Punishment and Cooperation in Stochastic Social Dilemmas

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Abstract

Previous findings on punishment have focused on environments in which the outcomes are known with certainty. In this paper, we conduct experiments to investigate how punishment affects cooperation in a two-person stochastic prisoner's dilemma environment where each person can decide whether or not to cooperate and the outcomes of alternative strategies are specified probabilistically. In particular, we study two types of punishment mechanisms: 1) both persons can punish; and 2) only cooperators can punish non-cooperators. Our data suggest significant evidence of retaliatory punishment under the first punishment mechanism. In contrast, the second type of punishment mechanism is significantly more effective at promoting cooperation than the first mechanism particularly in an environment where the outcomes are known with certainty than when they are stochastic. Our findings provide useful information for designing efficient incentive mechanisms to induce cooperation in a stochastic social dilemma environment.

Keywords

social dilemmas; uncertainty; punishment; cooperation; experimental economics

JEL classification

C72; C91; D03; D81

I. Introduction

Punishment is widely used to enforce cooperation in social and economic exchange.[1] Controlled experiments reveal that individuals are often willing to incur costs to punish defectors, even in non-repeated interactions, and that this willingness to punish can be strong enough to enforce cooperation by others (e.g. Fehr and Gächter, 2000). These studies on punishment have focused on environments where agents' actions determine the outcomes with certainty. In this paper, we conduct experiments to investigate how agents apply and react to punishment in a stochastic social dilemma environment where the outcomes of alternative strategies are specified probabilistically.

Social dilemma problems, such as polluting the environment and free-riding on public goods have been studied experimentally in the context of deterministic games. Realistically, however, outcomes are determined not only by agents' decisions, but also by external uncertainty (see Kunreuther et al., 2009). Stochastic social dilemmas include a wide variety of problems involving interdependent risks in naturally-occurring environments. Some examples are airlines investing in security measures, branches of firms undertaking risk-reducing measures to avoid a catastrophic loss that may cause the entire firm to go bankrupt, and apartment owners investing in fire sprinklers. One feature common to all of these problems is that you can suffer a loss even if you protect yourself because you can be adversely impacted by the actions of others. For instance, in the airline security problem, when one airline invests in security, it still faces the risk of dangerous luggage transferred from other airlines unless it also inspects all transferred luggage.[2]

[1] See, Andreoni et al., 2003; Dickinson, 2001; Fehr and Fischbacher, 2004; Fehr and Gächter, 2000; Fowler, 2005; Ostrom et al., 1992; Sefton et al., 2007; Xiao and Houser, 2005, 2010; Yamagishi, 1988.
[2] For more details see Heal and Kunreuther (2005).

In these stochastic social dilemma situations, agents often must decide whether to incur the costs of reducing their risk of experiencing some negative outcome. Each individual recognizes, however, that even if she invests in a risk-reducing measure, she may still be subject to indirect losses if some other people choose not to invest in similar measures.

Introducing peer punishment is one common practice used to enhance cooperation in social dilemmas. Controlled experiments reveal that individuals are often willing to incur costs to punish defectors in both repeated and non-repeated social dilemma games, despite the fact that a backward induction argument shows that this is not the optimal decision from a game theoretic vantage point. This willingness to punish can enforce group cooperation. (see, Fehr and Gächter, 2000; Ostrom et al., 1992; Yamagishi, 1988).

Recent research has also revealed that this mechanism is limited due to the possibility of anti-social punishment (i.e., punishing cooperators) and retaliatory behavior by those who are punished (see, Casari and Luini, 2009; Cinyabuguma et al., 2006; Dreber et al., 2008; Falk et al., 2005; Herrmann et al., 2008; Nikiforakis, 2008).[3] For example, Herrmann et al. (2008) investigate the peer punishment mechanism in public goods games using 16 different subject pools from different areas around the world such as Zurich, Seoul, and Boston. Their data show that when counter-punishment or anti-social punishment is pervasive, punishment may not be effective in enforcing cooperation.

In this paper, we argue that peer punishment mechanisms are likely to achieve different outcomes in the stochastic social dilemma game than in the standard (deterministic) social dilemma game because it is less clear what decisions should be punished in the former

[3] Recent research on incentives also point out other mechanisms that may lead sanctions to backfire. For example, external incentives may crow out intrinsic motivation (e.g., Ariely et al., 2009; Falk and Kosfeld, 2006; Fehr and Falk, 2002; Fehr and List, 2004; Fehr and Rockenbach, 2003; Frey and Oberholzer-Gee, 1997; Fuster and Meier, 2009; Gneezy and Rustichini, 2000; Herrmann et al., 2008; Houser et al., 2008).

environment when the outcomes of one's behavior involves external uncertainty. Previous studies have shown that punishment decisions are correlated with norm violations (e.g., Fehr and Gächter, 2000; Bicchieri, 2006) and perceived negative intentions (e.g., Blount, 1995; Nelson, 2002; Offerman, 2002; Charness and Levin, 2007). In a stochastic environment one's non-cooperative behavior does not necessarily lead to bad outcomes, in which case it does not impose an explicit cost on the other person. Thus, a norm of cooperation (that is, to cooperate is the "right thing" to do) is less salient in stochastic environments. Furthermore, if individuals' decisions on whether to impose a costly punishment depend on whether they experienced a negative outcome due to *outcome bias* (see Baron and Hershey1988), then non-cooperators may be spared punishment in some rounds of a repeated stochastic game.

As a first step in understanding how people apply and react to punishment when there is an external uncertainty related to the outcome, we study peer punishment in a two-person stochastic prisoner's dilemma game (SPD) with one Nash equilibrium (both parties decide *not* to cooperate). In this SPD game, two agents determine whether to incur a cost to invest in protection so as to reduce the risk of losses due to the occurrence of some negative event. We compare behavior in this environment with actions taken in an equivalent two-person deterministic prisoner'ser's dilemma (DPD) game. In both games, the negative event will *not* occur if both players invest. In the DPD game, a negative event is certain to occur whenever one player does not invest, while in the SPD there may not be a negative event even if both players do not invest in protection. The losses from the negative event for the SPD game given the actions of each player will be specified so that the expected loss [E(L)] approximately equals the outcome in the DPD game. If the criterion utilized by both players for determining whether or not to invest in protection is to minimize E(L) , then their strategy should be identical for an SPD game and DPD game.

We study two types of punishment mechanisms that are compared to the baseline condition of no punishment. In Option 1, each person can punish her counterpart at the end of any given period after learning her strategy and the outcome of the game in that period (henceforth *BothPun*). In Option 2, only those individuals investing in protection can incur a cost to punish if their counterpart has not invested in protection (henceforth *InvPun*). Since punishment is costly to both parties, standard game theory implies that the subgame-perfect equilibrium is not to punish so the outcome should be identical to the baseline treatment (Fehr and Gächter, 2000). The *BothPun* mechanism has been widely studied in a deterministic environment. The *InvPun* has not been investigated in either a deterministic or stochastic environment, even though it comes closer to the nature of punishment in real world settings.[4] For example, in contractual relationships when one individual breaks a contract, the legal system always permits the victim the right to punish the defector.

We find *BothPun* leads to retaliation and anti-social punishment and is significantly less effective in enforcing cooperation than *InvPun*. However, *InvPun* mechanism is less effective in promoting cooperation in SPD games than DPD game since non-investors are less likely to be punished in the former environment than the latter. Our findings provide useful information for designing efficient incentive mechanisms for inducing cooperation in a stochastic environment.

[4] Some research has been conducted to compare the effectiveness of different types of punishment mechanisms in deterministic environments. For example, Casari and Luini (2009) investigated a "consensual institution" in a public goods game. Under this institution, a request to punish a specific group member will be implemented only if at least two agents request such a punishment.

II. Experiment

Design

As shown in Table 1, our experiment consists of six treatments determined by the baseline case and two punishment mechanisms applied to either a DPD game or an SPD game. The number of pairs in each treatment is given in parentheses. In each treatment, subjects are told that they will anonymously play with the same person for 10 periods, after which they will be matched with a different participant to play the same game for another 10 periods.

Baseline cases without punishment In the baseline SPD game, two subjects are paired and play together for 10 periods. At the beginning of each period, each subject is given 48 talers (2 talers = $1). The two agents must make a joint decision on whether to invest in a risk-reduction measure to prevent a random negative event (with a loss of 24 talers) from occurring. If both agents choose to INVEST, then the negative event will not happen. The investment cost to each player is 12 talers. If only one player invests, then there is a 40% chance that the negative event will happen. In other words, there is a 40% chance the investor will lose 36 talers and the non-investor will lose 24 talers, and there is a 60% chance that the investor will lose 12 talers and the non-investor will lose 0 talers. If both choose to NOT INVEST, then there is a 64% chance that the negative event will happen, in which case each agent will lose 24 talers. Thus, there is a 36% chance that each will lose 0 talers in this situation. In each period, after both agents have made their investment decisions, agents are informed about: 1) their counterpart's decision; 2) whether the negative event happened; and 3) their total losses in that period.

In a DPD game without punishment treatment, the known losses are the expected losses (rounded upwards) of the corresponding scenario of the SPD game. Both agents are informed about their counterpart's decision and their current total losses after they have made their decisions as to whether or not to invest. The payoff tables for the SPD and DPD games are shown in Tables 2(a) and 2(b), respectively.

Treatments with Punishment In the DPD_*BothPun* treatment, after each agent makes a decision on whether or not to invest, she sees the counterpart's decision and her current payoff. She then decides whether to punish the counterpart. The *DPD_InvPun* treatment differs from the *DPD_BothPun* treatment in that only those who have invested can punish a counterpart if the counterpart has *not* invested.

In the SPD_*BothPun* treatment, we introduce the same punishment mechanism as in the DPD_*BothPun* treatment. In particular, agents decide whether or not to punish their counterparts after they are informed as to their counterpart's decision and whether or not the negative event occurred. In the *SPD_InvPun* treatment, we introduce the same *InvPun* punishment mechanism as in the *DPD_InvPun* treatment. An agent who invested can, after being informed whether or not the negative event occurred, determine whether or not to punish her counterpart, but only if the counterpart has not invested.

In all the punishment treatments, subjects must determine whether to punish the other person, and if so by how much, before learning what their counterpart has done in this regard. In each period, a punisher can have up to 24 talers deducted from the counterpart's payoff. Every 3 talers deducted from the counterpart costs the punisher 1 taler. In the two *BothPun* treatments, subjects might have negative earnings in one or more periods. In this case, they are told that their earnings for that period were zero. At the end of each period, each subject learns what his/her earnings were in that period and whether his/her counterpart inflicted any punishment

Procedure

We conducted the experiment at the Behavioral Lab at the Wharton School (University of Pennsylvania) by recruiting 310 subjects from the general student population at the University of Pennsylvania, each of whom participated in only one treatment. The experiment was conducted using Z-tree (Fischbacher, 2007). Subjects were told that, in addition to a fix payment of $10, one pair would be randomly selected at the end of the experiment and would receive their actual payments from a single period in one of the games that was also randomly chosen. Each subject was randomly assigned to one computer terminal. Before the experiment started, each subject completed an exercise to make sure he or she understood the payoffs under different strategies.

Hypotheses

Our first two hypotheses are based on previous findings regarding the effectiveness of peer punishment mechanisms in a deterministic environment. Hypotheses 3 and 4 discuss the performance of a new punishment mechanisms (*InvPun*) that has not been tested empirically in social dilemma games.

Hypothesis 1: Non-investors will be punished when a punishment opportunity is available even if it is costly.

This hypothesis is based on the findings showing that people are often willing to incur costs to punish non-cooperators in social dilemma environments (e.g., Fehr and Gächter, 2000).

Hypothesis 2: The *BothPun* mechanism will lead to retaliation by those who are punished and to anti-social punishment by punishing investors who inflicted punishment on their counterparts.

Previous research provides evidence that those receiving punishment are likely to retaliate against their punishers (see, Casari and Luini, 2009; Cinyabuguma et al., 2006; Dreber et al., 2008; Falk et al., 2005; Herrmann et al., 2008; Nikiforakis, 2008). Unlike the public goods game with punishment opportunities, where subjects are often unsure about who punished them (Fehr and Gächter, 2000; Herrmann et al., 2008), punishment receivers in two- player DPD games always know who punished them. This knowledge may lead to more retaliation than in a game where there are two or more counterparts. Furthermore, retaliatory punishment may lead to anti-social punishment where cooperators are punished when they inflict punishment on others (e.g., Herrmann et al., 2008; Falk et al., 2005; Nikiforakis, 2008).

Note that in a repeated game, the punishment opportunity under the *BothPun* mechanism has a dual effect: norm enforcing and retaliation. An individual is more likely to cooperate when she expects her counterpart is willing to incur costs to punish non-cooperative behavior (i.e., norm-enforcing effect). However, being punished could also lead to retaliation against the punisher. This retaliatory punishment can lead to less cooperation for several reasons. One possibility is that subjects may receive retaliatory punishment even when they cooperated and thus they cannot avoid being punished by cooperating. Another possibility is that subjects simply dislike being retaliated against and respond by not cooperating with the counterpart.

Hypothesis 3: The *BothPun* mechanism is less effective than the *InvPun* mechanism in promoting cooperation in both a DPD and SPD game.

The *BothPun* mechanism promotes lower cooperation than in the baseline case with no punishment, if the detrimental effect of retaliatory punishment is greater than the positive norm-enforcing effect of punishment. In contrast, the *InvPun* mechanism places constraints on anti-social and retaliatory punishments. Under this mechanism, for a person to retaliate, one has to first cooperate. One can also avoid being punished by cooperating. We thus hypothesize that *InvPun* will promote greater cooperation than the baseline no punishment treatment and the *BothPun* mechanism.

Hypothesis 4: The *InvPun* mechanism is more effective in enforcing cooperation in a DPD game than in a SPD game.

Due to the uncertainty of a negative outcome in the SPD environment, a risk-taking agent might prefer not to invest and hope that she and her counterpart will not suffer a loss. She may also think the counterpart's decision is determined by his/her risk-preference rather than social preference (e.g., to what degree the counterpart cares about others' welfare). In other words, a subject may not interpret her counterpart's investment decision as signaling positive intention, or a non-investment decision as signaling negative intention. Moreover, she may also think that it is not wrong for the counterpart to take the risk by not investing. Thus, compared with the DPD environment, it is less clear whether a person should be punished for Not Investing in the SPD environment. Since *InvPun* mechanism places constraints on anti-social and retaliatory punishments, we expect that less implementation of punishment will only diminish the norm-enforcing function of punishment.[5] Therefore, our hypothesis is that the *InvPun* mechanism is less effective in promoting cooperation rate in the SPD game than in a DPD game.

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[5] In view of our previous discussion on the dual effect of punishment, under the *BothPun* mechanism, the difference in punishment behavior between SPD and DPD environments may also have dual effect on the effectiveness of the punishment mechanism on promoting cooperation. For example, less implementation of punishment may diminish the norm-enforcing function of punishment but it can also lead to less retaliation which can help maintain cooperation. Thus, how the relative effectiveness of punishment in enforcing cooperation under the *BothPun* mechanism depends on the magnitude of the two effects in the SPD and DPD games.

III. Results

Each subject played the game with one partner for 10 periods and a different partner for another 10 periods. Data in both sessions support our hypothesis, although we observe some differences between the two sessions. Here, we report analysis based on the data in the first 10 periods where subjects did not have any experience. We report full analysis of the second 10 periods in the Appendix, where we also note any differences between the first 10 periods and the second 10 periods.[6]

We first report the aggregate analysis of investment rate in each treatment and then investigate how subjects make their punishment decisions and how investment decisions are affected by punishment in the previous period.

Aggregate analysis

Result 1: The InvPun mechanism is more effective in promoting cooperation than the BothPun mechanism in both the SPD game and DPD game. The InvPun mechanism, however, is less effective in promoting cooperation in an SPD game than in a DPD game.

Figure 1 plots the dynamics of investment rates over time in each treatment. It shows that in both the DPD and SPD environments, the *InvPun* mechanism achieves a significantly higher cooperation rate in almost every period. Table 3 reports the average investment rate in each treatment. In both the DPD and SPD context, both the *BothPun* and *InvPun* punishment mechanisms increase the average investment rate compared to the baseline treatment but only the increase under the *InvPun* mechanism is statistically significant, thus supporting Hypothesis 3 (see Mann-Whitney test results in Table 3).

[6] The effect of experience on individuals' decisions on whether to invest or not invest is an interesting question but is beyond the scope of this paper.

Table 3 also shows that DPD_InvPun achieves significantly higher investment rate than the SPD_InvPun treatment (84.77% vs. 65.43%, Mann-Whitney test, p=0.01), although the investment rate in their corresponding baseline SPD and DPD treatments are not significantly different. This result provides supporting evidence for Hypothesis 4 that the *InvPun* mechanism is more effective in promoting cooperation in a DPD game than in an SPD game.

Individual analyses

Punishment decisions

Table 4 reports descriptive data of punishment decisions in the SPD and DPD games. The data suggests a significant amount of punishment behavior in all treatments, a finding consistent with Hypothesis 1. Punishment tends to be much less severe (less frequent and much smaller penalties) in the *InvPun* mechanism than in the *BothPun* mechanism. This difference reflects by the presence of retaliatory punishment in the *BothPun* mechanism, as we report below.

Result 2: Punishment decisions do not depend on whether or not the negative event occurred.

We calculate the percentage of punishment when a loss occurred and when it did not in an SPD game. In the SPD_BothPun treatment, following the occurrence of a negative event, the frequency of punishment is 17% compared to 19% when the negative event did not happen. In the SPD_*InvPun* treatment, for the cases where one invested and the counterpart did not invest, about 62% investors punished the non-investor counterpart when the negative event occurred and about 53% investors did so when the negative event did not occur.

To determine whether the occurrence of a loss plays a significant role in punishment decisions, we define a variable ($WTPPun_{i,t}$): subject *i*'s willingness to pay to punish the period *t* counterpart. This variable equals: (i) "0" if the subject did not punish the counterpart; (ii) "1" if the amount the subject paid to punish is positive and does not exceed four (punishment cost ratio of 1:3); and (iii) "2" if the amount paid to punish is greater than four. Using this as the dependent variable, we conducted a random individual effect ordered probit regression analysis (we used three categories for punishment decisions in order to ensure that the number of observations in each cell is sufficiently large).

In the SPD_BothPun treatment, the independent variables include a constant as well as three dummies for decision outcomes consisting of one's own decision and one's counterpart's decision: (i) oneself invested and one's counterpart did not invest; (ii) oneself did not invest and one's counterpart invested; (iii) neither invested. The baseline is the case where both invested. In addition, for each decision outcome, we differentiate the case when the negative event happened ($NE_{i,t}$=1) and when the negative event did not happen ($NE_{i,t}$=0). The regression results reported in Table 5 Regression (1). We find the coefficients of $(Inv, NotInv)_{i,t}*NE_{i,t}$,$(NotInv, Inv)_{i,t}*NE_{i,t}$, and $(NotInv, NoInv)_{i,t}*NE_{i,t}$ are neither jointly nor individually significant (chi-square test, p>0.20).

In the SPD_InvPun treatment, since only the investors can punish only the non-investor counterpart, we include only the cases where the individual did not invest but her counterpart invested in the current period and $NE_{i,t}$ is the only independent variable. This regression result is reported in Table 5 Regression (2). As shown in Regression (2), the coefficient of $NE_{i,t}$ is also not significant (p>0.20). Thus the two regression results suggest that the occurrence or absence of a negative event does not have a significant effect on one's punishment decision.

Result 3. Retaliatory and anti-social punishment occurs in the BothPun mechanism.

The percentage of investors/non-investors who received punishment in each treatment where punishment was allowed is reported in Table 6. We separate the case when the subject punished the counterpart in the previous period from the case when she did not.[7] The frequency of punishment is much higher when one was punished in the previous period than when one was not in the *BothPun* treatments for both the DPD and SPD games, thus providing support for Hypothesis 2. For example, in the SPD_BothPun treatment, when subjects did not invest, they are punished 70% of the time (42 out of 60) if they inflicted punishment on their counterparts in the previous period. In contrast, if the non-investors did not punish their counterparts in the previous period, they are punished only 8% of the time (19 out of 239). This difference suggests that the implementation of punishment is dominated by retaliatory motives.

Table 6 also suggests that, in the *BothPun* treatments, there is a significant amount of anti-social punishment. For example, investors who punished their counterparts in the previous period are punished 11 out of 26 (42.31%) in the DPD_BothPun treatment, and 31 out of 41 (75.61%) in the SPD_BothPun treatment.

To provide statistical evidence for the presence of retaliatory punishment, we conducted a random individual effect ordered probit regression analysis of punishment decisions. The dependent variable is $WTPPun_{i,t}$. The independent variables include dummy variables for whether the subject *i* was punished in period *t-1* ($Punished_{i,t-1}$ and $NotPunished_{i,t-1}$). We allow different coefficients for the case when the counterpart invested in period *t* and when the counterpart did not invest. The baseline is when subject *i* was not punished in period *t-1* and the counterpart invested in period *t*. The regression results are reported in Table 7. The coefficients of "..$Punished_{i,t-1}$" are jointly significantly higher than the coefficients of "..Not $Punished_{i,t-1}$" in

[7] We also tried to break down the data further to separate the case when the individual invested in the previous round from when she did not. However, under such a classification, we ended up with less than 10 observations in some cells. Moreover, the data does not provide much new information.

each treatment (chi-square test, p<0.01). This suggests that a subject is willing to pay more to punish her counterpart should the counterpart punish her in the previous period.[8]

Result 4: The difference in received punishment amount when one invested and when one did not invest is greater in the DPD environment than in the SPD environment.

As we discussed in Hypothesis 4, due to the uncertainty of a negative outcome in SPD game, we expect that, compared with the DPD environments, it is less clear whether an Invest or Not Invest decision should be punished in the SPD environments. Our data provide supporting evidence for this. About 30.94% of non-investors and 8.02% investors were punished in DPD_BothPun. The difference in the fraction of subjects being punished when they invested and when they did not invest is much smaller in the SPD_BothPun treatment (20.56% non-investors and 15.72% investors are punished).[9] In addition, under the *InvPun* mechanism, when the counterpart did not invest, about 86.49% in DPD_InvPun and only 56.34% in SPD_InvPun were punished.

To provide statistical evidence, using the subject's received punishment amount as the dependent variable, we conducted a random individual effect ordered probit regression analysis in SPD_BothPun and DPD_BothPun. Similar to the analysis of punishment decisions, the dependent variable is ($CPunAmtReceived_{i,t}$) which equals: (i) "0" if subject *i* received no

[8] Regression results from Table 7 also show that the coefficient of "$CtpInv_{i,t}$*$Punished_{i,\ t-1}$" is not significantly different from that of "$CtpNotInv_{i,t}$*$Punished_{i,\ t-1}$" in both the SPD_BothPun and DPD_BothPun treatments (1.62 vs. 1.65, 1.97 vs. 1.99, chi-square test, p>0.90). This suggests that when one is punished in the previous period, she is equally likely to punish the counterpart when the counterpart invested as when the counterpart did not invest in the current period. In contrast, the coefficient of "$CtpNotInv_{i,t}$*$NotPunished_{i,\ t-1}$" is significantly positive in both the SPD_BothPun (0.63) and DPD_BothPun (1.55) treatments (p< 0.05), implying that when one is not punished in the previous period, she is more likely to punish non-investors than investors in the current period since the baseline case is $CtpInv_{i,t}$*$NotPunished_{i,\ t-1}$

[9] Note that under the *BothPun* mechanism, both the investors and the non-investors can be punished. Thus, to test our hypothesis, we compare the difference in the fraction of subjects being punished when they invested and when they did not invest in the SPD and DPD environments. In contrast, when the *InvPun* mechanism is provided, only non-investors can be punished and therefore, we compare only the fraction of non-investors who are punished in the SPD and DPD enviornments.

punishment; (ii)) "1" if subject *i* received a positive punishment amount that is no more than 12; (iii) "2" if subject *i* received punishment exceeding 12. We include the subject's investment decision as the independent variable ($Inv_{i,t}$ and $NotInv_{i,t}$) and allow different coefficients for each treatment (SPD_BothPun or DPD_BothPun). Given the results of retaliatory punishment above, we also allow different coefficients for the cases when the subject punished the counterpart in the previous period ($Punisher_{i,t-1}=1$) and those where she did not ($NPunisher_{i,t-1}=1$).

The result, as reported in Table 8 Regression (1), suggests that when subjects did not punish the counterpart (i.e., excluding the possibility of retaliatory punishment by the counterpart), the difference in the punishment amount received by investors compared with those received by non-investors is significantly smaller in the SPD environment than in the DPD environment. To see this, the difference between the coefficient of "$Inv_{i,t}$ *$NPunisher_{i,t-1}$* SPD_BothPun" (-1.70) and "$NotInv_{i,t}$ *$NPunisher_{i,t-1}$* SPD_BothPun" (-1.09) is significantly less than the difference between the coefficient of "$Inv_{i,t}$ *$NPunisher_{i,t-1}$* DPD_BothPun" (-2.02) and of "$NotInv_{i,t}$ *$NPunisher_{i,t-1}$* DPD_BothPun" (-0.42) (chi-square test, p=0.02).

We ran a similar regression analysis to compare the punishment amount received by non-investors between the SPD_InvPun and DPD_InvPun treatments (see Table 8 Regression (2)). Since in these two treatments, only non-investors can be punished and only when their counterpart invested, we include only those observations when subject *i* did not invest and her counterpart invested in period *t*. We find again that when subjects did not punish the counterpart in the previous period, non-investors are less likely to be punished in the SPD_InvPun than the DPD_InvPun treatment. The coefficient of "$NPunisher_{i,t-1}$* SPD_InvPun" is significantly different than that of "$NPunisher_{i,t-1}$* DPD_InvPun" (0.15 vs. 1.51, chi-square test, p<0.01).

In sum, we find evidence of retaliating punishment in both DPD and SPD games. People who were punished in period *t-1* spent more to punish their counterpart. The punishment behavior also suggests that it is less clear what behavior should be punished in the SPD environment than the DPD environment. We next examine how individuals react to punishment in each treatment.

Effect of punishment on investment.

We ran a random individual effect probit regression analysis of each individual's investment decision in period *t* for each punishment treatment. The independent variables include whether the individual *i* invested in period *t-1*($Inv_{i, t-1}$), whether the counterpart invested in period *t-1* ($CtpInv_{i,t-1}$), the amount of punishment the individual *i* received in the period *t-1* ($PunAmtReceived_{i, t-1}$). As we pointed out earlier, punishment may have a detrimental effect when it is anti-social (i.e., punishment is imposed on the investors); therefore, we allow the investor and the non-investor to have different coefficients for this variable ($NotInv_{i,t-1}$* $PunAmtReceived_{i, t-1}$ and $Inv_{i, t-1}$* $PunAmtReceived_{i, t-1}$) in the *BothPun* treatment for the SPD and DPD games. We first ran the regression including all the above variables, a period variable and the dummy of the end period. Since these last two variables are not significant and they do not change the findings we report below, we report only the regression result of the model that does not include the period variables.

Result 5: Under the BothPun mechanism, a subject is less likely to invest if she invested but was punished in the previous period.

The regression results reported in Table 9 suggests that, when the *BothPun* mechanism is applied, the more punishment amount one received in the previous period when she invested, the less likely she will invest in the current period. The coefficient of $Inv_{i,t-1}$*$PunAmtReceived_{i, t-1}$ is significantly negative in both the SPD_BothPun and DPD_BothPun treatments ($p<0.01$).

Using the regression results of the two *BothPun* treatments in Table 9, we calculate the marginal effect of punishment on the investment decisions for those who invested in the previous period ($Inv_{i,t-1}$=1).[10] The marginal effect is calculated as the mean of $PunAmtReceived_{i,t-1}$, separately for the case when the counterpart invested and when the counterpart did not invest in SPD_BothPun and DPD_BothPun ($CtpInv_{i,t-1}$=1 and 0). Our results show that if the counterpart invested in period *t-1*, the marginal effect is around -0.01 in both treatments, suggesting that one more taler of punishment received in period *t-1* will decrease one's probability of investing in period t by 1%. On the other hand, we find if the counterpart did not invest in period *t-1*, one more taler of punishment by the counterpart will decrease one's probability of investing by 2% in SPD_BothPun and 4% in DPD_BothPun. This result indicates the detrimental effect of anti-social punishment on cooperation.

Although the magnitude of the marginal effect seems small, note that punishment has a further indirect detrimental effect on cooperation because a subject is less likely to cooperate in period t when the counterpart did not cooperate in period *t-1*. To see this, in the SPD_BothPun and DPD_BothPun treatments, an individual's investment decision has a significant impact on her counterpart's investment decision in the following period (the coefficient of $CtpInv_{i,t-1}$ is both statistically and economically significant). The marginal effect of $CtpInv_{i,t-1}$ (change from 1 to 0) (calculated at the mean of $Inv_{i,t-1}$* $PunAmtReceived_{i, t-1}$ and for the case $Inv_{i, t-1}$=1) is -0.42 in SPD_BothPun and -0.31 in DPD_BothPun. This suggests that, all other things being equal,

[10] The marginal effect is calculated by assuming random individual effect equals to zero.

compared with the case when the counterpart invested in the previous period, the probability of one investing will be 42% less in SPD_BothPun and 31% less in DPD_BothPun if her counterpart did not invest. Thus, the detrimental effect of anti-social punishment can lead to a significant reduction in cooperation over time.

On the other hand, as shown in Table 9, if one did not invest in period *t-1*, the punishment amount does not have any significant positive effect on investment decisions in period *t*. More specifically, the coefficient of $NotInv_{i,t-1}$* $PunAmtReceived_{i,t-1}$ in the SPD_BothPun (0.01) is not significant and, in fact, it is marginally significantly negative in the DPD_BothPun treatment (-0.03)).

These results suggest that under *BothPun* mechanisms, the implementation of punishment does not promote cooperation. In fact, punishing investors even has a negative effect on cooperation. In contrast, in the SPD_InvPun treatment, the more punishment one receives in the previous period, the more one is likely to invest in the next period (the coefficient of $PunAmtReceived_{i,t-1}$ is significant, p=0.04). The marginal effect of the punishment amount is 0.02, implying that the probability of investing increases by 2% with each taler of punishment levied by one's counterpart who did invest.[11]

These findings are consistent with other studies showing that anti-social punishment can have a detrimental effect on cooperation as mentioned in the introduction (Dreber et al., 2008; Falk, et al., 2005; Herrmann, et al., 2008; Nikiforakis, 2008). In our study, the presence of anti-social punishment due to retaliation in the *BothPun* mechanism causes the punishment mechanism to be much less effective than *InvPun* mechanism.

[11] The marginal effect is calculated at $Inv_{i,t-1}$=0, Ctp $Inv_{i,t-1}$=1 and the mean of $PunAmtReceived_{i,t-1}$: 0.95. The coefficient of $PunAmtReceived_{i,t-1}$ is also positive in the DPD_InvPun treatment, but it is not significant (p=0.17).

IV. Discussion

We conducted experiments to investigate the impact of peer punishment on promoting cooperation in stochastic social dilemma environments where the payoffs are decided not only by agents' behavior, but also by some exogenous uncertainty. In particular, we studied two types of punishment mechanisms: one where both individuals can punish (*BothPun*) and one where only investors can punish non-investors (*InvPun*).

Our data provide evidence supporting all the hypotheses. We find that under the *BothPun* mechanism the implementation of punishment leads to retaliatory and anti-social punishment. Under this mechanism, investors are less likely to invest in the period *t* if they are punished in period *t-1*. Earlier studies on peer punishment have suggest the potential detrimental effect of anti-social punishment and retaliation (see, Casari and Luini, 2009; Cinyabuguma et al., 2006; Dreber et al., 2008; Falk et al., 2005; Herrmann et al., 2008; Nikiforakis, 2008). We provide convergent evidence that allowing the possibility of retaliation against the punishers in the *BothPun* mechanism can significantly diminish the effectiveness of peer punishment mechanism in promoting cooperation.

The positive evidence for the effectiveness of the *InvPun* mechanism highlights the importance of restricting punishment options to only cooperators and limiting the targets of punishment to non-cooperators. This result supports the rationale for modern societies shunning retaliation and centralizing punishment in the hands of the state (Herrmann et al., 2008). Constraining punishment as we have done by only allowing an investor to punish a non-investor may be even more important in one-to-one interactions than in multiple agent interactions because it is easier to identify and less costly to retaliate the punisher when there is only one counterpart than multiple individuals. More importantly, receiving punishment from a group might be more likely to be interpreted as a norm violation, while punishment from a particular individual might be more likely to be interpreted as negative intention. For example, Tyran and Feld (2006) show that in a public goods environment, compliance improves greatly when punishment is imposed by group members rather than exogenously. Further studies need to be conducted to understand how group punishment decisions differ from individual punishment decisions in triggering retaliation.

Our study also contributes to the understanding of how exogenous uncertainty affects people's decisions in imposing and reacting to peer punishment. We provide supporting evidence for the hypothesis that non-investors are less likely to be punished in the stochastic than the deterministic environment and, as a consequence, the *InvPun* mechanism is more effective in the DPD game than in the SPD game.

This paper takes a first step in understanding the effect of peer punishment in stochastic social dilemma problems. Another important and commonly used incentive is reward. In view of our results on retaliatory punishment, we may expect less retaliation in reward mechanisms. We are conducting further studies to investigate how peer reward mechanism works in a stochastic environment.

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Table 1. Conditions and Treatments and Number of Pairs in each condition/treatment.

Treatments \ Conditions	SPD	DPD
No punishment (Baseline)	SPD (32)	DPD (24)
Subjects can punish each other	SPD_BothPun (31)	DPD_BothPun (23)
Only investors can punish non-investor counterparts	SPD_InvPun (23)	DPD_InvPun (22)

Note: The number in the parenthesis is the number of pairs in each treatment.

Table 2.

a. Possible outcomes in the SPD game

		Agent j	
		Invest	Not Invest
Agent i	Invest	-12; -12	40% lose 36 , 60% lose 12; 40% lose 24 , 60% lose 0
	Not Invest	40% lose 24 , 60% lose 0; 40% lose 36 , 60% lose 12;	64% lose 24, 36% lose 0; 64% lose 24, 36% lose 0

b. Possible outcomes in the DPD game

		Agent j	
		Invest	Not Invest
Agent i	Invest	-12; -12	-22; -10
	Not Invest	-10; -22	-15; -15

Note: The top number in each cell is agent *i*'s loss and the bottom number is agent *j*'s loss. The loss outcomes in the DPD game in each scenario equal the expected value of the losses (rounded upwards) in the SPD game of the corresponding scenario.

Table 3. Investment percentage by treatment

Treatment	Mean	s.e.	Obs	p-value * (Mann-Whitney test)
SPD	36.88	6.15	32	
SPD_BothPun	48.23	6.84	31	0.21
SPD_Invpun	65.43	6.43	23	0.01
DPD	33.96	6.82	24	
DPD_BothPun	51.52	8.44	23	0.10
DPD_InvPun	84.77	5.24	22	< 0.01

Note: standard error is calculated using each pair as one observation.
* This column reports the p-value of Mann-Whitney test of the investment percentages between the punishment treatment and the baseline without punishment treatment under each condition. We calculate the average investment rate of 10 periods for each pair. We count each pair as one observation.

Table 4. Punishment decisions by treatment

Treatment	Punishment frequency(%)	Amount of talers paid to punish			
		Mean	Median	95th percentile	Max
SPD_BothPun	18.23	0.90	0	8.00	8
SPD_Invpun	8.70	0.32	0	2.50	8
DPD_BothPun	19.13	0.84	0	7.00	8
DPD_InvPun	7.27	0.44	0	5.50	8

Table 5. Random Individual Effect Ordered Probit Regression Analysis of Punishment Decisions in the SPD_BothPun and SPD_InvPun treatments

	Dependent variable: *WTPPun* $_{i,t}$ (=0 if subject *i* did no punish the counterpart; =1 if subject *i* paid no more than 4 to punish the counterpart; =2 if subject *i* paid more than 4 to punish the counterpart)	
	SPD_BothPun Regression (1)	SPD_InvPun* Regression (2)
	Coef. (s.e.)	Coef. (s.e.)
(Inv, NotInv) $_{i,t}$	1.07 (0.30)	
(Inv, NotInv) $_{i,t}$*NE $_{i,t}$	-0.56 (0.48)	
(NotInv, Inv) $_{i,t}$	0.66 (0.30)	
(NotInv, Inv) $_{i,t}$*NE $_{i,t}$	0.05 (0.40)	
(NotInv, NoInv) $_{i, t}$	0.24 (0.32)	
(NotInv, NoInv) $_{i,t}$*NE $_{i,t}$	0.16 (0.30)	
NE $_{i,t}$		0.17 (0.30)
cut1_cons	2.19 (0.35)	-0.14 (0.22)
cut2_cons	3.10 (0.37)	0.89 (0.24)

Note: parenthesis is denoted as (i's decision, i's counterpart's decision) $_{i,t}$ in period t;
NE $_{i,t}$=1 if the negative event happened in period t; =0, o.w.
*includes only the cases where the individual did not invest but his/her counterpart invested in the current period

Table 6. Frequency of punishment in period *t* under each condition

Investment decision in period *t*	Punishment decision in period *t-1*	Total # of obs.	Receive punishment in period t
			Freq. (percentage)
SPD_BothPun			
Investor	Not Punish	218	10 (4.59%)
	Punish	41	31 (75.61%)
Non-Investor	Not Punish	239	19 (7.95%)
	Punish	60	42 (70%)
DPD_BothPun			
Investor	Not Punish	186	6 (3.23%)
	Punish	26	11 (42.31%)
Non-Investor	Not Punish	153	31 (20.26%)
	Punish	49	31 (63.27%)
SPD_InvPun			
Non-Investor	Not Punish	54*	31 (57.41%)
	Punish	9*	6 (66.67%)
DPD_InvPun			
Non-Investor	Not Punish	23*	20 (86.96%)
	Punish	4*	3 (75%)

*****The total observations for these two treatments include only the cases where subjects did not invest and the counterpart invested.

Table 7. Random Individual Effect Ordered Probit Regression Analysis of Punishment Decisions in the SPD_BothPun and DPD_BothPun treatments

	Dependent variable: *WTPPun* $_{i,t}$ (=0 if subject *i* did no punish the counterpart; =1 if subject *i* paid no more than 4 to punish the counterpart; =2 if subject *i* paid more than 4 to punish the counterpart)			
	SPD_BothPun		DPD_BothPun	
	Coef	s.e.	coef.	s.e.
CtpInv $_{i,t}$*Punished $_{i,\ t-1}$	1.62	0.35	1.97	0.38
CtpNotInv $_{i,t}$*NotPunished $_{i,\ t-1}$	0.63	0.31	1.55	0.30
CtpNotInv $_{i,t}$*Punished $_{i,\ t-1}$	1.65	0.34	1.99	0.34
cut1_cons	2.46	0.34	2.50	0.33
cut2_cons	3.42	0.37	3.31	0.37

Note:
CtpInv $_{i,t}$=1 if i's counterpart invested in period t; =0, o.w.
CPtNotInv $_{i,t}$=1 if i's counterpart did not invest in period t; =0, o.w.
NotPunished $_{i,\ t-1}$=1 if i was not punished in period t-1; =0, o.w.
Punished $_{i,\ t-1}$=1 if i was punished in period t-1; =0, o.w.
The baseline is when i was not punished in the period t-1 and the counterpart invested in period t.

Table 8. Random Individual Effect Ordered Probit Regression Analysis of of Punishment Amount Received

	Dependent variable: *CPunAmtReceived* $_{i,t}$ (=0 if subject i' received no punishment in period *t;* =1 if 0< subject i''s received punishment amount ≤ 12; =2 if subject i''s received punishment amount >12)			
	Regression (1)		Regression (2)*	
	Coef.	s.e.	Coef.	s.e.
Inv $_{i,t}$ *Punisher$_{i,t-1}$* SPD_BothPun	-0.03	0.31		
Inv $_{i,t}$ *NPunisher$_{i,t-1}$* SPD_BothPun	-1.70	0.32		
NotInv $_{i,t}$ *NPunisher$_{i,t-1}$* SPD_BothPun	-1.09	0.29		
Inv $_{i,t}$ *Punisher$_{i,t-1}$* DPD_BothPun	0.01	0.39		
NotInv $_{i,t}$ *Punisher$_{i,t-1}$* DPD_BothPun	-0.02	0.37		
Inv $_{i,t}$ *NPunisher$_{i,t-1}$* DPD_BothPun	-2.02	0.40		
NotInv $_{i,t}$ *NPunisher$_{i,t-1}$* DPD_BothPun	-0.42	0.33		
NPunisher$_{i,t-1}$* SPD_InvPun			0.15	0.49
Punisher$_{i,t-1}$* DPD_InvPun			0.89	0.90
NPunisher$_{i,t-1}$* DPD_InvPun			1.51	0.67
cut1_cons	0.64	0.31	-0.19	0.47
cut2_cons	1.53	0.32	0.96	0.49

Note: Inv $_{i,t}$=1 if i invested in period t; =0, o.w. NotInv$_{i,t}$=1 if i did not invest in period t; =0, o.w.
NPunisher $_{i,\ t}$=1 if i did not punish the counterpart in period t; =0, o.w..
Punisher $_{i,\ t}$=1 if i punished the counterpart in period t; =0, o.w.
The baseline for each regression is the case when subject i in SPD treatments did not invested in period i and punished the counterpart in period t-1.
*includes only the cases where the individual did not invest but his/her counterpart invested in the current period.

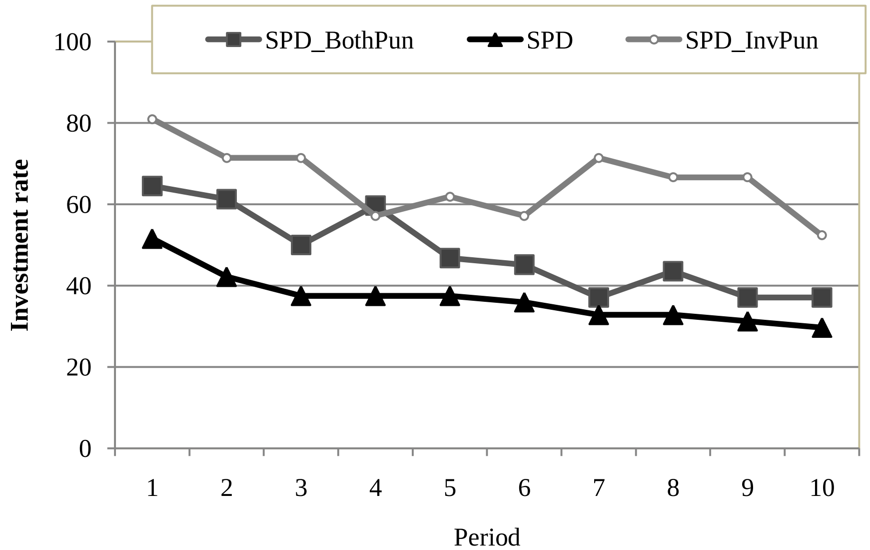
Table 9. Random Individual Effect Probit Regression Analysis of Investment Decisions.

invest	Dependent variable: Invest$_{i,t}$ =1 if i invest in period t; =0, o.w.			
	SPD_BothPun	SPD_InvPun	DPD_BothPun	DPD_InvPun
	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)
Inv $_{i,t-1}$	1.36*** (0.24)	0.37 (0.23)	1.86*** (0.21)	1.35*** (0.42)
CtpInv $_{i,t-1}$	1.28*** (0.16)	0.54*** (0.20)	1.24*** (0.20)	0.85*** (0.34)
NotInv $_{i,t-1}$* PunAmtReceived $_{i,t-1}$	0.01 (0.01)		-0.03* (0.02)	
Inv $_{i,t-1}$* PunAmtReceived $_{i,t-1}$	-0.05*** (0.02)		-0.10*** (0.03)	
PunAmtReceived $_{i,t-1}$		0.05** (0.02)		0.03 (0.02)
_cons	-1.39*** (0.18)	-0.11 (0.29)	-1.46*** (0.15)	-0.13 (0.65)

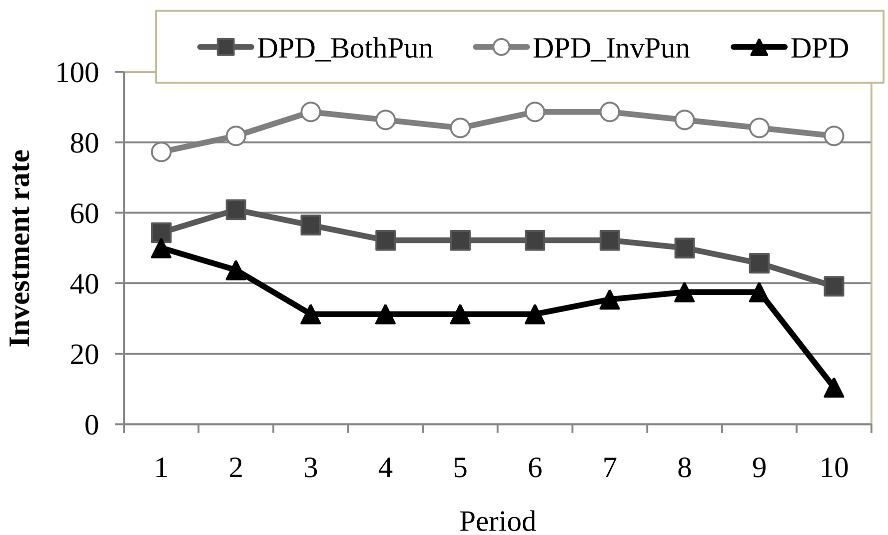
Note:
Inv $_{i,t-1}$=1 if i invested in period t; =0, o.w.
CtpInv $_{i,t}$=1 if i's counterpart invested in period t; =0, o.w.
NotInv$_{i,t-1}$=1 if i did not invest in period t; =0, o.w.
PunAmtReceived$_{i,t-1}$: the punishment amount imposed on subject i by her counterpart in period *t-1*.
*** significant at 1% level; **significant at 5% level; *significant at 10% level

Figure 1. Investment rate over period by treatment

A) SPD



B) DPD



Appendix. Analysis of the second session data

Each subject played the game with one partner for 10 periods and then with a different partner for another 10 periods. We analyze the data in the second session of the experiment using the same methods we use for the first ten periods. Here we report all tables and figures for the second session's data in the same order as we report the first ten periods' data in the paper. Although we observe some differences between the two sessions, the data from the second session support our hypothesis. In each table and figure, we report if any behavior we observe in the data from the first ten periods is different than what we observe in the second ten periods.

Table 3. Investment Percentage by Treatment (second session)

Treatment	Mean	s.e.	Obs	p-value
SPD	24.84	4.78	32	
SPD_BothPun	39.84	6.55	31	0.11
SPD_Invpun	69.57	6.39	23	<0.01
DPD	39.38	8.05	24	
DPD_BothPun	53.26	8.98	23	0.29
DPD_InvPun	92.05	3.97	22	<0.01

Note: standard error is calculated using each pair as one observation.
*This column reports the p-value of the Mann-Whitney test of the investment percentages between the punishment treatment and the baseline without punishment treatment under each condition.

As we observe in the first session's data, the comparison of the investment rate between the baseline and the punishment treatments drawn from the second session data also supports Hypothesis 3. In addition, and supporting Hypothesis 4, the second session data again suggest that the *InvPun* mechanism is more effective in the DPD environment than in the SPD game. To see this, note that the investment rate in the SPD treatment is not significantly different than in the DPD treatment (24.84% vs. 39.38%, Mann-Whitney test, p=0.32). However, the investment rate in the DPD_InvPun treatment is significantly higher than in the SPD_InvPun treatment (92.05% vs. 69.57%, Mann-Whitney test, p<0.01).

Table 4. Punishment Decisions by Treatment (second session)

Treatment	Punishment frequency(%)	Amount of talers paid to punish			
		Mean	Median	95th percentile	Max
SPD_BothPun	20.48	1.18	0	8	8
SPD_Invpun	8.04	0.38	0	4.5	8
DPD_BothPun	15.65	1.00	0	8	8
DPD_InvPun	3.64	0.24	0	0	8

The second session's data suggest a significant amount of punishment, just as we observe in the first session's data. Also, punishment is smaller and less frequent under the *InvPun* mechanism than under the *BothPun* mechanism.

Table 5. Random Individual Effect Ordered Probit Regression Analysis of Punishment Decisions in the SPD_BothPun and SPD_InvPun treatments(second session)

	Dependent variable: *WTPPun* $_{i,t}$ (=0 if subject *i* did no punish the counterpart; =1 if subject *i* paid no more than 4 to punish the counterpart; =2 if subject *i* paid more than 4 to punish the counterpart)	
	SPD_BothPun Regression (1)	SPD_InvPun* Regression (2)
	Coef. (s.e.)	Coef. (s.e.)
(Inv, NotInv) $_{i,t}$	2.47 (0.41)	
(Inv, NotInv) $_{i,t}$*NE $_{i,t}$	-0.57 (0.32)	
(NotInv, Inv) $_{i,t}$	1.37 (0.48)	
(NotInv, Inv) $_{i,t}$*NE $_{i,t}$	0.32 (0.45)	
(NotInv, NoInv) $_{i, t}$	0.68 (0.44)	
(NotInv, NoInv) $_{i,t}$*NE $_{i,t}$	1.20 (0.32)	
NE $_{i,t}$		0.21 (0.45)
cut1_cons	2.79 (0.37)	-2.69 (27.13)
cut2_cons	3.51 (0.38)	2.04 (27.13)

Note: parenthesis is denoted as (i's decision, i's counterpart's decision) $_{i,t}$ in period t;
NE $_{i,t}$=1 if the negative event happened in period t; =0, o.w.
*includes only the cases where the individual did not invest but his/her counterpart invested in the current period

In the second session of SPD_BothPun treatment, when both players did not invest, players were more likely to punish the counterpart when the negative event happened than when it did not. This result differs from the first session data where we find that the occurrence of the negative event has no effect on the punishment decision in any case. The occurrence of the negative event has no significant effect on the punishment decision for other scenarios. This result is the same as for the first session's data.

In the second session of SPD_InvPun treatment, same as the first session, we again find that the occurrence of the negative event has no significant effect on the punishment decision.

Table 6. Frequency and Percent of Receiving Punishment in Period *t* under each Condition (second session)

Investment decision in period *t*	Punishment decision in period *t-1*	Total # of obs.	Receive punishment in period t	
			Freq.	Percentage
SPD_BothPun				
Investor	Not Punish	179	17	9.50
	Punish	34	9	26.47
Non-Investor	Not Punish	271	41	15.13
	Punish	74	47	63.51
DPD_BothPun				
Investor	Not Punish	195	4	2.05
	Punish	23	7	30.43
Non-Investor	Not Punish	159	26	16.35
	Punish	37	25	67.57
SPD_InvPun				
Non-Investor	Not Punish	52*	30	57.69
	Punish	3*	1	33.33
DPD_InvPun				
Non-Investor	Not Punish	15*	13	86.67
	Punish	0*	0	

*****The total observations for these two treatments include only the cases where subjects did not invest and the counterpart invested.

Like the first session's data, the second session's descriptive data suggest that one is more likely to be punished if she punished the counterpart in the previous period.

Table 7. Random Individual Effect Ordered Probit Regression Analysis of Punishment Decisions in the SPD_BothPun and DPD_BothPun treatments(second session)

	Dependent variable: *WTPPun* $_{i,t}$ (=0 if subject *i* did no punish the counterpart; =1 if subject *i* paid no more than 4 to punish the counterpart; =2 if subject *i* paid more than 4 to punish the counterpart)			
	SPD_BothPun		DPD_BothPun	
	Coef	s.e.	coef.	s.e.
CtpInv $_{i,t}$*Punished $_{i,\ t-1}$	1.17	0.49	1.06	0.46
CtpNotInv $_{i,t}$*NotPunished $_{i,\ t-1}$	0.99	0.30	1.67	0.38
CtpNotInv $_{i,t}$*Punished $_{i,\ t-1}$	1.53	0.39	2.46	0.43
cut1_cons	2.12	0.36	2.80	0.38
cut2_cons	2.77	0.37	3.15	0.40

Note:
CtpInv $_{i,t}$=1 if i's counterpart invested in period t; =0, o.w.
CPtNotInv $_{i,t}$=1 if i's counterpart did not invest in period t; =0, o.w.
NotPunished $_{i,\ t-1}$=1 if i was not punished in period t-1; =0, o.w.
Punished $_{i,\ t-1}$=1 if i was punished in period t-1; =0, o.w.
The baseline is when i was not punished in the period t-1 and the counterpart invested in period t.

In the first session, for each treatment, the coefficients of the variables "…*Punished$_{i,t-1}$" are jointly significantly different from the coefficient of the variable "…*NotPunished$_{i,t-1}$" (($p<0.01$). We found the same results for in the second session data. In particular, the corresponding joint test is significant in DPD_BothPun treatment ($p=0.01$) and SPD_BothPun treatment ($p=0.04$).

Table 8. Random Individual Effect Ordered Probit Regression Analysis of Punishment Amount Received(second session)

	Dependent variable: CPunAmtReceived $_{i,t}$ (=0 if subject i' received no punishment in period *t;* =1 if 0< subject i''s received punishment amount ≤ 12; =2 if subject i''s received punishment amount >12)	
	Regression (1)	
	Coef.	s.e.
Inv $_{i,t}$ *Punisher$_{i,t-1}$* SPD_BothPun	-0.45	0.45
Inv $_{i,t}$ *NPunisher$_{i,t-1}$* SPD_BothPun	-1.50	0.29
NotInv $_{i,t}$ *NPunisher$_{i,t-1}$* SPD_BothPun	-0.67	0.32
Inv $_{i,t}$ *Punisher$_{i,t-1}$* DPD_BothPun	-1.66	0.51
NotInv $_{i,t}$ *Punisher$_{i,t-1}$* DPD_BothPun	-0.06	0.50
Inv $_{i,t}$ *NPunisher$_{i,t-1}$* DPD_BothPun	-2.63	0.46
NotInv $_{i,t}$ *NPunisher$_{i,t-1}$* DPD_BothPun	-0.80	0.43
cut1_cons	0.58	0.22
cut2_cons	1.10	0.22

Note: Inv $_{i,t}$=1 if i invested in period t; =0, o.w. NotInv$_{i,t}$=1 if *i* did not invest in period t; =0, o.w.
NPunisher $_{i,t}$=1 if *i* did not punish the counterpart in period t; =0, o.w.
Punisher $_{i,t}$=1 if *i* punished the counterpart in period t; =0, o.w.
The baseline for each regression is the case when subject i in SPD treatments did not invested in period *t* and punished the counterpart in period *t-1*.
*includes only the cases where the individual did not invest but her counterpart invested in the current period.

Results from Regression (1) using the first session's data suggest that when subjects did not punish the counterpart (i.e., excluding the possibility of retaliatory punishment), the difference in the punishment amount received by investors compared with those received by non-investors is significantly smaller in the SPD environment than in the DPD environment. We find the same result in the second session's data: the difference between the coefficient of "Inv $_{i,t}$ *NPunisher$_{i,t-1}$* SPD_BothPun" (-1.50) and "NotInv $_{i,t}$ *NPunisher$_{i,t-1}$* SPD_BothPun" (-0.67) is significantly different than the difference between the coefficient of "Inv $_{i,t}$ *NPunisher$_{i,t-1}$* DPD_BothPun" (-2.63) and of "NotInv $_{i,t}$ *NPunisher$_{i,t-1}$* DPD_BothPun" (-0.80) (chi-square test, p<0.05).
In the DPD_InvPun treatment, when including only the cases where the individual did not invest but his/her counterpart invested in the current period, we do not observe any case where subjects punished the counterpart in the previous period. Thus, we did not report Regression (2) in Table 8.

Table 9. Random Individual Effect Probit Regression Analysis of Investment Decisions (second session)

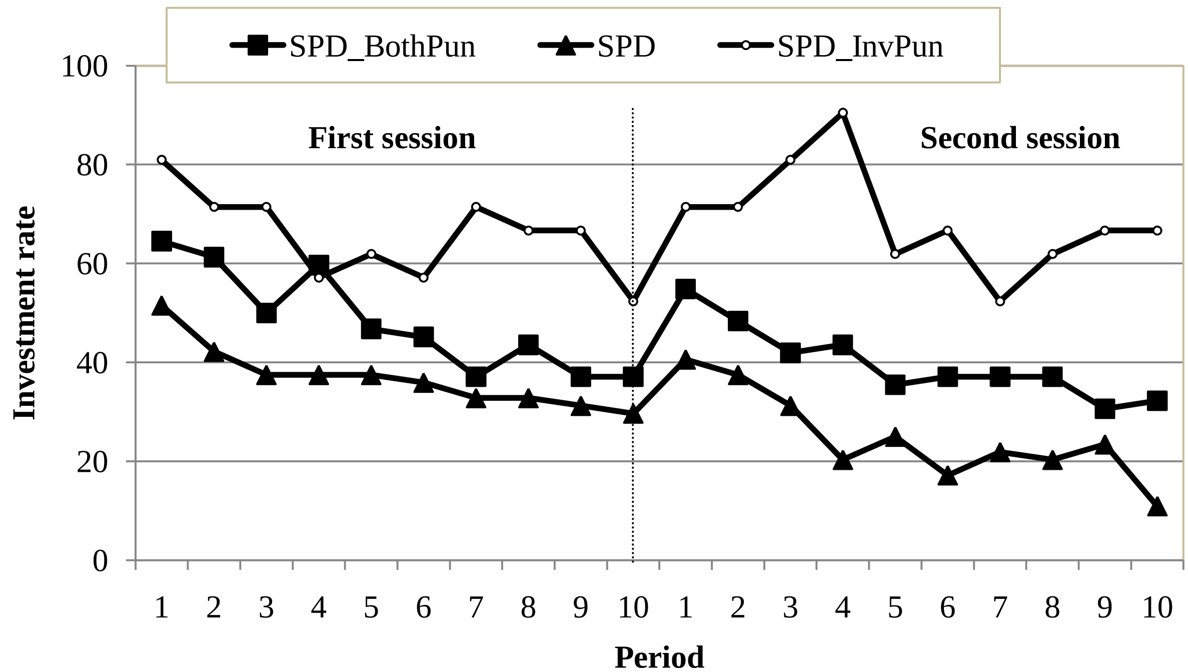
	Dependent variable: $Invest_{i,t}$ =1 if i invest in period t; =0, o.w.			
	SPD_BothPun	SPD_InvPun	DPD_BothPun	DPD_InvPun
	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)
$Inv_{i,t-1}$	1.52*** (0.24)	0.86*** (0.25)	2.57*** (0.28)	1.90*** (0.74)
$CtpInv_{i, t-1}$	1.07*** (0.17)	1.15*** (0.21)	1.38*** (0.22)	1.57** (0.72)
$NotInv_{i,t-1}$* $PunAmtReceived_{i, t-1}$	0.001 (0.01)		0.03** (0.01)	
$Inv_{i, t-1}$* $PunAmtReceived_{i, t-1}$	-0.04** (0.02)		-0.07*** (0.02)	
$PunAmtReceived_{i, t-1}$		-0.003 (0.016)		0.06* (0.04)
_cons	-1.15*** (0.16)	-0.63** (0.30)	-2.15*** (0.24)	-0.67 (0.93)

Note:
$Inv_{i,t-1}$=1 if i invested in period t; =0, o.w.
$CtpInv_{i,t}$=1 if i's counterpart invested in period t; =0, o.w.
$NotInv_{i,t-1}$=1 if i did not invest in period t; =0, o.w.
$PunAmtReceived_{i, t-1}$: the punishment amount imposed on subject i by her counterpart in period *t-1*.
*** significant at 1% level; **significant at 5% level; *significant at 10% level

The second session's data also suggest a detrimental effect of anti-social punishment. When the "BothPun" mechanism is applied, the more punishment amount one received in the previous period when she invested, the less likely she will invest in the current period. The coefficient of $Inv_{i,t-1}$* $PunAmtReceived_{i, t-1}$ is significantly negative in both the SPD_BothPun and the DPD_BothPun treatment ($p<0.05$).

Figure 1. Investment Rate over Period by Treatment (includes both the sessions)

A) SPD



B) DPD