the following. It starts in the reward state with both players cooperating. In case of a defection, they enter the punishment state, in which the player who defected plays C while the other player plays D for one period. After this period, the game returns to the reward state. For this to be a renegotiation-proof equilibrium, the following three conditions have to be fulfilled:

1. No player has an incentive to deviate in the reward stage:

$$1 \geq (1-\delta)(1+g) - \delta(1-\delta)l + \delta^2$$

2. In the punishment stage, the player being punished has no incentive to deviate:

$$-(1-\delta)l + \delta \geq -\delta(1-\delta)l + \delta^2$$

3. The punisher wants to enter the punishment stage:

$$(1-\delta)(1+g) + \delta \geq (1-\delta)l + \delta^2$$

For our experimental parameters it is easy to verify that all three conditions are satisfied. Hence, our candidate equilibrium is, indeed, an equilibrium.

A.3.2 Imperfect Public Monitoring

The construction becomes slightly more complicated under imperfect public monitoring. Renegotiation-proofness criteria can only be applied if players play public strategies, that is, strategies that condition only on the public history. A special case that has to be considered is the public signal dd, that occurs with positive probability even when both players cooperate.

The simplest candidate equilibrium is the following. It starts in the reward state with both players cooperating. In case of a cc or a dd signal, they stay in the reward state. In case of a dc or cd signal, they transition to the punishment state, in which the player who appears to have defected plays C, while the other player plays D for one period. In case the public signal contains a c for the punished, the game returns to the reward state. Otherwise, the punishment phase is repeated. Note that in comparison to the equilibrium under perfect monitoring, the incentive to comply as a punished player in the punishment state is weakened by the positive probability of getting away with playing D and still producing a c signal with probability ϵ. The continuation payoff of the reward stage of this candidate equilibrium is:

$$V_r = c + \delta(\epsilon^2 + (1-\epsilon)^2)V_r + \delta(\epsilon(1-\epsilon))V_{pd} + \delta((1-\epsilon)\epsilon)V_{pp}$$

where:

$$V_{pd} = s + \delta(1-\epsilon)V_r + \delta\epsilon V_{pd}$$

$$V_{pp} = b + \delta(1-\epsilon)V_r + \delta\epsilon V_{pp}$$

By plugging V_{pd} and V_{pp} into V_r and simplifying the equation we get:

$$V_r = \frac{c(1-\delta\epsilon) + \delta(1-\epsilon)\epsilon(b+s)}{(1+\delta-2\delta\epsilon)(1-\delta\epsilon) - 2\delta(1-\epsilon)^2}$$

The continuation payoff of deviating from cooperation is:

$$V_d = b + 2\delta\epsilon(1-\epsilon)V_r + \delta(1-\epsilon)^2 V_{pd} + \delta\epsilon^2 V_{pp}$$

By plugging V_{pd} and V_{pp} into V_d and simplifying the equation we get:

$$V_d = b + \frac{\delta\epsilon^2(b+s) - 2s\delta\epsilon}{1-\delta\epsilon} + \frac{\delta(1-\epsilon)[2\epsilon + \delta(1-\epsilon)^2 + \epsilon^2]V_r}{1-\delta\epsilon}$$

It is easy to verify that with the parameters of our paper, $V_r > V_d$, and thus no player has incentive to deviate in the reward stage.

However, the player who is punished in the punishment stage has an incentive to deviate in the punishment state. His continuation payoffs from complying and deviating are:

$$V^{punished}_{comply} = s + \delta(1-\epsilon)V_r + \delta\epsilon V_{pd}$$

$$V^{punished}_{deviate} = d + \delta\epsilon V_r + \delta(1-\epsilon)V_{pd}$$

Plugging V_{pd} and V_r into the two equations above and simplifying yields:

$$\begin{aligned} V^{punished}_{comply} &= \frac{s}{1-\delta\epsilon} + \frac{c\delta(1-\epsilon)}{(1-\delta-2\delta\epsilon)(1-\delta\epsilon)-2\delta(1-\epsilon)^2} + \\ &\quad \frac{\delta^2(1-\epsilon)^2\epsilon(b+s)}{(1-\delta-2\delta\epsilon)(1-\delta\epsilon)^2-2\delta(1-\epsilon)^2} \end{aligned}$$

$$\begin{aligned} V^{punished}_{deviate} &= \frac{d+\delta\epsilon-\delta\epsilon(d+s)}{1-\delta\epsilon} + \frac{\delta^2(1-\epsilon)\epsilon(b+s)(\epsilon+\delta-2\delta\epsilon)}{(1-\delta-2\delta\epsilon)(1-\delta\epsilon)^2-2\delta(1-\epsilon)^2} + \\ &\quad \frac{c\delta(\delta+\epsilon-2\delta\epsilon)}{(1-\delta-2\delta\epsilon)(1-\delta\epsilon)-2\delta(1-\epsilon)^2} \end{aligned}$$

With our experimental parameters, the condition $V^{punished}_{comply} \geq V^{punished}_{deviate}$ is violated, which means that the punished player has incentive to deviate in the punishment stage. Hence, this candidate equilibrium is not an equilibrium in our parametrization.

However, if we add a second round to the punishment state, in which both play D, we have found a renegotiation-proof equilibrium for our parametrization. The continuation payoff of the reward stage is still:

$$V_r = c + \delta(\epsilon^2 + (1-\epsilon)^2)V_r + \delta(\epsilon(1-\epsilon))V_{pd} + \delta((1-\epsilon)\epsilon)V_{pp}$$

Since we add a second punishment stage, V_{pd} and V_{pp} change to:

$$V_{pd} = d + \delta[s + \delta(1-\epsilon)V_r + \delta\epsilon V_{pd}]$$

$$V_{pp} = d + \delta[b + \delta(1-\epsilon)V_r + \delta\epsilon V_{pp}]$$

By plugging V_{pd} and V_{pp} into V_r and simplifying the equation we get:

$$V_r = \frac{c(1-\delta^2\epsilon) + \delta\epsilon(1-\epsilon)[2d + \delta(b+s)]}{[1-\delta(1-2\epsilon+2\epsilon^2)](1-\delta^2\epsilon) - 2\delta^3\epsilon(1-\epsilon)^2}$$

The (unchanged) continuation payoff of deviating from cooperation is:

$$V_d = b + 2\delta\epsilon(1-\epsilon)V_r + \delta(1-\epsilon)^2 V_{pd} + \delta\epsilon^2 V_{pp}$$

By plugging V_{pd} and V_{pp} into V_d and simplifying the equation we get:

$$V_d = \frac{\delta(1-2\epsilon+2\epsilon^2)d}{1-\delta^2\epsilon} + \frac{[1-\delta^2\epsilon(1-\epsilon)]b}{1-\delta^2\epsilon} + \frac{\delta^2(1-\epsilon)^2 s}{1-\delta^2\epsilon} + \frac{[\delta\epsilon(2-\delta^2\epsilon)+\delta^3(1-\epsilon)^2](1-\epsilon)V_r}{1-\delta^2\epsilon}$$

And it is easy to verify that under the parameterization of our paper, $V_r > V_d$, and thus no player has incentive to deviate in the reward stage.

Next, we have to check whether the punisher and the player who gets punished have an incentive to deviate in the punishment stage. The continuation payoff is the same as in the previous case. For the punisher it is obvious that there is no incentive to deviate in the punishment stage. For the player who gets punished, the continuation payoff is:

$$V_{comply}^{punished} = s + \delta(1-\epsilon)V_r + \delta\epsilon V_{pd}$$

$$V_{deviate}^{punished} = d + \delta\epsilon V_r + \delta(1-\epsilon)V_{pd}$$

Plugging V_{pd} and V_r into the two equations and simplifying yields:

$$\begin{aligned} V_{comply}^{punished} \quad = \quad & \frac{s+d\delta\epsilon}{1-\delta^2\epsilon} + \frac{c\delta(1-\epsilon)}{[1-\delta(1-2\epsilon+2\epsilon^2)](1-\delta^2\epsilon)-2\delta^3\epsilon(1-\epsilon)^2} + \\ & \frac{\delta^2\epsilon(1-\epsilon)^2[2d+\delta(b+s)]}{[1-\delta(1-2\epsilon+2\epsilon^2)](1-\delta^2\epsilon)^2-2\delta^3\epsilon(1-\delta^2\epsilon)(1-\epsilon)^2} \end{aligned}$$

$$\begin{aligned} V_{deviate}^{punished} \quad = \quad & d + \frac{\delta(1-\epsilon)(d+s\delta)}{1-\delta^2\epsilon} + \\ & \frac{\delta[c(1-\delta^2\epsilon)+\delta\epsilon(1-\epsilon)(2d+\delta(b+s))](\epsilon-2\delta^2\epsilon+\delta^2)}{[1-\delta(1-2\epsilon+2\epsilon^2)](1-\delta^2\epsilon)-2\delta^3\epsilon(1-\epsilon)^2} \end{aligned}$$

With our parameters, $V_{comply}^{punished} \geq V_{deviate}^{punished}$ is satisfied. Thus, this candidate equilibrium is, indeed, a renegotiation-proof equilibrium.

Note that renegotiation-proof equilibria can be constructed in a way that makes them substantially more efficient than the most efficient equilibrium in strongly-symmetric strategies. This requires the use of a public randomization device to determine whether or not the punishment stage is entered after *cd* or *dc* signals with a probability less than one, such that V_{pd} equals the continuation value of the punishment state with strong symmetry. Efficiency will then be higher because $V_{pp} \geq V_r > V_{pd}$. So, even if they are more complicated than equilibria in strongly-symmetric strategies, players have an incentive to coordinate on them, in addition to potential renegotiation concerns.

A.3.3 Imperfect Private Monitoring

Truthful communication equilibria have a similar structure as renegotiation-proof equilibria, but for a different reason. The condition $V_{pp} = V_r$ stems from the fact that players must not have an incentive to lie about their private signal. In other words, reporting a c must lead to the same continuation value as a report of d. An equilibrium can be constructed as follows. Players start in the reward state, where they cooperate and report their private signals truthfully every round, which essentially transforms the game into one of imperfect public monitoring. Instead of the public signal under public monitoring, the reported signals are used to determine whether the players stay in the reward state or enter the punishment state. Unlike under public monitoring, a dd (reported) signal combination cannot be treated as a cc signal, as this would create an incentive to report d. Instead, the probability of having to enter the punishment state as the punished player must be independent of the own report. To this end, the public randomization device can be used to determine which of the two reports is considered (if any), each with a probability $\pi \leq 1/2$, and never both at the same time. If a report is considered and the reported signal is c, the game stays in the reward state. Otherwise, it transitions to the punishment state, in which the player who appeared to have defected, according to the considered report, becomes the punished player.

The punishment state starts with one period of mutual defection. After this round, the public randomization device determines whether or not a second round of mutual defection is entered with probability ρ. In these one or two rounds of mutual defection, no reports are necessary. In the next and last round of the punishment phase, the punished player plays C while the punisher plays D. After this round, the punisher reports the signal. If the punisher reports a d, the punishment phase is repeated, otherwise the players return to the reward state. With our experimental parameters and $\pi = 0.5$ and $\rho = 0.0498$, it can easily be verified that this is, indeed, an equilibrium (see below). Moreover, it is an equilibrium with a strict incentive not to deviate in the reward state. Hence, it survives Heller's (2017) stability criteria.

The continuation payoff of the reward stage of the proposed equilibrium is:

$$V_r = c + \delta(\pi(1-\epsilon)^2 + (1-\pi))V_r + \delta(\pi(1-\epsilon)\epsilon)V_{pp} + \delta\pi\epsilon V_{pd}$$

Where:

$$V_{pd} = d + \rho[\delta d + \delta(\delta s + \delta(\delta(1-\epsilon)V_r + \delta\epsilon V_{pd}))] + (1-\rho)[\delta s + \delta(\delta(1-\epsilon)V_r + \delta\epsilon V_{pd})]$$

is the continuation payoff from being punished. The continuation payoff as a punisher is:

$$V_{pp} = d + \rho[\delta d + \delta(\delta b + \delta(\delta(1-\epsilon)V_r + \delta\epsilon V_{pp}))] + (1-\rho)[\delta b + \delta(\delta(1-\epsilon)V_r + \delta\epsilon V_{pp})]$$

Moreover, the truthful communication constraint has to hold:

$$V_{pp} = V_r$$

We get a solution for ρ by solving the system of equations. With our experimental parameters and $\pi = 0.5$ we get $\rho = 0.0498$. Moreover, we get:

$$V_{pp} = V_r = \frac{d + \delta b + \rho\delta(d - b + \delta b)}{1 - \rho\delta^3 - (1-\rho)\delta^2}$$
$$V_{pd} = \frac{(1 - \delta + \delta\pi\epsilon)[\delta(1 - \rho + \rho\delta)b + (1 + \rho\delta)d]}{\delta\pi\epsilon[1 - \rho\delta^3 - (1-\rho)\delta^2]} - \frac{c}{\delta\pi\epsilon}$$

Now, we are ready to check whether there are incentives to deviate from following the proposed equilibrium strategies. First, consider whether players have an incentive to deviate in the reward stage. The continuation payoff from deviating is:

$$V_d = b + \delta[\pi\epsilon + (1-\pi)]V_r + \delta\pi(1-\epsilon)V_{pd}$$

Plugging V_r, V_{pd} into the equation above yields:

$$V_d = b + \frac{[(1 + \rho\delta)d + \delta(1 - \rho + \rho\delta)b][1 - \delta - \epsilon + 2\delta\epsilon]}{\epsilon[1 - \rho\delta^3 - (1-\rho)\delta^2]} - \frac{c(1-\epsilon)}{\epsilon}$$

Plugging in $\pi = 0.5$ and $\rho = 0.0498$ we see that $V_d < V_r$. Thus, there is no incentive to deviate in the reward stage.

For the punishment stage, we have to check that the punished player has no incentive to deviate. His continuation payoffs from deviating and complying are as follows:

$$V_{deviate}^{punished} = d + \delta(\epsilon V_r + (1-\epsilon)V_{pd})$$
$$V_{comply}^{punished} = s + \delta((1-\epsilon)V_r + \epsilon V_{pd})$$

Plugging V_r, V_{pd} into these equations, we can verify that the first condition $V_{comply}^{punished} > V_{deviate}^{punished}$ holds for our parameters and $\pi = 0.5$.

For the punisher it is obvious that there is no incentive to deviate in the punishment stage either. Thus, the proposed strategy profile is, indeed, a truthful communication equilibrium.

Appendix B Communication Content

Table B1: Categories Generated from Subcategories

Category	Subcategories	Freq.	PerPre	PubPre	PrivPre	PerRep	PubRep	PrivRep	$\bar{\kappa}$
			Frequency in Treatment						
All Supergames									
Coordination (C)	1-16,51,52,71,72	0.503	0.958	0.929	0.946	0.341	0.454	0.479	0.93
Deliberation (D)	17-26,34-41,57,70	0.274	0.643	0.643	0.606	0.192	0.219	0.218	0.72
Relationship (R)	30-33,42-45,47-50,58	0.228	0.103	0.181	0.200	0.219	0.270	0.236	0.71
Trivia (T)	53-55	0.605	0.886	0.810	0.711	0.633	0.515	0.552	1.00
Information (I)	27-29,46,56,59-69	0.215	-	-	-	0.184	0.297	0.285	0.81
Report of action	27,29,46,61,62,66-69	0.008	-	-	-	0.003	0.020	0.006	0.85
Report of action C	27,29,61,66,68	0.062	-	-	-	0.054	0.087	0.081	0.77
Report of action D	46,62,67,69	0.058	-	-	-	0.025	0.070	0.113	0.92
Report of signal	28,56,59,60,66-69	0.141	-	-	-	0.128	0.187	0.190	0.84
Report of signal c	59,68,69	0.066	-	-	-	0.028	0.091	0.118	0.91
Report of signal d	28,56,60,66,67	0.204	-	-	-	0.183	0.273	0.272	0.80
Last 3 Supergames									
Coordination (C)	1-16,51,52,71,72	0.404	0.975	0.974	0.973	0.241	0.328	0.381	0.95
Deliberation (D)	17-26,34-41,57,70	0.223	0.543	0.654	0.58	0.146	0.167	0.186	0.68
Relationship (R)	30-33,42-45,47-50,58	0.258	0.117	0.244	0.293	0.208	0.301	0.29	0.7
Trivia (T)	53-55	0.708	0.963	0.91	0.833	0.73	0.641	0.66	1
Information (I)	27-29,46,56,59-69	0.24	-	-	-	0.176	0.325	0.338	0.79
Report of action	27,29,46,61,62,66-69	0.003	-	-	-	0.001	0.007	0.002	0.8
Report of action C	27,29,61,66,68	0.066	-	-	-	0.06	0.083	0.086	0.75
Report of action D	46,62,67,69	0.064	-	-	-	0.012	0.076	0.139	0.91
Report of signal	28,56,59,60,66-69	0.161	-	-	-	0.112	0.219	0.232	0.82
Report of signal c	59,68,69	0.067	-	-	-	0.013	0.083	0.141	0.91
Report of signal d	28,56,60,66,67	0.227	-	-	-	0.175	0.301	0.318	0.78

Notes: Categories are 1 if the rater identified content related to at least one of the subcategories for a give text unit and 0 otherwise. Frequency indicates the probability that both raters indicated one of the respective subcategories for a randomly selected text unit. Frequencies < 0.001 omitted (-). $\bar{\kappa}$ is the average Cohen's Kappa over all treatments. Mean $\bar{\kappa}$ of all generated categories is 0.84.

Table B2: Battery of Subcategories for Coding – All Supergames

#	Subcategory	Category	Freq.	Frequency in Treatment: PerPre	PubPre	PrivPre	PerRep	PubRep	PrivRep	$\bar{\kappa}$
1	Proposal: both C	C	0.246	0.542	0.420	0.500	0.169	0.210	0.231	0.85
2	Proposal: both D	C	0.033	0.071	0.077	0.054	0.012	0.039	0.030	0.81
3	Proposal: alternate	C	0.013	0.024	0.058	0.066	0.005	0.001	0.013	0.75
4	Proposal: self D other C	C	0.010	0.013	0.047	0.031	0.006	0.004	0.008	0.72
5	Proposal: self C other D	C	0.005	0.008	0.008	0.009	0.001	0.001	0.010	0.56
6	Proposal: other coordination	C	0.006	0.029	0.044	0.017	-	0.005	0.002	0.41
7	Question: what action other	C	0.009	0.024	0.025	0.017	0.009	0.005	0.005	0.51
8	Announcement: C	C	0.009	0.016	0.047	0.006	0.006	0.006	0.008	0.59
9	Announcement: D	C	0.007	0.021	0.014	0.017	0.006	0.006	0.004	0.76
10	Rejection of proposal	C	0.004	0.005	0.005	0.017	0.002	0.004	0.002	0.59
11	Acceptance proposal	C	0.297	0.685	0.585	0.617	0.189	0.256	0.268	0.85
12	Implicit punishment threat for D	C	0.003	0.005	0.003	0.029	-	0.004	0.001	0.33
13	Punishment threat grim	C	0.003	0.005	0.014	0.003	0.005	-	-	0.57
14	Punishment threat lenient grim	C	-	-	-	-	-	-	-	-
15	Approval of punishment threat	C	0.002	-	-	0.014	0.002	0.001	0.001	0.41
16	Ask for coordination	C	0.041	0.119	0.115	0.120	0.011	0.031	0.041	0.79
17	Benefits of C	D	0.051	0.161	0.099	0.151	0.038	0.034	0.035	0.63
18	Benefits of D	D	0.007	0.013	0.027	0.023	0.002	0.005	0.005	0.53
19	Benefits of asymmetric play	D	0.003	0.003	0.008	0.011	0.002	0.001	0.003	0.50
20	Related to fairness discussion	D	0.009	0.040	0.025	0.031	0.002	0.002	0.010	0.66
21	Related to strategic uncertainty	D	0.050	0.095	0.206	0.100	0.026	0.042	0.036	0.56
22	Related to payoffs	D	0.055	0.188	0.181	0.154	0.029	0.035	0.036	0.71
23	Related to Prisoner's dilemma	D	0.004	0.058	0.003	-	0.002	-	-	0.84
24	Related to game theory	D	0.002	0.011	0.005	0.009	-	0.001	-	0.54
25	Future benefit of C	D	0.009	0.016	0.019	0.054	0.006	0.007	0.003	0.49
26	Short term incentives of D	D	-	0.005	-	-	-	-	-	0.05
27	Attribute other d to randomness	I	0.004	-	-	-	0.006	0.006	0.002	0.34
28	Attribute own d to randomness	I	0.006	-	-	-	0.010	0.007	0.005	0.36
29	Assurance to have played C	I	0.002	-	-	-	-	0.003	0.003	0.21
30	Promise	R	0.021	0.040	0.069	0.077	0.014	0.015	0.013	0.71
31	Distrust	R	0.002	0.005	-	-	0.002	0.001	0.002	0.27
32	Trust	R	0.012	0.016	0.019	0.023	0.011	0.010	0.012	0.63
33	Argue for trustworthy behavior	R	0.026	0.048	0.102	0.111	0.021	0.011	0.014	0.62
34	Report payoff from past games	D	0.028	0.063	0.022	0.006	0.030	0.025	0.027	0.72
35	Report signals of past games	D	0.013	0.042	-	0.009	0.013	0.014	0.011	0.42
36	Good past experience with CC	D	0.051	0.151	0.126	0.100	0.028	0.048	0.037	0.75
37	Good past experience with DD	D	0.001	0.003	0.003	0.003	-	0.002	0.001	0.43
38	Bad past experience with CC	D	0.008	0.021	0.060	0.014	0.002	0.001	0.007	0.44
39	Bad past experience with CC	D	-	-	0.003	-	-	0.001	0.001	0.24
40	Good past experience asym. play	D	0.001	0.005	0.011	0.003	-	-	0.001	0.53
41	Bad past experience asym. play	D	0.001	0.003	0.003	0.006	-	0.002	-	0.52
42	Positive feedback after CC	R	0.119	-	-	-	0.115	0.167	0.143	0.81
43	Positive feedback after DD	R	0.002	-	-	-	0.002	0.003	0.001	0.65
44	Positive feedback after asym. play	R	0.001	-	-	-	0.001	0.002	0.002	0.64
45	Empathy	R	0.016	-	0.003	-	0.014	0.022	0.020	0.57
46	Confess D	I	-	-	-	-	-	0.001	-	0.40
47	Apology	R	0.002	-	-	-	0.004	0.001	0.001	0.48
48	Justification of play	R	0.001	-	-	-	0.003	0.001	-	0.19
49	Accusation of cheating	R	0.007	-	-	-	0.004	0.008	0.014	0.55
50	Verbal punishment	R	0.001	-	-	-	0.001	0.001	-	0.57
51	Renegotiation	C	0.001	-	-	-	-	0.001	0.001	0.06
52	Argument against punishment	C	-	-	-	-	-	-	-	-
53	Small talk	T	0.247	0.820	0.739	0.583	0.176	0.141	0.168	0.70
54	Off topic	T	0.283	0.193	0.093	0.094	0.368	0.229	0.330	0.58
55	Boredom	T	0.011	0.021	-	0.014	0.012	0.012	0.010	0.57
56	Disappointed after d signal	I	0.024	-	-	-	0.029	0.030	0.025	0.55
57	Confusion	D	0.033	0.058	0.085	0.026	0.015	0.036	0.037	0.35
58	Motivational talk	R	0.026	-	-	-	0.030	0.041	0.022	0.51
59	Report: own signal c	I	0.004	-	-	-	0.001	0.006	0.008	0.65
60	Report: own signal d	I	0.012	-	-	-	0.005	0.021	0.016	0.82
61	Report: own action C	I	0.005	-	-	-	0.001	0.013	0.005	0.50
62	Report: own action D	I	0.003	-	-	-	-	0.009	0.001	0.78
63	Ask for others payoff	I	0.019	-	-	-	0.010	0.023	0.035	0.83
64	Ask for others signal	I	0.006	-	-	-	0.003	0.004	0.014	0.45
65	Ask for others action	I	0.006	-	-	-	0.003	0.011	0.007	0.85
66	Report: own payoff 0	I	0.025	-	-	-	0.012	0.032	0.047	0.95
67	Report: own payoff 17	I	0.004	-	-	-	0.002	0.009	0.003	0.90
68	Report: own payoff 30	I	0.022	-	-	-	0.011	0.016	0.051	0.96
69	Report: own payoff 37	I	0.001	-	-	-	0.001	0.002	0.001	0.73
70	Being cheated on in past games	D	0.005	-	-	0.003	0.003	0.007	0.006	0.45
71	Counter-proposal	C	-	-	-	-	-	0.001	0.001	0.46
72	Rejection of punishment	C	-	-	0.003	-	-	-	-	0.67

Notes: Subcategories are 1 if the rater identified content related to the subcategory for a given text unit and 0 otherwise. Category are Coordination (C), Deliberation (D), Relationship (R), Trivia (T) and Information (I). Frequency indicates the probability that both raters indicated the respective subcategory for a randomly selected text unit. Frequencies < 0.001 omitted (-). $\bar{\kappa}$ is the average Cohen's Kappa over all treatments. Mean $\bar{\kappa}$ of all subcategories with an overall frequency > 0.01 is 0.65.

Table B3: Battery of Subcategories for Coding – Last Three Supergames

				Frequency in Treatment						
#	Subcategory	Category	Freq.	PerPre	PubPre	PrivPre	PerRep	PubRep	PrivRep	$\bar{\kappa}$
1	Proposal: both C	C	0.224	0.673	0.487	0.613	0.131	0.177	0.195	0.88
2	Proposal: both D	C	0.01	0.012	0.058	0.013	0.004	0.011	0.005	0.78
3	Proposal: alternate	C	0.005	0.025	0.032	0.013	-	-	0.007	0.75
4	Proposal: self D other C	C	0.002	-	0.026	-	-	-	0.004	0.76
5	Proposal: self C other D	C	0.002	-	0.006	0.007	-	-	0.005	0.64
6	Proposal: other coordination	C	0.005	0.012	0.071	0.007	-	0.002	-	0.56
7	Question: what action other	C	0.003	-	0.026	0.007	0.001	-	0.005	0.44
8	Announcement: C	C	0.007	0.006	0.058	-	0.002	0.004	0.01	0.54
9	Announcement: D	C	0.001	0.006	0.019	-	-	-	0.001	0.83
10	Rejection of proposal	C	0.003	0.006	0.006	0.013	-	0.003	0.002	0.6
11	Acceptance proposal	C	0.246	0.747	0.59	0.66	0.15	0.185	0.207	0.88
12	Implicit punishment threat for D	C	0.003	0.006	-	0.033	0.001	0.003	-	0.28
13	Punishment threat grim	C	0.002	-	-	0.007	0.005	-	-	0.52
14	Punishment threat lenient grim	C	-	-	-	-	-	-	-	-
15	Approval of punishment threat	C	0.002	-	-	0.027	0.002	-	-	0.4
16	Ask for coordination	C	0.022	0.062	0.096	0.093	0.004	0.01	0.024	0.79
17	Benefits of C	D	0.04	0.123	0.122	0.167	0.024	0.025	0.026	0.62
18	Benefits of D	D	0.001	-	0.006	0.007	-	0.001	-	0.28
19	Benefits of asymmetric play	D	-	-	0.006	-	-	-	-	0.4
20	Related to fairness discussion	D	0.007	0.037	0.019	0.033	0.002	-	0.008	0.66
21	Related to strategic uncertainty	D	0.036	0.068	0.237	0.093	0.013	0.028	0.024	0.54
22	Related to payoffs	D	0.032	0.136	0.147	0.113	0.01	0.02	0.02	0.71
23	Related to Prisoner's dilemma	D	0.003	0.056	-	-	0.002	-	-	0.88
24	Related to game theory	D	0.001	0.012	-	0.013	0.001	-	-	0.71
25	Future benefit of C	D	0.007	0.006	0.013	0.067	0.006	0.006	0.001	0.54
26	Short term incentives of D	D	-	-	-	-	-	-	-	-
27	Attribute other d to randomness	I	0.004	-	-	-	0.005	0.006	0.002	0.31
28	Attribute own d to randomness	I	0.006	-	-	-	0.01	0.004	0.005	0.3
29	Assurance to have played C	I	0.002	-	-	-	-	0.003	0.005	0.22
30	Promise	R	0.026	0.062	0.103	0.12	0.015	0.017	0.012	0.72
31	Distrust	R	0.002	0.006	-	-	0.002	0.001	0.003	0.36
32	Trust	R	0.012	0.006	0.019	0.02	0.012	0.006	0.016	0.6
33	Argue for trustworthy behavior	R	0.029	0.062	0.135	0.18	0.014	0.012	0.015	0.61
34	Report payoff from past games	D	0.025	0.043	0.019	-	0.024	0.023	0.03	0.65
35	Report signals of past games	D	0.017	0.062	-	0.02	0.014	0.016	0.014	0.44
36	Good past experience with CC	D	0.055	0.142	0.179	0.167	0.029	0.048	0.039	0.73
37	Good past experience with DD	D	0.001	0.006	0.006	-	-	-	-	0.36
38	Bad past experience with CC	D	0.01	0.019	0.109	0.033	0.001	-	0.007	0.43
39	Bad past experience with CC	D	0.001	-	-	-	-	0.001	0.001	0.31
40	Good past experience asym. play	D	0.001	-	0.013	-	-	-	-	0.5
41	Bad past experience asym. play	D	0.001	-	-	-	-	0.002	-	0.67
42	Positive feedback after CC	R	0.14	-	-	-	0.11	0.201	0.178	0.8
43	Positive feedback after DD	R	0.001	-	-	-	0.001	-	0.001	0.44
44	Positive feedback after asym. play	R	-	-	-	-	-	-	-	-
45	Empathy	R	0.02	-	-	-	0.017	0.025	0.029	0.59
46	Confess D	I	-	-	-	-	-	0.001	-	1
47	Apology	R	-	-	-	-	0.001	-	-	0.15
48	Justification of play	R	0.001	-	-	-	0.001	0.001	-	0.12
49	Accusation of cheating	R	0.009	-	-	-	0.002	0.01	0.018	0.61
50	Verbal punishment	R	-	-	-	-	-	0.001	-	0.29
51	Renegotiation	C	0.001	-	-	-	-	-	0.002	0.05
52	Argument against punishment	C	-	-	-	-	-	-	-	-
53	Small talk	T	0.241	0.92	0.821	0.66	0.156	0.127	0.177	0.66
54	Off topic	T	0.394	0.315	0.122	0.14	0.473	0.342	0.455	0.58
55	Boredom	T	0.014	0.043	-	0.02	0.016	0.012	0.011	0.52
56	Disappointed after d signal	I	0.029	-	-	-	0.039	0.038	0.021	0.56
57	Confusion	D	0.022	0.031	0.006	0.027	0.012	0.023	0.031	0.25
58	Motivational talk	R	0.028	-	-	-	0.027	0.046	0.026	0.49
59	Report: own signal c	I	0.002	-	-	-	-	0.003	0.005	0.5
60	Report: own signal d	I	0.01	-	-	-	0.002	0.016	0.017	0.8
61	Report: own action C	I	0.005	-	-	-	-	0.011	0.005	0.43
62	Report: own action D	I	0.001	-	-	-	-	0.002	0.001	0.75
63	Ask for others payoff	I	0.018	-	-	-	0.006	0.017	0.04	0.77
64	Ask for others signal	I	0.002	-	-	-	0.002	0.002	0.003	0.2
65	Ask for others action	I	0.004	-	-	-	0.002	0.006	0.006	0.82
66	Report: own payoff 0	I	0.028	-	-	-	0.01	0.034	0.054	0.94
67	Report: own payoff 17	I	0.001	-	-	-	-	0.004	0.001	0.91
68	Report: own payoff 30	I	0.023	-	-	-	0.002	0.017	0.063	0.96
69	Report: own payoff 37	I	0.001	-	-	-	0.001	0.001	-	0.67
70	Being cheated on in past games	D	0.008	-	-	-	0.004	0.011	0.012	0.47
71	Counter-proposal	C	-	-	-	-	-	-	0.001	0.33
72	Rejection of punishment	C	-	-	-	-	-	-	-	-

Notes: See notes of Table B2. Data from last three supergames.

Table B4: Communication after First Defection Signal - All Supergames

	Public Repeated				Private Repeated			
Category	d signal	c signals	diff	p-value	d signal	c signal	diff	p-value
Coordination	0.45	0.29	0.17	0.01	0.48	0.29	0.19	0.01
Deliberation	0.12	0.13	-0.01	0.85	0.08	0.09	-0.01	0.85
Relationship	0.26	0.40	-0.14	0.03	0.24	0.32	-0.08	0.26
Information	0.66	0.34	0.33	0.00	0.64	0.34	0.29	0.00
Trivia	0.38	0.53	-0.15	0.00	0.39	0.54	-0.15	0.04
Report of action	0.41	0.02	0.39	0.00	0.44	0.09	0.35	0.00
Report of C	0.40	0.02	0.38	0.00	0.44	0.09	0.35	0.00
Report of D	-	-	-	-	-	-	-	-
Report of signal	0.56	0.33	0.23	0.00	0.64	0.33	0.31	0.00
Report of c	0.09	0.33	-0.24	0.00	0.01	0.32	-0.31	0.00
Report of d	0.48	-	-	-	0.64	0.00	0.63	0.00

Notes: Frequency of communication categories for subject-round observations with cooperative history of both players up to round t. A participant has a cooperative history if all her previous actions were C and all signals she observed in rounds $< t$ were c. Columns compare the communication in round $t+1$ conditional on the signals received in round t. Frequencies indicate the probability that both raters indicated the category for a text unit. P-values derived from logit models with standard errors clustered on participant and match. Zero frequencies omitted (-).

Appendix C Strategy Estimation

We use the strategy frequency estimation method (Dal Bó and Fréchette, 2011) and its adaptation to behavior strategies (Breitmoser, 2015) to analyze participants' strategies across treatments. The estimation is perfomed with the R package *stratEst* (Dvorak, 2021). A detailed documentation of the method can be found in Dvorak (2020).

Model Definition

Let p_k denote the share of strategy $k \in \{1, \cdots, K\}$ in the population and $\pi_{s_k} \in [0, 1]$ the probability of cooperation prescribed by strategy k in state $s_k \in S_k$. When estimating pure strategies, we assume that there exists a pure underlying response probability $\xi_{s_k} \in \{0, 1\}$ to each π_{s_k}. The pure responses are confounded by a tremble which implements the wrong action and occurs with probability $\gamma \in [0, 0.5]$. We assume that the probability of a tremble is the same for all individuals, supergames and rounds and that the realizations of trembles are independent across these dimensions.[20] The probability of cooperation for pure strategy

[20] See Bland (2020) for a recent adaptation of SFEM which allows for heterogeneity in the trembles.

Table B5: Communication after First Defection Signal – All Supergames

		Public Repeated			Private Repeated		
#	Subcategory	*d* signal	*c* signals	diff	*d* signal	*c* signal	diff
1	Proposal: both C	0.164	0.145	0.019	0.168	0.143	0.025
2	Proposal: both D	0.013	0.012	0.001	-	0.011	-0.011
3	Proposal: alternate	-	-	-	-	0.005	-0.005
4	Proposal: self D other C	-	-	-	0.017	0.003	0.014
5	Proposal: self C other D	0.007	-	0.007	-	-	-
6	Proposal: other coordination	-	0.004	-0.004	-	-	-
7	Question: what action other	-	-	-	-	-	-
8	Announcement: C	0.007	0.002	0.005	0.025	0.003	0.022
9	Announcement: D	0.007	-	0.007	-	-	-
10	Rejection of proposal	-	-	-	-	0.002	-0.002
11	Acceptance proposal	0.178	0.164	0.014	0.143	0.165	-0.022
12	Implicit punishment threat for D	-	-	-	-	0.002	-0.002
13	Punishment threat grim	-	-	-	-	-	-
14	Punishment threat lenient grim	-	-	-	-	-	-
15	Approval of punishment threat	-	-	-	-	0.002	-0.002
16	Ask for coordination	0.013	0.004	0.009	0.025	0.005	0.02
17	Benefits of C	0.007	0.008	-0.001	0.008	0.017	-0.009
18	Benefits of D	-	-	-	-	-	-
19	Benefits of asymmetric play	-	-	-	-	-	-
20	Related to fairness discussion	-	-	-	-	-	-
21	Related to strategic uncertainty	0.013	0.017	-0.004	0.025	0.011	0.014
22	Related to payoffs	0.013	0.006	0.007	0.017	0.016	0.001
23	Related to Prisoner's dilemma	-	-	-	-	-	-
24	Related to game theory	-	0.002	-0.002	-	-	-
25	Future benefit of C	0.007	0.002	0.005	0.008	0.002	0.006
26	Short term incentives of D	-	-	-	-	-	-
27	Attribute other d to randomness	0.033	-	0.033	-	0.002	-0.002
28	Attribute own d to randomness	0.053	-	0.053	0.042	-	0.042
29	Assurance to have played C	-	-	-	0.008	0.003	0.005
30	Promise	-	0.012	-0.012	0.008	-	0.008
31	Distrust	-	-	-	0.008	-	0.008
32	Trust	0.013	0.006	0.007	0.084	0.003	0.081
33	Argue for trustworthy behavior	0.013	-	0.013	-	0.003	-0.003
34	Report payoff from past games	-	0.019	-0.019	0.008	0.003	0.005
35	Report signals of past games	-	0.004	-0.004	-	0.005	-0.005
36	Good past experience with CC	-	0.017	-0.017	-	0.002	-0.002
37	Good past experience with DD	-	-	-	-	-	-
38	Bad past experience with CC	-	-	-	-	-	-
39	Bad past experience with CC	-	-	-	-	0.002	-0.002
40	Good past experience asym. play	-	-	-	-	-	-
41	Bad past experience asym. play	-	-	-	-	-	-
42	Positive feedback after CC	-	0.321	-0.321	0.017	0.233	-0.216
43	Positive feedback after DD	-	-	-	-	-	-
44	Positive feedback after asym. play	-	-	-	0.008	0.002	0.006
45	Empathy	0.132	-	0.132	-	0.027	-0.027
46	Confess D	-	-	-	-	-	-
47	Apology	-	0.002	-0.002	-	-	-
48	Justification of play	-	-	-	-	-	-
49	Accusation of cheating	0.046	-	0.046	0.143	-	0.143
50	Verbal punishment	0.007	-	0.007	-	-	-
51	Renegotiation	-	0.002	-0.002	-	-	-
52	Argument against punishment	-	-	-	-	-	-
53	Small talk	0.02	0.014	0.006	0.059	0.046	0.013
54	Off topic	0.118	0.269	-0.151	0.151	0.38	-0.229
55	Boredom	-	0.015	-0.015	-	0.008	-0.008
56	Disappointed after d signal	0.191	-	0.191	0.185	-	0.185
57	Confusion	0.059	0.044	0.015	-	0.027	-0.027
58	Motivational talk	0.033	0.089	-0.056	0.008	0.029	-0.021
59	Report: own signal c	0.007	0.004	0.003	0.008	0.008	-
60	Report: own signal d	0.151	-	0.151	0.16	0.002	0.158
61	Report: own action C	0.092	0.004	0.088	0.008	0.006	0.002
62	Report: own action D	-	-	-	-	-	-
63	Ask for others payoff	0.086	0.008	0.078	0.059	0.035	0.024
64	Ask for others signal	0.013	0.002	0.011	0.034	0.016	0.018
65	Ask for others action	0.066	-	0.066	0.042	-	0.042
66	Report: own payoff 0	0.197	-	0.197	0.395	0.003	0.392
67	Report: own payoff 17	-	-	-	-	-	-
68	Report: own payoff 30	0.066	0.015	0.051	-	0.076	-0.076
69	Report: own payoff 37	-	-	-	-	-	-
70	Being cheated on in past games	-	0.006	-0.006	-	0.003	-0.003
71	Counter-proposal	-	-	-	-	0.002	-0.002
72	Rejection of punishment	-	-	-	-	-	-

Notes: Frequency of subcategories for subject-round observations with cooperative history in round t. A Subject has a cooperative history if her previous actions were C and all signals she observed in rounds $< t$ were c. Frequencies illustrate the use of subcategories dependent on signals in round t. Frequency indicates the probability that both raters indicated the respective subcategory for a randomly selected text unit. Frequencies < 0.001 omitted (-).

Table B6: Communication after First Defection Signal – Last Three Supergames

		Public Repeated			Private Repeated		
#	Subcategory	*d* signal	*c* signals	diff	*d* signal	*c* signal	diff
1	Proposal: both C	0.136	0.094	0.042	0.182	0.112	0.07
2	Proposal: both D	-	0.01	-0.01	-	0.013	-0.013
3	Proposal: alternate	-	-	-	-	0.005	-0.005
4	Proposal: self D other C	-	-	-	-	0.005	-0.005
5	Proposal: self C other D	-	-	-	-	-	-
6	Proposal: other coordination	-	-	-	-	-	-
7	Question: what action other	-	-	-	-	-	-
8	Announcement: C	-	0.003	-0.003	0.03	0.005	0.025
9	Announcement: D	-	-	-	-	-	-
10	Rejection of proposal	-	-	-	-	0.003	-0.003
11	Acceptance proposal	0.123	0.094	0.029	0.121	0.142	-0.021
12	Implicit punishment threat for D	-	-	-	-	-	-
13	Punishment threat grim	-	-	-	-	-	-
14	Punishment threat lenient grim	-	-	-	-	-	-
15	Approval of punishment threat	-	-	-	-	-	-
16	Ask for coordination	-	-	-	0.045	0.003	0.042
17	Benefits of C	-	-	-	-	0.013	-0.013
18	Benefits of D	-	-	-	-	-	-
19	Benefits of asymmetric play	-	-	-	-	-	-
20	Related to fairness discussion	-	-	-	-	-	-
21	Related to strategic uncertainty	-	0.01	-0.01	-	0.003	-0.003
22	Related to payoffs	0.012	0.006	0.006	0.015	0.008	0.007
23	Related to Prisoner's dilemma	-	-	-	-	-	-
24	Related to game theory	-	-	-	-	-	-
25	Future benefit of C	0.012	0.003	0.009	-	-	-
26	Short term incentives of D	-	-	-	-	-	-
27	Attribute other d to randomness	0.037	-	0.037	-	-	-
28	Attribute own d to randomness	0.025	-	0.025	0.045	-	0.045
29	Assurance to have played C	-	-	-	0.015	0.005	0.01
30	Promise	-	0.01	-0.01	-	-	-
31	Distrust	-	-	-	0.015	-	0.015
32	Trust	0.025	0.003	0.022	0.136	0.005	0.131
33	Argue for trustworthy behavior	0.025	-	0.025	-	0.003	-0.003
34	Report payoff from past games	-	0.026	-0.026	-	-	-
35	Report signals of past games	-	0.003	-0.003	-	0.008	-0.008
36	Good past experience with CC	-	0.023	-0.023	-	0.003	-0.003
37	Good past experience with DD	-	-	-	-	-	-
38	Bad past experience with CC	-	-	-	-	-	-
39	Bad past experience with CC	-	-	-	-	0.003	-0.003
40	Good past experience asym. play	-	-	-	-	-	-
41	Bad past experience asym. play	-	-	-	-	-	-
42	Positive feedback after CC	-	0.314	-0.314	-	0.254	-0.254
43	Positive feedback after DD	-	-	-	-	-	-
44	Positive feedback after asym. play	-	-	-	-	-	-
45	Empathy	0.16	-	0.16	-	0.037	-0.037
46	Confess D	-	-	-	-	-	-
47	Apology	-	-	-	-	-	-
48	Justification of play	-	-	-	-	-	-
49	Accusation of cheating	0.074	-	0.074	0.182	-	0.182
50	Verbal punishment	0.012	-	0.012	-	-	-
51	Renegotiation	-	-	-	-	-	-
52	Argument against punishment	-	-	-	-	-	-
53	Small talk	0.025	-	0.025	0.091	0.064	0.027
54	Off topic	0.185	0.353	-0.168	0.197	0.479	-0.282
55	Boredom	-	0.01	-0.01	-	-	-
56	Disappointed after d signal	0.235	-	0.235	0.136	-	0.136
57	Confusion	0.062	0.036	0.026	-	0.035	-0.035
58	Motivational talk	0.049	0.071	-0.022	-	0.024	-0.024
59	Report: own signal c	-	0.003	-0.003	-	0.005	-0.005
60	Report: own signal d	0.111	-	0.111	0.121	0.003	0.118
61	Report: own action C	0.086	-	0.086	0.015	0.011	0.004
62	Report: own action D	-	-	-	-	-	-
63	Ask for others payoff	0.062	-	0.062	0.091	0.045	0.046
64	Ask for others signal	-	0.003	-0.003	-	0.003	-0.003
65	Ask for others action	0.049	-	0.049	0.045	-	0.045
66	Report: own payoff 0	0.21	-	0.21	0.5	0.003	0.497
67	Report: own payoff 17	-	-	-	-	-	-
68	Report: own payoff 30	0.074	0.006	0.068	-	0.091	-0.091
69	Report: own payoff 37	-	-	-	-	-	-
70	Being cheated on in past games	-	0.01	-0.01	-	0.005	-0.005
71	Counter-proposal	-	-	-	-	0.003	-0.003
72	Rejection of punishment	-	-	-	-	-	-

Notes: See notes of Table B5. Data from last three supergames.

Table B7: Frequency and Truthfulness of Private Information Exchange - All Supergames

	Public		Private	
	p(report)	p(true)	p(report)	p(true)
Actions				
Report of action	0.11	0.94	0.14	0.89
Report of C	0.09	0.95	0.14	0.88
Report of D	0.02	0.97	0.01	1.00
Report of C if $\omega_i = d$	0.11	0.83	0.14	0.61
D and report of D if $\omega_i = d$	0.12	1.00	0.03	1.00
C and report of C $\omega_i = d$	0.30	1.00	0.30	1.00
D and report of C if $\omega_i = d$	0.03	0.00	0.08	0.00
Signals				
Report of signal	-	-	0.33	0.95
Report of c	-	-	0.23	0.98
Report of d	-	-	0.10	0.86
Report of d if $\omega_{-i} = d$	-	-	0.33	-

Notes: Frequencies of coding in all participant-round observations after round one for the repeated communication treatments with public monitoring (columns 2 and 3) and private monitoring (columns 4 and 5). A coding is considered valid if both raters indicated the same sub-category for a participant-round observation. Values might not add up as expected due to rounding.

Table B8: Private Information Exchange and Mutual Cooperation - All Supergames

	Public			Private		
	estimate	std. error	p-value	estimate	std. error	p-value
intercept	-0.14	0.23	0.55	-0.76	0.32	0.02
Report of C	0.65	0.36	0.07	2.42	1.16	0.04
Report of d	-	-	-	1.42	0.41	0.00
Report of C $\times$ Report of d	-	-	-	-2.12	1.15	0.06
Trivia	0.76	0.30	0.01	-0.12	0.32	0.70

Notes: Table shows coefficients of logit models with standard errors clustered on participant and match. Report of C is a dummy that indicates if C is reported by the player for whom the signal indicated d in the last round. Report of d is a dummy that indicates whether the defection signal was reported by the player who received the signal. Data of all supergames. A coding is considered valid if both raters indicated the same sub-category for a participant-round observation.

k in state s_k is given by: $\pi_{s_k} = \xi_{s_k}(1-\gamma) + (1-\xi_{s_k})(1-\gamma)$. Let y_{is_k} denote the number of times individual $i \in \{1, \cdots, N\}$ cooperates in n_{is_k} observations of state s_k of strategy k. We report the maximum-likelihood estimates of the parameters p_k, π_{s_k} (or alternatively ξ_{s_k} and γ) that maximize the log-likelihood

$$\ln L = \sum_{i=1}^{N} \ln \left(\sum_{k=1}^{K} p_k \prod_{s_k \in S_k} (\pi_{s_k})^{y_{is_k}} (1-\pi_{s_k})^{n_{is_k} - y_{is_k}} \right).$$

To find the global optima of the parameters, we execute the EM-algorithm (Dempster et al., 1977) from multiple random starting points and use the Newton-Raphson method to check for convergence.

To obtain the results reported in Table C1, we perform treatment-wise strategy estimation starting with the candidate set of 24 strategies listed in Tables C2-C5. We assume that all strategies of the same model condition on the same information and report the model with the highest likelihood. The strategies fitted to the data of the perfect monitoring treatments condition on the action profile $\{a_i, a_{-i}\}$ observed in the previous round. The strategies fitted to the data of the imperfect monitoring treatments condition on the action-signal profile $\{a_i, \omega_{-i}\}$ observed in the previous round.

SFEM Results

Table C1 depicts the estimated strategy shares and standard errors. The main result of the strategy estimation is that the shares of lenient and forgiving strategies increase substantially with communication under all three monitoring structures. Under imperfect monitoring, repeated communication further increases the use of lenient and forgiving strategies.

Adaptation of Strategies

Tables C2-C5 list the set of 24 strategies used to obtain the strategy estimation results reported in Table C1. Circles in Table C4 represent strategy states and arrows deterministic state transitions. In the treatments with perfect monitoring, the state traditions can in principle be triggered by action profiles, the two public signals or action-signal combinations. In the treatments with public monitoring, transitions can be triggered by the two public signals or action-signal combinations. We assume that all strategies in the set condition on the same information, run the estimation for the 3 (2) possibilities and report the results with the highest log-likelihood.

Table C1: Strategy Frequency Estimation

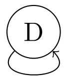
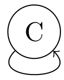
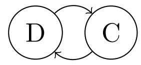
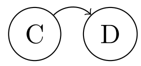
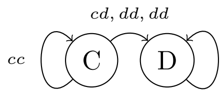
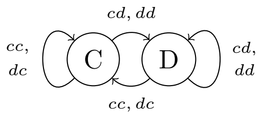
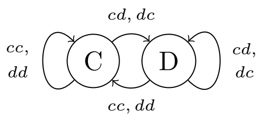
		Perfect			Public			Private		
	lenient/forgiving	No	Pre	Rep	No	Pre	Rep	No	Pre	Rep
ALLD	no	0.42	-	-	0.61	0.02	-	0.50	0.02	-
		(0.07)	-	-	(0.08)	(0.02)	-	(0.07)	(0.02)	-
ALLC	yes	-	-	-	-	-	0.32	-	-	0.27
		-	-	-	-	-	(0.19)	-	-	(0.20)
DC	no	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-
FC	no	-	-	-	-	0.08	0.01	-	-	-
		-	-	-	-	(0.04)	(0.02)	-	-	-
GRIM	no	0.08	0.23	-	-	0.02	-	0.03	-	-
		(0.06)	(0.16)	-	-	(0.02)	-	(0.04)	-	-
TFT	yes	0.08	-	-	0.03	-	-	-	-	-
		(0.06)	-	-	(0.04)	-	-	-	-	-
PTFT	yes	-	-	0.17	-	-	-	-	-	-
		-	-	(0.18)	-	-	-	-	-	-
T2	yes	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-
TF2T	yes	-	-	-	0.01	0.01	-	-	0.07	0.07
		-	-	-	(0.02)	(0.04)	-	-	(0.09)	(0.08)
TF3T	yes	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-
T2FT	yes	-	-	-	-	0.04	-	-	0.05	-
		-	-	-	-	(0.04)	-	-	(0.06)	-
T2F2T	yes	0.04	-	0.40	-	0.15	-	-	0.24	0.09
		(0.03)	-	(0.21)	-	(0.10)	-	-	(0.15)	(0.10)
GRIM2	yes	-	-	0.44	-	0.20	0.21	0.19	0.10	0.15
		-	-	(0.20)	-	(0.10)	(0.15)	(0.07)	(0.14)	(0.09)
GRIM3	yes	-	-	-	0.04	0.02	0.32	-	0.01	0.12
		-	-	-	(0.03)	(0.04)	(0.18)	-	(0.06)	(0.17)
PT2FT	yes	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-
DTFT	yes	0.12	-	-	-	-	-	-	-	-
		(0.06)	-	-	-	-	-	-	-	-
DTF2T	yes	0.02	-	-	0.07	-	-	-	-	-
		(0.02)	-	-	(0.04)	-	-	-	-	-
DTF3T	yes	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-
DGRIM2	yes	-	-	-	0.02	-	-	0.01	-	-
		-	-	-	(0.04)	-	-	(0.02)	-	-
DGRIM3	yes	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-
SGRIM	yes	0.09	-	-	0.09	-	0.04	0.24	0.22	0.05
		(0.08)	-	-	(0.06)	-	(0.04)	(0.09)	(0.11)	(0.05)
M1BF	yes	-	-	-	0.03	0.38	-	-	0.10	0.08
		-	-	-	(0.05)	(0.10)	-	-	(0.09)	(0.09)
T1BF$_{as}$	yes	0.11	0.77	-	0.05	-	0.06	-	0.07	0.13
		(0.07)	(0.28)	-	(0.05)	-	(0.05)	-	(0.08)	(0.09)
RAND	no	0.03	-	-	0.05	0.08	0.05	0.03	0.11	0.03
		(0.03)	-	-	(0.03)	(0.05)	(0.04)	(0.04)	(0.05)	(0.03)
$\sum$ lenient/forgiving		0.46	0.77	1.00	0.34	0.79	0.94	0.45	0.87	0.97
		(0.09)	(0.16)	(0.01)	(0.08)	(0.06)	(0.04)	(0.08)	(0.06)	(0.04)
γ		0.06	0.01	0.01	0.07	0.06	0.03	0.05	0.02	0.04
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Notes: Treatment-wise maximum-likelihood shares of the 24 strategies listed in Tables C2-C5 assuming constant strategy use over the last three supergames. Strategies condition on action profiles in perfect treatments, and on action-signal profiles in public and private treatments. γ indicates the probability of a tremble. Zero shares are omitted (-). Analytic standard errors in parentheses. Values might not add up as expected due to rounding.

Strategies 1-20 and their descriptions are taken from Fudenberg et al. (2012). The remaining four strategies are behavior strategies. Two of the behavior strategies are motivated by Backhaus and Breitmoser's (2021) analysis, who present evidence suggesting that subjects play semi-grim M1BF strategies, and further find that a small share of (noise) players randomize 50–50 in all states. Taking these findings into account, we include a strategy RAND that predicts a 50% cooperation probability after all histories. We also include a semi-grim strategy SGRIM which starts with cooperation and cooperates with probability of 1 in the *cc*-state, probability 0 in the *dd*-state, and probability 0.35 in the *cd* and *dc* states. The value 0.35 is the average cooperation probability that Backhaus and Breitmoser (2021) report for these states in the lower panel of Table 1 of their paper. We choose this value instead of estimating the probability from our data, as this would give the strategy an additional free parameter and therefore an advantage over the other strategies in the set.

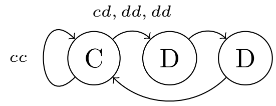
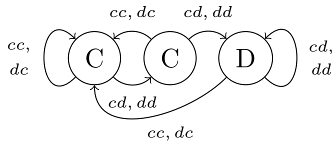
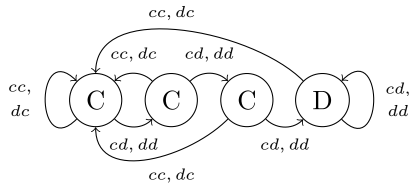
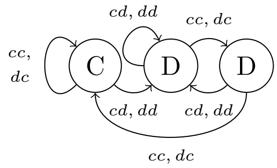
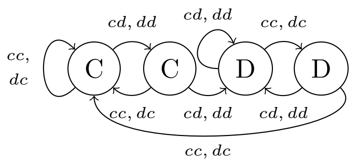
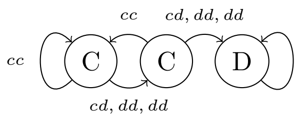
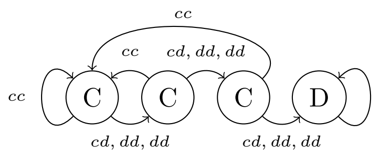
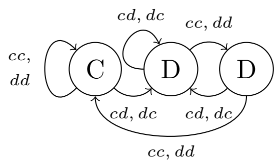
The third behavioral strategy that we include is a M1BF strategy that conditions on the observed actions ($\sigma_\emptyset = 1, \sigma_{cc} = 1, \sigma_{cd} = 0.75, \sigma_{dc} = 0.5, \sigma_{dd} = 0$). The M1BF strategy results for $\delta = 0.8$ when assuming that subjects start with cooperation, cooperate after mutual cooperation, and defect after mutual defection. The fourth behavior strategy that we include is the T1BF strategy that which conditions on the own action and the signal about the action of the partner in the previous round ($\sigma_\emptyset = 1, \sigma_{cc} = 1, \sigma_{cd} = 0.5, \sigma_{dc} = 1, \sigma_{dd} = 0$). The behavior of T1BF$_{as}$ after round one is the unique behavior of all memory-one belief-free equilibrium strategies that can be played under imperfect monitoring (see Appendix A for the derivation of these equilibrium strategies).

Table C2: Strategies 1-7

Acronym	Description	Automaton
ALLD	Always play D.	
ALLC	Always play C.	
DC	Start with D, then alternate between C and D.	
FC	Play C in the first round, then D forever.	
Grim	Play C until either player plays D, then play D forever.	
TFT	Play C unless partner played D last round.	
PTFT (WSLS)	Play C if both players chose the same move last round, otherwise play D.	

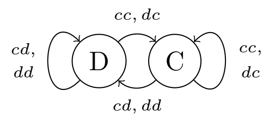
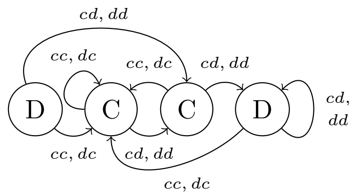
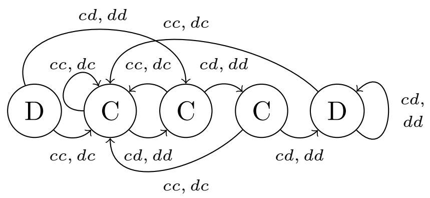
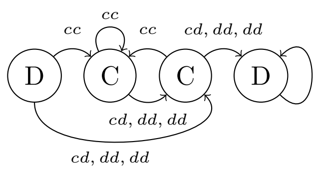
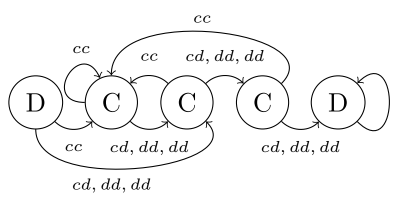
Notes: Circles represent the states of an automaton. The first state from the left is the start state. The labels C and D indicate whether the automaton prescribes cooperation or defection in the state. Arrows represent deterministic state transitions. The labels indicate the information profiles of the previous periods which trigger the transitions. An unlabeled arrows indicates an unconditional transition that occurs independent of the observed profile.

Table C3: Strategies 8-15

Acronym	Description	Automaton
T2	Play C until either player plays D, then play D twice and return to C (regardless of all actions during the punishment rounds).	
TF2T	Play C unless partner played D in both of the last 2 rounds.	
TF3T	Play C unless partner played D in all of the last 3 rounds.	
T2FT	Play C unless partner played D in either of the last 2 rounds (2 rounds of punishment if partner plays D).	
T2F2T	Play C unless partner played 2 consecutive Ds in the last 3 rounds (2 rounds of punishment if partner plays D twice in a row).	
GRIM2	Play C until 2 consecutive rounds occur in which either player played D, then play D forever.	
GRIM3	Play C until 3 consecutive rounds occur in which either player played D, then play D forever.	
PT2FT	Play C if both players played C in the last 2 rounds, both players played D in the last 2 rounds, or both players played D 2 rounds ago and C last round. Otherwise play D.	

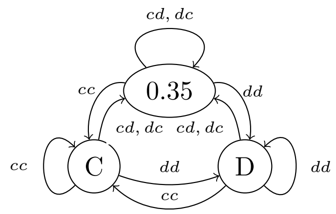
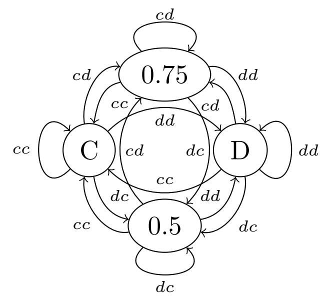
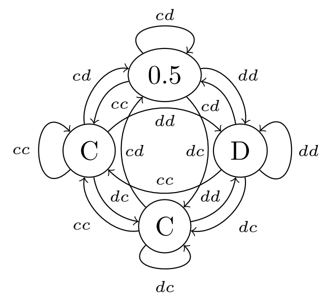
Notes: Circles represent the states of an automaton. The first state from the left is the start state. The labels C and D indicate whether the automaton prescribes cooperation or defection in the state. Arrows represent deterministic state transitions. The labels indicate the information profiles of the previous periods which trigger the transitions. An unlabeled arrows indicates an unconditional transition that occurs independent of the observed profile.

Table C4: Suspicious Strategies 16-20

Acronym	Description	Automaton
DTFT	Play D in the first round, then play TFT.	
DTF2T	Play D in the first round, then play TF2T.	
DTF3T	Play D in the first round, then play TF3T.	
DGRIM2	Play D in the first round, then play GRIM2.	
DGRIM3	Play D in the first round, then play GRIM3.	

Notes: Circles represent the states of an automaton. The first state from the left is the start state. The labels C and D indicate whether the automaton prescribes cooperation or defection in the state. Arrows represent deterministic state transitions. The labels indicate the information profiles of the previous periods which trigger the transitions. An unlabeled arrows indicates an unconditional transition that occurs independent of the observed profile.

Table C5: Behavior Strategies 21-24

Acronym	Description	Automaton
SGRIM	Play C if both players played C, and D if both players played D. If one player played D and the other C, play C with probability 0.35.	
M1BF	Play C if both players played C, and D if both players played D. If the own action was C and the other player played D, play C with probability 0.75. If the own action was D and the other player played C, play C with probability 0.5.	
T1BF$_{as}$	Play C if you played C and the signal was c, and D if you played D and the signal was d. If the own action was C and the signal was d, play C with probability 0.5. If the own action was D and the signal was c, play C with probability 1.	
RAND	Always randomize between C and D with $\sigma = 0.5$.	

Notes: Circles represent the states of an automaton. The first state from the left is the start state. The labels C and D indicate whether the automaton prescribes cooperation or defection in the state. Numbers in indicate the probability of cooperation in the current state of the automaton. Arrows represent deterministic state transitions. The labels indicate the information profiles of the previous periods which trigger the transitions. An unlabeled arrows indicates an unconditional transition that occurs independent of the observed profile.

Appendix D Experimental Instructions and Quiz

[Below are the instructions for the perfect-monitoring treatment with repeated communication. Instructions for the other treatments were very similar and are therefore omitted here. They can be obtained from the authors upon request, along with the original instructions in German.]

Overview

Welcome to this experiment. We ask you not to speak with other participants during the experiment and to switch off your mobile phones and other mobile electronic devices.

For your participation in today's session, you will be paid in cash at the end of the experiment. The amount of the payout depends in part on your decisions, partly on the decisions of other participants and partly on chance. It is therefore important that you carefully read and understand the instructions before the start of the experiment.

In this experiment, every interaction between participants goes through the computers you are sitting in front of. You will interact with each other anonymously. Neither your name nor the names of other participants will be made public, either today or in future written evaluations.

Today's session includes several rounds. Your payout amount is the sum of the earned points in all rounds, converted into euros. The conversion of points into euros is done as follows. Each point is worth 2 cents, so the following applies: 50 points = EUR 1.00.

All participants will be paid privately, so that other participants will not be able to see how much they have earned.

Experiment

Interactions and Matching

This experiment comprises 7 identical interactions, each consisting of a randomly determined number of rounds.

At the very beginning, before the first interaction, you are randomly placed in a group with other participants. In each of the 7 interactions, you will interact with a different participant in your group.

In concrete terms, this is how it works: Before the first interaction, you are assigned to a person from your group with whom you interact in all rounds of the first interaction. In the second interaction, you are then assigned to a new person from your group, with whom you interact in all rounds of the second interaction, etc. In this way, you interact with each person assigned to your group in exactly one interaction, but in all rounds of that interaction.

Length of an Interaction

The length of an interaction is determined randomly. After each round there is an 80% chance that there will be at least one more round.

You can imagine this as follows. A 100-sided dice is rolled after each round. If the roll is 20 or less, there is no further round. If the roll is a different number (21-100), the interaction continues. Note that the probability of another round does not depend on the round you are in. The probability of a third round when you are in round 2 is 80%, as is the probability of a tenth round when you are in round 9.

As soon as chance decides after a round that there is no further round in the interaction, the interaction is finished and you are assigned to a new person for the next interaction. After the seventh interaction, the experiment ends.

Interactions and Sequence of Events in a Round

Before each round of interaction, you can chat with the other person on your screen. The chat takes place in an anonymous chat window. In order to protect your anonymity, it is important that you do not provide any information about yourself or your seat number during communication. Otherwise we reserve the right not to pay you any money in the end. The entire chat content is displayed during the interaction and can be read again.

After the first chat the first round begins.

In each round, you select one of two possible options, A or B. The other person also selects one of two possible options, A or B.

There is a 90% probability that the option you have chosen will be correctly communicated to the other person. There is a 10% probability that the option you have not selected will be transmitted. What the other person receives is what we call the other person's signal. The same applies to the other person's option and your signal. For example, if the other person chooses option A, you receive Signal A with 90% probability and with 10% probability you get Signal B. Assuming you choose Option B, the other person receives Signal A with 10% probability and Signal B with 90% probability.

Your round income depends on your selected option and the signal received. Likewise, the payout of the other person depends on their chosen option and the signal they receive.

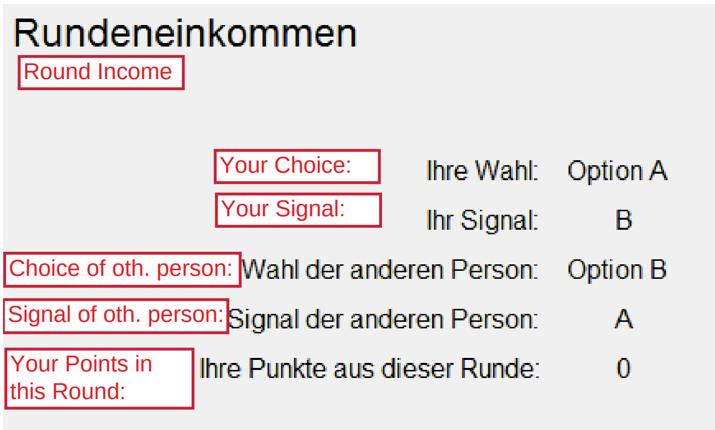
Once you and the other person have chosen an option, chance decides which signals are transmitted and what round earnings result from them with the probabilities given above.

Figure D1: Round Income [Figure 1 from Instructions]

Ihre Optionen Your options	Ihr Einkommen bei Signal Your income with signal		Erwartetes Einkommen, wenn die andere Person Expected income if the other person	
	A	B	Option A wählt chooses option A	Option B wählt chooses option B
Option A	30	0	27	3
Option B	37	17	35	19

The four cells on the right in Figure 1 show the expected earnings depending on your option choice and the option choice of the other person. For example, if you select option B and the other person selects option A, you receive Signal A with 90% probability and Signal B with 10%. Therefore you will receive 37 points with 90% probability and 17 points with 10% probability, that is, your expected earnings in this case are: 0.9*37+0.1*17=35 points.

Figure D2: Part of Feedback Screen (Example) [Figure 2 from Instructions]



At the end of the round, you will receive feedback on your chosen option, the signal received, the other person's choice of an option, the signal received by the other person, and your own round earnings (see Figure 2).

All possible following rounds are identical in sequence. The course of the current interaction, that is, the feedback that you received at the end of all previous rounds, is shown in a table in every round.

End and Payoff

As soon as chance ends the seventh interaction, the experiment is over.

At the end of the experiment, the points from all rounds are converted into euros and paid out privately.

The last screen of the last round of the seventh interaction shows you how much you have earned in euros.

Questions?

Take your time to go over the instructions again. If you have any questions, please raise your hand. An experimenter will then come to your place.

If you think you have understood everything well, you can start the quiz on your screen. The quiz is only to ensure that everyone has understood the instructions well. The answers do not affect your payout.

Quiz [on screen]

[The quiz was the same in all nine treatments. The correct answers appeared on the next screen.]

1. How many interactions are there?

   [1,7, it is random]

2. What is the probability that there is a first round of an interaction?

   [20%, 80%, 100%]

3. What is the probability that there will be a second round in an interaction when you are currently in the first?

   [20%, 80%, 100%]

4. What is the probability that there will be a third round in an interaction when you are currently in the second?

   [20%, 80%, 100%]

5. What is the probability that there will be a third round in an interaction when you are currently in the first?

   [64%, 80%, 100%]

6. You choose Option B and the other person cooses Option B.

   (a) What is the probability that you receive Signal A?

   [10%, 90%, 100%]

   (b) What is the probability that the other person receives Signal B?

   [10%, 90%, 100%]

   (c) How high is your payoff in case you receive Signal A?

   [19, 35, 37]

   (d) How high is the expected payoff of the other person?

   [19, 35, 37]