Do upfront investments increase cooperation? A laboratory experiment

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1 Introduction

The tension between opportunistic and cooperative behavior, resulting from a misalignment of individual and group interests, is pervasive in human interactions. A vast literature in economics and the social sciences has therefore investigated institutions that foster cooperation.[1] Part of this literature has experimentally analyzed the effects on cooperative behavior of exogenous and endogenous institutions, and has shown that a given policy is more successful at increasing cooperation when it is endogenously chosen than when it is exogenously imposed.[2]

In these prior experiments, subjects are presented with different institutions and decide, through voting, on the rules governing their interactions. The focus has been mostly on formal and informal sanctions (so that subjects choose whether and how much to punish free-riders), and it has been implicitly assumed the presence of an enforcement mechanism. However, in many circumstances agents cannot choose or vote for an enforcement institution. Even if institutional arrangements exist, cooperation is not always easily enforced. This is the case, for instance, for groups where agents, even though willing to cooperate, are not willing to punish,[3] or when there is no institution with coercive power. A prominent example is given by international environmental agreements. Environmental treaties lack behind in their effectiveness in reducing greenhouse gas emissions, and this is thought to be associated with the lack of a functioning enforcement mechanism capable of mitigating the inherent free-rider problem. Similarly, academic co-authorship, employment relationships, recycling, littering are all examples of situations where cooperation is desirable, but difficult to enforce. This is the kind of situations we address in this paper.

We investigate whether voluntary decentralised upfront investments help promoting cooperation in a social dilemma, and whether this effect depends on the investments being endogenous (chosen by the participants) or exogenous (imposed by the experimenter). In our experiment, investments are a cost that agents have to incur before deciding whether to cooperate or not, and increase the payoff resulting from the choice to cooperate. We are interested in understanding whether agents themselves are able to create situations that are conducive to cooperation, in a setting where there is no enforcement mechanism and cooperation is not easily sustained voluntarily. For instance, countries that invest in green technologies might find it easier to comply to environmental agreements and reduce emissions; co-authors that invest in a new project (for instance, by learning new literature) might be more likely to contribute to finalise the paper; equipping a space with multiple bins for different materials might

[1]Examples of such institutions include peer punishment (Fehr and Gächter [2000], Noussair and Tucker [2005]), competition (Markussen et al. [2014b]), communication (Isaac and Walker [1988]), redistribution (Sausgruber and Tyran [2007]), group member selection (Gunnthorsdottir et al. [2010]) and advice (Chaudhuri et al. [2006a]), among others.

[2]See Tyran and Feld [2006], Dal Bó et al. [2010], Sutter et al. [2010], Markussen et al. [2014a], Kamei [2016], among others.

[3]See, for instance, Sutter et al. [2010].

help individuals recycle more.

The social dilemma situation we consider is an infinitely repeated prisoners' dilemma (PD), which captures the tension at the heart of social dilemmas in a simple form. Recent experiments on infinitely repeated PD games have shown that individuals cooperate more when the probability of future interactions (i.e., the probability of continuation of the game) is high (Dal Bó [2005], Dal Bó and Fréchette [2011]), when cooperation is risk dominant (Blonski et al. [2011]), and when both continuation probabilities and cooperation payoff are sufficiently high (Dal Bó and Fréchette [2011]). Our experiment is inspired by Dal Bó and Fréchette [2011], with the important difference that the (cooperation) payoffs in our main treatment are not given exogenously, but endogenously determined by the participants' choice of an investment.

To test whether upfront investment opportunities increase cooperation levels, we compare a condition without investments (NoInv) with a condition where participants can choose how much to invest (Endo). In the treatments with no investment opportunities, subjects just play a two-player repeated PD game for 12 matches, where each match lasts for a randomly determined number of periods. In the investment treatments, subjects decide, at the beginning of each match, how much of a given endowment they want to invest. Then, they learn each others' investment choices and choose between cooperation and defection. To determine whether it matters if investments are chosen or exogenously imposed, we compare the Endo condition with a condition where participants are presented with pre-determined investments (Exo). This also allows us to explore whether participants use investments to signal the intention to cooperate. To study whether changes in δ affect cooperation rates in the investigated context, we implement each treatment (NoInv, Endo and Exo) using a low probability of continuation of 0.35 (labeled Short) and a high probability of continuation of 0.75 (labeled Long), which are exogenously imposed. When δ=0.35, cooperation can never be supported as a subgame perfect Nash equilibrium in the NoInv treatment. In Endo (and Exo), investments have the potential to transform a game where mutual defection is the only subgame perfect equilibrium into a game in which both mutual defection and mutual cooperation are equilibria, but only when investments are high enough. When δ=0.75, both defection and cooperation are always sustainable in equilibrium.

Two recent papers are similar in spirit to our study. Benoît et al. [2017] consider an infinitely repeated prisoners' dilemma game preceded by an investment decision, and find that high investments are associated with higher cooperation rates. Their focus, however, is on how investment levels are affected by the institutional regime in place (legal protection of investment returns or not) and by the volatility of returns from investments. Andreoni et al. [2018] allow subjects to choose how to allocate stakes across the two periods of a PD game, and find higher rates of cooperation when subjects "start small" (i.e., when they allocate higher stakes to the second period), and when stakes are chosen endogenously. We share with Andreoni et al. [2018] the idea that people can, on their own, successfully structure their interactions in a way that fosters cooperation, but we use an indefinitely repeated game and are specifically interested in how upfront investments affect future cooperation.[4]

Our results can be summarized as follows. Cooperation rarely emerges in treatments where investments are not possible, for both low and high probabilities of continuation. When investments are possible but low, cooperation levels are not different from those observed in the no investment condition, but are significantly *lower* than when the same investments are exogenous. This result holds both in the Short and in the Long treatments, and is consistent with low investments being interpreted as a signal for unwillingness to cooperate, which triggers non-cooperative choices. When high investments are endogenous, cooperation is significantly higher than when investments are not possible, but not statistically significantly different from cooperation in the exogenous conditions. One interpretation is that high investments might not serve as signal for willingness to cooperate, as they increase cooperation independent of the mode of implementation. However, in many cases pairs who choose high investments defect in the subsequent PD. This behavior is individually optimal only if high investments are expected to be followed by cooperation, since by defecting players end up with the higher temptation payoff. It seems our participants might use investments strategically, to induce cooperation while planning to defect, suggesting that investments might indeed be perceived as a means to signal own willingness to cooperate, and/or own beliefs about the partner's willingness to cooperate. This strategic use of high investments reduces cooperation rates, and might explain why there are no differences between endogenous and exogenous treatments in this case.

Even though investments have the potential to foster cooperation, participants in our experiment frequently choose not to invest (in about 40 percent of the cases), or to invest little (slightly more than 20 percent of the cases). The investment decision entails a coordination problem, in that individuals would like to invest if others invest as well. One explanation for the observed investment behavior is that our subjects are not able to solve such coordination problem. In most cases, indeed, and especially in the beginning of the experiment, subjects who choose high investments have partners who choose low investments. This results in the former switching to low investments (especially 0) throughout the experiment, which always guarantees the mutual defection payoff in every period. In our game, not investing and defecting is, in fact, the risk dominant equilibrium. Hence, this finding is in line with empirical results on coordination problems, which show a tendency to select the risk-dominant equilibrium.[5]

In line with the experimental literature on infinitely repeated PD, we find that

[4]Theoretical work has also considered similar settings. Ramey and Watson [1997] propose a theory of labor contracting where the employment relationship is modeled as a prisoners' dilemma and is preceded by an investment choice. The authors hint at the idea that higher upfront investments favor cooperation, though they are mostly interested in how the initial investment affects job destructions over the business cycle. In the context of international environmental agreements, Harstad et al. [2019] use the infinitely repeated prisoner's dilemma game to model the choice to abate emissions, and allow players to invest in technologies before choosing whether to cooperate (i.e., to reduce emissions) or not. They show that investments in green technologies are necessary for cooperation to be sustained.

[5]See, for instance, Camerer [2003], Brandts and Cooper [2006a,b], Blume and Ortmann [2007], Chaudhuri et al. [2006b].

higher cooperation payoffs together with a high probability of continuation increase cooperation. In contrast to previous results, we find relatively high levels of cooperation also when δ is rather low, and no significant differences in cooperation rates between Short and Long treatments. We argue that this is due to the fact that investments affect and explain cooperation behavior irrespective of the equilibrium refinement used, making it easier for cooperation to emerge also under unfavorable conditions.

2 Experimental design

The experiment is structured as a 2×3 design and thus consists of six treatments. Two treatments are without investment opportunities (NoInvShort and NoInvLong). In two treatments players could invest before playing an indefinitely repeated PD game (EndoShort and EndoLong), and in two other treatments investments were exogenously imposed (ExoShort and ExoLong). The suffixes "Short" and "Long" refer to the probability of continuation used in the corresponding treatment: matches continued from period to period with probability $\delta = 0.35$ in the Short treatments, and with probability $\delta = 0.75$ in the Long treatments.

In all treatments, subjects were randomly paired within matching groups of 8 participants and played a sequence of 12 *matches*. In each match, subjects were initially endowed with $w_i = 8$ Experimental Currency Units (ECU) and played a repeated PD for a randomly determined number of *periods*. In each period, players chose between two actions, either cooperate or defect.[6] Pairs remained fixed throughout a match, and subjects were randomly paired with a new partner within their matching group at the beginning of a new match.[7] Since the matching groups consisted of 8 participants playing in 12 matches, subjects met the same partner 1.71 times on average. However, pairs were formed so that each participant would never play with the same partner two matches in a row.

Table 1 displays the stage PD game. The parameters are calibrated following Dal Bó and Fréchette [2011], who exogenously vary the payoff from mutual cooperation and the probability of continuation δ to study how cooperation depends on whether mutual cooperation can be supported in a subgame perfect equilibrium (SPE), and in a risk dominant equilibrium (RD). In their experiment, the payoff from mutual cooperation (R) takes one of three possible values: 32, 40, and 48, while the sucker payoff is constant and equal to 12; δ is equal to either 0.5 or 0.75. Different combinations of R and δ determine whether cooperation can be sustained as an SPE and whether it is RD.[8]

[6] We used a neutral language throughout the experiment, with players choosing between option "A" (cooperate) and option "B" (defect).

[7] Rematching within the same group ensures that observations are independent at the matching group level.

[8] In particular, for $R = 32$ and $\delta = 0.5$ cooperation is never sustainable in equilibrium, while for any other combination of R and δ, cooperation can always be supported in an SPE. Cooperation is risk dominant under $R = 48$ and $\delta = 0.5$, and under $R = 40, 48$ and $\delta = 0.75$.

Table 1: Prisoner's dilemma game payoff matrix

	Cooperate	Defect
Cooperate	$32 + 2r_i, 32 + 2r_j$	$4 + 2r_i, 50$
Defect	$50, 4 + 2r_j$	25, 25

In our PD game, both the payoff from mutual cooperation and the sucker payoff increase with investment levels r_i, r_j, which are integers in $\{0, 1, ..., 8\}$. When $r_i = 0$, the cooperation payoff is 32 and the sucker payoff is 4. When $r_i = 8$, the cooperation payoff is 48, and the sucker payoff is 20. This guarantees the conditions for cooperation to switch from not being sustainable in equilibrium to being supported as SPE as the investments increase. In particular, under $\delta = 0.35$, cooperation is not supported as SPE for $r_i, r_j \leq 4$, while it is for $r_i, r_j > 4$. Under $\delta = 0.75$, cooperation is always supported as an SPE regardless of investment levels. The equilibrium conditions will be derived and explained in detail in Section 3.

In the treatments with endogenous investments (EndoShort and EndoLong), participants could decide at the beginning of each match how much of their endowment they wish to invest, by choosing a number in $\{0, 1, ..., 8\}$. Players within a pair were informed of the investment decision made by their partner before the PD started. Any non-invested unit produced one unit of direct private benefit, while the invested units were doubled and added to the payoff from cooperation in the subsequent PD game. Once a match ended, the new match began with a new investment decision. Hence, the investment decision was made once at the beginning of each match, and subjects were bound by that decision for the duration of that match.[9]

The only difference between the endogenous and the exogenous treatments (ExoShort and ExoLong) is that in the latter investments were not chosen by the participants. For each pair in the endogenous treatments, instead, we created a twin pair in the exogenous treatments, so that the participants in the exogenous condition were presented with the same sequence of investments as chosen by the participants in the endogenous condition. The purpose of the exogenous treatments is to disentangle the effect of the changes in the cooperation payoffs (induced by the investments) and the signaling effect implicit in the active choice of an investment level.

In the treatments without investment opportunity, the endowment of $w_i = 8$ was added to the PD game payoff in every period. The resulting subgame is then the same as the one induced by $r_i, r_j = 0$ in the investment treatments.

At the end of each PD stage game, subjects within a pair received information on

[9] As we are mainly interested in the role of investments in affecting cooperation levels, our primary concern is whether choices in the PD are responsive to investment decisions and, therefore, whether investments are used as a device to trigger future cooperation. If investment choices were to be revised in every period of a match, we could not rule out the possibility of them being used as a punishment device instead. Keeping investment decisions constant within matches, besides making the data more easily tractable, helps their interpretation to be less exposed to this confounding effect.

their own and their partner's actions and payoffs. In the investment treatments, players were reminded of the investment levels as well. Earnings at the end of a match were the sum of the payoffs realized in each period. At the end of the experimental session, for each matching group one out of the 12 matches was randomly picked. Subjects in a matching group were paid in cash according to the earnings of that match.

2.1 Procedures

The instructions for the experiment were provided on paper, and participants had the opportunity to ask questions at any time during a session. All questions were asked and answered in private. Participants were asked to answer a series of comprehension questions to verify their full understanding of the game. The experiment started only after all participants had answered correctly all questions. The experiment ended with a questionnaire.

The experiment was conducted at the BEElab of Maastricht University using z-Tree (Fischbacher [2007]). Participants were recruited through ORSEE (Greiner [2015]), and each of them took part in only one session. In total 432 students participated in the experiment. We ran 18 sessions overall, 3 per treatment, with 3 matching groups per session. Each session took approximately 50 minutes for the Short treatments, and 80 minutes for the Long treatments.

Within a treatment, the length of a match differed across matches and matching groups. However, to ease the comparison between treatments with the same probability of continuation, the same random sequence of match lengths was used in treatments with equal δ. That is, match lengths across matching groups in NoInvShort were the same as in EndoShort and ExoShort, and match lengths across matching groups in NoInvLong were the same as in EndoLong and ExoLong.[10]

3 Theoretical background

Table 2 shows a prisoner's dilemma payoff matrix, where: c is the reward from mutual cooperation; d is the payoff from mutual defection; t is the temptation payoff, obtained from defecting when the other cooperates; and s is the sucker payoff, obtained from cooperating when the other defects. The presentation in Table 2 allows for potentially asymmetric payoffs by using indexes i and j. For a game to have the structure of a PD, two conditions have to hold. First, $t_k > c_k > d_k > s_k$ for $k = i, j$. Second, it is also required that $c_i + c_j > \max[t_i + s_j, s_i + t_j]$. This condition guarantees that cooperation is more profitable than alternating between cooperation and defection.

In a PD with asymmetric payoff parameters and common discount factor δ, the critical value δ^{SPE} for which mutual cooperation is sustainable in an SPE is given by (see Blonski and Spagnolo [2015]):

[10] Table A1 in Appendix A presents the sequences of match lengths for the different matching groups that were implemented in the three sets of treatments.

Table 2: Prisoner's dilemma payoff matrix

	C	D
C	c_i, c_j	s_i, t_j
D	t_i, s_j	d_i, d_j

$$\delta^{SPE} = \max\left\{\delta_i^{SPE}, \delta_j^{SPE}\right\} = \max\left\{\frac{t_i - c_i}{t_i - d_i}, \frac{t_j - c_j}{t_j - d_j}\right\}. \quad (1)$$

For our parameters, the critical value δ^{SPE} for which cooperation can be sustained in equilibrium is 0.72 when $r_i, r_j = 0$ (or when investments are not allowed), and it is 0.08 when $r_i, r_j = 8$. For other combinations of r_i and r_j, δ^{SPE} lies within these two extremes, i.e. $0.08 \leq \delta^{SPE} \leq 0.72$, depending on the investment level chosen.

3.1 Predictions

In a setting where both mutual cooperation and mutual defection are sustainable as equilibrium outcomes,[11] investments could be 0 or 8 depending on the action expected to be chosen by the other player. Subjects that expect to coordinate on the cooperative equilibrium should invest 8, in order to maximize payoffs. Conversely, subjects that expect defection to be selected as equilibrium outcome should not invest at all. Investing 8 and cooperating in the PD is the payoff dominant equilibrium, while not investing and defecting is the risk dominant one. We formulate the following hypothesis.

H1: *Investment levels* r_i, r_j *are such that* $r_i, r_j \in \{0, 8\}$.

When $\delta = 0.35$ and investments are not allowed (NoInvShort), defection is the only possible equilibrium outcome. When investment opportunities are introduced while keeping $\delta = 0.35$ (EndoShort), three different cases need to be distinguished. If *a)* both players choose investment levels of 4 or less, or *b)* one player chooses an investment level in the interval $[5, 8]$, while the other chooses to invest less, then cooperation cannot be supported as an equilibrium outcome. If, instead, *c)* both players choose investment levels in the interval $[5, 8]$, trigger strategies can sustain mutual cooperation as part of an SPE, while defection still constitutes an equilibrium outcome. Given these theoretical predictions, we expect no cooperation in NoInvShort. Moreover, we expect behavior in the first two cases of EndoShort (*a)* and *b)*) to be similar to NoInvShort, and cooperation rates to stabilize at a higher level in the last case of EndoShort (*c)*).

The comparison between NoInvShort and EndoShort allows us to study the effect of investments on cooperation, and whether cooperation levels depend on cooperation being sustainable in equilibrium. On the other hand, we do not expect any difference

[11] In the following, "cooperation (not) being sustainable in equilibrium" and "cooperation (not) being sustainable as equilibrium outcome" indicate that there are (no) strategies that support mutual cooperation as equilibrium outcome.

between NoInvLong and EndoLong ($\delta = 0.75$) as in both of these conditions cooperation is supported as equilibrium outcome, regardless of the possibility to invest and the specific investment choices. We hence formulate the following hypothesis.

H2: *When $\delta = 0.35$, then*

(i) For $r_i \leq 4, r_j \in [0, 8]$, there is no difference in cooperation rates between NoInvShort and EndoShort.

(ii) For $r_i, r_j > 4$, cooperation rates in EndoShort are larger than in NoInvShort.

When $\delta = 0.75$, then

(i) There is no difference in cooperation rates between NoInvLong and EndoLong, independent of r_i and r_j.

Since the exogenous treatments are an exact replica of the endogenous treatments, SPE predictions do not differ between the Short investment treatments (EndoShort and ExoShort), and between the Long investment treatments (EndoLong and ExoLong).

H3: *For any r_i, r_j, there is no difference in cooperation rates between EndoShort and ExoShort, and between EndoLong and ExoLong.*

However, investments might convey a signal regarding the action that will be chosen in the PD, in which case cooperation levels might vary depending on whether investments have been endogenously chosen or exogenously imposed.[12] Such signal might affect beliefs in two ways. First, investments might signal a player's (un)willingness to cooperate in the subsequent PD. Second, they might signal a player's beliefs on the partner's (un)willingness to cooperate in the subsequent PD.[13] Therefore, if low investment levels (i.e. below or at the threshold of 4) serve as signal of unwillingness to cooperate, we would expect cooperation in the Endo conditions to be lower than in Exo conditions. Similarly, if high investments (i.e. above the threshold) signal willingness to cooperate, we would expect higher cooperation rates in Endo than in Exo. For the case where investments diverge, signals are contrasting and it is not easy to predict which one will prevail, if any. On the one hand, if a high investment signals willingness to cooperate, the player who chose a low investment might cooperate after seeing the high investment of the partner. If this effect is strong enough, we would observe higher cooperation in the Endo treatments. On the other hand, if a low investment signal unwillingness to cooperate, the player with high investment might decide to defect after seeing the low investment chosen by the partner, which could result in lower cooperation rates in Endo than in Exo. These two effects might also offset each other, resulting in no difference in cooperation rates between Endo and Exo. We formulate the following alternative hypothesis.

[12] Selection effects might also play a role in our experiment. Such effects might arise if subjects choose to invest and cooperate because of unobservable characteristics (for example, preferences for cooperative behavior) that differ from those of subjects who choose to not invest and not cooperate. We will address this issue in Section 4.3.

[13] Disentangling these two effects goes beyond the scope of this paper. Therefore, we use the term signal to include both effects.

H4:

(i) For $r_i, r_j \leq 4$, cooperation rates in Endo are smaller than in Exo.

(ii) For $r_i, r_j > 4$, cooperation rates in Endo are larger than in Exo.

By comparing the two NoInv, the two Endo and the two Exo conditions across the two levels of δ, we can assess the impact on cooperation levels of a higher probability of future interactions. Given previous experimental evidence, we expect that the higher probability of continuation leads to higher cooperation rates.[14] For the NoInv conditions, this follows from the theoretical reasoning that cooperation is sustainable as an equilibrium action in NoInvLong but not in NoInvShort. In the investment conditions, we have seen that cooperation is always sustainable for the high probability of continuation, while it is so for the low probability of continuation only when $r_i, r_j > 4$. Hence, if $r_i \leq 4$ in the Short treatments, we expect cooperation rates to be higher in the Long treatments. If δ plays a role in determining cooperation rates, we would expect higher cooperation in the Long conditions also when in the Short treatments investments are such that $r_i, r_j > 4$. This leads to the following hypothesis.

H5: *Cooperation in Long treatments is higher than in Short treatments.*

4 Results

In this section we present the main results. We first present the investment choices made in EndoShort and EndoLong (Section 4.1). Thereafter, we describe the results on cooperation levels. Introducing investments gives players the opportunity to influence the payoff received from the cooperation action. We are specifically interested in the changes in cooperation rates that are induced by the introduction of the opportunity to invest and by the actual investment level chosen. We first describe the effects on cooperation of introducing investments and how the level of investment affects cooperation, by comparing treatments without investments and treatments with endogenous investments (Section 4.2). Thereafter, we test whether the endogeneity of the investment choices induces cooperation by comparing treatments with endogenous and exogenous investments (Section 4.3). In both cases, we keep the probability of continuation (δ) constant. In Section 4.4, we discuss whether changes in the probability of future interactions affect cooperation. We will hence compare treatments across the Short and the Long conditions while keeping the investment dimension constant. Lastly, we briefly describe the evolution of cooperation over time (Section 4.5).

For each treatment, we collected a sequence of decisions over twelve matches for nine different matching groups. This yields 9 independent observations per treatment. Therefore, for the data analysis we will use matching group averages as the primary unit of observation.

[14] A number of previous experiments (see for instance Dal Bó [2005], Dal Bó and Fréchette [2011], Blonski et al. [2011]) have provided evidence in favor of people being reactive to changes in the discount rate in laboratory experiments.

4.1 Investments

In this section we describe the investment choices made by subjects, and compare them across the two treatments with endogenous investment opportunities.

On average, investments do not differ between the EndoShort and EndoLong treatments. When looking at the first match only, the average investment is 4.08 in EndoShort and 4.49 in EndoLong. When aggregating data over all matches, average investments are 3.25 and 3.57, respectively. In neither case the difference is statistically significant according to two-sided Mann-Whitney U (MW) tests (Table 3).

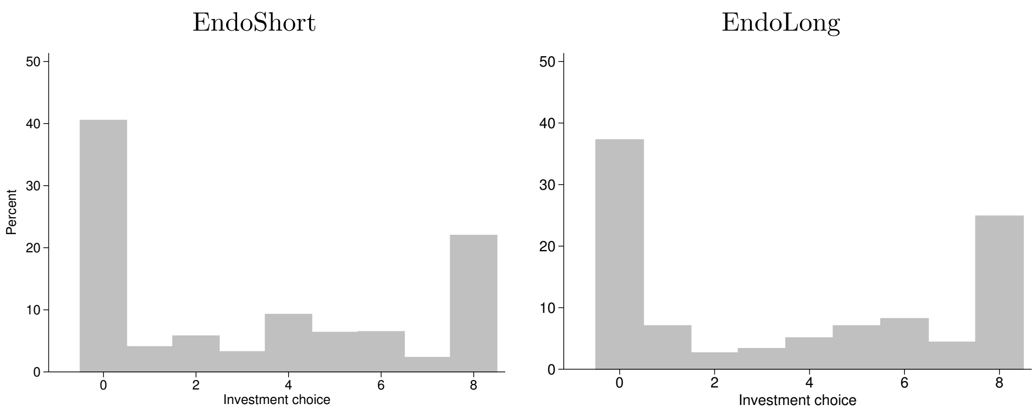
Table 3: Average investments

	EndoShort	EndoLong	MW p-values
First match	4.08	4.49	0.2883
All matches	3.25	3.57	0.6267

Averages are taken over matching groups. p-values are from two-sided Mann-Whitney tests which take averages over matching groups as unit of observation.

H1 predicts that investments should be either 0 or 8. Figure 1 shows histograms of the investments chosen in the treatments EndoShort (left panel) and EndoLong (right panel). The most frequent investment is 0, which is chosen in both treatments in about 40 percent of the cases. In slightly more than 20 percent of the cases the chosen investments are 8. Investment choices in the middle of the range occur much less frequently, and distribute differently across the two treatments. The two investment distributions are indeed statistically different, according to a Kolmogorov-Smirnov test ($p = 0.017$). While subjects do not exclusively invest either 0 or 8, they largely behave according to the predictions of H1.

Figure 1: Distribution of investments



4.2 The effect of endogenous investments on cooperation

Subjects' cooperation rates in each treatment are shown in Figure 2, averaged over the first period of each match and over all periods.[15] According to MW tests, cooperation rates are significantly higher in treatments with investment opportunities, both in the Short and Long conditions.[16]

Figure 2: Average cooperation by treatment

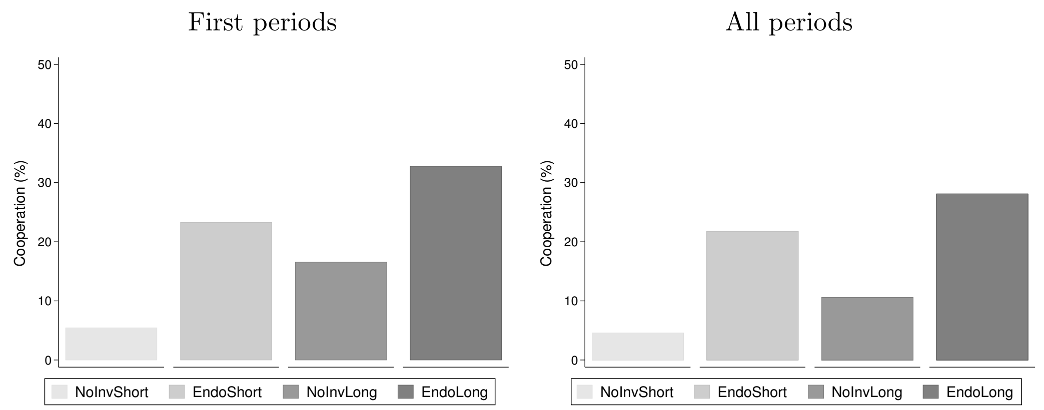
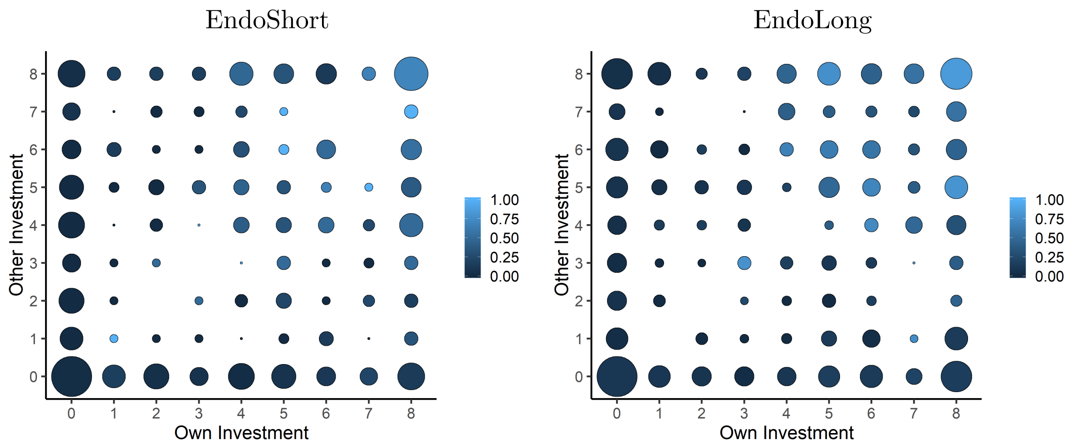


Figure 3 gives an overview of how the different investments affect the actions chosen in the subsequent PD.

Figure 3: Average cooperation by pairs of investments



Note: The size of the circle indicates how frequently a pair of investments is observed. The color intensity indicates the average cooperation for a given combination of i (Own) and j (Other) investment levels. The lighter the circle, the higher the average cooperation. Cooperation rates are averaged over all periods.

[15]Looking separately at first periods is important since matches have a different number of periods and cooperation rates might vary across periods. Moreover, choices in the first periods indicate how subjects start playing, which potentially affects how they play in the next periods.

[16]MW test results are reported in Table C2 in Appendix C.2, and are consistent with the regression results shown in Table C3.

In general, low investments seem to lead to defection, while high-investment pairs lead to higher cooperation on average. Cooperation rates are very low when own (other) investment is zero, independent of the other's (own) investment choice. Choosing the same investment level mostly results in higher cooperation, unless both subjects in a pair choose zero. However, subjects rarely choose the same investment. Moreover, there seem to be no large differences between Short and Long endogenous treatments.

In order to test our hypotheses, we look at the three following cases (see Section 3.1): both players invested at most 4, one player invested at most 4 and the other invested (strictly) more than 4, and both invested (strictly) more than 4. In the Short treatments, cooperation is sustainable in an SPE in the last case, while defection is the only equilibrium in the first two cases. For simplicity and clarity of exposition, the data in the Long treatments are organized according to the same categories, even though cooperation is always sustainable in an SPE independent of the investment level.

Figure 4 shows cooperation rates by treatment, and considers the three abovementioned cases separately for the treatments with investment opportunities. Figure 4 clearly shows that investments do not always trigger high(er) cooperation rates. For instance, first period cooperation rates are about 6 percent both in NoInvShort and in EndoShort when both investments are below 4.

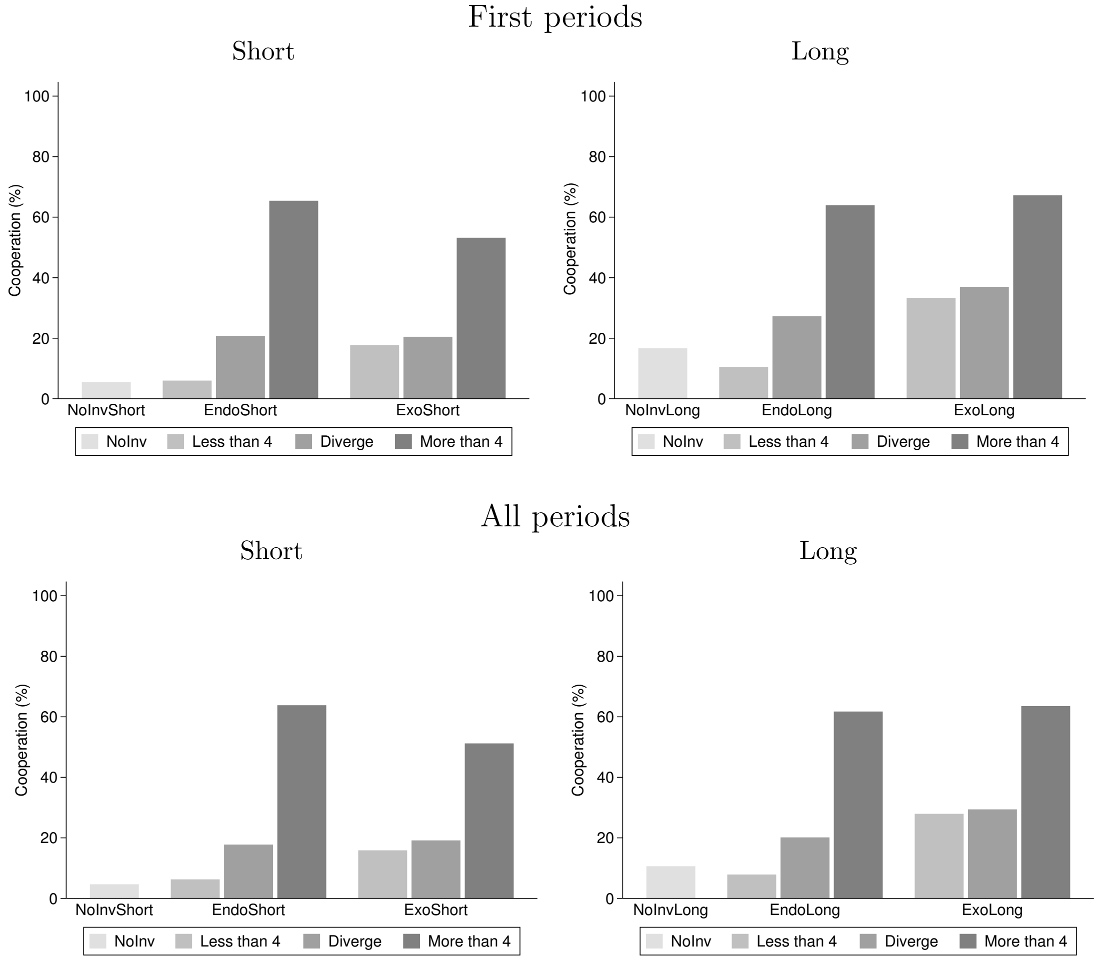
According to H2, we should observe no differences in cooperation rates between NoInvShort and EndoShort when investment levels are such that cooperation cannot be supported in equilibrium ($r_i \leq 4$ for at least one $i \in \{1, 2\}$), while cooperation rates should be larger in EndoShort when investment levels are such that cooperation is sustainable in an SPE ($r_i, r_j > 4$). To test this hypothesis, therefore, we compare average cooperation rates in NoInvShort with those in EndoShort when $r_i \leq 4$ for at least one player, and with those in EndoShort when $r_i, r_j > 4$. According to MW tests, average cooperation is not statistically different between NoInvShort and EndoShort when $r_i, r_j \leq 4$, both when looking at the first period of each match ($p = 0.5623$) and when aggregating data over all periods ($p = 0.2482$). In contrast, when subjects' investments diverge or when both investments are strictly larger than 4, cooperation is higher in EndoShort – this difference is highly significant at 0.1% level for first periods cooperation rates ($p = 0.0009$ for divergent investments, $p = 0.0008$ for investments strictly larger than 4) and for cooperation rates averaged over all periods ($p = 0.0009$ in both cases).[17]

H2 predicts no difference in cooperation rates between NoInvLong and EndoLong, since cooperation is sustainable in an SPE in both treatments. However, we find that in EndoLong investments do have an effect on cooperation. Disaggregating data in the EndoLong treatment in the same way as for EndoShort reveals that behavior is quite similar across the Short and the Long conditions (see Figure 4). In particular, while there are no significant differences in cooperation rates between NoInvLong and EndoLong with $r_i, r_j \leq 4$ (first periods: $p = 0.4013$, all periods: $p = 0.6272$), average

[17]See Table C4 for MW test results, and Table C5 for regression results, both in Appendix C.2.

cooperation is significantly higher in EndoLong when $r_i, r_j > 4$ (first periods: $p = 0.0013$, all periods: $p = 0.0007$). Cooperation rates when players' investments diverge are higher than when investments are not allowed, but significantly so only when considering data aggregated over all periods (first periods: $p = 0.1022$, all periods: $p = 0.0243$).

Figure 4: Average cooperation by treatment and investment category



To summarize, we find that investment opportunities have no effect on cooperation rates when both investments are below the threshold level for cooperation to be sustainable in an SPE, while they positively affect cooperation as compared to the no investments condition when investments are above the threshold. This is in line with H2. However, contrary to H2, one player investing above the threshold for cooperation to be an equilibrium action is sufficient for cooperation to significantly increase. When the probability of continuation is high, we find similar results, even though this effect is not predicted by subgame perfection.

4.3 The effect of endogenous versus exogenous investments on cooperation

The comparison NoInv-Endo serves as baseline to examine cooperative behavior with and without the investment institution, but does not permit to pin down the mechanism behind the observed cooperation rates. The comparison between Endo and Exo treatments, instead, allows us to disentangle whether cooperation rates are determined by changes in the PD payoffs, or by the very act of choosing a specific investment level. If payoff is what drives cooperation rates, then we should observe, for given investment levels, the same cooperation rates in Endo and Exo treatments. This is what H3 states. If investments provide information on whether a subject is going to defect or cooperate in the PD game, we should instead observe that the same investments induce different cooperation rates in Endo and Exo. As H4 states, cooperation rates in Endo should be lower for investment levels of 4 or less, and larger for investments strictly higher than 4.

Using Figure 4 again, we see that when both players invest at most 4, cooperation is significantly lower in the Endo treatments according to MW tests, both in Long and Short conditions, and both when looking only at first periods (Short: $p = 0.0135$, Long: $p = 0.0080$) and when aggregating data over all periods (Short: $p = 0.0274$, Long: $p = 0.0193$). If investments diverge, cooperation tends to be higher in the Exo treatments, both in the Short and in the Long conditions. The difference is not statistically significant (MW $p > 0.1$ in all cases).[18] When both investments are above 4, cooperation in EndoShort is around 10 percentage points higher than in ExoShort, while cooperation rates are quite similar in EndoLong and ExoLong. In neither case, however, the difference is statistically significant (MW $p > 0.1$ in all cases).[19]

One interpretation is that choosing low investments signals unwillingness to cooperate, while the increase in cooperation is mostly induced by the high payoffs associated with high investments. However, a closer look at the PD actions of those subjects who chose high investments reveals an interesting pattern. In about 42 and 32 percent of the cases in EndoShort and EndoLong, respectively, subjects who invested more than 4, and whose partners invested more than 4 as well, chose to defect.[20] This behavior is individually optimal only if players expect a partner's investment to be followed by cooperation, in which case, by defecting, they would end up with the higher temptation payoff. This suggests that investments might be used strategically, to persuade the partner to cooperate while planning to defect, and might indeed be perceived as a means to signal both own willingness to cooperate, and own beliefs about the partner's

[18]In this case, we further split the data into two sub-categories: one for $r_i \leq 4$ and $r_j > 4$, the other for $r_i > 4$ and $r_j \leq 4$. In both cases, we do not find any differences in cooperation rates between Endo and Exo treatments, according to MW tests.

[19]See Tables C6 and C7 in Appendix C.2.

[20]In ExoShort and EndoLong these percentages are 55 and 32, respectively. If we look at pairs where both subjects chose to invest 8, defection is chosen in 23 and 21 percent of the cases in EndoShort and EndoLong, respectively.

willingness to cooperate. This strategic use of high investments, though, pushes cooperation rates down, and might explain why we find no significant differences between Endo and Exo treatments in this case.

Another interpretation might be that selection effects play a role in the endogenous treatments. In this case, cooperation rates might be due not to the investment level chosen, but to some unobservable characteristics (for example, preferences for (un)cooperative behavior) that differ across subjects. For instance, assuming that cooperative subjects choose high investments, if two cooperative subjects are randomly paired, investments and cooperation rates will be high in this pair. High cooperation would then result from selection effects, not from the investment chosen.

To control for selection effects, we consider separately cooperation rates of subjects who chose investments above 4, and those of subjects who chose investments below or at 4 (Table 4). If selection effects affect results, then subjects who invest $r_i > 4$ ($r_i \leq 4$) would cooperate (not cooperate) irrespective of the investment chosen by their partners.

Table 4: Average cooperation rates by player i and j's investment categories

	EndoShort		EndoLong	
	$r_i \leq 4$	$r_i > 4$	$r_i \leq 4$	$r_i > 4$
$r_j \leq 4$	5.56	24.96	8.50	26.70
$r_j > 4$	11.77	63.27	14.41	61.85
p-value	0.3865	0.0009	0.1711	0.0041

Averages are taken over all periods. p-values are from two-sided Mann-Whitney tests.

Table 4 shows that both subjects who choose $r_i > 4$ and subjects who choose $r_i \leq 4$ cooperate more when the partners choose $r_j > 4$, both in EndoShort and in EndoLong. This difference is statistically significant according to MW tests only for subjects who invest more than 4.[21] We interpret these results as indicating that cooperation rates are not determined by selection effects, but by the signaling effect implied by the choice of an investment level.

Our second set of results can be summarized as follows. Investments seem to work as a negative signal of willingness to cooperate: when both players invest at most 4, we find lower cooperation rates in the Endo than in the Exo treatments, as H4 predicts. In line with H3, we do not find statistically significant differences between Endo and Exo treatments when investments are high. This could be due to a strategic use of high investments, which reduces cooperation rates in Endo, or it might suggest that the increased payoffs are the main driving force behind the cooperation levels we observe.

[21] We find similar patterns in the exogenous treatments. None of the differences in this case is statistically significant.

4.4 The effect of time horizon on cooperation

Early experiments on the infinitely repeated PD have shown that cooperation tends to increase with the probability of continuation, but only marginally, as subjects often fail in fully exploiting the possibility to cooperate (Murnighan and Roth [1978, 1983], Feinberg and Husted [1993]). Recent experiments, by allowing subjects to play more repeated games and gain experience, suggest instead that the effect of repetition on cooperation can be substantial (Dal Bó [2005], Dal Bó and Fréchette [2011]; see Dal Bó and Fréchette [2018] for a suvey). Given these results, we expect that subjects cooperate more when the probability of future interactions is high. According to H5, we should observe higher cooperation rates in the Long than in the Short treatments.

In the treatments without investments, cooperation is higher in the Long condition, but this difference is marginally statistically significant only when averaging over the first period of each match.[22] Similarly, in Endo cooperation rates do not significantly differ between Short and Long treatments. In the Exo condition, cooperation levels are higher in the Long treatments, but the hypothesis of equality of cooperation rates cannot be rejected. Only exceptions are found when looking at averages over the first period of each match for investments lower than 4, and when investments diverge: in both cases, cooperation is marginally significantly higher in ExoLong.

Differently from previous experiments, we find that a higher probability of continuation does not substantially increase cooperation rates. This result partly contradicts H5. We will discuss this result further in Section 5.2.[23]

4.5 Evolution of cooperation over time

We check now whether investments help sustain cooperation over time. Figure 5 illustrates the evolution of cooperation in the treatments without and with endogenous investments, averaged over matching groups and first period of each match.[24] Data in Endo are separated by investment category. In the treatments with no investments, cooperation reaches zero quickly (in Short) or stays at low levels throughout (in Long).

[22] In this section we refer to results from MW tests reported in Table C9 in Appendix C.2. Results from probit regressions are in Tables C10, C11 and C12.

[23] For the purpose of providing a benchmark, we compare our results with those in Dal Bó and Fréchette [2011]. The best comparable treatments are our NoInvLong and ExoLong with $r_i = r_j = 0, 4, 8$ and $\delta = 0.75$, and their games with cooperation payoffs of $R = 32, 40$ and 48 and $\delta = 0.75$. Compared to our games, their sucker payoff is higher when $R = 32$, which would suggest lower cooperation in our treatments. We do find substantially lower cooperation rates in our NoInvLong, but similar levels of cooperation in ExoLong (averaged over all periods in all matches). When $R = 48$, our sucker payoff is higher, which would suggest higher cooperation in our games. Indeed, we find greater cooperation rates in ExoLong. We do not have any observations in ExoLong where $r_i = r_j = 4$. When comparing games in EndoLong with the games in Dal Bó and Fréchette [2011], we find lower cooperation in our games when $R = 32$, and higher when $R = 48$.

[24] Plotting only the first period of each match provides an incomplete representation of behavior in a match. However, since matches have different number of periods, this eases the comparisons across them. Similar patterns are discernible when considering all periods of a match (see Figures C1 and C2 in Appendix C.2).

When subjects in a pair invest at most 4, we observe very similar patterns in treatments with and without investment opportunities. When investments diverge, cooperation rates gradually decrease over time in EndoShort, while they fluctuate a lot in EndoLong. For investments larger than 4, cooperation rates exhibit a much different trend. In EndoShort, cooperation decreases over the first six matches and then slightly increases over the last six matches. In EndoLong, cooperation rates tend to increase over time (with a slight decrease in the last two matches).

Figure 5: Average cooperation over time, NoInv and Endo

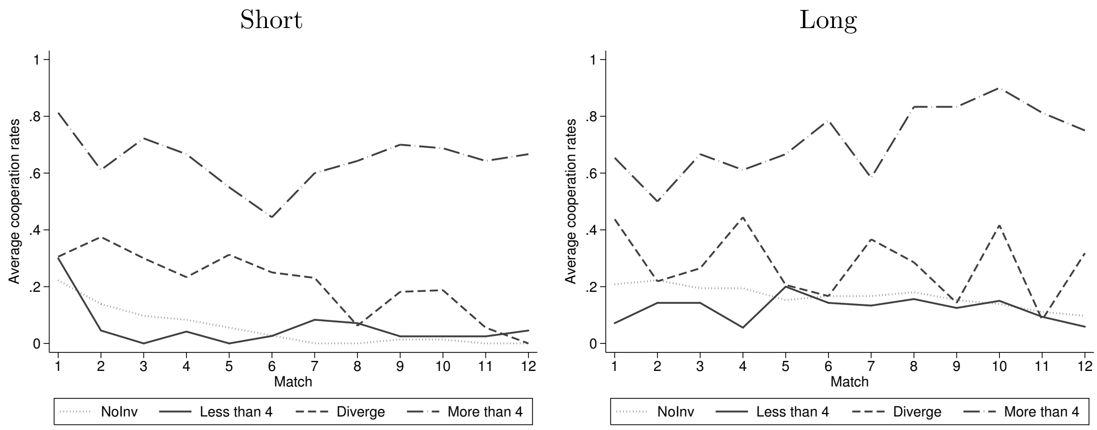
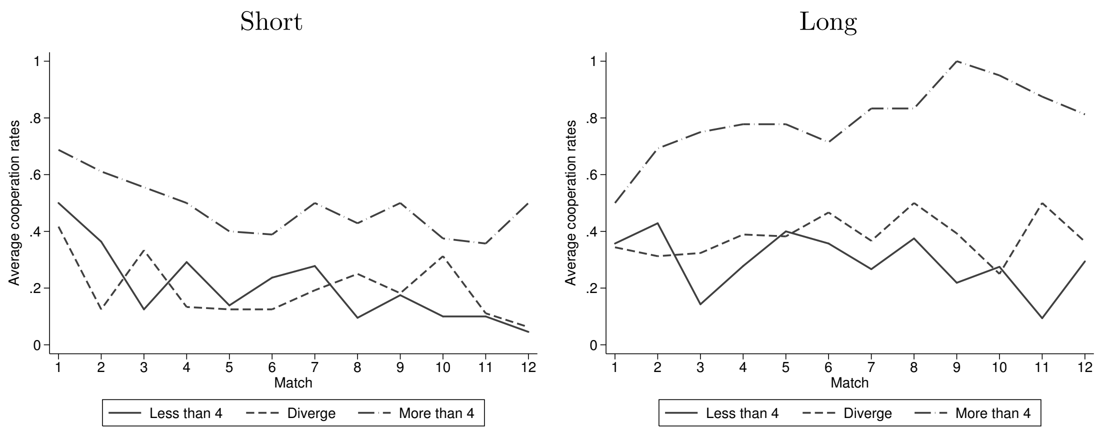


Figure 6 shows the time evolution of cooperation in the exogenous treatments, again separately for the three investment categories and averaged over matching groups and first period of each match. In Exoshort, cooperation tends to decrease over time fro low and divergent investments. When investments are high, cooperation rates are always larger than in the other two cases, but they decrease in first six matches and stabilizes at a lower rate in the last six. In ExoLong, cooperation rates oscillate when investments are low or diverge, but increase over time when investments are high.

Figure 6: Average cooperation over time, Exo



Overall, it seems that subjects quickly learn to defect when cooperation is not sustainable as an SPE equilibrium. In the endogenous treatments, subjects manage to maintain cooperation at relatively high levels when the investments chosen are such that cooperation is part of an SPE. This holds true in the exogenous condition only when a high probability of future interactions is implemented.

5 Discussion

5.1 Investments as coordination problem

Investments boost overall cooperation levels, independent of whether they are endogenously chosen or exogenously imposed. Yet, in 60 percent of the cases subjects choose low investments, between 0 and 4 (recall Figure 1). In the following, we focus on subjects' investment decisions and discuss a potential explanation for the observed investment behavior. We therefore restrict our attention to the endogenous treatments (EndoShort and EndoLong).

The investment decision entails a coordination problem, in that individuals would like to invest if others invest as well. Figure 7 shows the distribution of investments in the first and in the last match, by treatment. The frequency of investments below or at 4 increases from 53 to 73 percent in EndoShort, and from 42 to 63 percent in EndoLong. This seems to be mostly due to a shift of investment choices from the middle of the range toward 0. Indeed, by comparing first match (upper panels) and last match (lower panels) investment choices, we see that, in both treatments, the percentage of 8 investments does not change much (it remains around 20 percent), the frequency of choices in the middle of the range decreases while the frequency of 0 investments increases substantially (reaching almost 60 percent).

The observed shift toward 0 might be due to the inability of our subjects to solve such coordination problem. Figure 8 shows the proportion of pairs who succeed at coordinating on the same investment category (either both players invest less than 4, or both strictly more than 4) and the proportion of pairs who do not.[25] In the first match, the "miscoordination rate" is relatively high: in roughly 60 percent of the cases in EndoShort and 40 percent of the cases in EndoLong, subjects who chose high investments had partners who chose low investments. By the end of the experiment, in match 12, the miscoordination rate is lower in both treatments, while the percentage of pairs that coordinates on low investments rises.[26]

[25]Choosing different investment levels, though in the same category, might also lead to the unravelling of investments. However, for the sake of consistency of exposition throughout the paper, and keeping in mind the threshold at 4 for cooperation to be supported in equilibrium in the Short treatments, we focus on investment categories rather than investment levels.

[26]Jonckheere-Terpstra (JT) test results show that in both treatments coordination on investments lower than 4 significantly increases over matches (EndoShort: $p = 0.0010$, EndoLong: $p = 0.0005$), while there is no significant trend for coordination on investments larger than 4 ($p > 0.1$ in both treatments). The miscoordination rate significantly decreases over matches (EndoShort: $p = 0.0006$, EndoLong: $p = 0.0033$). The JT test is a nonparametric test for ordered differences among classes. Here, we test the null hypothesis that average (mis)coordination rates do not differ among matches,

Figure 7: Distribution of investments

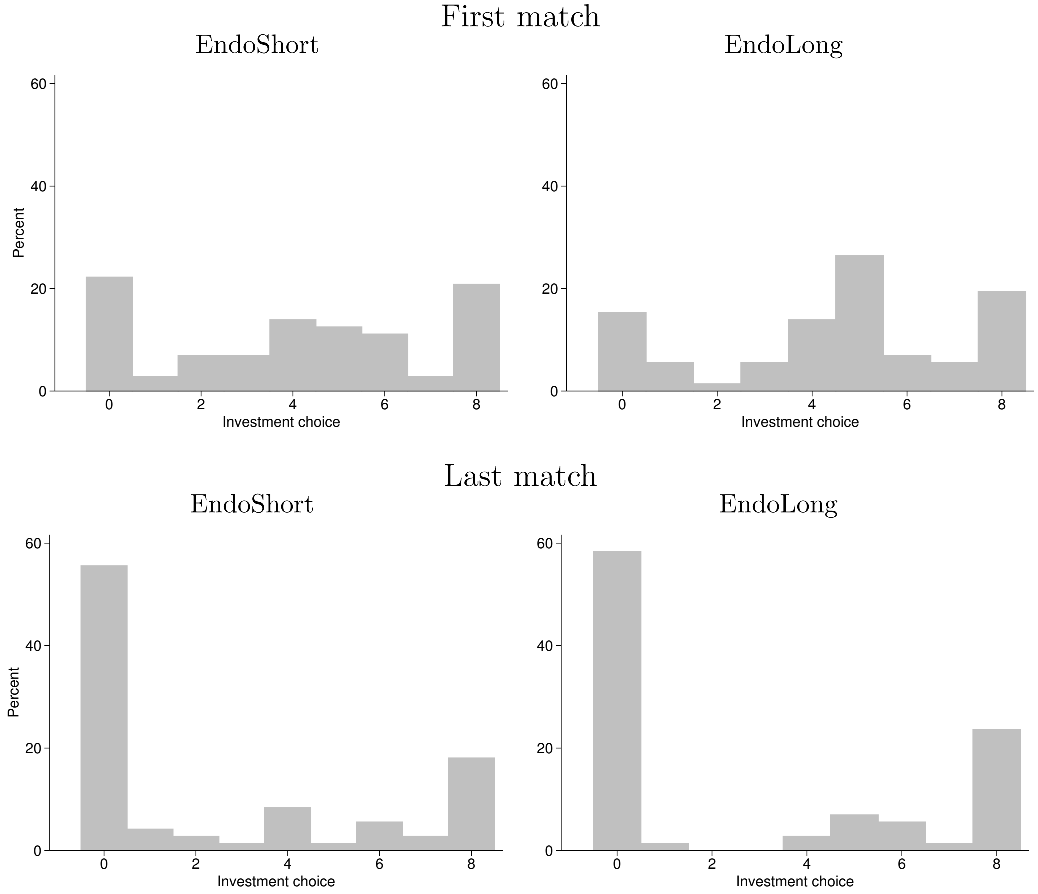


Figure 8: Coordination on the same investment category

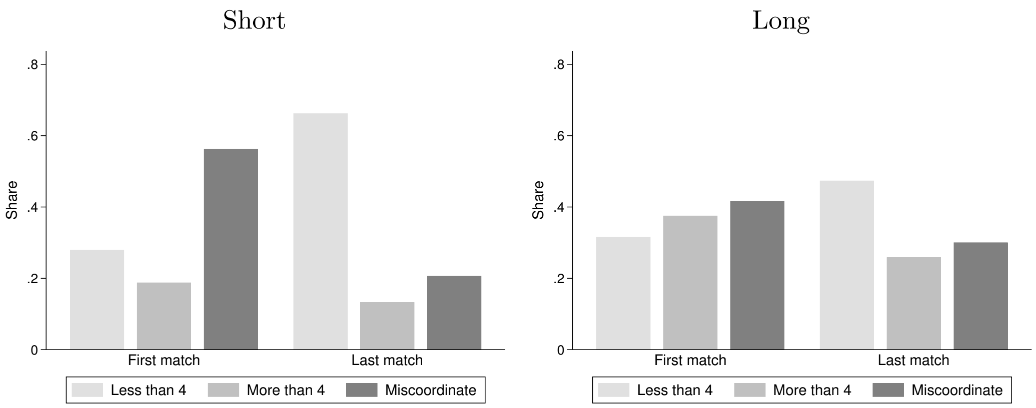
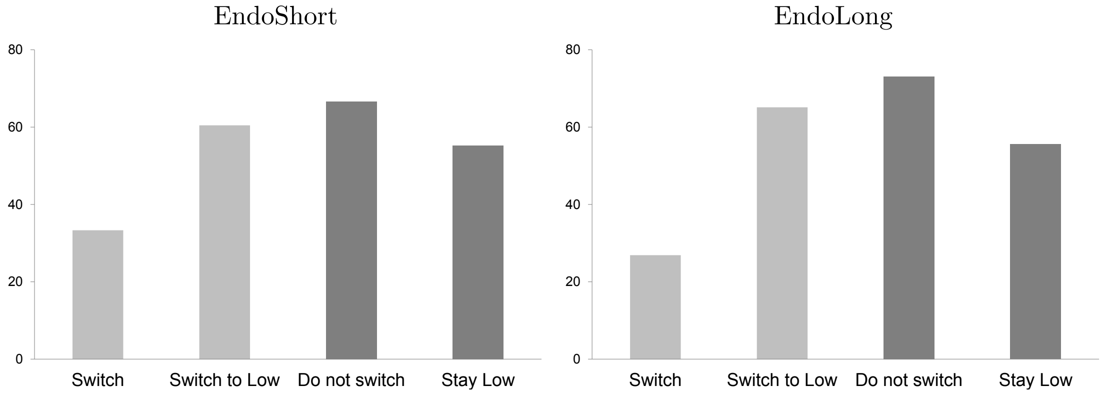


Figure 9 shows the percentage of subjects who, after experiencing miscoordination in the previous match, switch to a different investment category (i.e. shift from investments choices in the Low category ($r_i \leq 4$) to investments in the High category ($r_i > 4$), and vice versa) and the percentage of subjects who do not. It additionally shows, among the subjects who switch, the proportion of subjects who lower their investments (i.e., who switch to the Low category) and, among the subjects who do not switch, the percentage of those who keep choosing investments in Low. In the Short condition, one third of the subjects switch investment category, while in the Long condition this percentage is slightly lower. In most cases, those subjects who switch lower their investments. In both treatments, in more than 60 percent of the cases subjects move to the Low category, where in about 40 percent of the cases they invest nothing. This finding is in line with previous experimental results on coordination games, which show a convergence toward the risk-dominant equilibrium (Camerer [2003], Brandts and Cooper [2006a,b], Blume and Ortmann [2007], Chaudhuri et al. [2006b]).

Figure 9: Investment choices given miscoordination in previous match

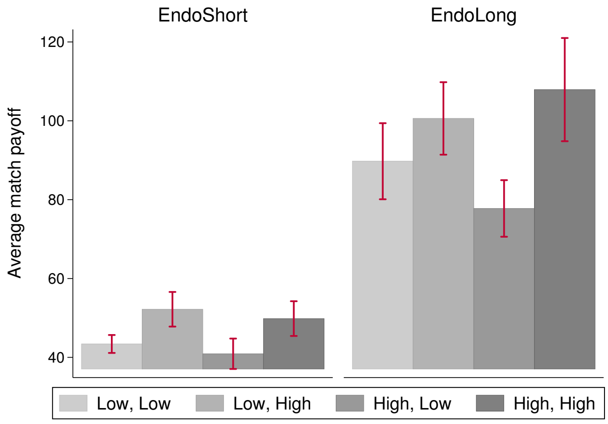


The highlighted coordination problem explains the shift to lower investments over time, but it only provides a partial explanation for low investments. As mentioned before, only about one third of the subjects decide to switch category. Among the majority of those who do not, the larger percentage (over 55 percent) invest and keep investing in the Low category (Figure 9). Figure 10 provides further insights into why players choose low investments so often. It shows the individual payoff of player i averaged over matches, separately for the following cases: both players invest less than 4 (Low, Low), player i invests less and player j invests strictly more than 4 (Low, High), and vice versa (High, Low), both players invest strictly more than 4 (High, High). Comparing the two darker bars (High, Low and High, High) shows that, in both treatments, choosing investments in the High category yields a relatively high payoff only if both players do so. Given the potential miscoordination, instead, ending up with somebody who chose in the Low category yields the lowest payoff on average. Moreover, even if both players choose investments in the High category (darkest bars),

against the alternative hypothesis that there is an ordered difference among matches.

there is a larger variability in the payoffs than when they both choose investments in the Low category (lightest bars). Therefore, choosing a low investment is the safest option, as it at least guarantees the mutual defection payoff in every period.

Figure 10: Average payoffs in a match



5.2 Cooperation

In the theoretical and experimental literature on indefinitely repeated PD, Subgame Perfection (SPE), Risk Dominance (RD) and Size of the Basin of attraction of the Always Defect strategy ($SizeBAD$) have been used as possible explanations for cooperation rates. In the following we discuss if these concepts provide an explanation for our results.

Experiments on the indefinitely repeated PD suggest that SPE fails to predict cooperative behavior, mostly because it does not recognize the importance of the risk that cooperating entails. The lower bound δ^{SPE} that equalizes short-run gains and long-run losses from defecting does not take into account that the sucker payoff as well may influence a player's propensity to cooperate. To capture this effect, Blonski and Spagnolo [2015] introduce a measure for the riskiness of cooperation, and use it to define the critical discount factor δ^{RD} for which cooperation is risk dominant.[27] The authors experimentally show that changes in the sucker payoff affect cooperation rates, so that the smaller the sucker payoff, the riskier it is to cooperate (and vice versa), and provide evidence that RD explains cooperation better than SPE alone does.

Dal Bó and Fréchette [2011] show that cooperation is on average higher when it is risk dominant, but they also find that a relatively large number of subjects still fail to coordinate on a cooperative equilibrium when it is risk dominant. They suggest a

[27] Blonski and Spagnolo [2015] transpose Harsanyi and Selten [1988]'s concept of RD from symmetric coordination games with two strategies to indefinitely repeated PD by focusing on only two strategies, the Grim (G, that starts by cooperating, and cooperates as long as the other player does so, but defects forever if the other player defects) and the Always Defect (AD). Hence, cooperation is said to be risk dominant if playing G is the best response to the other player choosing G or AD with probability one half.

different index to explain cooperation: $SizeBAD$, defined as the largest set of beliefs that make the Always Defect strategy optimal against Grim. Values of $SizeBAD$ close to one predict that cooperation would hardly emerge, since a player needs to have an extremely strong belief that the partner will cooperate for her to cooperate as well. The opposite holds for values of $SizeBAD$ close to zero.[28] Dal Bó and Fréchette [2011] find that the likelihood of choosing a cooperative action significantly and negatively correlates with $SizeBAD$.[29]

In our experiment, cooperation is not risk dominant in the treatments without investments, NoInvShort and NoInvLong (though it is an SPE in the latter). Moreover, $SizeBAD$ is 1 in NoInvShort, since cooperation is never an equilibrium in this treatment, while $SizeBAD$ is 0.875 in NoInvLong. This might explain why we find low cooperation rates in these treatments, and only a slightly and not statistically significantly higher cooperation in NoInvLong.

Investments, instead, make cooperation choices less risky by increasing the sucker payoff, so that cooperation becomes part of a risk dominant equilibrium for investments beyond a given level.[30] In the Short treatments, cooperation is risk dominant for $r_i, r_j \geq 7$. In the Long condition, the higher r_j, the lower is the investment r_i required for cooperation to be risk dominant.[31] Moreover, investments decrease $SizeBAD$. More precisely, in the Short condition $SizeBAD$ is 1 as long as at least one player invests $r_i \leq 4$, and it decreases with investments when $r_i, r_j > 4$. In the Long condition, $SizeBAD$ is never 1 (cooperation is always sustainable as equilibrium).[32]

Table 5 presents the results from a linear probability model of the effects of SPE, RD, $SizeBAD$, and their interaction with the investment level, on cooperation. *SPE* is a dummy variable that takes value 1 if cooperation is sustainable in a subgame perfect equilibrium, and 0 otherwise. *RD* takes value 1 if cooperation is sustainable in a risk dominant equilibrium, and 0 otherwise. Table 5 shows that the fact that

[28]The size of the basin of attraction is calculated as follows:

$$SizeBAD = \begin{cases} 1 & \text{if } \delta < \frac{g}{1+g} \\ \frac{(1-\delta)\ell}{(1-(1-\delta)(1+g-\ell))} & \text{otherwise} \end{cases}$$

where $g = \frac{t-c}{c-d}$ and $\ell = -\frac{s-d}{c-d}$. If cooperation cannot be supported as an SPE, $SizeBAD$ is 1.

[29]In Dal Bó and Fréchette [2018] the authors report the results of a meta-study of experiments on infinitely repeated PD games. The analysis shows that, while SPE is not enough to understand cooperation levels, cooperation rates are also relatively low when cooperation can be supported by a risk dominant equilibrium. Cooperation rates decrease with $SizeBAD$, especially when cooperation is risk dominant.

[30]Since different investments imply different cooperation payoffs, the resulting PD might be asymmetric depending on the investment chosen by the players. We take this potential asymmetry into account when determining the critical value δ^{RD} for which cooperation is risk dominant (see Blonski and Spagnolo [2015]). The condition for cooperation to be part of a risk dominant equilibrium is presented in Appendix B.

[31]This implies that cooperation is risk dominant also in cases where, for example, $r_i = 8$ and $r_j = 0$.

[32]Note that, since the PD might be asymmetric, $SizeBAD$ might differ between players in a pair. We therefore define $SizeBAD = \max\{SizeBAD_i, SizeBAD_j\}$. In the Short treatments, $0.33 \leq SizeBAD \leq 0.91$ for $r_i, r_j > 4$. In the Long treatments, $0.07 \leq SizeBAD \leq 0.88$.

Table 5: Effects on cooperation of SPE, RD, *SizeBAD* and investments

	Short	Long	Short	Long	Short	Long
SPE	−0.343					
	(0.348)					
Investment×SPE	0.106*	0.052***				
	(0.050)	(0.007)				
Investment×Not_SPE	0.023***					
	(0.004)					
RD			−1.139	−0.011		
			(1.895)	(0.029)		
Investment×RD			0.211	0.052***		
			(0.237)	(0.006)		
Investment×Not_RD			0.029***	−0.015		
			(0.004)	(0.015)		
SizeBAD					−0.718***	−0.695***
					(0.136)	(0.089)
Investment×*SizeBAD*					0.024***	0.010*
					(0.004)	(0.005)
Constant	0.079***	0.111***	0.076***	0.123***	0.796***	0.708***
	(0.021)	(0.033)	(0.021)	(0.036)	(0.135)	(0.064)
Nr of obs.	2976	7744	2976	7744	2976	7744

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. All results are from linear probability model regressions. Bootstrapped robust standard errors, clustered over matching groups, in parentheses. SPE takes value 1 if cooperation is sustainable in a sub-game perfect equilibrium, and 0 otherwise. RD takes value 1 if cooperation is sustainable in a risk dominant equilibrium, and 0 otherwise.

cooperation is sustainable in an SPE or an RD equilibrium does not increase, per se, the likelihood of choosing the cooperative action. Investments, instead, have a positive and significant effect on cooperation, both when cooperation is an SPE and when it is not. Investments increase cooperation also when cooperation is RD, with this effect being significant only in the Long treatments. This might be due to the fact that in the Short treatments very high investment levels are required for cooperation to be RD. Similarly, investments have a positive and significant effect on cooperation when it is not RD only in the Short treatments. In the Long treatments this effect disappears possibly because cooperation is not RD only for rather low investment levels. We find that cooperation significantly increases when the size of the basin of attraction decreases. Also in this case, investments have a positive impact on cooperation rates, indicating that, for a given $SizeBAD$, the higher the investment the higher the cooperation rates. This suggests that, even when $SizeBAD$ is too large for cooperation to emerge, cooperation would be increasing in the investment level.[33]

Taken together, these results help understand why we observe very similar cooperation patterns in Short and Long treatments. In both cases, investments lower the minimum δ necessary for cooperation to be an SPE and an RD, and decrease the $SizeBAD$, making it easier for cooperation to emerge. This suggests that investments affect and explain cooperation behavior beyond the equilibrium refinement used.

6 Summary and conclusions

In this paper we ask whether individuals are able to create situations that are conducive to cooperation in settings where there is no enforcement mechanism and cooperation is not easily sustained voluntarily. We introduce upfront investment opportunities and investigate whether they help promoting cooperation in a social dilemma, and whether this effect depends on the investments being endogenous or exogenous. In our experiment, investments are a cost that individuals have to incur before deciding whether to cooperate or not, and increase the payoff resulting from the choice to cooperate.

We compare a condition without investments with an endogenous condition where participants can choose their investment level to test whether investments increase cooperation levels. To determine whether the endogeneity of the investment decision matters for cooperation to increase, we compare the endogenous treatments with an exogenous condition. Participants in the exogenous treatments are presented with pre-determined investment levels, which are exactly the same as the investment levels chosen by the participants in the endogenous treatments. Finally, we ask how the probability of continuation of the PD game interacts with the investment decision, and study whether changes in this probability affect cooperation rates in this specific context.

Our main results show that low cooperation levels in treatments where investments are not allowed, and in treatments where investments are low. When high investments are chosen, cooperation is significantly higher than when investments are not allowed. Moreover, we find that when players choose low investments, cooperation rates are lower in the endogenous than in the exogenous treatments. However, the opposite is not true: cooperation levels are not significantly higher in the endogenous treatments when investments are high, compared to their exogenous counterpart. This suggests that, while low investments might signal unwillingness to cooperate, high investments do not necessarily signal the opposite. An alternative explanation is that, since high investments are frequently followed by defection, participants use them strategically to induce cooperation while planning to defect. This would be in line with the interpret-

[33]These effects are visible in Figures C3, C4 and C5 in Appendix C.2. Figure C3 shows that cooperation rates increase in the investment level even when cooperation is not RD. Figures C4 and C5 show that, overall, cooperation decreases with $SizeBAD$, but also that, given $SizeBAD$, cooperation might increase with the investment level.

ation that investments are perceived as a way to signal own willingness to cooperate, and/or own beliefs about a partner's willingness to cooperate. This strategic use of high investments reduces cooperation rates, and would explain why we find no differences between endogenous and exogenous treatments in this case.

We find that cooperation may not prevail when it is sustainable in a subgame perfect equilibrium, and that it does emerge when it is risk dominant or when the the size of the basin of attraction of the Always Defect strategy decreases. Moreover, cooperation increases with the investment level also under unfavorable conditions (for instance, a large $SizeBAD$). This suggests that investments affect and explain cooperation behavior irrespective of the equilibrium refinement used. While investments boost overall cooperation levels, independent of the mode of implementation, we observe that our participants do not always fully exploit the possibility to create situations favorable to cooperation, and frequently choose low to no investments. We argue that this can be due to lack of coordination, which makes choosing a high investment riskier (in terms of earned payoffs) than choosing a low investment.

Our results show that requiring individuals to invest upfront generates cooperative behavior in situations where a functioning enforcement mechanism lacks. Combining endogenous and exogenous elements, such as requiring a minimum investment level, might help overcome the coordination problem embedded in the investment decision, and reduce the strategic use of investments. This result seems to provide preliminary support to a theoretical finding in the environmental economics literature. There, the idea is that environmental treaties should focus on investments in green technology rather than on emission limits, arguing that such upfront investments, by reducing a country's temptation to defect, make future cooperation credible and the treaty self-enforcing (see Harstad et al. [2019]).

We would like to conclude by pointing out directions for future research. In this paper, we let investments increase both the cooperation and the sucker payoff. Moreover, we focus on selfish investments, which only affect a player's payoff from cooperation. Our intention was to capture the effect of investments per se, isolated from free-riding and other regarding concerns that might play a role if own decisions affect others' payoffs. This obviously does not reflect many real-life situations, where investments are lost once the other party defects, or where investments are directly beneficial to the other party. While we believe that endogenizing the parameters of the game brings the lab setting closer to many real-life situations, much remains to be done to understand whether and how cooperation develops in relationships that are not, or cannot be, governed by "standard" institutions.

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A Design - number of periods per match

Table A1: Number of periods across matching groups

(a) Short treatments

Matching group	Match 1	2	3	4	5	6	7	8	9	10	11	12	Total
1	1	2	3	2	1	1	1	1	2	1	3	2	20
2	1	2	5	7	1	1	1	2	2	1	1	2	26
3	3	1	1	1	1	1	1	1	4	1	4	3	22
4	1	6	1	2	1	2	1	1	1	2	2	2	22
5	2	2	1	1	2	1	1	3	1	1	4	1	20
6	1	1	2	2	1	2	1	1	2	1	2	1	17
7	1	1	1	1	1	2	2	1	1	3	2	1	17
8	1	1	5	1	2	1	2	2	1	2	1	1	20
9	1	1	2	5	1	2	1	1	1	1	2	4	22

(b) Long treatments

Matching group	Match 1	2	3	4	5	6	7	8	9	10	11	12	Total
1	1	2	1	1	7	7	1	5	4	1	2	1	33
2	1	11	7	3	8	7	3	6	2	2	2	5	57
3	1	1	8	7	6	5	15	9	7	2	5	3	69
4	3	1	4	1	7	5	1	4	2	10	4	3	45
5	6	1	8	4	2	8	14	10	4	1	6	5	69
6	8	8	17	3	1	2	5	1	2	2	1	3	53
7	7	4	2	4	3	1	2	1	9	9	2	3	47
8	11	7	1	1	9	2	5	1	9	12	3	2	63
9	4	5	2	1	3	2	8	6	3	1	8	5	48

B Theoretical background

For a PD with asymmetric payoff parameters and symmetric discount factor δ, the critical values δ^{RD} for which cooperation is part of a risk dominant equilibrium is given by (see Blonski and Spagnolo [2015]):

$$\delta^{RD} = \frac{Y+Z}{2W} + \sqrt{\left(\frac{Y+Z}{2W}\right)^2 - \frac{X}{W}} \tag{2}$$

where

$$\begin{aligned}
X &= (d_i - s_i)(d_j - s_j) - (t_i - c_i)(t_j - c_j), \\
Y &= (d_i - s_i)(d_j - s_j) - (t_i - d_i)(t_j - c_j), \\
Z &= (d_i - s_i)(d_j - s_j) - (t_i - c_i)(t_j - d_j) \quad \text{and} \\
W &= (d_i - s_i)(d_j - s_j) - (t_i - d_i)(t_j - d_j).
\end{aligned}$$

C Additional material

C.1 Investments

Table C1: Treatment effects, investments

	Investment	
	First match	All matches
Long	0.321	0.288
	(0.88)	(0.90)
Constant	3.252***	3.219***
	(0.69)	(0.72)
Nr of obs.	1728	5360

Results are from OLS regressions. *** $p < 0.001$. Bootstrapped standard errors, clustered over matching groups, in parentheses. Long takes value 1 if the observation comes from the EndoLong treatment and 0 otherwise.

C.2 Cooperation

The effect of endogenous investments on cooperation

Table C2: Percentage of cooperation by treatment

	NoInvShort	EndoShort	p-value	NoInvLong	EndoLong	p-value
First periods	5.44	23.26	0.0115	16.55	32.75	0.0301
All periods	4.58	21.75	0.0091	10.55	28.08	0.0092
Nr of obs.		18			18	

Averages are taken over matching groups. p-values are from two-sided Mann-Whitney tests which take averages over matching groups as unit of observation.

A probit regression of the probability of choosing the cooperative action is used to assess the impact of introducing the opportunity to invest.[34] Table C3 reports the results for both the treatments with $\delta = 0.35$ and the treatments with $\delta = 0.75$. The reference group in both cases is the treatment NoInv.

[34] All reported regressions use cluster-robust bootstrapped standard errors, corrected for potential correlations at the matching group level.

Table C3: Effects of investment treatment on the probability to cooperate

	$\delta = 0.35$		$\delta = 0.75$	
	First periods	All periods	First periods	All periods
Investment	0.873^{***}	0.913^{***}	0.525^{*}	0.728^{**}
	(0.22)	(0.24)	(0.24)	(0.24)
Constant	-1.604^{***}	-1.771^{***}	-0.972^{***}	-1.389^{***}
	(0.10)	(0.08)	(0.19)	(0.19)
Nr of obs.	1728	2976	1728	7744

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Bootstrapped standard errors, clustered over matching groups, in parentheses. Investment takes value 1 if the observation comes from EndoShort or EndoLong, and 0 otherwise. In each regression, the reference group is the treatment without investments.

Table C4: Differences in cooperation between NoInv and Endo

		(1)	(2)	(3)		NoInv vs	
	NoInv	$r_i, r_j \leq 4$	$r_i \leq 4, r_j > 4$	$r_i, r_j > 4$	(1)	(2)	(3)
Short							
First periods	5.44	5.93	20.71	65.34	0.5623	0.0009	0.0008
All periods	4.58	6.21	17.71	63.74	0.2482	0.0009	0.0009
Nr of obs.					17	18	16
Long							
First periods	16.55	10.45	27.22	63.89	0.4013	0.1022	0.0013
All periods	10.55	7.81	20.08	61.67	0.6272	0.0243	0.0007
Nr of obs.					18	18	18

Averages are taken over matching groups. p-values are from two-sided Mann-Whitney tests which take averages over matching groups as unit of observation.

Table C5: Effects of investments on the probability to cooperate, by investment category

	$\delta = 0.35$		$\delta = 0.75$	
	First periods	All periods	First periods	All periods
$r_i, r_j \leq 4$	-0.048	0.019	-0.186	0.032
	(0.14)	(0.12)	(0.28)	(0.29)
$r_i \leq 4, r_j > 4$	0.865***	0.854***	0.383	0.337
	(0.16)	(0.16)	(0.23)	(0.21)
$r_i, r_j > 4$	1.966***	1.977***	1.499***	1.848***
	(0.21)	(0.21)	(0.25)	(0.26)
Constant	-1.604***	-1.771***	-0.972***	-1.389***
	(0.10)	(0.08)	(0.19)	(0.19)
Nr of obs.	1728	2976	1728	7744

*** $p < 0.001$. Bootstrapped standard errors, clustered over matching groups, in parentheses. In each regression, the reference group is the treatment without investments.

The effect of endogenous versus exogenous investments on cooperation

Table C6: Differences in cooperation between Endo and Exo

	$r_i, r_j \leq 4$			$r_i \leq 4, r_j > 4$			$r_i, r_j > 4$		
	Endo	Exo	p-value	Endo	Exo	p-value	Endo	Exo	p-value
Short									
First periods	5.93	17.67	0.0135	20.71	20.40	0.8945	65.34	53.12	0.4428
All periods	6.21	15.80	0.0274	17.71	19.08	0.7573	63.74	51.13	0.3706
Nr of obs.		16			18			14	
Long									
First periods	10.45	33.25	0.0080	27.22	36.87	0.2888	63.89	67.17	0.6272
All periods	7.81	27.87	0.0193	20.08	29.33	0.4529	61.67	63.44	0.6272
Nr of obs.		18			18			18	

Averages are taken over matching groups. p-values are from two-sided Mann-Whitney tests which take averages over matching groups as unit of observation.

In addition, a probit regression of the probability of choosing the cooperative action is used to assess treatment differences between Endo and Exo. Table C7 reports the results for the treatments with $\delta = 0.35$ and $\delta = 0.75$, both for the first period of each match and all periods. The reference groups in each specification are the corresponding investment category in the Exo treatment.

Table C7: Endo versus Exo

	$\delta = 0.35$					
	1st periods	All periods	1st periods	All periods	1st periods	All periods
$r_i, r_j \leq 4$×Endo	-0.736***	-0.667***				
	(0.17)	(0.16)				
$r_i, r_j > 4$×Endo			0.403	0.334		
			(0.34)	(0.32)		
$r_i \leq 4, r_j > 4$×Endo					0.062	-0.007
					(0.18)	(0.17)
Constant	-0.916***	-1.085***	-0.041	-0.128	-0.801***	-0.910***
	(0.14)	(0.13)	(0.28)	(0.26)	(0.13)	(0.09)
Nr of obs.	812	1352	368	588	548	1036

	$\delta = 0.75$					
	1st periods	All periods	1st periods	All periods	1st periods	All periods
$r_i, r_j \leq 4$×Endo	-0.583*	-0.348				
	(0.28)	(0.32)				
$r_i, r_j > 4$×Endo			-0.215	0.006		
			(0.33)	(0.33)		
$r_i \leq 4, r_j > 4$×Endo					-0.300	-0.460*
					(0.23)	(0.23)
Constant	-0.576**	-1.009***	0.742*	0.453	-0.290	-0.593**
	(0.20)	(0.21)	(0.30)	(0.29)	(0.19)	(0.21)
Nr of obs.	616	2724	428	1876	684	3144

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Bootstrapped standard errors, clustered over matching groups, in parentheses. In each regression, the reference group is the corresponding category in the exogenous treatment.

Table C8: Within treatment differences in cooperation rates, across investment category

	$\delta = 0.35$			
	Endo		Exo	
	1st periods	All periods	1st periods	All periods
$r_i, r_j \leq 4$	-0.913^{***}	-0.834^{***}	-0.116	-0.175
	(0.10)	(0.13)	(0.09)	(0.14)
$r_i, r_j > 4$	1.101^{***}	1.123^{***}	0.760^{***}	0.782^{***}
	(0.22)	(0.18)	(0.18)	(0.20)
Constant	-0.739^{***}	-0.917^{***}	-0.801^{***}	-0.910^{***}
	(0.12)	(0.14)	(0.13)	(0.09)
Nr of obs.	864	1488	864	1488

	$\delta = 0.75$			
	Endo		Exo	
	1st periods	All periods	1st periods	All periods
$r_i, r_j \leq 4$	-0.569^{**}	-0.305	-0.286	-0.417^{*}
	(0.20)	(0.22)	(0.20)	(0.17)
$r_i, r_j > 4$	1.117^{***}	1.512^{***}	1.032^{***}	1.046^{***}
	(0.11)	(0.17)	(0.26)	(0.29)
Constant	-0.589^{***}	-1.052^{***}	-0.290	-0.593^{**}
	(0.12)	(0.08)	(0.20)	(0.22)
Nr of obs.	864	3872	864	3872

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Bootstrapped standard errors, clustered over matching groups, in parentheses. In each regression, the reference group is the category $r_i > 4, r_j \leq 4$.

The effect of time horizon on cooperation

Table C9: Differences in cooperation between Short and Long

No Investments									
	Short	Long	p-value						
First periods	5.44	16.55	0.0687						
All periods	4.58	10.55	0.1575						
Nr of obs.		18							
	$r_i, r_j \leq 4$			$r_i \leq 4, r_j > 4$			$r_i, r_j > 4$		
	Short	Long	p-value	Short	Long	p-value	Short	Long	p-value
Endo									
First periods	5.93	10.45	0.3862	20.71	27.22	0.1709	65.34	63.89	1.0000
All periods	6.21	7.81	0.9233	17.71	20.08	0.4529	63.74	61.67	1.0000
Nr of obs.		17			18			16	
Exo									
First periods	17.67	33.25	0.0675	20.40	36.87	0.0636	53.12	67.17	0.4584
All periods	15.80	27.87	0.2482	19.08	29.33	0.3538	51.13	63.44	0.3404
Nr of obs.		17			18			16	

Averages are taken over matching groups. p-values are from two-sided Mann-Whitney tests which take averages over matching groups as unit of observation.

Additionally, we regress the probability to cooperate over a dummy for δ being high (see Table C10). Results confirm that, in our experiment, increasing the probability of continuation does not necessarily increase the probability of a cooperative outcome.

Table C10: Effects of δ on the probability to cooperate

	No Investments	
	First periods	All periods
Long	0.632^{**}	0.381
	(0.22)	(0.21)
Constant	-1.604^{***}	-1.771^{***}
	(0.10)	(0.08)
Nr of obs.	1728	5360

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Robust standard errors, clustered over matching groups, in parentheses. Long takes value 1 if the observation comes from a treatment with $\delta = 0.75$ and 0 otherwise. In each regression, the reference category is the Short treatment.

Table C11: Effects of δ on the probability to cooperate

	Endogenous					
	First periods			All periods		
	$r_i, r_j \leq 4$	$r_i \leq 4, r_j > 4$	$r_i, r_j > 4$	$r_i, r_j \leq 4$	$r_i \leq 4, r_j > 4$	$r_i, r_j > 4$
Long	0.494*	0.150	0.165	0.394	-0.135	0.253
	(0.21)	(0.18)	(0.24)	(0.25)	(0.16)	(0.26)
Constant	-1.652***	-0.739***	0.362	-1.751***	-0.917***	0.206
	(0.10)	(0.12)	(0.19)	(0.09)	(0.14)	(0.19)
Nr of obs.	714	616	398	2038	2090	1232

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Robust standard errors, clustered over matching groups, in parentheses. Long takes value 1 if the observation comes from a treatment with $\delta = 0.75$ and 0 otherwise. In each regression, the reference category is the Short treatment.

Table C12: Effects of δ on the probability to cooperate

	Exogenous					
	First periods			All periods		
	$r_i, r_j \leq 4$	$r_i \leq 4, r_j > 4$	$r_i, r_j > 4$	$r_i, r_j \leq 4$	$r_i \leq 4, r_j > 4$	$r_i, r_j > 4$
Long	0.341	0.511*	0.165	0.075	0.317	0.582
	(0.24)	(0.23)	(0.24)	(0.26)	(0.23)	(0.37)
Constant	-0.916***	-0.801***	0.362	-1.085***	-0.910***	-0.128
	(0.14)	(0.13)	(0.19)	(0.14)	(0.09)	(0.23)
Nr of obs.	714	616	398	2038	2090	1232

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Robust standard errors, clustered over matching groups, in parentheses. Long takes value 1 if the observation comes from a treatment with $\delta = 0.75$ and 0 otherwise. In each regression, the reference category is the Short treatment.

Evolution of cooperation over time

Figure C1: Average cooperation over time, NoInv and Endo - All periods

Short Long

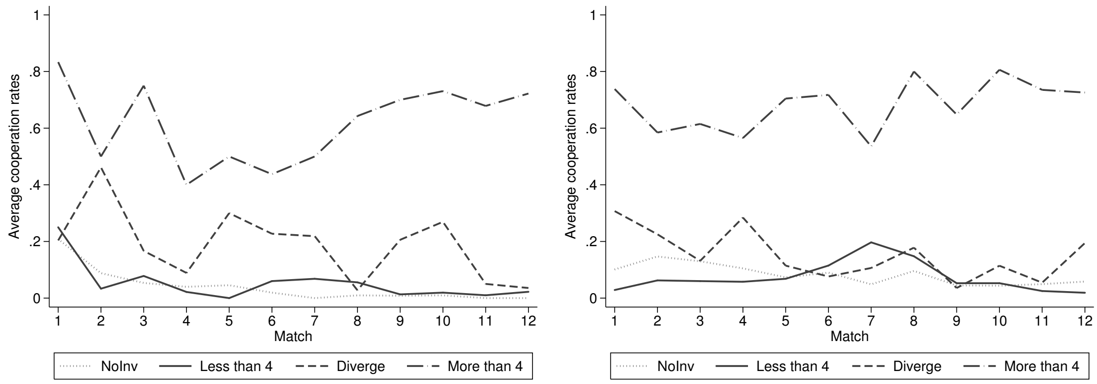
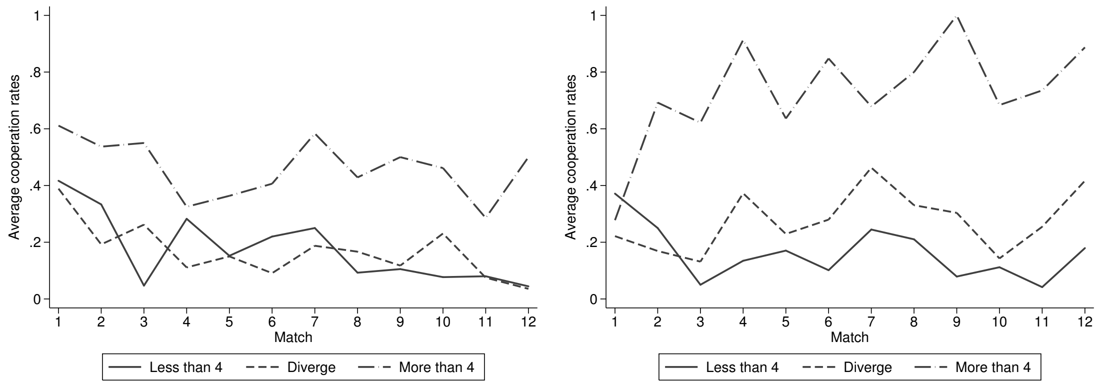


Figure C2: Average cooperation over time, Exo - All periods

Short Long



Discussion

Figure C3: Risk dominance and cooperation, by investment level

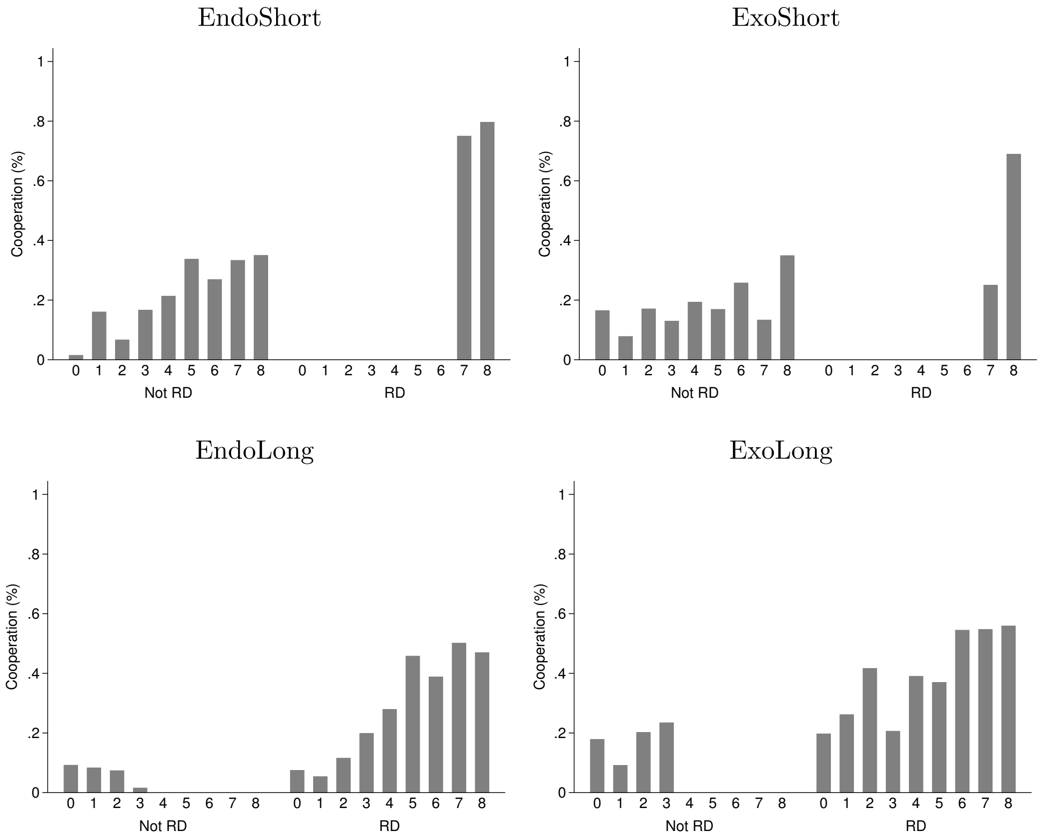


Figure C4: Cooperation and $SizeBAD$

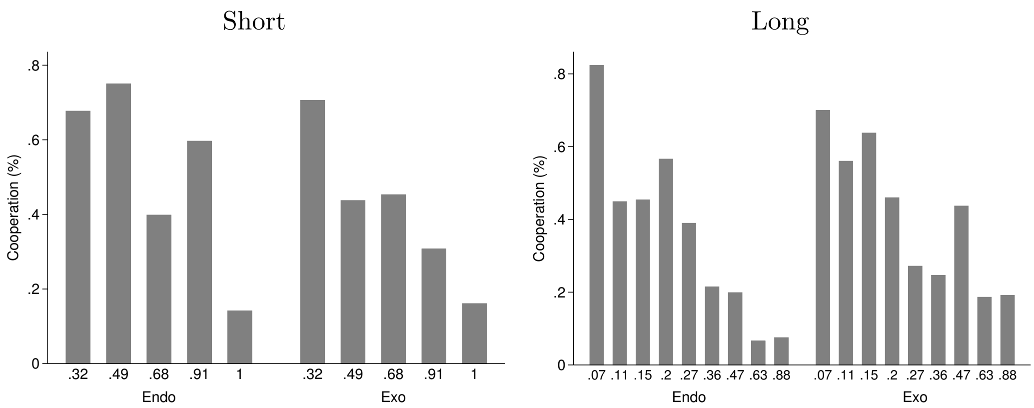


Figure C5: Cooperation, investments and *SizeBAD*