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Cooperation in Multiplayer Dilemmas*

Ismael Martínez-Martínez† and Hans-Theo Normann‡

September 2025

Abstract

We analyze infinitely repeated multiplayer prisoner's dilemmas in continuous-time experiments. As the number of players changes, our design keeps the payoffs of the all-defection, all-cooperation, and unilateral-defection and -cooperation outcomes constant, thus controlling for the minimum discount factor required for cooperation to be an equilibrium. For all group sizes, we study three different variants of the prisoner's dilemma. In further treatments, we allow actions to be chosen from a continuous set. We find that cooperation rates decrease with the number of players, a result that we can attribute to the increased strategic uncertainty in larger groups. The different payoff matrices also affect cooperation. For the payoff matrices with lower levels of cooperation, the group-size effect is weaker. The availability of a continuous action set strongly reduces cooperation rates.

Keywords: cooperation; dilemma; experiment.

JEL Classification: C72, C73, C92.

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1 Introduction

Seventy-five years after its introduction, there is a striking surge of research on the prisoner's dilemma. One part of this current stream of research looks at the determinants of cooperation in the infinitely repeated game where meta data from supergames yield new insights (Dal Bó and Fréchette, 2018),[1] and a key factor can be related to concepts of strategic uncertainty (Blonski et al., 2011; Blonski and Spagnolo, 2015; Dal Bó and Fréchette, 2011). In terms of experimental methodology, the continuous-time experiments are an important leap forward, allowing immediate and asynchronous action adjustments (Friedman and Oprea, 2012; Oprea et al., 2014; Bigoni et al., 2015). These and other[2] lines of new research suggest that the prisoner's dilemma continues to inspire exciting and innovative research.

Our paper extends these approaches and new methodological advances to multiplayer prisoner's dilemmas. Whereas the above research exclusively uses the standard two-player environment, we study the prisoner's dilemma in groups of different sizes, with up to nine players. Group sizes larger than two are rather frequent and relevant when it comes to issues such as team collaboration, joint effort to provide collective goods, or common pool extraction. So it seems important to go beyond the classic two-player setup. While a number of experiments have examined the effects of group size on cooperation, most of these study finitely repeated games, and many of them are oligopoly studies. An exception is the closely related study by Boczoń et al. (2024), which was conducted independently of of our paper. See our literature survey in Section 2.

A key feature of our experiment and our main contribution is that we control for the minimum discount factor required for cooperation to be an equilibrium in the infinitely repeated game: For any number of players, we keep constant the payoffs in the all-defect, all-cooperate, unilateral-defection, and unilateral-cooperation outcomes. This implies that the repeated-game incentive constraint, as reflected in the

[1]See Embrey et al. (2018) and Mengel (2018) for meta-studies of finitely repeated prisoners' dilemmas and one-shot games (Mengel, 2018).

[2] Several papers address the question of the strategies players adopt in repeated prisoner's dilemmas (Dal Bó and Fréchette, 2011; Fudenberg et al., 2012; Friedman and Oprea, 2012; Bigoni et al., 2015; Dal Bó and Fréchette, 2019). Furthermore, there are novel analyses of memory-one (or Markov) strategies; Belief-free equilibria (Ely and Välimäki, 2002; Ely et al., 2005; Breitmoser, 2015) and zero-determinant strategies (Press and Dyson, 2012; Hilbe et al., 2014, 2015).

minimum discount factor, for cooperation is identical for all group sizes.[3] Because of this design feature, we can make a clean comparison of the cooperation rates across different group sizes. This important difference distinguishes our study from previous N-player studies.[4]

Whereas the repeated-game constraint in our experiments is the same for all group sizes, we expect the number of players to have an effect due to strategic uncertainty. Blonski et al. (2011), Blonski and Spagnolo (2015), and Dal Bó and Fréchette (2011) propose this concept for two-player infinitely repeated dilemma games. Our theory part extends the concepts of strategic uncertainty to more than two players. The traditional repeated-game approach as reflected in the incentive constraint compares the gain from a unilateral defection vs. the loss from a punishment path in a given equilibrium. Strategic uncertainty, by contrast, captures the uncertainty (or riskiness) when choosing a cooperative or defective repeated-game strategy. Put differently, strategic uncertainty is about equilibrium selection. Our design can disentangle the two possible mechanisms by which an increase in the number of players may affect cooperation: One, by making cooperative outcomes more difficult to be supported in equilibrium, and, two, by making cooperative equilibria less likely to be selected. As we control for the first mechanism, increased riskiness remains as an explanation for group-size effects. We show how strategic uncertainty changes theoretically in the number of players and we compare these predictions with experimental data.

Our research also contributes to the discussion about the determinants of cooperation. In their meta study, Dal Bó and Fréchette (2018) show how payoffs (gain from unilateral defection, loss from unilateral cooperation) affect cooperation. We study three different prisoner's dilemma payoff matrices to show how payoff differences affect cooperation in multiplayer games, that is, how they interact with the number of players.

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[3] It may seem that larger groups "naturally" require a higher minimum discount factor for cooperation, suggesting that our goal of controlling for this is somewhat artificial. However, a larger number of players does not always imply a higher minimum discount factor. Fonseca and Normann (2008) and Kühn (2012) present standard oligopoly models where larger groups require a *lower* minimum discount factor. Thus, the theory does not suggest a general relationship between group size and the minimum discount factor.

[4] This is also true in linear public good games that adjust the marginal per capita rate of contributions for N: Since the payoff from unilateral defection increases in N, the minimum discount factor is larger for larger groups.

The paper's third contribution is its study of the effect of continuous time (Friedman and Oprea, 2012; Bigoni et al., 2015) on larger groups. While a couple of papers with continuous-time experiments depart from the two-player setup (Oprea et al., 2014; Benndorf et al., 2021), these experiments are difficult to compare because the action spaces and incentives differ. Our research connects these isolated islands by analyzing a comprehensive set of group sizes for comparable prisoner's dilemmas, in continuous time.

In addition to the classic "cooperate or defect" pure-strategy setup of the prisoner's dilemma, we study an experimental treatment in which participants have access to a continuous action set. One motivation for these experiments is that in larger groups, subjects face intermediate levels of cooperation, which can complicate the comparison of two- and multiplayer experiments. Beyond simply changing the action space, the continuous action set variants may have some merit per se. There is considerable research interest in notions of gradualism (Kartal et al., 2021, for example, for the trust game): players can gradually increase the level of cooperation, thereby reducing the potential loss from unilateral cooperation.

To summarize, our experiments study groups with two, three, four, six, and nine players, and we keep constant the minimum discount factor required for cooperation. Subjects play 21 supergames with three different multiplayer prisoner's dilemma payoff matrices in continuous time and with a stochastic horizon. In addition to a standard two-action version, we analyze games with a continuous action set.

Our results are as follows. First, cooperation rates decrease with the number of players, conditional on having cooperation being equally difficult to be supported in equilibrium for all group sizes, and consistent with strategic uncertainty. Second, our variations of the payoff matrices, which make cooperative outcomes more difficult to be supported in equilibrium, also play a role. For these payoff matrices, the effect of larger groups is reduced. Third, allowing a continuous action set strongly reduces cooperation rates, suggesting that the availability of intermediate levels of cooperation leads to an escalation of conflict rather than gradual cooperation.

Section 2 is the literature review. Section 3 introduces our experimental design and the theory. Section 4 presents our results. Section 5 discusses the results, and Section 6 concludes.

2 Literature

A number of laboratory experiments analyze the effect of the player numbers. For oligopoly, early contributions are the Cournot and Bertrand experiments of Fouraker and Siegel (1963) and Dolbear et al. (1968) comparing two vs. three and two vs. four players, respectively.[5] A first comprehensive set of group sizes (two to five player Cournot games) is analyzed in Huck et al. (2004). Potters and Suetens (2013) survey the oligopoly literature, and further oligopoly data and metadata on group sizes can be found in Engel (2015) and Horstmann et al. (2018). Numbers effects have also been investigated in repeated public goods experiments, again mostly finitely repeated. Isaac et al. (1994) have groups of four, ten, 40 and 100, and Weimann et al. (2019) have voluntary contribution mechanisms (VCMs) with groups of size eight, 60 and 100. Diederich et al. (2016) conduct a VCM experiment with 1,110 subjects divided into groups of 10, 40, and 100. They find a positive and significant group size effect. Nosenzo et al. (2015) study four- and eight-player VCMs with a high and low marginal per capita return (MPCR). They observe a positive effect of group size in the low MPCR condition but a negative effect of group size in the high MPCR condition. The evidence is more limited for infinitely repeated games. Lugovskyy et al. (2017) is an exception as they compare finitely vs. infinitely repeated for two- and four-player VCMs.

Closely related to this study are the recent N-player dilemma experiments by Boczoń et al. (2024). They run infinitely repeated games with two, four and ten players. Like our us, they study infinitely repeated N-player prisoner's dilemma experiments in conjunction with variations of the payoff parameters and make predictions based on strategic uncertainty, as suggested by Blonski et al. (2011); Blonski and Spagnolo (2015) and Dal Bó and Fréchette (2011).[6] However, Boczoń et al. (2024) are more directly concerned with the assessment of strategic uncertainty.

[5] Dolbear et al. (1968) present a finitely repeated oligopoly experiment with differentiated price competition, where a firm's sales and profits depend only on the average price of its competitors, regardless of their number. Their results are difficult to compare because their experiments have an uncertain duration, sometimes incomplete payoff information, and a continuous action set which allows for below-Nash pricing.

[6] Strategic uncertainty has recently found other interesting and important applications. Ghidoni and Suetens (2022) and Kartal and Müller (2021) show theoretically how strategic uncertainty in the prisoner's dilemma is affected when moves are sequential rather than simultaneous, and they provide experimental evidence confirming these effects.

They use the N-player dilemma with both perfectly correlated and independent beliefs (player's expectations over the opponents' cooperativeness) as a tool. They also analyze how explicit communication affects strategic uncertainty. The focus of our paper is an evaluation of the comparative statics of N for a larger set of group sizes in the N-player game to see how these differ from those in the two-player case. The two papers also also differ in other more technical dimensions.[7]

As for dilemma experiments in in continuous time, the seminal contribution is Friedman and Oprea (2012). They find very high cooperation rates, higher than in comparable discrete-time variants. Bigoni et al. (2015) run two-player prisoner's dilemmas in continuous time and show that a deterministic horizon leads to more cooperation than an indefinite horizon. Friedman et al. (2015) run Cournot two- and three-player games over 1,200 periods and find some cooperation after an initial competitive phase. For medium-sized groups, Oprea et al. (2014) find some cooperation in four-player public goods experiments. However, this depends on whether time is continuous or discrete and on the availability of communication. At the lower end of the spectrum, Benndorf et al. (2021) find near-zero cooperation in groups of 12.[8] Our experiment is the first to use a continuous action space for the prisoner's dilemma with $N \geq 2$, and the first to use continuous time to test a wide range of group sizes.

There are few prisoner's dilemma experiments in which the action set differs from the standard two pure actions. See Gangadharan and Nikiforakis (2009), Lugovskyy et al. (2017), and Heuer and Orland (2019). We discuss these in Section 5.

[7] The two experiments have a different payoff structure when $N > 2$: In the design of Boczoń et al. (2024), rival cooperation is only successful when all of the other $N - 1$ players cooperate, resembling Bertrand competition. In contrast, we pay a payoff weighted by the number of cooperating/defecting rival players. Boczoń et al. (2024) assume that the unilateral gain from defection equals the unilateral loss from cooperation.

[8] Benndorf et al. (2021) analyze a large number of different 2×2 games in continuous-time experiments. Here, we refer to the prisoner's dilemma games played in the single-population setup. In this setting, players earn the expected payoff as if they were playing against the aggregate strategy of their population. Since the population size is 12, it is essentially like playing in a group of 12.

Table 1. Stage-game matrices of the prisoner's dilemma.

	Normalized		Neutral		Defensive		Offensive	
	Cooperate	Defect	Cooperate	Defect	Cooperate	Defect	Cooperate	Defect
Cooperate	1, 1	$-l$, $1+g$	14, 14	6, 18	14, 14	2, 18	14, 14	6, 22
Defect	$1+g$, $-l$	0, 0	18, 6	10, 10	18, 2	10, 10	22, 6	10, 10

3 The Experiment

3.1 Design

We implement a series of experimental prisoner's dilemma supergames in a multiplayer environment. The main treatment variable is the group size, with five realizations, $N \in \{2, 3, 4, 6, 9\}$.

In the $N = 2$ version of a prisoner's dilemma game, players simultaneously choose whether to cooperate (C) or defect (D) and receive payoffs according to a matrix of the form

$$\begin{pmatrix} R & S \\ T & P \end{pmatrix}.$$

The four entries are: the reward for joint cooperation, R, the temptation payoff resulting from unilateral defection when the other player cooperates, T, the sucker payoff resulting from cooperation when the other player defects, S, and the punishment payoff from mutual defection, P. The constraint $T > R > P > S$ makes D the dominant strategy. It is useful to normalize the payoffs to facilitate comparisons between different experimental designs. By scaling R to 1 and P to 0, the two normalized off-diagonal entries are as in the left matrix of Table 1, with $g = (T - P)/(R - P) - 1 > 0$ and $l = (P - S)/(R - P) > 0$. With this normalization, g is the gain from unilateral defection whereas $-l$ is the loss from unilateral cooperation.

The following prisoner's dilemma game for $N \geq 2$ players ensures that the payoffs in the key outcomes (all cooperate, all defect, and unilateral cooperation and defection) remain constant as we vary the group size. For a player i in a group of size N, $\bar{c}_{-i} = m/(N-1)$ denotes the fraction of cooperators among the $N-1$ other players ($m \leq N-1$). The normalized payoffs of player i from choosing C and D are then $\pi_i(C_i, \bar{c}_{-i}) = \bar{c}_{-i} - (1 - \bar{c}_{-i})\, l$ and $\pi_i(D_i, \bar{c}_{-i}) = \bar{c}_{-i}(1 + g)$. The reward from full cooperation is $\pi_i(C_i, 1) = 1$, the payoff from all defect is $\pi_i(D_i, 0) = 0$, the temptation to defect unilaterally is $\pi(D_i, 1) = 1 + g$, and the payoff to a unilateral cooperator is $\pi_i(C_i, 0) = -l$. Thus, these payoffs are the same as for $N = 2$, regardless of the group size.

The second treatment variable concerns the stage-game payoffs. Participants in the experiment play the three different payoff matrices shown in Table 1, to the right of the normalized game. We refer to them as *neutral*, *defensive*, and *offensive*, following Dixit (2003) and Heller and Mohlin (2018). The payoffs from joint cooperation and complete defection are 14 and 10, respectively, in all games. This yields an efficiency gain from cooperation of 40%, common across treatments. The neutral matrix serves as the base case with $l = g = 1$. The defensive and offensive matrices are derived from the neutral one by increasing either l or g by one. In the defensive prisoner's dilemma, the incentive to defect is greater against a defector than against a cooperator ($l = 2 > g = 1$). The opposite is true in the offensive case ($l = 1 < g = 2$).[9]

Supergames are implemented in continuous time, as infinitely repeated games with an expected duration of 60 seconds. The experiments were run with ConG (Pettit et al., 2014), a software package for continuous-time experiments.[10] In each supergame, subjects had 30 seconds to make their initial choice before continuous play began. The stopping time, T, of each supergame was determined by one random draw from the exponential distribution with an inverse scale of 1/60 s. The expected length of the games did not vary and subjects had no prior information on the actual duration. The underlying stochastic termination rule was explained in the instructions (see the Supplementary Material) in two complementary ways: by showing a mock sample of lengths (including unusually short and long supergames)

[9] With respect to other prisoner's dilemma experiments in continuous time, Bigoni et al. (2015) implement a matrix with $l = 2$ and $g = 1$, as in our defensive case. Friedman and Oprea (2012) use four prisoner's dilemma matrices, allowing for changes in the diagonal entries. Their Easy and Hard games are neutral, with $l = g = 2/3$ and $l = g = 4$, respectively. Their Mix-a and Mix-b variants are offensive ($l = 2/3$, $g = 4/3$) and defensive ($l = 4$, $g = 2$), respectively, both with a $1:2$ ratio, similar to our design.

[10] All relevant information about the state of the system (choices, payoffs, history timelines, etc.) was recorded at very rapid intervals of 0.1 seconds. To put this scale into perspective, the only other quasi-continuous time experiment with an stochastic termination rule (that we are aware of) is Bigoni et al. (2015), who define intervals of 0.16 seconds in z-Tree. Other ConG experiments with deterministic duration use similar scales (Friedman and Oprea, 2012; Benndorf et al., 2021).

and by providing a discrete-time analog of a high continuation probability ($0.998\bar{3}$), as done in Bigoni et al. (2015).[11] We committed to a seeded sequence of random realizations to allow for replications and extensions of the study. The realized durations in the experiments (126 observations) show that the experimental sample of game durations and the exponential distribution are not significantly different (Anderson-Darling test, $p = 0.779$).

Figure 1 illustrates our experimental design. In each session, there are 24 subjects who were divided into groups with 2, 3, 4, 6, and 9 players in each supergame. Subjects played 21 supergames in all sessions. Each supergame was randomly assigned one of the three prisoner's dilemma matrices in Table 1 as the base game. The only restriction was that each payoff matrix should be used seven times per session. In other words, while the payoff matrix was random in every supergame, the draw was without replacement at the session level. Our design implies that five groups of different sizes played parallel games with one specific combination of payoff matrix and supergame duration in each of the 21 supergames. Figure 1 provides an example. The comparisons of the group size and game matrix is within subjects accordingly.[12] The player partitions were randomized and reshuffled prior to the start of each supergame.[13] Subjects were informed that no distinct group composition would be repeated more than once per session. (Group composition would be reshuffled until this constraint was met). To reiterate: The group size was not random. The payoff matrix was random without replacement. The length of a supergame was random. Player partitions were random, subject to the aforementioned constraint.

[11] The following calculation illustrates this. Consider the stopping time in a discrete time infinitely repeated game, $T_{\Delta t}$. This is a geometric random variable with parameter $1 - \delta_{\Delta t} = \lambda \, \Delta t$, where λ is a fixed positive parameter and Δt is the length of each time step in the stochastic game. When Δt is sufficiently small, the distribution of the geometric random variable $T_{\Delta t}$ tends to an exponential random variable with λ as the inverse of the expected duration: $\lambda = 1/\langle T \rangle$. For the particular case of our experiment, we get $\delta_{\Delta t} = 1 - \Delta t/\langle T \rangle = 1 - 0.1\text{ s}/60\text{ s} = 0.998\bar{3}$.

[12] One rationale for using a within-subjects design is cost effectiveness as this design requires fewer participants than a between-subjects design. A second motive is that we expected subjects to learn whether or not to cooperate when they experience different group sizes. See footnote 24 with evidence on this. A downside of a within-subjects design is that carryover or order effects can occur. We addressed this issue in the econometric analysis by including dummy variables that capture the properties of the previously played game. The results in Table 2 suggest that order effects were probably not overly strong.

[13] The median subject in the Pure experiment participated two times in a group of size $N = 2$, three times with $N = 3$, three times with $N = 4$, five times with $N = 6$, and eight times with $N = 9$.

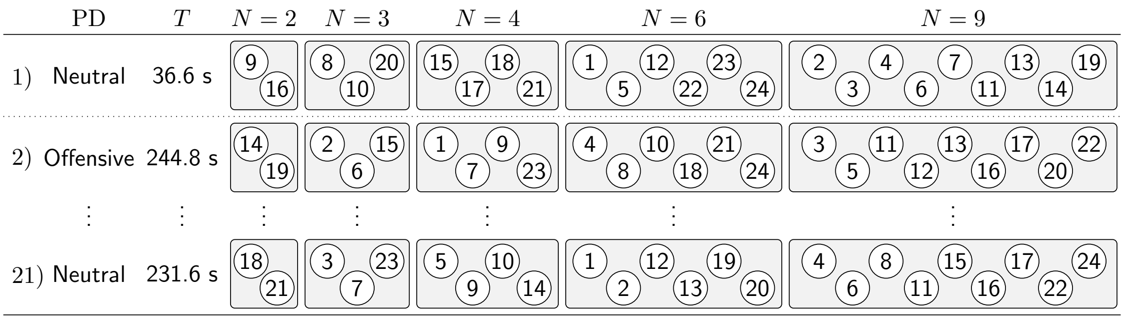

Figure 1. Experimental design. Example of one session: Subject 18 played the Neutral game in a group of 4 in supergame 1, the Offensive game in a group of 6 in supergame 2, and the Neutral game again in a group of 2 in supergame 21. Column T shows the random duration of the supergames.

The decision screen (see screenshot in the instructions in the Supplementary Material) continuously informed subjects about their own action, the proportion of cooperators ("A" players) in their group, and their current and cumulative payoffs in this supergame. In $N > 2$ groups, subjects can infer how many cooperators are in the group, but they do not know who defected.

Finally, we run the N-player supergames in two basic variants that differ in the set of available actions, and we will refer to the two variants as Pure and Cont. In the Pure experiment, subjects had to select a pure action, either to cooperate (C) or to defect (D). In the Cont experiment, subjects could also choose intermediate levels of cooperation by fixing any action between zero and one with a slider.[14] Let $\sigma_i \in (0,1)$ denote player i's action, meaning that she cooperates with weight σ_i and defects with $1-\sigma_i$. Then, her realized payoff in the Cont treatment reads:

$$\sigma_i \frac{\sum_{j\neq i} \sigma_j - (1-\sigma_j)l}{N-1} + (1-\sigma_i)\frac{\sum_{j\neq i}\sigma_j(1+g)}{N-1}. \tag{1}$$

That is, subjects choose and realize intermediate levels of cooperation, they do not randomize between the two pure strategies. The computer interface is implemented with a customized extension of ConG (Pettit et al., 2014). Screenshots are available as part of the instructions in the Supplementary Material.

[14] The multiplayer extension of the prisoner's dilemma, explained above for Pure strategies, also holds in Cont, interpreting $\bar{c}_{-i}$ as the average level of cooperation among the $N-1$ co-players (continuous between 0 and 1).

3.2 Theoretical background

Consider the normalized game in Table 1, repeated infinitely many times. Future payoffs are discounted with a factor δ. Appendix A contains detailed derivations and refers to the general payoffs (R, T, S, P).

We begin with the Pure experiment. A first benchmark for cooperation is the default minimum discount factor when players follow a grim-trigger strategy (start by cooperating, and defect forever if a player defected in a previous round). Cooperating yields $1/(1-\delta)$, while defecting yields $1+g$. The grim trigger is thus a subgame-perfect Nash equilibrium if the following holds for the actual discount factor:

$$\delta > \frac{g}{1+g} \equiv \underline{\delta}. \tag{2}$$

The discount factor implemented in the experiments ($\delta = 0.998\bar{3}$) exceeds this threshold, relevant to all treatments.

Whereas our design ensures that the various payoffs do not depend on N ($\underline{\delta}$ is the same for all group sizes), the minimum discount factor does differ for the different payoff matrices. The g payoff in Neutral and Defensive (both $g = 1$) is different from the one in Offensive ($g = 2$), so we obtain $\underline{\delta}_{\text{Neutral}} = \underline{\delta}_{\text{Defensive}} = 1/2$ and $\underline{\delta}_{\text{Offensive}} = 2/3$. Defensive differs from Neutral and Offensive with respect to the l payoff, but the standard minimum discount factor does not take into account the loss from unilateral cooperation as it merely reflects incentives to defect from a *given* equilibrium.

We now assume that players face strategic uncertainty (Blonski et al., 2011; Blonski and Spagnolo, 2015; Dal Bó and Fréchette, 2011). Players choose between two repeated-game strategies, grim trigger (GT) and always defect (AD), but they are uncertain of the strategy their opponents will play. Let p be the (identical) probability that any of i's opponents play GT, and $1-p$ is the probability that any player $\neq i$ plays AD. We generalize existing two-player analyses to the N-player case.

We calculate the expected payoffs from GT and AD. First, suppose that player i plays GT. After the initial period (that is, in $t = 1$), there are only two contingencies. With probability p^{N-1}, all players cooperate in $t = 0$ and, accordingly, earn $R = 1$ throughout the supergame, yielding an expected payoff of $p^{N-1}\delta/(1-\delta)$. With the counter probability, at least one rival player fails to cooperate in $t = 0$ and therefore everyone defects afterwards such that payoffs are $P = 0$. Period $t = 0$ is a bit more complicated, since the expected payoff is given by the different combinations with which i faces m cooperators, $0 \leq m \leq N-1$. In Appendix A, we show that the expected payoff from playing GT in $t = 0$ boils down to $p - (1-p)\,l$. Altogether, $p - (1-p)\,l + p^{N-1}\delta/(1-\delta)$ is player i's discounted payoff from GT. Now assume player i chooses AD. Regardless of the choices of the other players, the initial defect action triggers defection by all players in periods $t = 1, ..., \infty$ and payoffs are zero. In $t = 0$, the expected payoff from choosing AD is $p \cdot (1+g) + (1-p) \cdot 0$ (see Appendix A). Accordingly, $p\,(1+g)$ is the discounted payoff from playing AD. Comparing expected payoffs from GT versus AD, we find that $p - (1-p)\,l + p^{N-1}\delta/(1-\delta) \geq p\,(1+g)$ if and only if

$$\frac{\delta}{1-\delta} \geq \frac{l}{p^{N-1}} + \frac{g-l}{p^{N-2}}. \tag{3}$$

This is a N-player condition for the emergence of cooperation (playing GT).

From (3), N-player versions of measures of strategic uncertainty can be obtained, and further results in the literature can be recovered. Blonski et al. (2011) and Blonski and Spagnolo (2015) propose an alternative minimum discount factor, δ^*. If this benchmark is exceeded, GT is the risk dominant strategy. So, the larger δ^*, the less likely a player is to cooperate. We solve (3) for δ and obtain:

$$\delta \geq \frac{gp + l(1-p)}{gp + l(1-p) + p^{N-1}}. \tag{4}$$

Intuitively, if $p = 1$ in (4), the standard minimum discount factor, $g/(1+g)$ as in (2), results, and if $p = 0$, (4) becomes $\delta \geq 1$. For equilibrium selection according to risk dominance, a common assumption is $p = 1/2$, in which case (4) yields:

$$\delta \geq \frac{g + l}{g + l + \left(\frac{1}{2}\right)^{N-2}} \equiv \delta^*. \tag{5}$$

For $N = 2$, we obtain $\delta^* = (g+l)/(g+l+1)$, the result of Blonski et al. (2011) and Blonski and Spagnolo (2015).

Dal Bó and Fréchette (2011, 2018) suggest the size of the basin of attraction of AD (sizeBAD). This is the belief of GT that would leave a player indifferent

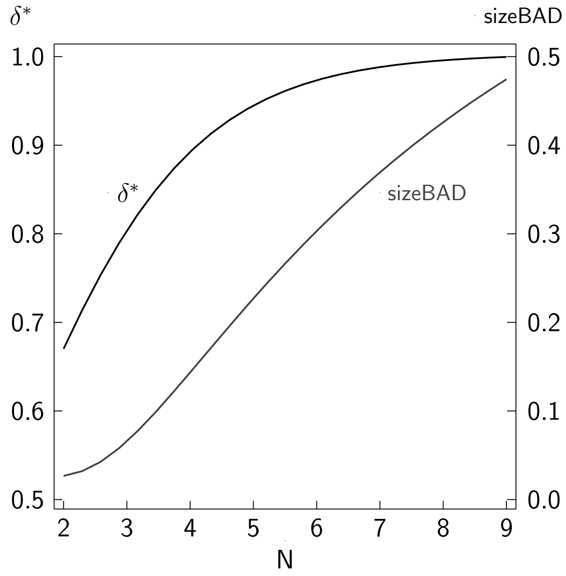

Figure 2. Alternative minimum discount factor δ^* as in (5), and sizeBAD as in (6) as functions of N and for the Neutral game.

between the two strategies, given the actual discount factor used in the experiment. The larger sizeBAD, the less likely a player will cooperate. The N-player sizeBAD is only implicitly defined by (3), but an explicit solution can be obtained for the Neutral matrix ($g = l$)

$$p = \left(l \frac{1-\delta}{\delta} \right)^{\frac{1}{N-1}}. \tag{6}$$

This is exactly the result of Boczoń et al. (2024) who generally impose $g = l$. For $N = 2$, (3) implies the finding of Ghidoni and Suetens (2022) which, for the normalized payoffs, reads $p \geq l/(l - g + \delta/(1-\delta))$.

What predictions does this analysis suggest for group size, N?[15] Figure 2 shows for the Neutral game matrix δ^* as in (5) and sizeBAD as in (6). Both metrics increase monotonically in N. This is true in general, not just for the Neutral matrix, as follows from (3) and (4). See Table 3 in the Supplemental Material which lists the numerical realizations of the sizeBAD (3) and δ^* (5) measures for the experimental group sizes and payoff matrices. We conclude:

Prediction 1 (Pure). Group size has a negative effect on cooperation rates.

[15] Because $\delta = 0.998\bar{3} > \delta^*$ throughout, cooperating is the risk-dominant equilibrium. Since all experiments were run with the same δ, using the difference $\delta - \delta^*$ instead of δ^* does not yield any additional insights.

We turn to the effects of the payoff matrices. Compared to Neutral, the Defensive and Offensive matrices are generally an obstacle to cooperation. Defensive and Offensive increase either l or g compared to Neutral, so the right-hand side in (3) and the expressions in (4) and (5) increase.

Prediction 2 (Pure). Cooperation rates are lower in Defensive and Offensive, compared to Neutral.

Although Predictions 1 and 2 can in principle both be supported by the data, they are potentially conflicting. We expect the impact of group size on cooperation to be smaller with the Defensive and Offensive payoff matrices than with the Neutral one due to a ceiling effect. Cooperation should indeed be more difficult to achieve and maintain, even when subjects interact in pairs.[16] Put differently, the group size should only have a smaller impact in Defensive and Offensive:

Prediction 3 (Pure). Group size has a smaller impact on cooperation in Defensive and Offensive, compared to Neutral.

Comparing Defensive and Offensive turns out to be ambiguous. To begin with, Offensive and Defensive share the same δ^*: In (5), only the sum $g + l$ matters for δ^*, and $g + l$ is the same for Offensive and Defensive. However, the more general benchmark (4) is the same for Offensive and Defensive if and only if $p = 1/2$, and it is greater for Defensive [greater for Offensive] if and only if $p < [>]\ 1/2$.[17] This is intuitive: When players believe that rival cooperation is likely, the defection payoff, d, is important, while the loss from cooperation, l, is not. And vice versa when beliefs are low. As for sizeBAD, given the δ and N used in the experiment, the minimum belief required to play GT is larger in the Defensive treatment compared to Offensive, see Table 3 in the Supplemental Material. This is consistent with (4) in that sizeBAD is less than one half for the experimental parameters (see Figure 2). If participants have different beliefs, or if they perceive the discount factor to be lower than implemented, the reverse sizeBAD prediction holds. We therefore refrain from making a prediction regarding Offensive vs. Defensive.

[16] See also Table 3 in the Supplementary Material. The δ^* entries are smaller for Neutral than for Defensive/Offensive throughout, but this difference is smaller for larger N.

[17] See Andres et al. (2023) for a detailed analysis of how δ^* is affected by beliefs.

We now turn to the Cont treatment. Given player i's action $\sigma_i \in (0,1)$ and her rivals' actions $\sigma_{j\neq i}$, equation (1) states the realized payoffs. The continuous action set allows for lower cooperation levels $\sigma_i \in (0,1)$, that is, players cooperate less than 100% and defect with a positive weight. Such limited defection is part of the cooperative strategy and is observable for all players. It can thus be distinguished from full defection which is still the myopic best reply and, in fact, the dominant action.

We focus on symmetric cooperative equilibria where $\sigma_1 = \sigma_2 = ... = \sigma_N = \sigma \in (0,1]$. Using (1), the R payoff when all players cooperate with σ and defect with $1-\sigma$ simplifies to $R = \sigma(1 + (g-l)(1-\sigma))$. The payoff from unilateral defection (that is, $\sigma_i = 0$ and $\sigma_{\neq i} = \sigma$) reads $T = \sigma(1+g)$ whereas unilateral cooperation ($\sigma_i = \sigma$ and $\sigma_{\neq i} = 0$) yields $S = -\sigma l$. The all-defect payoff remains $P = 0$. Substituting $\sigma = 1$ in these formulas yields the corresponding payoffs in the Pure setting whereas employing $\sigma = 0$ (all defect) implies zero payoffs in all cases.

Next, we derive the minimum discount factor required for a GT strategy to be a subgame-perfect equilibrium. Using the above payoffs for R, D and T, one obtains

$$\underline{\delta} = \frac{l + \sigma(g-l)}{1+g}$$

for the continuous-action-set case, where $\sigma = 1$ implies $\underline{\delta} = g/(1+g)$ as in (2).

The question is whether a lower cooperation level in Cont, $\sigma \in (0,1)$, can reduce the minimum discount factor compared to the one under full cooperation, $\sigma = 1$ (as in Pure). The sign of $\partial\underline{\delta}/\partial\sigma$ depends on the sign of $g - l$: For our Neutral ($g = l$) setup, we obtain $\underline{\delta} = 1/2$ for all σ, unchanged to the Pure case. For the Defensive ($g = 1 < l = 2$) treatment, we obtain $\underline{\delta} = 1 - \sigma/2$, so cooperating with $\sigma \in (0,1)$ *increases* the minimum discount factor required compared to full cooperation. This suggests that, as with the Pure action set, cooperation will be more difficult than with Neutral. In Offensive ($g = 2 > l = 1$), we get $\underline{\delta} = (1+\sigma)/3$, so cooperating with $\sigma \in (0,1)$ requires a *lower* minimum discount factor than cooperating with $\sigma = 1$. We conclude that lower cooperation levels $\sigma \in (0,1)$ can be more plausible in Offensive than in Defensive or Neutral. For low levels of cooperation ($\sigma \leq 1/2$), we obtain for Offensive that $\underline{\delta} = (1+\sigma)/3 \leq 1/2$. Hence, there exist levels of δ such that cooperation with $\sigma \in (0, 1/2)$ can be an equilibrium in Cont but not in Pure (where $\sigma = 1$). We dismiss this case because the actual discount factor implemented in the experiment is much larger than 1/2, and, even of this was not the case, the cooperation level would need to be substantially lower, such that cooperation can hardly be claimed to improve.[18] In Appendix A, we extend our N-player condition for the emergence of cooperation (3) for a continuous action set. As with pure strategies, the analysis for the continuous action set suggest that larger group sizes will be an impediment to cooperation.

Prediction 4 (Cont). Group size has a negative impact on cooperation rates.

Prediction 5 (Cont). Cooperation rates are lower in Defensive and Offensive compared to Neutral.

Prediction 6 (Cont). Group size has less impact in Defensive and Offensive, compared to Neutral.

3.3 Procedures

We conducted six sessions, three for Pure and three for Cont. No subject participated in more than one session and all sessions included 24 subjects, except for one session with 22 subjects.[19] This makes a total of 142 participants. Appendix B contains power calculations for this sample size and the type of empirical analysis.

Subjects' earnings in the experiment were determined by the combination of their own and their rivals' choices, summed over the duration of each supergame, and scaled with respect to the expected length. While playing a supergame s, each individual i accumulated earnings $\Pi_{i,s} \equiv \frac{1}{60} \int_0^{T_s} \pi_i(\sigma_{i,s,t}, \bar{c}_{-i,s,t})\, dt$. The final payout to each subject was the average of the 21 supergames. Participants earned between €10 and €18.

Further details of the experimental procedures were as follows. The experiments took place at the DICElab of the University of Duesseldorf. We conducted the experiments between May 6 and May 20 2019, beginning with the three Pure sessions.

[18]Similar partially cooperative equilibria may also exist in the Pure setting. When risk-neutral players randomize and their mixed strategies are observable, the equilibria resemble the low-cooperation level equilibria in the Cont variant.

[19] In that session, we had two groups of four players and none with six players.

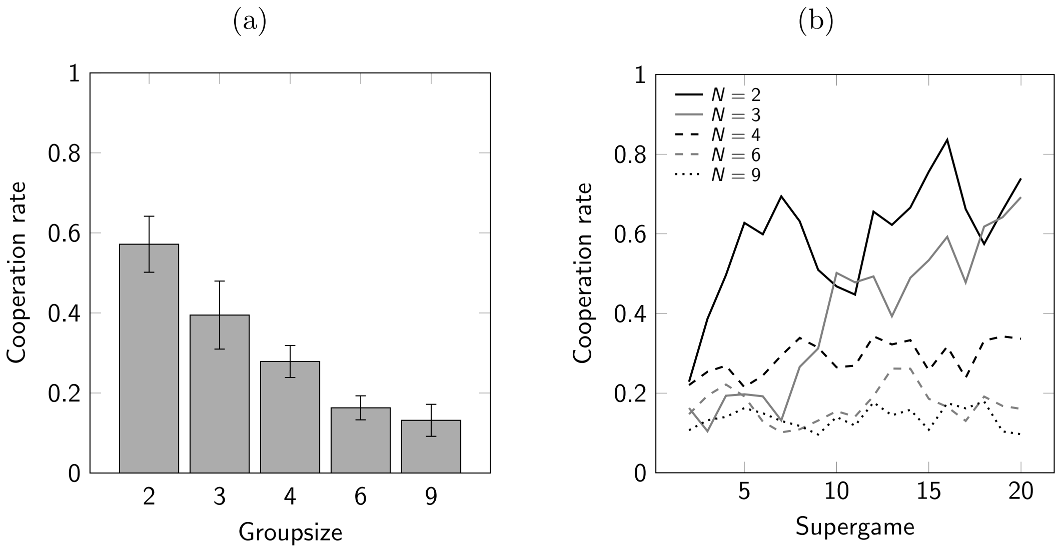

Figure 3. (a) Mean cooperation in Pure by group size N, 95% confidence intervals based on bootstrapped standard errors clustered at the session level. (b) Evolution of average group cooperation over supergames in Pure. For both panels, the unit of observation is defined as in footnote 20.

No pilot sessions were conducted. Subjects were recruited from the lab subject pool using ORSEE (Greiner, 2015). Upon arrival at the lab, participants were randomly assigned a cubicle number. Printed instructions were distributed and summarized verbally. Participants were also given ample opportunity to ask questions individually and privately. The expected duration of the supergames is invariant (60 s), but the realized durations naturally differ. After the 21 supergames were completed, we collected additional data on demographics and individual preferences. Subjects completed a questionnaire based on Falk et al. (2016, 2018)–details are available in Table 4 in the Supplementary Material. The average duration of the sessions including the time for reading the instructions, the questionnaires, and payout was around one hour. The experiments themselves took about half an hour. We maintained anonymity throughout.

4 Results

We begin with an analysis of the Pure experiment in Section 4.1. Section 4.2 analyzes the Cont data. For the regression results, we report non-parametric bootstrapped standard errors, repeatedly resampling the observed data with replacement and

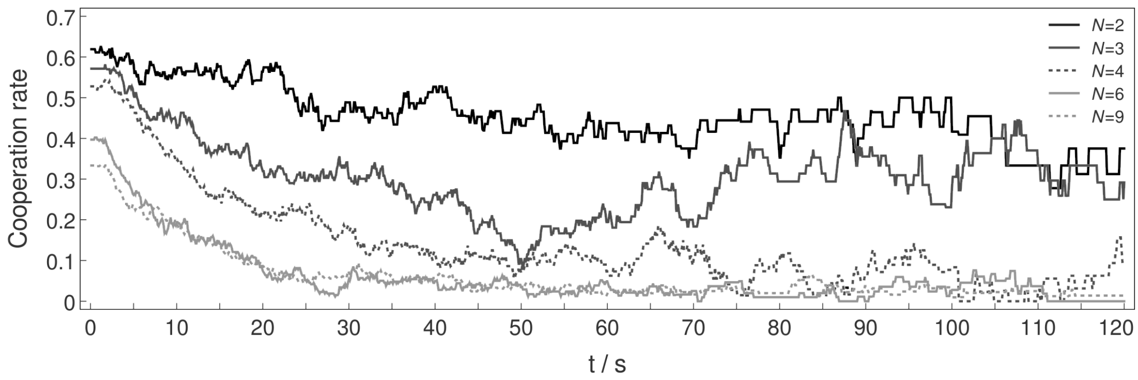

Figure 4. Evolution of cooperation over time, by group size N, Pure data, group averages are conditional on a group being active: Out of the initial 63 groups, 43 were active after 30 seconds, 24 after 60 seconds, 15 after 90 seconds, and 8 after 120 seconds (for all N).

recalculating the standard errors that are clustered at the session level. The results are robust when using regular (non-bootstrapped) standard errors either clustered at the session or subject level, or with subject fixed effects.

4.1 The Pure experiment

The effect of the number of players

Figure 3a shows the average cooperation rates for the different group sizes. Consistent with Prediction 1, cooperation rates decrease monotonically with group size. The treatment variable N seems to produce a smooth pattern, a decrease of cooperation in N. The highest cooperation rates are obtained for the smallest groups, with a mean of $\langle \bar{c} \rangle = 0.572$ for $N = 2$, and the lowest rates are observed for $N = 9$, with a mean of $\langle \bar{c} \rangle = 0.132$.[20] In Table 2 below, we report regression analyses that confirm the statistical significance of these findings.

How does average play develop over the course of the 21 supergames? Figure 3b shows the moving mean of group cooperation rates for all N, with a span of three

[20] Averaging the data at the group-supergame level, the experiment contains 315 data points, namely five group sizes in 21 supergames, times three sessions. Let $c_{i,t}$ be the cooperation level of player i at time t in a supergame, and $\bar{c}_t = \frac{1}{N}\sum_i^N c_{i,t}$ be the mean cooperation level among the N players that form a group. Then group cooperation rates are defined as time-averages, $\langle \bar{c} \rangle = \frac{1}{T}\int_0^T \bar{c}_t \, dt$, where $\langle\rangle$ indicate that the average is taken at the group level, and T is the realized length of the supergame. Figure 10 in the Supplementary Material provides additional details by session.

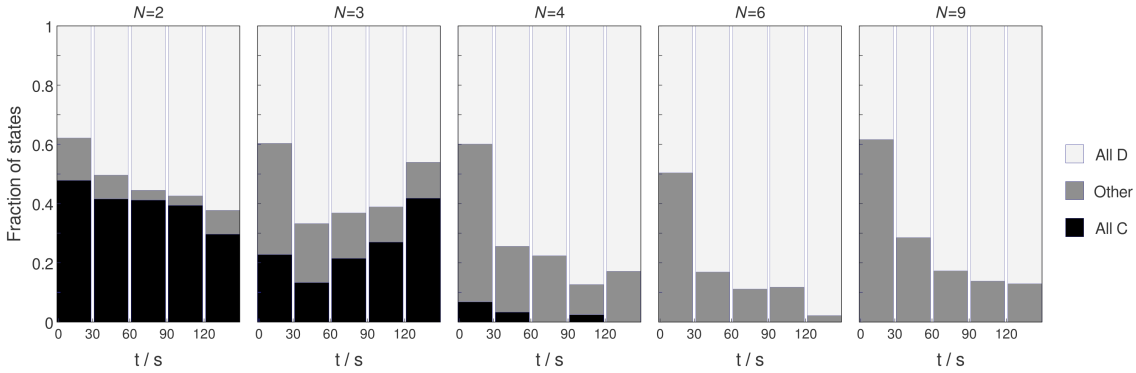

Figure 5. Fraction of time spent in the different outcomes, Pure data.

supergames to reduce noise. Cooperation in small groups increase over supergames. In the last seven supergames, the cooperation rates are 29.3 (45.3) percentage points for $N = 2$ ($N = 3$) higher than in the first seven supergames. That is, subjects learn to cooperate with supergame repetition. This is not the case for the larger groups with $N \geq 4$.

Not only do subjects gain experience in how to play across supergames, but cooperation also shows pronounced time trends within supergames. Figure 4 shows five timelines, one for each N. Cooperation decreases with time, especially in the first 30 to 50 seconds. Cooperation rates for $N = 2$ suffer the least from this decrease over time. Groups of three players start with a decrease, but manage to increase again, seem to stabilize towards the end of the interval, and later reach the level of the $N = 2$ groups.[21] The negative effect of duration on cooperation is stronger for $N \geq 4$. They lose almost all of their cooperative choices within the first minute of play.

The time trends in the data raise the question of miscoordination. To what extent do players coordinate on outcomes where all players cooperate or defect? Figure 5 shows coordination rates over time in five panels, one corresponding to each group size. The data are summarized in bins of 30 seconds, with the last bin

[21]The increase in the average cooperation of the $N = 3$ groups at about 50 seconds in Figure 4 seems to be the result of several groups being able to coordinate on cooperative outcomes again, after the marked initial drop that is also seen for $N > 3$. Consistent with this, Figure 5 shows an increase in the proportion of "all cooperate" states beginning after the 30 second bin. Conspicuously, the reverse trend for the $N = 3$ groups in Figure 4 occurs when cooperation rates were rather low (below 10%), and the reverse differs from the trend of the $N = 2$ groups which (at least on average) did not experience such low cooperation rates.

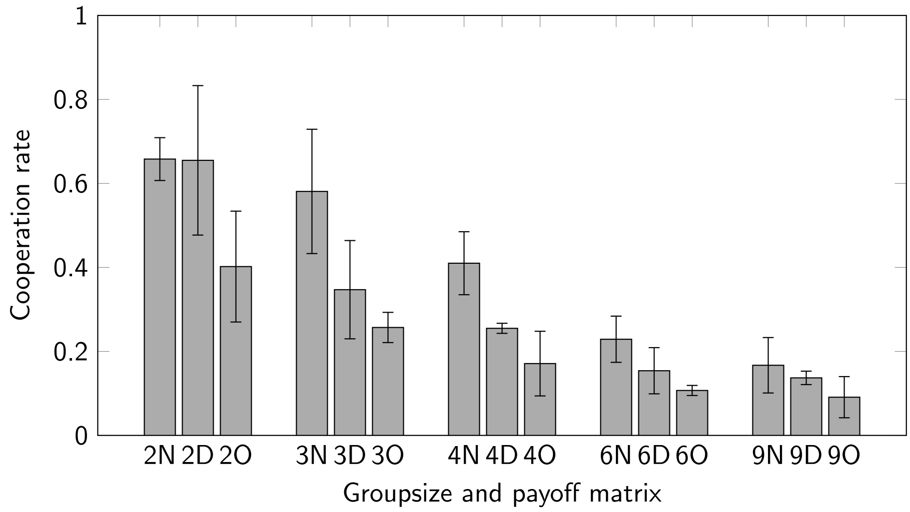

Figure 6. Average group cooperation conditional on payoff matrix, N, D, and O refer to the Neutral, Defensive, and Offensive payoff matrix, respectively, 2–9 refer to the group size, 95% confidence intervals based on estimations with bootstrapped standard errors clustered at the session level, Pure data.

containing all $t > 120$ s. We highlight the outcomes $\langle \bar{c} \rangle = 0$ (all defect) in gray, $\langle \bar{c} \rangle = 1$ (all cooperate) in black and pool in gray all other outcomes involving some degree of coordination failure. For the groups with $N \leq 3$, there is a substantial share of full cooperation outcomes right at the beginning of the supergame. For $N = 2$, this share declines moderately over time. The $N = 3$ groups manage to increase the proportion of $\langle \bar{c} \rangle = 1$ states and reduce the share of miscoordination after the first bin. For groups with $N \geq 4$, there are few or no full cooperation outcomes. The outcome where all players defect already accounts for roughly 40% of the outcomes in the first bin and, over the course of the play, the proportion of coordination failures (shown as "Other") decreases and is replaced by complete defections.

Whereas the average cooperation rates in Figure 3a decrease gradually and smoothly in N, Figure 5 rather suggests an abrupt collapse of "all C" for groups of four or more players. This is not contradictory: The pronounced decline in cooperation during the first minute, as shown in Figure 4, is reflected by the high degree of coordination failure in the first bins of Figure 5. The decrease also implies that the average cooperation differs in a less pronounced manner than the rate of coordination on "all C".

The impact of the payoff matrices

We will now address the question of how significant the various payoff matrices are. Figure 6 shows the cooperation rates per matrix conditional on group size. For a given N, there is more cooperation with the Neutral payoff matrix than with Defensive payoffs, and more with Defensive payoffs than with the Offensive matrix throughout. This is consistent with Prediction 2. (As noted in the theory section, we do not make a prediction regarding Offensive vs. Defensive.) For all three matrices, cooperation decreases monotonically in N.

Regression analysis

The linear probability models in Table 2 provide a thorough econometric analysis and formal testing of our predictions. The dependent variable in all regressions is the time-averaged cooperation rate of subject i in supergame s.[22] Our main independent variables are the continuous variable Group Size, $N_{i,s}$ and the dummy variables for the Defensive (d.) and Offensive (d.) payoff matrices. To address the issue of experience, we add the continuous variable Supergame to the regression, and we also include the length of the supergame (Length T_s), also continuous. We interact the main variables with the dummy variable for the Cont (d.) treatment (discussed below), so that the effects of the independent variables can be obtained from the table for both the Pure and Cont treatments. Regression (1) includes the main variables and their interactions with with the Cont (d.). Regression (2) adds the interactions with group size. Regression (3) additionally includes three sets of control variables.

In regression (1), the non-interacted coefficients (the first set of regressors) apply to the Pure data. We find that the coefficient of Group size, $N_{i,s}$ is negative and significant, consistent with Prediction 1. We also see that Offensive and Defensive have a negative and significant effect on cooperation, consistent with Prediction 2. Supergame is positive and (weakly) significant, confirming the descriptive evidence in Figure 3b. Length, T_s /60 s is negative and significant, as is evident from the

[22] With 142 subjects and 21 supergames, there are 2,982 observations. The specification in the last column includes variables referring to the previous supergame, resulting in the removal of 142 observations. An additional 240 observations were dropped due to 12 subjects for whom the questionnaire measures were unavailable.

Table 2. Regression analyses of cooperation choices

	Cooperation, $c_{i,s}$					
	(1)		(2)		(3)	
Group size, $N_{i,s}$	−0.047***	(0.006)	−0.034***	(0.008)	−0.037***	(0.005)
Defensive (d.)	−0.091***	(0.025)	−0.192***	(0.030)	−0.191***	(0.021)
Offensive (d.)	−0.123***	(0.020)	−0.278***	(0.045)	−0.247***	(0.049)
Supergame	0.004*	(0.002)	0.021**	(0.008)	0.019***	(0.007)
Length, T_s / 60 s	−0.075***	(0.020)	−0.095**	(0.039)	−0.088*	(0.053)
Cont (d.)	−0.289***	(0.036)	−0.283***	(0.083)	−0.249*	(0.129)
Group size, $N_{i,s}$ × Cont (d.)	0.036***	(0.007)	0.035***	(0.011)	0.036***	(0.012)
Defensive (d.) × Cont (d.)	0.089***	(0.028)	0.209***	(0.044)	0.193***	(0.051)
Offensive (d.) × Cont (d.)	0.073*	(0.041)	0.144**	(0.065)	0.085	(0.058)
Supergame × Cont (d.)	−0.005**	(0.002)	−0.015*	(0.009)	−0.013	(0.009)
Length, T_s / 60 s × Cont (d.)	0.026	(0.032)	0.070	(0.067)	0.060	(0.071)
Defensive (d.) × Group size, $N_{i,s}$			0.017**	(0.007)	0.017***	(0.005)
Offensive (d.) × Group size, $N_{i,s}$			0.025***	(0.004)	0.023***	(0.004)
Supergame × Group size, $N_{i,s}$			−0.003***	(0.001)	−0.002***	(0.001)
Length, T_s / 60 s × Group size, $N_{i,s}$			0.003	(0.004)	0.002	(0.006)
Defensive (d.) × Group size, $N_{i,s}$ × Cont (d.)			−0.020**	(0.008)	−0.018**	(0.007)
Offensive (d.) × Group size, $N_{i,s}$ × Cont (d.)			−0.011*	(0.007)	−0.004	(0.006)
Supergame × Group size, $N_{i,s}$ × Cont (d.)			0.002	(0.001)	0.001	(0.001)
Length, T_s / 60 s × Group size, $N_{i,s}$ × Cont (d.)			−0.007	(0.007)	−0.006	(0.008)
Previous supergame:						
Group smaller previsous game					0.006	(0.010)
Defensive previous game					−0.002	(0.024)
Offensive previous game					0.002	(0.024)
Length, T_s / 60 s previous game					0.029**	(0.013)
Demographics:						
Age					−0.002*	(0.001)
Female (d.)					−0.054***	(0.012)
Lab experience (cat.)					−0.008	(0.014)
Bachelor (d.)					−0.089	(0.069)
Master (d.)					−0.126**	(0.056)
Economics & Business (d.)					−0.028	(0.048)
Science & Medicine (d.)					−0.044	(0.059)
Arts, Humanities & Law (d.)					−0.072*	(0.038)
Preference survey:						
Risk taking					−0.031**	(0.013)
Time discounting					0.007	(0.015)
Trust					0.030**	(0.012)
Altruism					0.028	(0.019)
Positive reciprocity					−0.009	(0.023)
Negative reciprocity					−0.000	(0.011)
Constant	0.621***	(0.021)	0.546***	(0.056)	0.748***	(0.082)
Observations	2982		2982		2600	
Adjusted R^2	0.171		0.192		0.236	

[1] Linear regressions, bootstrapped standard errors, clustered at the session level
[2] One unit of observation is the cooperation rate (time-average) of subject i in supergame s
[3] Significance levels: *, **, and *** indicate p-values lower than 0.10, 0.05, and 0.01, respectively.

negative time trends in Figure 4.

When we add the interactions with Group size, $N_{i,s}$ in regressions (2) and (3),[23]

[23] While the (non-interacted) main variables discussed above are still statistically significant and have the same sign also in regressions (2) and (3), their interpretation changes: Group size, $N_{i,s}$ only applies to the Neutral matrix and the coefficients of the other main variables correspond to a hypothetical group size of zero.

we expect from Prediction 3 a diminished effect of the group size with the Defensive and Offensive payoff matrix. The regressions confirm this: Defensive (d.) $\times$ Group size, $N_{i,s}$ and Offensive (d.) $\times$ Group size, $N_{i,s}$ are both positive and significant. They further suggests that the effect of Supergame is weaker in larger groups, as the interaction Supergame $\times$ Group size, $N_{i,s}$ is in regression (2) negative and significant. Length, T_s /60 s $\times$ Group size, $N_{i,s}$ is insignificant.

Prediction 3 leaves open the question of whether the group size has a significant overall impact for these payoff matrices. To answer this question, we tested the conditional effect of group size for the Defensive payoff matrix, which is the sum of the coefficients Group size, $N_{i,s}$ and Defensive (d.) $\times$ Group size, $N_{i,s}$. This conditional effect was negative and significant in post-hoc Wald tests of regression (2) ($p = 0.026$), meaning that group size has a negative effect in Defensive. However, the same is not true for Offensive where the sum of Group size, $N_{i,s}$ and Offensive (d.) $\times$ Group size, $N_{i,s}$ is not significantly different from zero ($p = 0.468$). The same holds in regression (3), with $p < 0.001$ for Defensive (d.) and $p = 0.117$ for Offensive (d.) Since Group size, $N_{i,s}$ alone is negative and significant in regressions (2) and (3), we conclude that it negatively affects cooperation separately with the Neutral and Defensive payoff matrix, but not with the Offensive one.

Regression (3) of Table 2 differs from regression (2) in that we add the three sets of control variables: The properties of the previous supergame, demographic characteristics, and the results of a preference survey. These controls are specific to individual subjects.

Regarding the properties of the previous supergame in regression (3), we included a dummy variable to indicate whether the subject was in a smaller group previously, as well as two dummy variables to indicate whether the subject's previous game matrix was Defensive or Offensive. We find that the "Group smaller previous game" dummy variable and the payoff matrices of the previous supergame have no significant impact. This is important because a correlation could have indicated that order effects may be present due to the within-subjects design.[24] We also analyze the length of the previous supergame. The variable does have a positive

[24] The same conclusion is supported by the results of Boczoń et al. (2024) who supplement their between-subjects analysis with a within-subjects robustness check, but find no effect. Their within-subjects data shows an even stronger effect when N changes from two to four than their between-subjects data does.

and significant effect on cooperation, confirming the evidence from the large meta data set in Mengel et al. (2022).

As for the vector of demographic characteristics and the results of the preference survey (Falk et al., 2016, 2018) in (3), it turns out that some of the demographic characteristics are statistically significant: Age (weakly significant), female, graduate student status ("Master"), and major (Arts, Humanities, and Law, weakly significant). All of these have a negative sign. Among the individual's preference items, we observe that the risk measure is negative and significant, while the trust measure is positive and significant. A main takeaway from adding the demographics and the preference survey in (3) is that this does not change the our main results.[25]

Consistent with Predictions 1, 2 and 3, we summarize:

Result 1.– Conditional on cooperation being equally difficult to be supported in equilibrium for all group sizes, we find that: (i) The average level of cooperation decreases with the number of players, N. (ii) The Defensive and Offensive payoff matrices negatively impact cooperation. (iii) Group size has a smaller impact on cooperation with the Defensive and Offensive payoff matrices than with the Neutral matrix.

The meta study of Dal Bó and Fréchette (2018) finds that the overall cooperation in $N = 2$ supergames depends on and is largely similar to the initial choices. We therefore implement the regressions in Table 2 also for the initial actions, omitting supergame length (which was unknown when the initial action was chosen). As the patterns of the initial choices are essentially the same as for the overall rate of cooperation in Table 2 (including demographics and preferences), and as the coefficients have similar magnitudes, we skip the details here and refer the reader to Table 5 in the Supplementary Material.

[25]Three interactions are significant in regression (2) but not in regression (3). We discuss in Section 4.2 that, whether these interpretations are significant, is immaterial to their interpretation.

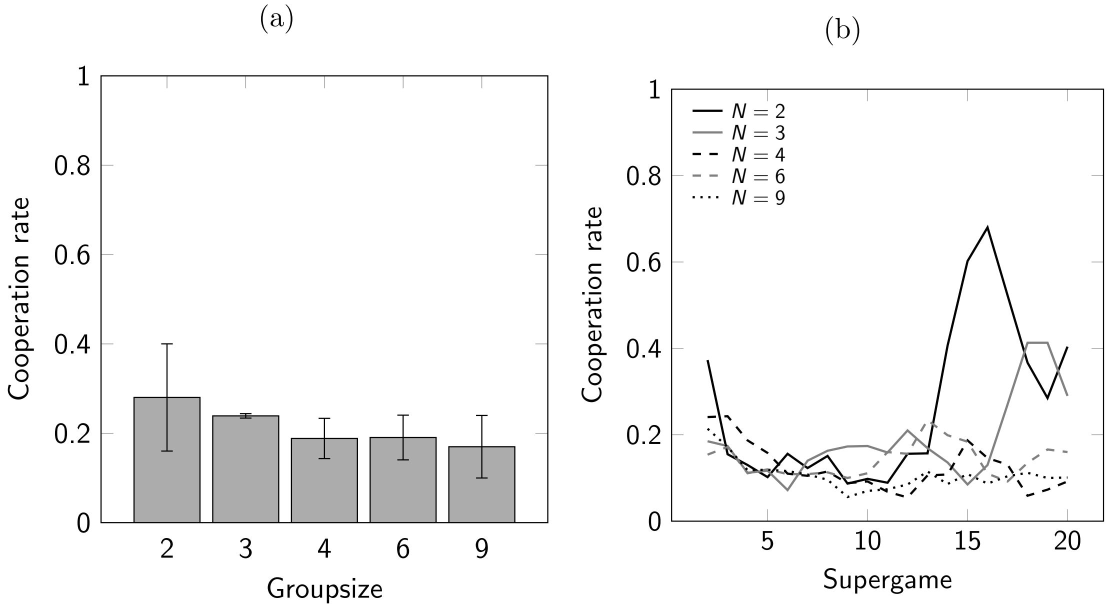

Figure 7. (a) Mean cooperation in the Cont experiment, by group size N, unit of observation defined as in footnote 20, 95% confidence intervals based on bootstrapped standard errors clustered at the session level, (b) Evolution of average group cooperation over supergames in Cont, unit of observation defined as in footnote 20.

4.2 The Cont experiment

The effect of the number of players

Figure 7a shows the cooperation rates for the different group sizes in the Cont experiment.[26] A decrease of cooperation in the group size, N, is noticeable, but it is not as pronounced as in the Pure data. Figure 7b shows the moving mean of group cooperation rates for all N, with a span of three supergames to reduce noise. Apart from short-lived surges toward the final supergames in the $N = 2$ and $N = 3$ groups, cooperation rates decline rather than increase. Overall, the impression from Figure 7a and Figure 7b is that cooperation rates in Cont are low, and they are substantially lower compared to Pure. While we do not have a prediction regarding the comparison of Cont vs. Pure, the regression analysis in Table 2 (discussed under "regression analysis") confirms that the difference is significant.

Figure 8 shows that cooperation rates either decline pronouncedly ($N > 3$) or stay roughly constant ($N \leq 3$). But even for groups of two and three, the levels

[26] Figure 11 in the Supplementary Material provides additional details by session.

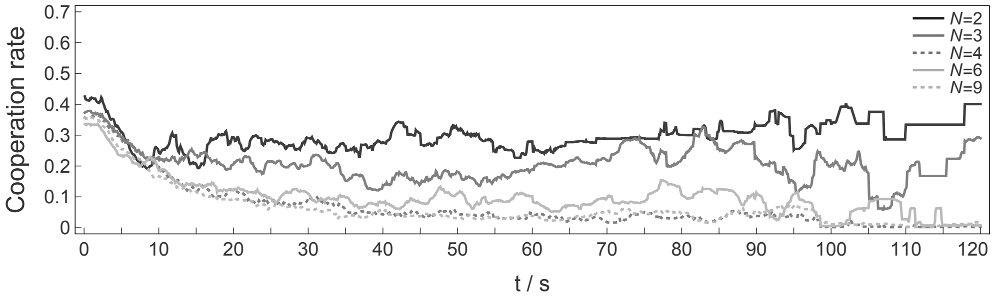

Figure 8. Evolution of cooperation over time, by group size N (Cont data), group averages are conditional on a group being active: Out of the initial 63 groups, 34 were active after 30 seconds, 23 after 60 seconds, 13 after 90 seconds, and 5 after 120 seconds (for all N).

achieved are markedly lower than in Figure 4 (Pure data). An analysis of the outcomes in Cont (as in Figure 5 for the Pure data) is not informative and hence omitted: The fraction of groups where players manage to (virtually) all cooperate is restricted to very few $N = 2$ groups.

The effect of the payoff matrices

Figure 9 shows how cooperation in Cont depends on the payoff matrix for a given N. Contrary to Prediction 5 and the Pure treatment, the cooperation rates are not always higher with the Neutral matrix. Neither does the Offensive matrix always have the lowest cooperation rates as in Figure 6. While for the Neutral and the Defensive matrix, cooperation rates decline in N (weak monotonicity), this is not the case for the Offensive matrix. Furthermore, the large confidence intervals indicate that any existing differences must be interpreted cautiously.

Regression analysis

Table 2 contains the linear probability models also for the Cont treatment. As expected from the descriptive results, cooperation rates are significantly lower in the Cont experiment. With the coefficient of Cont being -0.289 in regression (1), the difference is substantial. We discuss this disruptive result in Section 5. Turning to the interactions of the main regressors with the Cont treatment (variable $\times$ Cont (d.)) in regression (1), we note that Group size, $N_{i,s}$, Defensive (d.), Offensive (d.), Supergame, and Length, T_s /60 s when interacted with Cont (d.) all have the

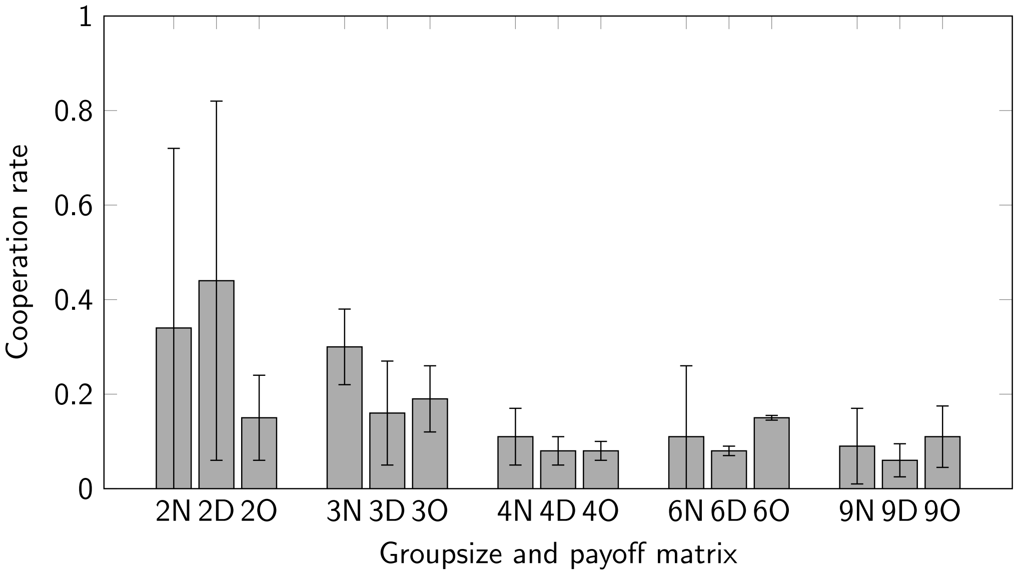

Figure 9. Average group cooperation conditional on payoff matrix, N, D, and O refer to the Neutral, Defensive, and Offensive payoff matrix, respectively, 2–9 refer to the group size, 95% confidence intervals based on estimations with bootstrapped standard errors clustered at the session level, Cont data.

opposite sign as the non-interacted variables. This means that their effect is weaker in Cont compared to the Pure treatment, which is intuitive because of the generally lower cooperation level in the Cont treatment. In regression (1), the interaction is significant for Group size, $N_{i,s}$, Defensive (d.) and Supergame, weakly significant for Offensive (d.), and insignificant for Length, T_s /60 s.

We now analyze Predictions 4 and 5 with the help of regression (1). To see whether the main variables Group size, $N_{i,s}$, Defensive (d.), and Offensive (d.) have impact in Cont, we test their conditional effect for the Cont data by adding the corresponding coefficient and its interaction. In post-hoc Wald tests, the sum of Group size, $N_{i,s}$ and Group size, $N_{i,s}$ $\times$ Cont (d.) is significantly different from zero (p = 0.007), as also evident in Figure 7a. As for the influence of the payoff matrices in Cont, the sum of the coefficients Defensive (d.) and Defensive (d.) $\times$ Cont (d.) is not significantly different from zero ($p = 0.847$), and neither is the sum of the coefficients of Offensive (d.) and Offensive (d.) $\times$ Cont (d.) ($p = 0.143$). We conclude that there is support for Prediction 4 but not for Prediction 5.

A further set of regressors in regressions (2) and (3) includes the two-way interactions of the main variables with the Cont treatment and group size (variable

$\times$ Group size, $N_{i,s}$ $\times$ Cont (d.)) which allows a test of Prediction 6. However, the coefficients have the opposite sign that we expected. Defensive (d.) $\times$ Group size, $N_{i,s}$ $\times$ Cont (d.) is negative and significant (in both regression (2) and (3)), and Offensive (d.) $\times$ Group size, $N_{i,s}$ $\times$ Cont (d.) is negative and either weakly significant (regression (2)) or not significant (in (3)). This means that the Defensive and the Offensive payoff matrices are (significantly or not) more strongly correlated with the group size than the Neutral matrix.

As above with the Pure data, we check whether there is a correlation of cooperation and group size when we look at the payoff matrices separately. For the Neutral matrix, we test whether Group size, $N_{i,s}$ plus Group size, $N_{i,s}$ $\times$ Cont (d.) differs from zero. This is not the case ($p = 0.877$ in (2) and $p = 0.953$ in (3)). Whether the group size has an effect for Defensive depends on whether the sum of Group size, $N_{i,s}$, Group size, $N_{i,s}$ $\times$ Cont (d.) and Defensive (d.) $\times$ Group size, $N_{i,s}$ $\times$ Cont (d.) is negative and different from zero. This is the case in both in regression (2) ($p = 0.042$) and regression (3) ($p = 0.011$). For Offensive, the sum is not significantly different from zero ($p = 0.212$ in (2) and $p = 0.605$ in (3)).[27]

Consistent with Prediction 4 but contradictory to Predictions 5 and 6, we conclude as follows:

Result 2.– Conditional on cooperation being equally difficult to be supported in equilibrium for all group sizes, we find that: (i) Cooperation rates in Cont are significantly lower than in Pure. (ii) The average level of cooperation decreases with the number of players, N. (iii) The Offensive and Defensive payoff matrix have no significant impact on cooperation. (iv) Group size has a greater impact on cooperation with the Defensive matrix than with the Neutral matrix.

5 Discussion

A first main result is that, in the Pure treatment, group size has a negative effect on cooperation rates. The result is significant because, in a methodological innovation, our setup makes cooperation equally difficult to be supported in equilibrium for all

[27] A regression analysis of initial actions in the Cont treatment can be found in Supplementary Material, Table 5.

group sizes. In contrast, in previous experimental studies, increasing the number of players can reduce cooperation, either because the larger groups make cooperative outcomes harder to be supported in equilibrium, or because larger groups make cooperative equilibria less likely to be selected. With our setup, we show that increased strategic uncertainty matters in larger groups even though we control for the minimum discount factor required for cooperation. This is consistent with the theory of strategic risk in repeated games (Blonski et al., 2011; Blonski and Spagnolo, 2015; Dal Bó and Fréchette, 2011), which we extend from the two- to the multi-player case: Larger groups make cooperation more difficult by increasing the risk that one or more players choose a defective strategy. Boczoń et al. (2024) find similar effects regarding the impact of strategic uncertainty in N-player games. By allowing for communication between players, they demonstrate how strategic uncertainty can be overcome and coordination can be improved. This finding is related to Oprea et al. (2014) who find a strong impact of communication in a four-player public good game when choices are in continuous time.

Coordination on the fully cooperative outcome is limited to two-player and three-player groups, as noted for example in Huck et al. (2004), who succinctly put this result as "two are few and four are many", Fonseca and Normann (2012), or Horstmann et al. (2018). The fact that our experiments are in continuous time does not seem to change this finding. Consistent with this, multi-period experiments show some cooperation for two and three players (Oprea et al., 2014), but not for four players (Oechssler et al., 2016).

Friedman and Oprea (2012) and Bigoni et al. (2015) also conduct prisoner's dilemma experiments in continuous time. Friedman and Oprea (2012) have games with a finite duration of one minute (corresponding to the expected duration of our games). The median cooperation rate in their Easy treatment (which is Neutral in our terminology, see footnote 9) reads 0.931. With a median of 0.784 (all supergames, $N = 2$), our rate for neutral games is similar, although not excessively proximate. Bigoni et al. (2015) have "long stochastic" games with an expected duration of 60 seconds, as in our experiments, and the payoffs correspond exactly to our Defensive setup (see footnote 9). Bigoni et al. (2015) find a cooperation rate of 0.669 (median 0.848). Figure 6 shows for $N = 2$ a mean cooperation rate of 0.655 in Defensive, and we find a median of 0.933. The similarity of the cooperation rates in our data may seem surprising, since in our experiment each individual experiences more defections and lower cooperation rates in the larger groups. However, this does not seem to strongly affect cooperation in small groups.

The most disruptive and perhaps surprising result we find is the low level of cooperation in the Cont treatment. Related findings, although not that pronounced, have been reported in finitely repeated settings. Gangadharan and Nikiforakis (2009) analyze a linear public good game with two and ten actions. Consistent with our results, they observe that the smaller action set somewhat improves the frequency of cooperative actions in the initial periods with four players. Different from our data, they find no effect in later periods and no change at all when there are two players. Lugovskyy et al. (2017) provide evidence on differences in cooperation between comparable prisoner's dilemma and public-good games. Their results suggest that, framing the game as a (two-action) VCM game as opposed to the common prisoner's dilemma, may lead subjects to be more cooperative. They also find that a binary-action VCM tends to cooperate better than the usual ten-action variant (both finitely repeated). Finally, Heuer and Orland (2019) analyze a two-player one-shot prisoner's dilemma where subjects either choose one pure action (cooperate or defect) or they can "mix" by deciding with how many out of ten rival players in the session they (purely) cooperate or defect, respectively. With "mixing", lower cooperation rates result.

Given the low cooperation rates in Cont, we conclude that gradualism does not occur in our data. Gradualism has been investigated, foremost theoretically, in different contexts by, for example, Sobel (1985), Kranton (1996) or Watson (2002). For our prisoner's dilemma, the notion of gradualism suggests that players initially and cautiously choose low levels of cooperation. If matched by the other players, they then slowly increase the cooperation. However, it is precisely this increase of cooperation that does not occur because too few players are willing to make the sacrifice, that is, raise their action and make others follow. A related experimental finding was recently reported by Kartal et al. (2021) for two- vs. three-action trust games. Kartal et al. (2021) find some evidence of gradualist strategies. They delineate circumstances under which gradualism is clearly beneficial and when its effect is minor compared to “all-or-nothing” setups which can lead to drastically improved trust levels.

6 Conclusion

We study cooperation in a social dilemma played by larger groups. We address the research questions raised by the recent and growing literature on the two-player prisoner’s dilemma: What are the determinants of cooperation? Does strategic uncertainty matter? Given the importance of these questions, it is somewhat unfortunate that the results have been obtained exclusively in two-player environments, limiting the applicability of this research. We modify the two-action prisoner’s dilemma to allow for arbitrary group sizes. Our innovative experiment controls for strategic incentives (same minimum discount factor for all group sizes). This novel design allows us to study larger group sizes using the same groundbreaking methods proposed for the two-player game.

We find both intuitive comparative statics effects as well as counterintuitive results: In addition to demonstrating the negative effect of group size on cooperation, we confirm in a clean setting that cooperation is limited to relatively small groups of two and three. Defect rates increase with group size. These results are consistent with notions of strategic uncertainty. Some of the determinants of cooperation found to be relevant in two-player games are quite similar and significant even in larger groups. These results suggest a potential for cooperation in larger groups if strategic uncertainty can be overcome. Finally, the availability of a continuous action set, which emerges as a natural extension of the multiplayer setting, leads to a drastic reduction in cooperative choices. While group size continues to influence cooperation, other determinants do not have explanatory power here.

In terms of future research, it seems promising to relate some of our key findings (conditional cooperation in large groups, but almost no cooperation with continuous action sets) to the literature on conditional cooperation in public goods experiments. The latter typically involve more than two players and more than two actions, but they still differ from our setup. Analyzing both in a unified framework may tell us more about the interaction of action space, group size and (conditional) cooperation.

Appendix

A Mathematical Derivations

We begin with the non-normalized prisoner's dilemma payoffs $\begin{pmatrix} R & S \\ T & P \end{pmatrix}$. Excluding player i, there are $N-1$ players and, among those, m cooperate. Accordingly, player i's stage-game payoff from cooperating is

$$\pi(C, m; N-1) = \frac{m}{N-1} R + \frac{N-m-1}{N-1} S$$

and the payoff when defecting reads

$$\pi(D, m; N-1) = \frac{m}{N-1} T + \frac{N-m-1}{N-1} P.$$

Players face strategic uncertainty. Let p be the (identical) probability that any of i's opponents play a grim trigger (GT) strategy, and $(1-p)$ is the probability that a player $\neq i$ plays always defect (AD).

First, suppose that player i plays GT. After the initial period (that is, in $t = 1$), there are only two contingencies. With probability p^{N-1}, all players cooperated in $t = 0$ and thus maintain cooperation throughout the supergame, yielding an expected payoff of

$$p^{N-1} \sum_{t=1}^{\infty} \delta^t R = p^{N-1} \frac{\delta}{1-\delta} R.$$

With the counter probability, at least one rival player failed to cooperate in $t = 0$ and therefore everyone defects afterwards:

$$\left(1 - p^{N-1}\right) \sum_{t=1}^{\infty} \delta^t P = \left(1 - p^{N-1}\right) \frac{\delta}{1-\delta} P.$$

In period $t = 0$, the expected payoff from choosing GT is given by the different factorial combinations with which i faces m cooperators (where $0 \leq m \leq N-1$):

$$\sum_{m=0}^{N-1} \binom{N-1}{m} p^m (1-p)^{N-m-1} \left(\frac{m}{N-1} R + \frac{N-m-1}{N-1} S \right)$$

This can be rewritten as

$$\frac{R}{N-1}\underbrace{\sum_{m=0}^{N-1}\binom{N-1}{m}p^m(1-p)^{N-m-1}m}_{=(N-1)p\,\rightarrow\,\text{the binomial mean}}+\underbrace{\frac{N-1}{N-1}}_{=1}S\underbrace{\sum_{m=0}^{N-1}\binom{N-1}{m}p^m(1-p)^{N-m-1}}_{=1\,\rightarrow\,\text{the total mass}}-\frac{S}{N-1}\underbrace{\sum_{m=0}^{N-1}\binom{N-1}{m}p^m(1-p)^{N-m-1}m}_{=(N-1)p}$$

Hence, the expected payoff from playing GT in $t=0$ is $p\,R+(1-p)\,S$. Summing up, the discounted payoff from GT is

$$p\,R+(1-p)\,S+\frac{\delta}{1-\delta}p^{N-1}R+\frac{\delta}{1-\delta}\left(1-p^{N-1}\right)P$$

Second, assume player i chooses AD. Regardless of the choices of the other players, the initial defect action triggers full defection by all players in periods $t=1,...,\infty$. Thus,

$$\sum_{t=1}^{\infty}\delta^t P=\frac{\delta}{1-\delta}\,P.$$

In $t=0$, the expected payoff from AD is given by

$$\sum_{m=0}^{N-1}\binom{N-1}{m}p^m(1-p)^{N-m-1}\left(\frac{m}{N-1}\,T+\frac{N-m-1}{N-1}\,P\right)$$

We can rewrite this (as above for GT) and obtain an expected payoff of $p\,T+(1-p)\,P$. Altogether, the discounted payoff from AD is

$$p\,T+(1-p)\,P+\frac{\delta}{1-\delta}P.$$

Comparing expected payoffs from GT versus AD, we obtain

$$p\,R+(1-p)\,S+\frac{\delta}{1-\delta}p^{N-1}R+\frac{\delta}{1-\delta}\left(1-p^{N-1}\right)P\;\;\geq\;\;p\,T+(1-p)\,P+\frac{\delta}{1-\delta}P$$

or

$$\frac{\delta}{1-\delta}\,p^{N-1}(R-P)\geq p\,(T+S-R-P)+(P-S). \tag{7}$$

Employing the normalization $R=1$, $P=0$, $T=1+g$ and $S=-l$, equation (7) reads

$$\frac{\delta}{1-\delta}\,p^{N-1}\geq p\,(g-l)+l.$$

Dividing by p^{N-1}, we obtain (3) in the main text.

This approach readily extends when the continuous action set is available. Plugging $R = \sigma(1 + (g - l)(1 - \sigma))$, $T = \sigma(1 + g)$, $S = -\sigma l$ and $P = 0$ (see main text) into (7), we obtain

$$\frac{\delta}{1-\delta} p^{N-1} \geq \frac{l + p\sigma(g-l)}{1 + (1-\sigma)(g-l)}. \tag{8}$$

One can verify that the partial derivative of the right-hand side with respect to σ depends on the sign of $g - l$ as claimed in the main text. As in the Pure case, this equation can be solved explicitly for sizeBAD when $g = l$, in which case σ has no effect. We finally derive the continuous-action-set version of δ^*. Substituting $p = 1/2$ in (8) and rearranging yields

$$\delta \geq \frac{2l + \sigma(g-l)}{2l + \sigma(g-l) + \left(\frac{1}{2}\right)^{N-2} (1 + (g-l)(1-\sigma))}.$$

Once again, plugging in $\sigma = 1$ yields the result of the pure-strategy setup.

B Power calculations

Our power calculations regarding N were based on the oligopoly experiments meta data by Engel (2015). Using the normalized averages and standard deviations from data reported in the working paper version of the paper (Engel, 2006, Table 10), we simulated three times 21 random observations in three clusters for 2, 3, 4, 6, and 8 firms (nine were unavailable, and there was only one observation for ten firms). We then regressed the cooperation variable on the number of players, clustering at the session level. In 1,000 runs, the probability of detecting a significant effect of group size was greater than 96.9%, assuming a p-value of 0.05.

For the power calculations of the effect of the Defensive and Offensive payoff matrices, we used the $N = 2$ prisoner's dilemma meta dataset in Dal Bó and Fréchette (2018). Our Neutral and Defensive/Offensive games have $\delta^* = 0.667$ and $\delta^* = 0.75$, respectively (see equation (5)); or $\delta - \delta^* = 0.248$ and $\delta - \delta^* = 0.332$. To estimate the expected effect size, we referred to Dal Bó and Fréchette (2018)'s data, identifying 13 supergames where $\delta - \delta^* = 0.233$ and 34 supergames where $\delta - \delta^* = 0.355$, which closely correspond to our game parameters. In these subsets of their data, the average cooperation rate was 76.75 (SD 11.03) for Neutral and 54.24 (SD 16.57) for Offensive/Defensive. This observed difference of 22.51 units served as the target effect size for our power simulation. Running 1,000 linear regressions with 7 randomly generated observations times three clusters each, the probability of correctly detecting a significant effect of a dummy variable for Defensive/Offensive matrix on cooperation, clustered at the session level and given $p = 0.05$ was 75.2%.

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Supplementary Material

Additional Figures

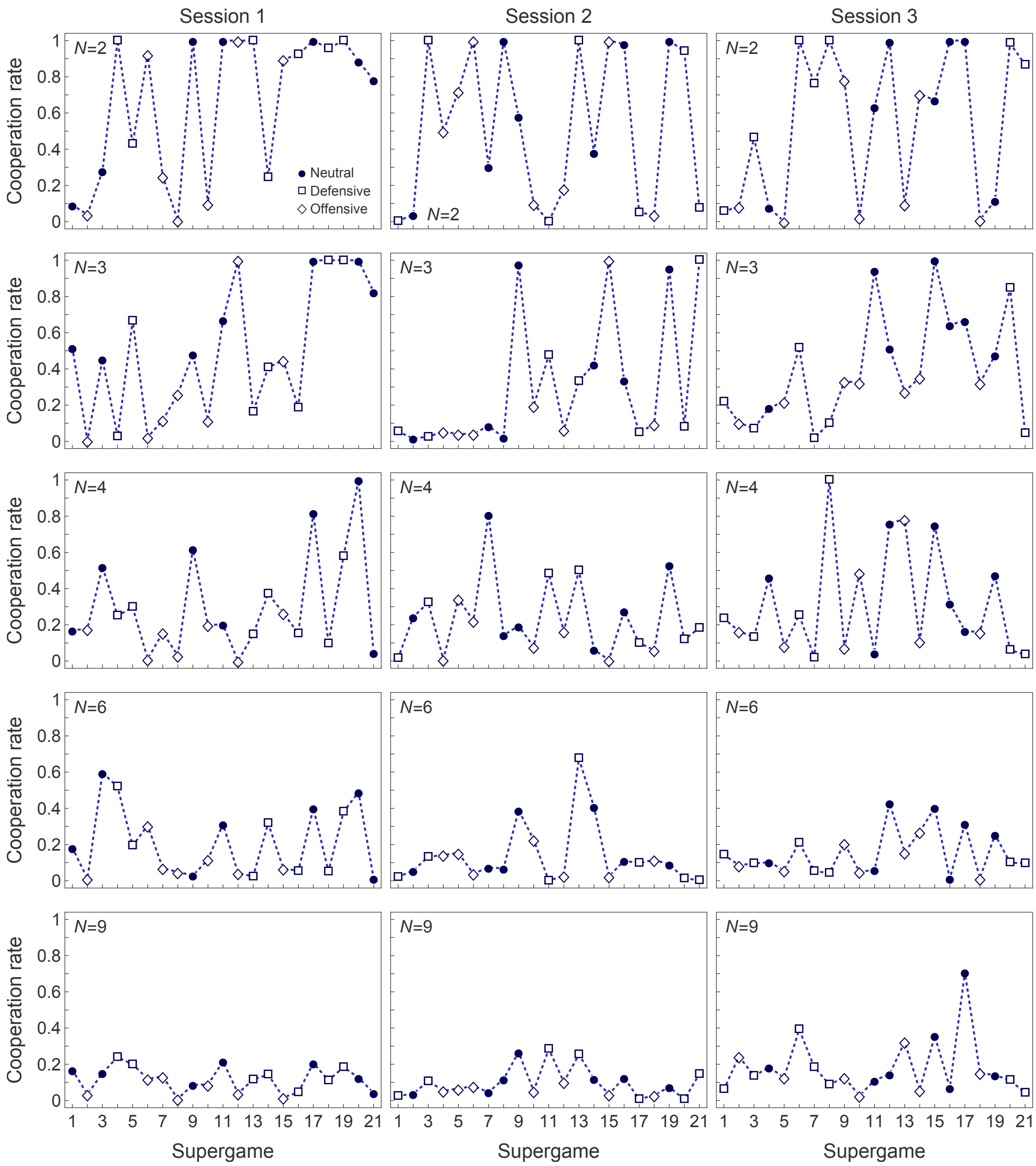


Figure 10. Evolution of group cooperation rates over supergames, by session. Different plot markers indicate the matrix that was played in each supergame.

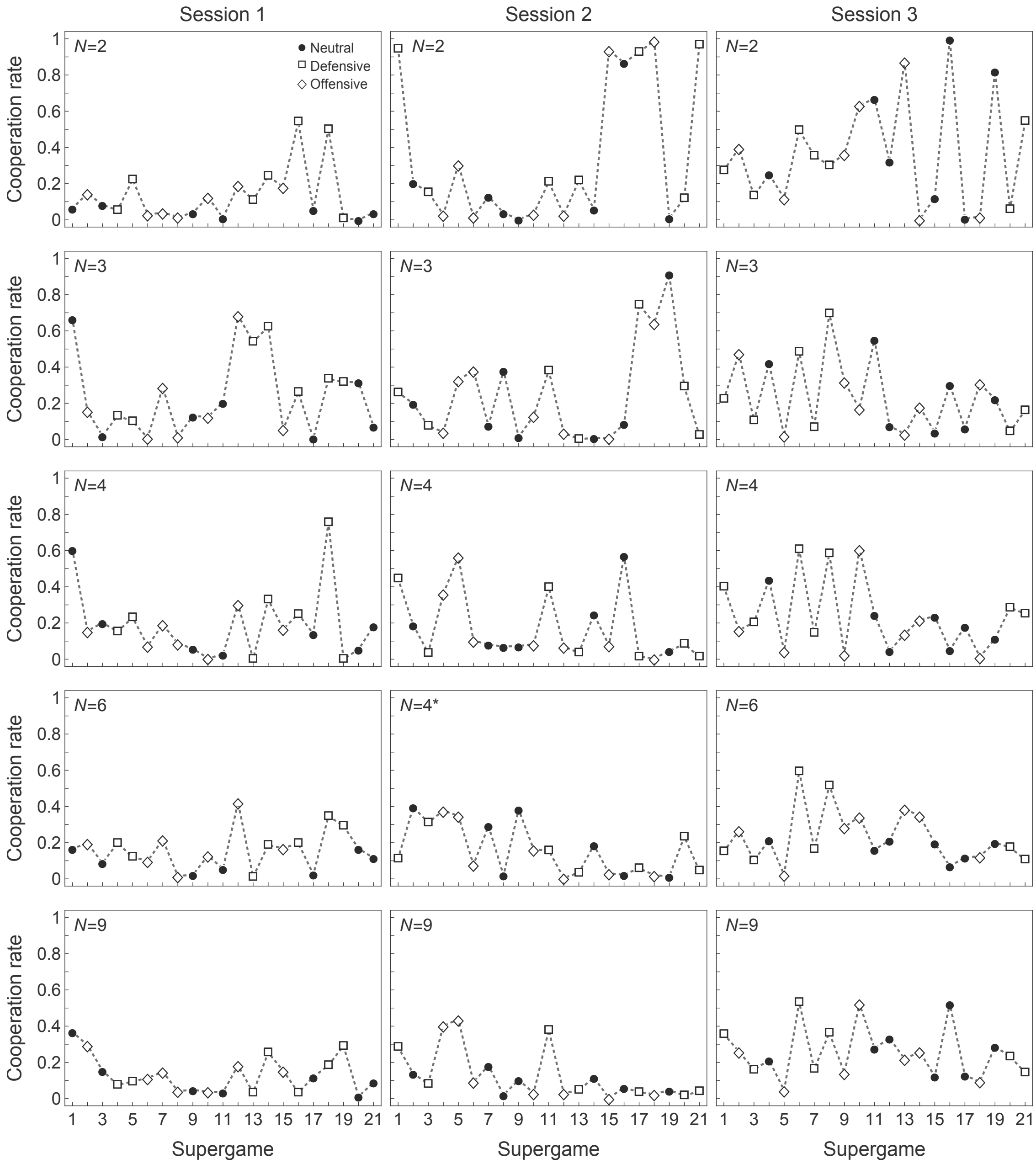


Figure 11. Evolution of group cooperation rates over supergames in the Cont experiment, by session. Different plot markers indicate the matrix that was played in each supergame.

Additional Tables

Table 3. Alternative minimum discount factor δ^* and SizeBAD

	sizeBAD			δ^*		
	Neutral	Offensive	Defensive	Neutral	Offensive	Defensive
$N = 2$	0.00170	0.00171	0.00340	0.66667	0.75000	0.75000
$N = 3$	0.04127	0.04213	0.05751	0.80000	0.85714	0.85714
$N = 4$	0.11942	0.12417	0.14668	0.88889	0.92308	0.92308
$N = 6$	0.27941	0.29420	0.31031	0.96970	0.97959	0.97959
$N = 9$	0.45071	0.47307	0.47512	0.99611	0.99740	0.99740

[1] SizeBAD as in (3) given the discount factor used in the experiment ($0.998\bar{3}$), and δ^* as in (5) given $p = 1/2$, both as a function of N and the game matrix.

Table 4. Descriptive statistics of the control variables

	Mean	Median	Std. Dev.	Min	Max	Obs.
Demographics						
Age / yr	24.6	23	6.8	18	60	71
Female (d.)	0.528	-	-	0	1	72
Lab experience (cat.)	1.99	2	0.81	1	3	72
Bachelor (d)	0.708	-	-	0	1	72
Master (d.)	0.236	-	-	0	1	72
Economics & Business (d.)	0.389	-	-	0	1	72
Science & Medicine (d.)	0.347	-	-	0	1	72
Arts, Humanities & Law (d.)	0.167	-	-	0	1	72
Not studying or incomplete (d.)	0.097	-	-	0	1	72
Preference survey						
Risk taking (qual.)	4.85	5	1.96	1	8	72
Risk taking (quan.)	4.63	5	1.55	2	8	71
Time discounting (qual.)	6.40	7	2.20	0	10	72
Time discounting (quan.)	5.10	5	2.78	1	11	72
Trust (qual.)	4.60	4	2.76	0	10	72
Trust (quan.)	9.50	10	5.94	0	20	71
Altruism (qual.)	5.76	6	2.36	1	10	72
Altruism (quan.)	120.42	50	140.30	0	500	71
Positive reciprocity (quan.1)	15.88	15	7.21	0	32	70
Positive reciprocity (quan.2)	18.26	20	6.98	5	30	72
Negative reciprocity (qual.)	5.42	6	2.35	0	10	72
Negative reciprocity (quan.)	42.46	50	12.07	10	70	71

[1] See the main text for a discussion of the control variables and the questionnaire employed in the preference survey (based on Falk et al. 2016, 2018).

Table 5. Regression analyses of initial cooperation choices, bootstrapped standard errors, clustered at the session level

	Initial cooperation rate, $c_{i,s}$ at $t = 0$					
	(1)		(2)		(3)	
Group size, $N_{i,s}$	−0.040***	(0.007)	−0.031***	(0.002)	−0.034***	(0.003)
Defensive (d.)	−0.112***	(0.022)	−0.182***	(0.028)	−0.169***	(0.023)
Offensive (d.)	−0.176***	(0.027)	−0.311***	(0.049)	−0.275***	(0.048)
Supergame	0.003	(0.004)	0.021***	(0.006)	0.020***	(0.005)
Cont (d.)	−0.341***	(0.040)	−0.190***	(0.059)	−0.165	(0.137)
Group size, $N_{i,s}$ × Cont (d.)	0.035***	(0.007)	0.030***	(0.005)	0.031***	(0.009)
Defensive (d.) × Cont (d.)	0.140***	(0.027)	0.195***	(0.049)	0.172**	(0.071)
Offensive (d.) × Cont (d.)	0.171***	(0.028)	0.173***	(0.063)	0.112	(0.069)
Supergame × Cont (d.)	−0.005	(0.004)	−0.017***	(0.006)	−0.015*	(0.008)
Defensive (d.) × Group size, $N_{i,s}$			0.016**	(0.007)	0.016***	(0.004)
Offensive (d.) × Group size, $N_{i,s}$			0.027***	(0.004)	0.024***	(0.003)
Supergame × Group size, $N_{i,s}$			−0.003***	(0.001)	−0.002***	(0.001)
Defensive (d.) × Group size, $N_{i,s}$ × Cont (d.)			−0.020**	(0.008)	−0.018***	(0.007)
Offensive (d.) × Group size, $N_{i,s}$ × Cont (d.)			−0.013**	(0.005)	−0.007	(0.005)
Supergame × Group size, $N_{i,s}$ × Cont (d.)			0.002	(0.001)	0.001	(0.001)
Previous supergame:						
Group smaller previsous game					0.003	(0.011)
Defensive previous game					0.017	(0.032)
Offensive previous game					0.017	(0.024)
Length, T_s / 60 s previous game					0.031**	(0.014)
Demographics:						
Age					−0.002*	(0.001)
Female (d.)					−0.055***	(0.012)
Lab experience (cat.)					−0.008	(0.014)
Bachelor (d.)					−0.098	(0.068)
Master (d.)					−0.134**	(0.055)
Economics & Business (d.)					−0.020	(0.044)
Science & Medicine (d.)					−0.038	(0.058)
Arts, Humanities & Law (d.)					−0.067*	(0.036)
Preference survey:						
Risk taking					−0.031**	(0.013)
Time discounting					0.007	(0.014)
Trust					0.032***	(0.012)
Altruism					0.029	(0.019)
Positive reciprocity					−0.010	(0.023)
Negative reciprocity					−0.000	(0.011)
Constant	0.745***	(0.038)	0.446***	(0.016)	0.642***	(0.054)
Observations	2982		2982		2600	
Adjusted R^2	0.047		0.148		0.195	

[1] Linear regressions with standard errors clustered at the session level, including subject fixed effects. One unit of observation is the initial choice of subject i, at the beginning of supergame s.
[2] Defaults: defensive and offensive games are compared to neutral games. Level and field of studies are compared to a baseline group declaring not to study or not specifying the level and field of the studies.

Experimental Instructions

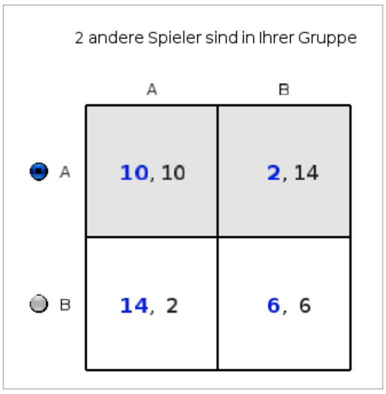
Welcome to our experiment!

Please read these instructions carefully. I need to say one thing before we start: Please do not talk to other participants once the experiment has started. The use of mobile phones or similar devices is also not permitted during the entire experiment. If you have any questions after reading these instructions, please raise your hand and we will come to your cubicle and answer your questions personally.

The experiment will be conducted anonymously, that means, you will not find out who among the other participants has interacted with you. It also means that we will not save any data in connection with your name. Depending on your choices and those of other players, you can earn real money today.

Basic idea

In each of several rounds, you will be randomly matched in a group with one or more other persons (your counterparts) in this room. You are informed about how many other people are playing with you each period. This will be indicated above your selector device.



You can choose between “A” and “B” by clicking the corresponding button. In the same way, your counterparts will also choose between “A” and “B”.

Your earning possibilities are represented with a payoff matrix like the one above. In each of the four cells in the matrix there are two numbers. The numbers in the first position, shown in blue, give your earnings from the combination of actions. The numbers in the second position, shown in black, would be your counterpart’s earnings, if there was only one other person in your group.

Your earnings depend on the combination of your choice and the choices of the other people in your group. Your choice determines whether row “A” or “B” is selected, marked by the gray shadow. The choices of your counterparts determine the impact of the two columns on your earnings.

Example. First imagine that you are matched in a group where only **1 other player** is in your group. If you chose “A” and your counterpart chose “A” you would earn 10 as would the other person in your group. If instead the other person in your group chose “B”, you would earn 2 and the other person in your group would earn 14.

Now imagine that you are matched in a group with an additional **2 other players**. You chose “A”. If both of the other people chose “A”, you would earn 10, and if instead both of them chose “B”, you would earn 2. If one of them chose “A” and the other one chose “B”, you would then earn the following:

$$0.5 \times 10 + 0.5 \times 2 = 5 + 1 = 6.$$

In general, your earnings are determined by your selection of the row “A” or B”, and by the fraction (or percentage) of the other people in your group that selects each column “A” or ‘B”.

The payoff matrix is not always the same in each round. There are three different game matrices in today’s experiment and one of them will be selected randomly for each round. You should always look at it carefully at the beginning of each round.

The next screenshot shows you an example with different earning levels (red graph) depending on your choices (blue line) and the choice of your counterparts (black line) over time. We explain how to interpret the computer display below as well.

Rounds and groups

There will be 21 rounds. At the beginning of each round the computer matches you randomly with other players in the room into one group. Your group includes you and the other people in your group. The total number of persons in one group (including you) can be 2, 3, 4, 6 or 9.

As shown in the screenshot, we inform you of how many “other players are in your group.” This number will then be **1**, **2**, **3**, **5** or **8**.

Before starting a new round, you are randomly rematched in a new group with different people. We ensure you that today you will not be matched in the same exact group of persons more than once.

The number of other persons in your group is not always the same as in the previous round. You should always look at it carefully at the beginning of each round.

Your initial choice

Before each round begins, you have 30 seconds (half a minute) to decide whether you want to select “A” or “B” to begin the round of play. The following message at the top-left part of your display will indicate that you should now make your initial choice for the next round that is about to start.

This period of 30 seconds starts with your selector in a random position, either “A” or “B”. This random choice to initialize the software has no particular meaning and you can change your initial choice as many times as you want during these 30 seconds. The only choice that matters is what is marked at the end of the 30 seconds.

Duration of each round

Each round will have a different duration. The clock at the top-left part of your display indicates how much time (in seconds) has elapsed in that round. In practice you will see time flowing in very fast ticks of one-tenth of a second each (0.1 s). You can think of it as if in each of these tenth-of-a-second intervals, there is a probability of 599 in 600 (99.83 percent) that the next tenth of a second will get to be played.

The specific duration of each round is not known in advance by you or by any other participants. We use a random draw by the computer to determine the exact length of each round.

The average duration of all rounds in this experiment is around 60 seconds (one minute). But you should assume considerable defections. Some rounds may be much shorter and some rounds may be much longer. There is no upper limit for the maximum duration and the experiment will last as long as determined by the random draw. We will not intervene during the duration of the experiment.

The table below illustrates an example. It shows the different lengths of 21 rounds, which are obtained from the same random computer draws that we use for your experiment today. Be aware that the length of the 21 rounds that you play today are not related to the ones in the example, but you can expect a similar pattern.

Round	Duration	Round	Duration	Round	Duration
1	7.9 s	8	44.1 s	15	32.3 s
2	39.0 s	9	84.3 s	16	79.9 s
3	147.0 s	10	16.5 s	17	5.0 s
4	58.4 s	11	0.9 s	18	51.5 s
5	267.2 s	12	91.7 s	19	0.8 s
6	4.5 s	13	46.7 s	20	31.9 s
7	36.6 s	14	7.3 s	21	149.5 s

During the time of play of each round, you can change your action at any time by clicking the radio buttons "A" or "B" in the selector device or by using the up and down arrow keys (↑↓) on your keyboard. You and all the other players in your group may change your actions as often as you like.

The end of each round will be announced in the space at the top-left occupied by the usual clock. At the end you will see that your selector device is frozen for about 10 seconds. After this small pause, you will move on automatically to the next round, starting with the 30 seconds to select your next initial choice.

Computer display

You can think of your computer display as divided into two parts. On the left, you will always have the selection between "A" and "B" with the payoff matrix. Above the matrix, you will see the information on how many other players make up your group.

At the very top, you will find the clock displaying the time that has elapsed in the current round and a counter with the earnings that you have accumulated so far in the current round.

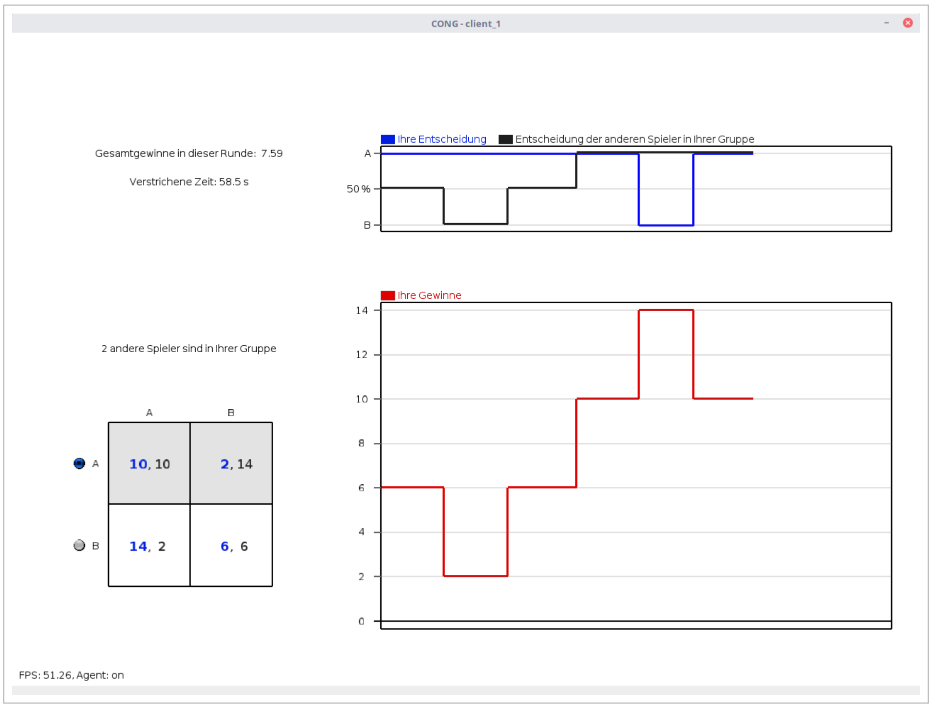
The messages indicating that a round is over or that you are now in the 30-second period to select your initial action will also appear here.

The right side of your screen displays the relevant information and the state of play in real time. You can see two charts. Both of them share the same horizontal axis: the time, moving toward the right.

Since the duration of a round is not known in advance, the length of your display is fixed to 60 seconds. When a round is shorter, the lines will stop at an intermediate point in the chart. If a round is longer, the charts will keep the current point fixed in your display and show the more recent 60 seconds. Older information will be replaced by the new one. You will have time to familiarize yourself with this display during the practice rounds.

There are two lines in the above chart. The **blue line** shows your own choice ("A" or "B") over the elapsed time. The **black line** shows the choices of actions made by the other players in your group (your co-players). It represents the fraction (or percentage) of them that is currently choosing "A". For example, if there are 4 other players in your group and you see that 25% of them (1 in 4) are choosing "A", then you also know that the other 3 are choosing "B".

You start each round with initial earnings of 0 and accumulate earnings over the course of the round depending on your choice and on the choice of the other players in your group as explained. The **red line** in the bigger chart shows how much you are earning over the course of the round. The higher the position of the red line the more you are currently earning. The cumulated earnings indicated in the counter correspond to the area below your read earnings line.



Earnings

In this experiment, you accumulate earnings over time in each round, and we take the expected average duration of the rounds of 60 seconds as a reference for scaling your earnings.

Example. We discuss now the details of the specific case that you can see in the big screenshot. In this example, there are 2 other players in your group.

First, you can see that the top-left part of the display indicates that play (so far) has lasted 58.5 seconds, and that the cumulated earnings for you would be 7.59 EUR.

The computer will compute your earnings in detail for you, but you can see here the rules of how earnings are calculated.

Looking at the right part of the display, the three lines charted (your actions in blue, the actions of the other players in your group in black, and your earnings in red) identify a sequence of six different configurations that last around 10 seconds each.

In this round (blue), your behavior would have been to choose row "A" for about 40.5 seconds with no changes, followed by a shorter period of 8.5 seconds where you would have chosen row "B", and finally a last period of another 10 seconds selecting "A" again.

The black line shows that during the first 10 seconds of play, one of the other players chose "A" and the other chose "B". This was followed by another 10 seconds where both other players chose "B", then 10.5 seconds where they split again with one choosing "A" and one choosing "B", and finally almost 30 seconds where both chose "A".

As a result of your choices made over time, combined with the actions chosen by the other players in your group, and considering the duration of these different outcomes, the sequence of earnings are:

- $0.5 \times 10 + 0.5 \times 2 = 6$ EUR over 10 seconds
- $1.0 \times 2 = 2$ EUR over 10 seconds
- $0.5 \times 10 + 0.5 \times 2 = 6$ EUR over 10.5 seconds
- $1.0 \times 10 = 10$ EUR over 10 seconds
- $1.0 \times 14 = 14$ EUR over 8.5 seconds
- $1.0 \times 10 = 10$ EUR over 10 seconds

Altogether, given the scale of 60 seconds of expected average duration, we have

$$\frac{1}{60\,s} \times \left(6 \times 10\,s + 2 \times 10\,s + 6 \times 10.5\,s + 10 \times 10\,s + 14 \times 8.5\,s + 10 \times 10\,s\right) \approx 7.59 \text{ EUR.}$$

You will not have to do these computations yourself while playing, the computer will do them for you. Since we scale your payoff by 60 seconds, you should expect that the longer rounds will allow you to accumulate more earnings than shorter rounds.

Practice rounds

Before the real experiment begins, you will get two training rounds to familiarize yourself with the computer. These practice rounds will not be paid.

The first training round lasts 20 seconds. In this round, the software will be initialized and you can use it to become familiar with the computer display. You can identify the charts where the relevant information will be shown: the number of other participants in your group, your own choices, the choices of the other players in your group, and your earnings. This first round will contain no information about the payoff matrix.

The second round lasts 80 seconds and you can use it to explore how to choose actions by clicking the radio buttons of the selector with the mouse or by using the up and down arrow keys in your keyboard. This will also give you a chance to see how the graphs in the display change with time, and how the window shows you all relevant information for the last minute of play.

In the 30-second interval, you can also experiment with what initial action you plan to select before the round begins. The payoff matrix in this second practice round will contain random numbers that are not related to the rest of the experiment.

Final payout

The session ends after the two training rounds and the 21 rounds are played. At the end of the session each of you will be paid in EUR the average number of points, that is, the average across the 21 rounds that you played.

After the last round of play finishes, please remain seated at your desk until we call you. Before making the final payments we will ask you to fill in a questionnaire that will help us better understand the data from the experiment. This questionnaire will be anonymous and we will not save any data in connection with your name. You can find your participant number next to your computer.

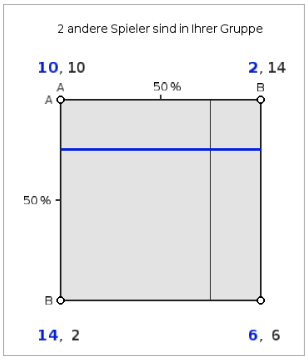
Summary

- You will play 21 rounds of random duration with no limit on their maximum length.
- You play these rounds matched with other players in this room. These groups are randomized for each round and vary also in the size (number of players).
- You have 30 seconds to choose your initial action and you can change your action (“A” or “B”) at any time during the round and as often as you like.
- Your cumulated earnings depend on your “A”/“B” choices, the “A”/“B” choices made by the other persons in your group and the duration of the game.
- At the end of the session you will be paid in cash the average earnings that you made over the 21 rounds.

Cont experiment (basic setup only)

You can choose between “A” and “B” and, in doing so with the **blue slider**, you can also select all intermediate levels. If your slider is completely at the top, then you are choosing 100% “A” and 0 percent “B”. Conversely, if your slider is completely at the bottom, then you are choosing 0 percent “A” and 100% “B”. As already mentioned, all intermediate positions are possible (60% “A” and 40% “B”; 18% “A” and 82% “B”; etc.)

The other persons in your group choose in the same way as you, with their sliders between “A” and “B”. The **black** vertical line shows you the average percentage of choice “A” (and “B”) by the other persons in your group.



In the example of the above screenshot, you choose 75% "A" and 25% "B". The average choice by the other players in your group is 25% "A" and the corresponding 75% "B". For instance, this average can be the result of one player selecting zero percent "A" and the other selecting 50% "B".

Your earning possibilities are represented with a payoff matrix like the one above. The numbers in the four corners represent your earning possibilities in the cases in which either 100% "A" or 100% "B" is played. In each of the four corners of the gray square, there are two numbers. The numbers in the first position, shown in blue, give your earnings. The numbers in the second position, shown in black, would be your counterpart's earnings, if there was only one other person in your group.

Your earnings depend on the combination of your choice and the choice of the other people in your group. Your choice determines whether the percentage of "A" and "B" that you play (blue slider). The average choice of the other persons in your group determines the average percentage of actions "A" and "B" that you confront (**black** slider).

Experimental Instructions (German original)

Willkommen zu unserem Experiment!

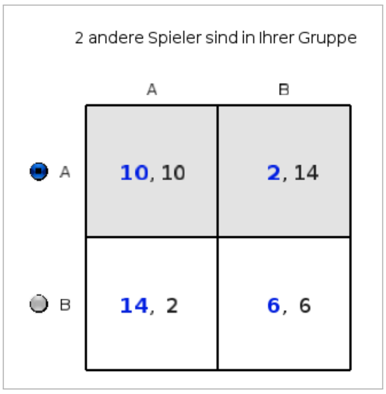
Bitte lesen Sie diese Anweisungen sorgfältig durch. Eine Sache vorweg: Bitte sprechen Sie nicht mit anderen Teilnehmern nachdem das Experiment begonnen hat. Die Benutzung von Mobiltelefonen oder ähnlichen Geräten ist während des gesamten Experiments ebenfalls nicht gestattet. Wenn Sie nach dem Lesen dieser Anleitung Fragen haben, heben Sie bitte Ihre Hand und wir werden in Ihre Kabine kommen und Ihre Fragen persönlich beantworten.

Das Experiment wird anonym durchgeführt, d. h. Sie erfahren nicht, wer unter den anderen Teilnehmerinnen und Teilnehmern mit Ihnen interagiert. Dies bedeutet auch, dass wir keine Daten in Verbindung mit Ihrem Namen speichern.

In Abhängigkeit von Ihren Entscheidungen und denen anderer Teilnehmerinnen und Teilnehmern können Sie heute echtes Geld verdienen.

Die Grundidee

In jeder Runde werden Sie zufällig in einer Gruppe mit einer oder mehreren anderen Personen (Ihren Mitspielern) in diesem Raum zusammengeführt. Sie werden darüber informiert, wie viele andere Personen in jeder Periode mit Ihnen spielen werden; dies wird über Ihrer Auszahlungsmatrix angegeben.



Sie können zwischen "A" und "B" wählen, indem Sie auf die entsprechende Schaltfläche klicken. In gleicher Weise wählen auch die anderen Personen in Ihrer Gruppe zwischen "A" und "B".

Ihre Verdienstmöglichkeiten werden durch eine Auszahlungsmatrix wie oben dargestellt. In jeder der vier Zellen in der Matrix gibt es zwei Zahlen. Die Zahlen in der ersten Position, die in blau angezeigt werden, geben die Ihre Einnahmen an. Die Zahlen in der zweiten Position, die in Schwarz angezeigt werden, sind die Einnahmen einer anderen Person in Ihrer Gruppe falls nur eine andere Person in Ihrer Gruppe ist.

Ihre Auszahlungen hängen von der Kombination Ihrer Entscheidungen und derer der anderen Personen in Ihrer Gruppe ab. Ihre Entscheidung legt fest, ob die Zeile "A" oder "B" ausgewählt ist, die durch den grauen Schatten markiert ist. Die Entscheidungen der anderen Personen in Ihrer Gruppe bestimmt den Einfluss der beiden Spalten auf Ihre Auszahlung.

Beispiel. Stellen Sie sich zunächst vor, Sie gehören zu einer Gruppe, in der nur **1 anderer Spieler** in Ihrer Gruppe ist. Wenn Sie "A" wählen und die andere Person in Ihrer Gruppe "A" wählt, würden Sie 10 und die andere Person in Ihrer Gruppe ebenfalls 10 verdienen. Wenn die andere Person in Ihrer Gruppe "B" wählt, würden Sie 2 und die andere Person in Ihrer Gruppe 14 verdienen.

Stellen Sie sich nun vor, Sie befinden sich in einer Gruppe, in der **2 andere Spieler** in Ihrer Gruppe sind. Sie haben "A" gewählt. Wenn die beiden anderen Personen in Ihrer Gruppe "A" wählen, verdienen Sie 10, und wenn die beiden anderen Personen in Ihrer Gruppe stattdessen "B" wählen, verdienen Sie 2. Wenn einer der beiden anderen in Ihrer Gruppe "A" und der andere "B" wählt. dann würden Sie Folgendes verdienen

$$0,5 \times 10 + 0,5 \times 2 = 5 + 1 = 6.$$

Generell werden Ihre Auszahlungen durch die Auswahl der Zeile "A" oder "B" und durch den Bruchteil (oder Prozentsatz) der anderen Personen in Ihrer Gruppe bestimmt, die die Spalten "A" oder "B" auswählen.

Die Auszahlungsmatrix ist nicht in jeder Runde immer gleich. Im heutigen Experiment gibt es **drei** verschiedene Auszahlungsmatrizen, von denen eine zufällig für jede Runde ausgewählt wird. Sie sollten es zu Beginn jeder Runde immer genau betrachten.

Der nächste Screenshot zeigt Ihnen ein Beispiel mit unterschiedlichen Verdienststufen (rote Grafik), abhängig von Ihren Auswahlmöglichkeiten (blaue Linie) und der Wahl Ihrer Gegenstücke (schwarze Linie) im Zeitverlauf. Im Folgenden wird auch erklärt, wie der Computerbildschirm interpretiert werden soll.

Runden und Gruppen

Es wird 21 Runden geben. Zu Beginn jeder Runde bringt der Computer Sie zufällig mit anderen Spielern im Raum in einer Gruppe zusammen. Ihre Gruppe umfasst Sie und anderen Personen in Ihrer Gruppe. Die Gesamtzahl der Personen in einer Gruppe (einschließlich Ihnen) kann 2, 3, 4, 6 oder 9 sein.

Wie im vorherigen Screenshot gezeigt, informieren wir Sie, wie viele "andere Spieler in Ihrer Gruppe" sind. Diese Nummer lautet dann **1**, **2**, **3**, **5** oder **8**.

Bevor wir eine neue Runde beginnen, werden Sie in einer neuen Gruppe mit verschiedenen Personen zufällig zusammen gebracht. Wir stellen sicher, dass Sie heute nicht mehr als einmal in derselben Gruppe zusammenkommen.

Die Anzahl der anderen Personen in Ihrer Gruppe ändert sich jeder Runde. Sie sollten diese Zahl zu Beginn jeder Runde stets genau beachten.

Ihre Anfangsentscheidung

Bevor eine Runde beginnt, haben Sie 30 Sekunden (eine halbe Minute) Zeit, um zu entscheiden, ob Sie "A" oder "B" zu Beginn der Runde wählen möchten. Die folgende Nachricht oben links im Display zeigt an, dass Sie jetzt die Anfangsentscheidung für die nächste Runde treffen müssen, die gerade beginnt.

Diese Zeitspanne von 30 Sekunden beginnt damit, dass zufällig "A" oder "B" ausgewählt sind. Diese zufällige Vorauswahl dient allein dem Initialisieren der Software und hat keinerlei Bedeutung. Sie können Ihre Wahl für Ihre Anfangsentscheidung während dieser 30 Sekunden beliebig oft ändern. Ihre Anfangsentscheidung ist einfach die, die Sie am Ende der 30 Sekunden einstellen.

Die Dauer der Runden

Jede Runde hat eine andere Dauer. Die Uhr oben links im Display zeigt an, wie viel Zeit (in Sekunden) in dieser Runde vergangen ist. In der Praxis wird die Zeit in sehr schnellen Intervallen von jeweils einer Zehntelsekunde (0,1 s) fließen. Sie können sich vorstellen, dass in jedem dieser Zehntelsekunden-Intervalle eine Wahrscheinlichkeit von 599 zu 600 (99,83 Prozent) besteht, dass eine weitere Zehntelsekunde weiter gespielt wird.

Die genaue Dauer jeder Runde ist weder Ihnen noch den anderen Teilnehmerinnen und Teilnehmern im Voraus bekannt. Wir nutzen einen zufälligen Computerzug, um die genaue Länge jeder Runde zu bestimmen.

Die durchschnittliche Dauer aller Runden in diesem Experiment beträgt etwa 60 Sekunden (eine Minute). Sie sollten aber von erheblichen Abweichungen von diesem Durchschnitt ausgehen. Die Runden können viel kürzer und auch viel länger sein. Es gibt keine Obergrenze für die maximale Dauer und das Experiment dauert so lange, wie es durch die Zufallsziehung bestimmt wird. Wir werden während der Dauer des Experiments nicht eingreifen.

Die folgende Tabelle zeigt Ihnen ein Beispiel. Sie zeigt Ihnen die unterschiedlichen Längen von 21 Runden, die mit dem gleichen zufälligen Computerzug gemacht wurden, den wir heute für Ihr Experiment verwenden. Beachten Sie, dass die Länge der 21 Runden, die Sie heute spielen, nicht mit denen in diesem Beispiel zusammenhängen, aber Sie können ein ähnliches Muster erwarten.

Runde	Dauer	Runde	Dauer	Runde	Dauer
1	7,9 s	8	44,1 s	15	32,3 s
2	39,0 s	9	84,3 s	16	79,9 s
3	147,0 s	10	16,5 s	17	5,0 s
4	58,4 s	11	0,9 s	18	51,5 s
5	267,2 s	12	91,7 s	19	0,8 s
6	4,5 s	13	46,7 s	20	31,9 s
7	36,6 s	14	7,3 s	21	149,5 s

Während der Spielzeit können Sie Ihre Aktion jederzeit ändern und zwar indem Sie auf die Schaltflächen “A” und “B” klicken oder die Aufwärts- und Abwärtspfeiltasten (↑↓) auf Ihrer Tastatur verwenden. Sie und alle anderen Personen in Ihrer Gruppe können Ihre Aktionen beliebig oft ändern.

Das Ende jeder Runde wird in dem Feld oben links bekannt gegeben; dort, wo sich die Uhr befindet. Am Ende werden Sie sehen, dass Ihre Auswahlschaltfläche für ungefähr 10 Sekunden eingefroren ist. Nach dieser kurzen Pause gehet es automatisch in die nächste Runde, und wir beginnen wieder mit den 30 Sekunden, in denen Sie Ihre Anfangswahl treffen.

Computerdisplay

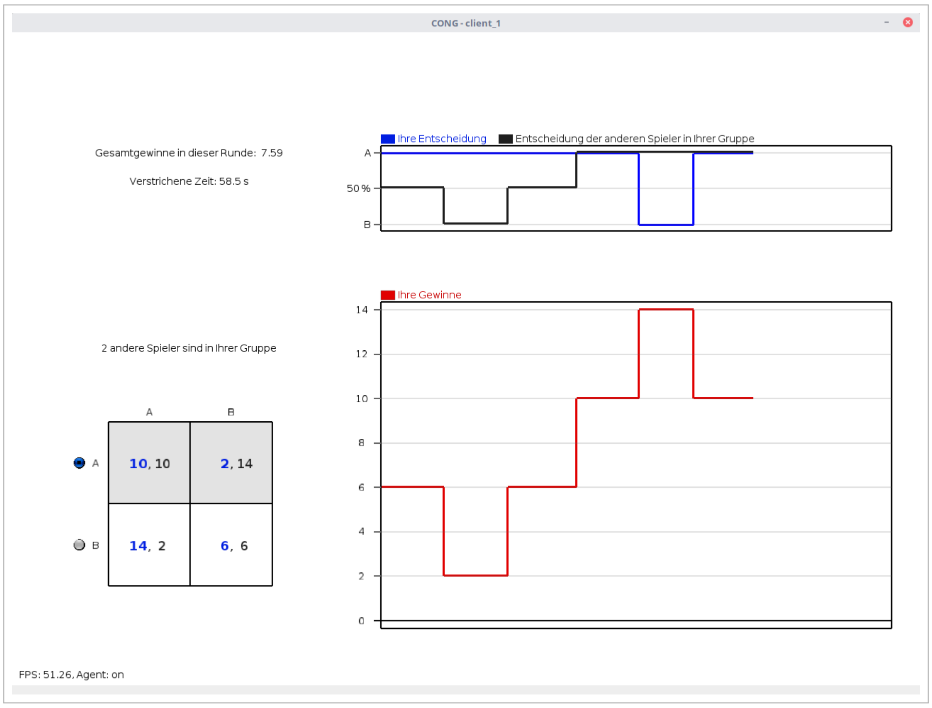
Sie können sich Ihr Computerdisplay als zweigeteilt vorstellen. Auf der linken Seite haben Sie immer die Auswahl zwischen “A” und “B” mit der Auszahlungsmatrix. Über der Matrix sehen Sie die Information, wie viele andere Spieler mit Ihnen in einer Gruppe sind.

Ganz oben finden Sie die Uhr mit der verstrichenen Zeit der aktuellen Runde und einen Zähler mit dem Verdienst, den Sie bisher in der aktuellen Runde gesammelt haben.

Hier werden auch die Meldungen angezeigt, die darauf hinweisen, dass eine Runde beendet ist oder dass Sie sich jetzt im 30-Sekunden-Zeitraum befinden, um Ihre Anfangswahl zu treffen.

Auf der rechten Seite Ihres Bildschirms werden die relevanten Informationen und der Status des Spiels in Echtzeit angezeigt. Sie sehen zwei Diagramme. Beide haben dieselbe horizontale Achse: die Zeit, die sich nach rechts bewegt.

Da die Dauer einer Runde nicht im Voraus bekannt ist, ist die Dauer in Ihrer Anzeige zunächst auf 60 Sekunden festgelegt. Wenn eine Runde kürzer als 60 Sekunden ist, werden die Linien an einem Zwischenpunkt im Diagramm angehalten. Wenn eine Runde länger ist, wird der aktuelle Punkt in den Diagrammen festgehalten und die letzten 60 Sekunden der Charts angezeigt. Ältere Informationen werden durch die neuen ersetzt. Sie haben Zeit, sich während der Übungsrunden mit dieser Anzeige vertraut zu machen.



Es gibt zwei Zeilen in der oberen Tabelle. Die **blaue Linie** zeigt Ihre Wahl ("A" oder "B") über die verstrichene Zeit. Die **schwarze Linie** zeigt die Auswahl der Aktionen, die von den anderen Spielern in Ihrer Gruppe (Ihren Kollegen) getroffen werden. Es stellt den Bruchteil (oder Prozentsatz) von ihnen dar, der aktuell "A" wählt. Wenn sich zum Beispiel 4 andere Spieler in Ihrer Gruppe befinden und Sie sehen, dass 25% (1 von 4) "A" wählen, wissen Sie auch, dass die anderen 3 "B" wählen.

Sie beginnen jede Runde mit einem ersten Verdienst von 0 und kumulieren im Laufe der Runde Ihren Verdienst, abhängig von Ihrer Entscheidung und der Entscheidungen der anderen Personen in Ihrer Gruppe, wie bereits erläutert. Die **rote Linie** in der größeren Grafik zeigt, wie viel Sie im Verlauf der Runde verdienen. Je höher die Position der roten Linie, desto mehr verdienen Sie aktuell. Die kumulierten Einnahmen im Zähler entsprechen dem Bereich unterhalb Ihrer roten Einnahmen-Linie.

Verdienst

In diesem Experiment sammeln Sie in jeder Runde **Einnahmen über die Zeit**, und wir nehmen die erwartete durchschnittliche Dauer der Runden von 60 Sekunden als Referenz für die Skalierung Ihrer Einnahmen.

Beispiel. Wir besprechen jetzt die Details des konkreten Falls, den Sie im großen Screenshot sehen können. In diesem Beispiel gibt es zwei weitere Spieler in Ihrer Gruppe.

Erstens können Sie sehen, dass der obere linke Teil der Anzeige anzeigt, dass das Spiel (bisher) 58,5 Sekunden gedauert hat und dass der kumulierte Gewinn für Sie 7,59 EUR betragen würde.

Der Computer wird für Sie den Verdienst in Detail berechnen, aber hier sind die Regeln, nach denen der Verdienst berechnet wird:

Wenn Sie den rechten Teil des Bildschirms betrachten, zeigen die drei Linien (Ihre Aktionen in Blau, die Aktionen der anderen Spieler in Ihrer Gruppe in Schwarz und Ihre Einnahmen in Rot) eine Sequenz von sechs verschiedenen Möglichkeiten, die jeweils etwa 10 Sekunden dauern.

Ihr Verhalten in dieser Runde (blau) wäre gewesen, "A" für ungefähr 40,5 Sekunden ohne Änderungen zu wählen, gefolgt von einem kürzeren Zeitraum von 8,5 Sekunden, in dem Sie "B" gewählt hätten, und schließlich eine letzte Zeitspanne von weiteren 10 Sekunden, wobei erneut "A" gewählt wird.

Die schwarze Linie zeigt, dass einer der anderen Teilnehmer in den ersten 10 Sekunden "A" und der andere "B" gewählt hat. Es folgten weitere 10 Sekunden, in denen beide "B" wählten, dann 10,5 Sekunden, in denen erneut einer "A" und einer "B" gewählt hatte, und schließlich fast 30 Sekunden, in denen beide "A" wählten.

Aufgrund Ihrer im Laufe der Zeit getroffenen Entscheidungen, kombiniert mit den von den anderen Spielern in Ihrer Gruppe gewählten Aktionen, und unter Berücksichtigung der Dauer dieser unterschiedlichen Ergebnisse sind die Verdienstsequenzen folgende:

- $0,5 \times 10 + 0,5 \times 2 = 6$ EUR für 10 Sekunden
- $1,0 \times 2 = 2$ EUR für 10 Sekunden
- $0,5 \times 10 + 0,5 \times 2 = 6$ EUR für 10,5 Sekunden
- $1,0 \times 10 = 10$ EUR für 10 Sekunden
- $1,0 \times 14 = 14$ EUR für 8,5 Sekunden
- $1,0 \times 10 = 10$ EUR für 10 Sekunden

Insgesamt haben wir angesichts von 60 Sekunden erwarteter durchschnittlicher Dauer:

$$\frac{1}{60\,s} \times \left(6 \times 10\,s + 2 \times 10\,s + 6 \times 10,5\,s + 10 \times 10\,s + 14 \times 8,5\,s + 10 \times 10\,s\right) \approx 7,59 \text{ EUR}.$$

Sie müssen diese Berechnungen während des Spiels nicht selbst durchführen, der Computer führt sie für Sie aus.

Da wir Ihre Einnahmen um 60 Sekunden skalieren, sollten Sie damit rechnen, dass Sie bei längeren Runden mehr Einnahmen erzielen können als kürzere Runden.

Trainingsrunden

Bevor das eigentliche Experiment beginnt, werden Sie zwei Trainingsrunden spielen, um sich mit dem Computer vertraut zu machen. Diese Übungsrunden werden nicht bezahlt.

Die erste Trainingsrunde dauert 20 Sekunden. In dieser Runde wird die Software initialisiert und Sie sollten die Zeit nutzen, um sich mit der Computeranzeige vertraut zu machen. Sie werden die Diagramme mit den relevanten Informationen sehen: Anzahl der anderen Teilnehmer in Ihrer Gruppe, Ihre eigene Auswahl, die Auswahl der anderen Spieler in Ihrer Gruppe und Ihre Einnahmen. Diese erste Runde enthält keine Informationen zur Auszahlungsmatrix.

Die zweite Runde dauert 80 Sekunden. In dieser Runde können Sie sehen, wie Sie Ihre Aktionen auswählen können; nämlich indem Sie mit der Maus auf die Optionsfelder der Auswahl klicken oder die Pfeiltasten nach oben und nach unten auf Ihrer Tastatur verwenden. Auf diese Weise können Sie auch sehen, wie sich die Grafiken in der Anzeige mit der Zeit ändern und wie das Fenster Ihnen alle relevanten Informationen für die letzte Spielminute anzeigt.

Sie können zudem in dem 30-Sekunden-Intervall experimentieren, wie Sie Ihre Anfangswahl vor Beginn der Runde auswählen. Die Auszahlungsmatrix dieser zweiten Übungsrunde enthält Zufallszahlen, die sich nicht auf den Rest des Experiments beziehen.

Auszahlung

Die Sitzung endet nachdem die zwei Trainingsrunden und die 21 Runden gespielt wurden. Am Ende der Sitzung erhält jeder von Ihnen die durchschnittliche Punktzahl in EUR ausgezahlt, d. h. den **Durchschnitt der 21 Runden**, die Sie gespielt haben.

Bleiben Sie nach dem Ende der letzten Runde bitte so lange an Ihrem Platz, bis wir Sie anrufen. Bevor Sie Ihre Auszahlung erhalten, bitten wir Sie, einen Fragebogen auszufüllen, der uns hilft, die Daten des Experiments besser zu verstehen. Dieser Fragebogen ist anonym und wir speichern keine Daten in Verbindung mit Ihrem Namen. Sie finden Ihre Teilnehmernummer neben Ihrem Computer.

Zusammenfassung

- Sie werden 21 Runden mit zufälliger Länge und ohne Begrenzung der maximalen Länge spielen.
- Sie spielen diese Runden mit anderen Personen in diesem Raum. Die Gruppen werden für jede Runde zufällig zusammengestellt und variieren auch in der Größe (Anzahl der Personen in Ihrer Gruppe).
- Sie haben zunächst 30 Sekunden Zeit, um Ihre Anfangswahl festzulegen, und Sie können Ihre Aktion ("A" oder "B") jederzeit während der Runde und so oft Sie möchten ändern.
- Ihr Gewinn hängt von Ihren "A"/"B" Entscheidungen, den "A"/"B" Entscheidungen der anderen Personen in Ihrer Gruppe und der Dauer des Spiels ab.

- Am Ende der Sitzung erhalten Sie Ihre Auszahlung (in bar), die sich nach dem durchschnittlichen Verdienst, den Sie in den 21 Runden erzielt haben, berechnet.

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