Precommitment and cooperation in stochastic versus deterministic social dilemmas

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Abstract

Many real-world social dilemmas require interdependent people to repeatedly protect against a large loss that has a low probability of occurring. Examples include protecting against disease outbreak (e.g., COVID-19), terrorism (shared border security), or extreme weather events (from climate change). Decisions on whether to invest in protection may be made year by year, or investment may be precommitted in advance for a number of years. How does precommitment influence cooperation? A series of four studies addressed this question, using incentive-compatible, repeated social dilemmas with large-magnitude, low-probability losses. These studies revealed that in stochastic social dilemmas, precommiment increases cooperation, but in deterministic social dilemmas, precommitment decreases cooperation.

Keywords: social dilemma; uncertainty; time; losses; interdependent security; choice bracketing

Precommitment and cooperation in stochastic versus deterministic social dilemmas

 In many real-world social dilemmas, interdependent actors must decide whether to invest in preventive measures against catastrophic loss. For example, people facing the COVID-19 pandemic must decide whether to engage in preventative measures such as social distancing, hand-washing, etc. The security of each person depends on their neighbors. If one person does not take preventative measures, it puts others at risk. Similarly, that person may free-ride and benefit from the protective measures of others. In contrast, if everyone engages in protective measures, everyone will be safe. A second example is border security; the United States and Canada share a huge undefended border and both must protect against terrorism and illegal smuggling. Each country relies on the security investments of the other. A third compelling example of interdependent security has been seen in financial firms, where catastrophic losses in one division may bring down the whole company (Kunreuther & Heal, 2005).

 In social dilemmas, individuals are incentivized to put their (short-term) self-interest over the collective benefit and therefore act non-cooperatively. To counteract this, a huge literature on social dilemmas has documented factors which promote cooperation and, hence, lead to mutual benefit (for a review, see Parks et al. 2013). While the vast majority of existing research has focused on social dilemmas without uncertainty, work on environmental dilemmas has found that the uncertainty over the replenishment rate (Roch & Samuelson, 1997), or the size of the resource (Botelho, Dinar, Pinto, & Rapoport, 2014; De Kwaadsteniet, van Dijk, Wit, & de Cremer, 2006) lead to reduced cooperation rates. Other studies have likewise shown that the uncertainty about the decision environment reduces cooperation rates (Budescu, Rapoport, & Suleiman, 1990; Gustafsson, Biel, & Gärling, 1999). In addition, Gaudeul, Crosetto, & Riener (2015) found that exit decisions from a public project were much higher under uncertainty because the subjects over-estimated the likelihood of their partner’s exit decision.

Many real-world examples motivate the research involving uncertain outcomes. For example, farmers investing in security for the crops do not know exactly what will happen given how much they spend. Thus, there is uncertainty not only about what other players in a social dilemma will do, but about what the outcome will be even if all players’ actions are known. The current research seeks to investigate the effect of this “outcome uncertainty” on cooperation decisions. Although some research has been done with uncertainty in game outcomes, the focus has been more on the efficiency of different punishment mechanisms in enhancing cooperation (Xiao & Kunreuther, 2016), and the comparison among cooperation rates in the cases where cooperation leads to certain damage reduction, decrease in the loss size of a potentially occurring damage, or reduction in the probability of an adverse phenomena (Köke, Lange, & Nicklisch, 2014). The aim of current work is to tackle the adverse effect of that uncertainty through precommitment.

 We build on the literature on interdependent security (IDS) dilemmas, one specific type of social dilemma, which explores the effects of outcome uncertainty on cooperation (Heal & Kunreuther, 2005), particularly in cases of possible catastrophic loss. Real-life examples of IDS dilemmas include disease prevention, computer security, fire protection, protection against bankruptcy, and theft protection. In each these cases, cooperation is manifested through investing in protection measures, which have some spillover and reduce the chance that counterparts will experience a loss. Overall, outcome uncertainty about losses lowers cooperation between individuals quite substantially. For example, while cooperation rates in a loss-framed, repeated prisoner's dilemma (PD) may hover around 60-75%, uncertainty lowers the cooperation rate to around 25-40% (Gong, Baron, & Kunreuther, 2009; Kunreuther, Silvasi, Bradlow, & Small, 2009).[[1]](#footnote-1)

Consistent with that finding, Xiao and Kunreuther (2016) argue that noncooperative behavior is less likely to get punished when there is uncertainty in the game outcomes. One theory on why this happens is that the motivations for cooperation in a PD game -- such as altruism, reciprocity, or commitment -- are diluted when outcomes are uncertain. For example, if someone cooperates in a typical PD game, he knows it will help his counterpart, while if someone cooperates in a stochastic PD, he does not know if it will result in a tangible benefit for his counterpart or not. Similarly, the ability to retaliate with a tit-for-tat strategy is reduced when outcomes are uncertain: defection will not necessarily hurt one's counterpart.

 Because individuals are less likely to cooperate under uncertainty, and because so many real-world situations of interest resemble IDS situations (with uncertain, negative prospects), behavioral research should explore ways to increase cooperation under uncertainty. One possibility comes from Redelmeier and Tversky's (1992) work on single vs multiple prospects: although many individuals make sub-optimal choices on a single risky gamble, their choices improve when playing multiple gambles simultaneously. For example, when offered a chance to play a gamble with a 50% chance of winning $2,000 and a 50% chance of losing $500, only 43% of participants indicated they would play this attractive gamble. However, when offered the chance to play this same gamble 5 times simultaneously, the number of participants wanting to play increased to 63%. Thus, about 20% of participants would not play the gamble once, but *would* play it five times. Presumably, these people want to avoid the possibility of a net loss from the gamble(s), and rightly perceive the chance of a net loss to be lower with 5 plays than with 1.

Past research has investigated the effect of broadening the decision-making time-horizon on individuals’ decisions with rare events. Slovic, Fischhoff, & Lichtenstein (1978) show that when the risk of death or injury over a lifetime of driving (versus over a single trip) is communicated to individuals, seatbelt use increases. As another example, communicating the cumulative chance of flood over 30 years as opposed to that of one year has been shown to be effective in selling flood insurance policies (Chaudhry, Hand, & Kunreuther 2018). Moreover, this effect has been shown to be robust to time delay and whether individuals actually suffer the big loss or not. Broadening the time-horizon goes hand-in-hand with broadening choice bracketing. When it comes to smoking, the positive utility of one single cigarette may outweigh the health risk it brings about. However, if 3700 individual decisions of smoking a cigarette over a year (one pack per day) are bracketed together and the aggregate health risk is considered, the negative consequences may not be deemed trivial anymore and exceed the positive utility (Read et al. 1999).

 Similarly, in real-world *social dilemmas*, decision makers may make different choices when considering one, five, or twenty years of policy. For example, an airline may decide whether or not to invest in costly baggage security checks. The chance of a loss from terrorist attack depends not only on what the airline itself does, but also on the security precautions of other airlines. For example, a bag transferred from one flight to another may contain a bomb, and escape the standard screening procedures of the second airline. Conversely, if most airlines employ rigorous screening, potential terrorists may be dissuaded from attempting an attack, and a particular airline may be able to free-ride on the reputations of the others, without investing heavily in security.

Faced with this kind of situation, where the natural structure of the decision outcomes does not motivate individuals to pursue mutual benefit, structural solutions can stimulate cooperative behavior (Messick & Brewer, 1983). Precommitment could be one such structural solution. Alternatively, precommitment may be used as a form of choice-bracketing (Read, Loewenstein, & Rabin, 1999), where repeated decisions can be mentally represented as either a series of one-off, individual choices (ie, narrow bracketing) or as a single, combined set of choices (broad bracketing). Precommitment naturally lends itself to broad-bracketing of decisions, and thus may improve long-term, holistic thinking and cooperation: the chance of a terrorist attack on a particular airline in any given year is small, and an airline considering only the next year will most often be more profitable by skipping the costly security checks. However, when considering multiple years, the aggregation of risks and costs may favor security.

 The present research set out to test the effect of precommitment as a method to increase investment rates in social dilemmas under uncertainty. Unlike previous research which has investigated verbal commitments to cooperate (Chen, 1996; Chen & Komorita, 1994; Kerr & Kaufman-Gilliland, 1994), we examine the case where individuals make *binding* choices in advance. The interdependence theory model suggested by Van Lange & Rusbult (2012) assumes that decision makers transform a “given payoff matrix” of objective outcomes to an “effective payoff matrix” of subjective outcomes. One of the factors influencing that transformation is temporal transformation. Rare events with a catastrophic loss pose a dilemma: Either to pay a certain cost (e.g., a financial cost or a time cost) and be safe, or to do nothing and to risk being exposed to the large loss. Individuals usually make more rational and reasoned choices for the future than for the present (Soll, Milkman, & Payne 2014). We argue that precommitment can be an effective tool to nudge people to invest in safer choices. We propose that precommitment does this through increasing the individuals’ decision-making time-horizon and in turn, the goals that they pursue and the weight of the large loss. In other words, when players make decisions one-at-a-time, they have the single goal of doing well in the next round. But when players precommit, they consider other goals as well, such as avoiding a negative cumulative result, achieving some overall payment threshold, or maximizing expected value.

We also hypothesize that individuals in IDS situations focus mostly on probability and less on the social dilemma nature of the situation and the actions of their counterpart. We further hypothesize that when participants are forced to precommit their actions for multiple rounds, it leads them to reflect on a longer time horizon, thereby changing their goals and goal weighting, leading them to increase their investment rates.

When a player considers one round, he compares a sure loss (investment) with a probabilistic loss, and opts for the risky option, consistent with prospect theory (Kahneman & Tversky, 1979). When precommitting for 20 rounds, however, the importance of the cumulative payout increases and the same player may now invest in protection. In other words, the focus of decision-maker will shift from one “individual” outcome to the “cumulative” distribution of outcomes, which in turn will lead to safer choices.

Yet, the player must also consider the actions of his counterpart; if he invests in protection, his counterpart may free-ride. For this reason, a precommitment to protection may risk opening the player up to exploitation, and thus precommitment might, instead, *decrease* investment in IDS situations. In line with that argument, Faillo, Greico, and Zarri (2013) found that eliminating the feedback of counterpart actions diminishes cooperation. Precommitment also reduces feedback of counterpart actions and thus, one needs to consider this hypothesis. The present research tested which of these possibilities would play out, and under which conditions.

**Overview of studies:**

The first study uses an environmental social dilemmas scenario to investigate the hypothesized effect of uncertainty in reducing the cooperation rates in a stochastic prisoner's dilemma compared to the deterministic version of the game. It also tests whether precommitment by participants buffers against this effect in a stochastic version of the game. Therefore:

**H1a: Uncertainty reduces the investment rates in the stochastic game compared to the deterministic game.**

**H1b: Precommitment buffers against the adverse effect of uncertainty in stochastic game such that players will invest more when they precommit than when they play round-by-round.**

The second study tested the same hypotheses with a financial scenario rather than an environmental one. To isolate the effect of risk perceptions and preferences from the effects of interaction (or lack of interaction) with the counterpart (Faillo et al., 2013), we designed Study 3, where the participants take part in a solo game, with having only themselves playing in the game against the odds of the loss happening. Again we predict that:

**H2: The investment rates in the stochastic solo game will be higher when the participants precommit their decisions.**

While Study 3 eliminated the counterpart to isolate the effect of uncertainty, Study 4 eliminates the uncertainty to investigate the effect of precommitment in a *deterministic* prisoner's dilemma. Since this type of design transforms the repeated game into a one-shot game (with the opportunity to defect without any consequences), we predict that:

**H3: Participants in the precommitment condition of the deterministic game will invest less often, compared to participants in the normal deterministic prisoner's dilemma condition.**

*Table 1: Summary of hypotheses, manipulations, and game types in Studies 1-4.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study** | **Hypothesis** | **Manipulation** | **Investment rates** | **Type of games** | **Present Components** |
| 1 & 2 | H1a | Uncertainty | Decrease | Stochastic compared to deterministic. | Both uncertainty and counterpart |
| 1 & 2 | H1b | Precommitment | Increase | Stochastic compared to deterministic. | Both uncertainty and counterpart |
| 3 | H2 | Precommitment | Increase | Stochastic “solo” games compared to deterministic “solo” games. | Uncertainty only |
| 4 | H3 | Precommitment | Decrease | Deterministic game with precommitment compared to deterministic with round-by-round decisions. | Counterpart only |

**Study1:**

The first study compared a typical repeated prisoner's dilemma with a stochastic version of the same game (ie, an IDS game), and a version of the stochastic game in which participants would be forced to precommit their choices for 20 rounds at a time. We hypothesized that cooperation rates would be lower in the stochastic game than the deterministic game, replicating previous research. We further hypothesized that precommitment would raise investment rates in the stochastic game, moving them closer to the deterministic condition.

*Study 1: Participants*

90 participants (61% female, mean age = 23.1, SD=4.5) were recruited for a study on Interdependent Security Games. Nearly all participants (96%) were students at Columbia University. Participants' compensation depended entirely on the outcome of the experiment, as described below.

*Study 1: Design Overview*

In a between-subjects design, participants played one of three versions of a social dilemma game: a deterministic prisoner's dilemma with repeated play (DPD-rep), a stochastic prisoner's dilemma with repeated play (SPD-rep), or a stochastic prisoner's dilemma with precommitted play (SPD-pre). Participants played 80 rounds, broken down into 4 blocks of 20. Participants were randomly assigned a counterpart for each block, and one block was randomly selected and paid out for real money at the end of the study.

*Study 1: Methods*

 The study materials (the complete texts of which can be found in the appendices), were modeled after Kunreuther et al (2009) and Gong et al (2009). Similar to previous studies, we used an experimental currency, the Indonesian Rupiah (Rp); this is done because larger numeric values have been found to motivate participants in social dilemmas even if objective values remain unchanged (Furlong & Opfer, 2008). At the end of the study, Rp were converted to dollars at the rate of 9,673 Rp = $1, which was the actual exchange rate at the time the study was designed.

 Experimental sessions were run in groups of 4 to 12 participants (mean 5.6). Each participant was seated at a computer and instructed not to communicate with any of the other participants. After agreeing to the consent form (which stated the average payout would be around $15), participants read 5 pages of instructions. They learned that they would play a scenario in which their payment would depend on their choices as well as those of a counterpart. They were told to imagine they were a farmer in Indonesia. Each "year" (ie, game round), they would earn 8,500 Rp from their potato crop. However, they had to use a pesticide, which caused groundwater contamination, also affecting their counterpart. In the DPD conditions, the pesticide caused a certain, moderate loss each year, while in the SPD conditions, pesticide had a low (4% or lower) probability of causing a large loss.

 Participants learned they had the option each year to invest in a safe, though more expensive pesticide, which would eliminate the risk of groundwater contamination. However, contamination was only completely eliminated if both counterparts invested. Participants learned that they would play a 20-year session with one anonymous counterpart, after which they would again be randomly paired with a new counterpart and play another session. They would play 4 sessions in total, one of which would be randomly selected and have all rounds paid out for real money (converted to dollars). Participants in the DPD-rep and SPD-rep conditions were told they would play one round at a time, while those in the SPD-pre condition learned that they would precommit their choices for all 20 rounds in a session.

 Participants were told that while average payments were around $15, it was theoretically possible (though unlikely) to finish with negative money, and if this happened they would have to stay after the study and complete additional surveys at the rate of 25 cents a minute to pay back their debt (one unfortunate participant actually had to do this).

 After reading the instructions, participants saw a payoff matrix summarizing the contingencies (see Table 2 and Table 3). Note that the expected values of the DPD and SPD conditions are identical. Both take the form of a prisoner's dilemma, whereby each individual can expect a higher payout through not investing (ie, defecting), while the overall expected value for the dyad is higher if both invest (ie, cooperate). The ratios of the expected values of each cell (in other words, the relative attractiveness of each option) matched those in previous work on IDS (Gong et al., 2009; Kunreuther et al., 2009). Participants then took a 4-item comprehension test. If participants got any items on the test wrong, they had to re-read the instructions and take the test again. Every page of the experiment had a note at the bottom that said "If you have questions at any time, please ask the experimenter." Participants did indeed ask questions, and the experimenter assisted as necessary.

*Table 2: Payoff matrix in the deterministic prisoner's dilemma (DPD) condition*

|  |  |
| --- | --- |
|  | Your Counterpart |
| INVEST | NOT INVEST |
| You | INVEST | - You lose **1,400 Rp**.- Your counterpart loses **1,400 Rp**. | - You lose **1,800 Rp**.- Your counterpart loses **1,200 Rp**. |
| NOT INVEST | - You lose **1,200 Rp**.- Your counterpart loses **1,800 Rp**. | - You lose **1,600 Rp**.- Your counterpart loses **1,600 Rp**. |

*Table 3: Payoff matrix in the stochastic prisoner's dilemma (SPD) condition*

|  |  |
| --- | --- |
|  | Your Counterpart |
| INVEST | NOT INVEST |
| You | INVEST | - You definitely lose **1,400 Rp**, and have a 0% chance of groundwater contamination.- Your counterpart definitely loses **1,400 Rp**, and has a 0% chance of groundwater contamination. | - You definitely lose **1,400 Rp** and have a 1% chance of groundwater contamination occuring and losing an additional **40,000 Rp**.- Your counterpart has a 3% chance of losing **40,000 Rp** due to groundwater contamination and a 97% chance of losing **0 Rp** |
| NOT INVEST | - You have a 3% chance of losing **40,000 Rp** due to groundwater contamination and a 97% chance of losing **0 Rp**.- Your counterpart definitely loses **1,400 Rp** and has a 1% chance of groundwater contamination occuring and losing an additional **40,000 Rp**. | - You have a 4% chance of groundwater contamination occurring and losing **40,000 Rp** and a 96% chance of losing **0 Rp**.- Your counterpart has a 4% chance of groundwater contamination occurring and losing **40,000 Rp** and a 96% chance of losing **0 Rp**. |

 Participants had to wait until all participants present had completed the knowledge test, and were then randomly paired with a counterpart for the first block of 20 rounds. Subsequently, participants were again presented with the appropriate payoff matrix, and were asked to choose whether to invest or not, and to predict whether their counterpart would invest (on a 4-point scale: "Definitely Not", "Probably Not", "Probably", or "Definitely).

 Participants in the DPD-rep and SPD-rep conditions made a choice and prediction for the first round, and then got feedback for the first round. The feedback specified their choice, the choice of their counterpart, and the end result. In the SPD-rep condition, participants were also told which number was randomly generated to determine if the groundwater contamination occurred. Participants then made their choice and prediction for the second round, got feedback for the second round, and so-on, until they finished all 20 rounds, at which time they saw a summary of the results of all 20 rounds. Participants in the SPD-pre condition first made choices and predictions for all 20 rounds at once (on the same page). They then saw round by round feedback for all 20 rounds, and then the summary of all 20 rounds. Note that when participants made their choices (and predictions), they could make a different choice for each round if they desired. For example, a participant could precommit to investing in the first 15 rounds and not in the last 5.[[2]](#footnote-2)

 After the summary, participants were again randomly paired with a counterpart (with replacement), and played another block. After completing all 4 blocks, participants were asked "What are your thoughts on playing the game? Please give a brief summary of why you chose to invest or not invest:", as well as a number of demographic questions. In the stochastic conditions, there was also a question about probability, "With no investment in protection, what do you think is the likelihood that a loss would occur at least once in 20 rounds? \_\_\_\_\_ out of 100." Finally, one block was randomly selected and each participant was paid accordingly.

*Study 1: Results*

 Average investment rates were computed for each participant in each block of 20 rounds and compared with a repeated-measures ANOVA. This revealed a main effect of condition, *F*(2,87)=24.1, *p*<.001, partial *η*2=.36, indicating that investment rates were highest in the repeated deterministic condition (at .80) and lowest in the repeated stochastic condition (at .29), with the precommitted stochastic condition in the middle (at .48). A condition by block interaction, *F*(6,261)=2.2, *p*<.05, partial *η*2=.07, indicated that the difference between conditions grew larger over time (See Figure 1).

*Figure 1: Proportion investing against loss in the repeated deterministic prisoner's dilemma (DPD-rep), repeated stochastic prisoner's dilemma (SPD-rep), and precommitted stochastic prisoner's dilemma (SPD-pre) conditions, all using environmental (E) scenarios. Each block represents 20 trials.*



 Participants' free responses at the end of the study about why they invested were coded by two independent coders, to classify whether they mentioned their counterpart or not, and whether they mentioned probability or not. The inter-rater reliability was quite high, at a correlation of *r*=.95 for mentioning the counterpart and *r*=.91 for mentioning probability.[[3]](#footnote-3)

 As seen in Figure 2, participants were much more likely to mention their counterpart in the deterministic version of the game, but much more likely to mention probability in the stochastic versions of the game. 97% of participants mentioned their counterpart in the deterministic prisoner's dilemma (DPD-rep), compared with only 37% in the repeated, stochastic game (SPD-rep) and 28% in the precommitted stochastic game (SPD-pre).

A contrast-coded logistic regression confirmed that while the proportion in the DPD-rep was higher than in the stochastic games, *B*=4.09, *SE*=1.06, *p*<.001, there was not a significant difference between the two stochastic games, *B*=-0.42, *SE*=0.56, *p*>.1. In contrast, only 10% of those in DPD-rep mentioned probability, as compared with 70% in SPD-rep and 59% in SPD-pre. Logistic regression showed that while the proportion of DPD-rep participants mentioning probability was lower than the proportion in the other two conditions, *B*=-2.76, *SE*=0.67, *p*<.001, there wasn't a significant difference between the SPD-rep and SPD-pre conditions, *B*=-.50, *SE*=.55, *p*>.1.

*Figure 2: Proportion of participants spontaneously mentioning their counterpart or probability, in response to the post-game open-ended question after playing the repeated deterministic prisoner's dilemma (DPD-rep), repeated stochastic prisoner's dilemma (SPD-rep), or precommitted stochastic prisoner's dilemma (SPD-pre) game, all using environmental (E) scenarios. Error bars represent +/- one standard error.*



 Another measure of participants' sensitivity to the actions of their counterpart can be seen in Figure 3. In the DPD-rep game, there was a strong linear relationship between what people expected their counterpart to do and their investment choice. If a participant thought his counterpart would definitely invest, then he himself was very likely to invest, and vice versa. However, participants in the stochastic games were less responsive to what they thought their counterpart would do. This pattern was confirmed through logistic regression by interactions between condition and "partner prediction" predicting investment. Taking the DPD-rep condition as the reference group, there were interactions with SPD-rep and partner prediction, *B*=-0.6, *SE*=0.13, *p*<.001, as well as SPD-pre and partner prediction, *B*=-1.5, *SE*=0.12, *p*<.001, confirming that the interaction seen in Figure 3 is significant. Moreover, in the DPD-rep condition, players' predictions of their counterpart's action were highly predictive of their own action, *B*=2.3, *SE*=0.10, *p*<.001, Nagelkerke *r*2=.61. In contrast, in the SPD-rep condition, the relationship was much weaker, though still significant, *B*=.831, *SE*=.058, *p*<.001, Nagelkerke *r*2=.13. The SPD-pre condition fell in the middle, *B*=1.79, *SE*=.083, *p*<.001, Nagelkerke *r*2=.31.

*Figure 3: Proportion investing against loss depending on their prediction of their counterpart's investment choice, in the repeated deterministic prisoner's dilemma (DPD-rep), repeated stochastic prisoner's dilemma (SPD-rep), and precommitted stochastic prisoner's dilemma (SPD-pre) conditions, all using environmental (E) scenarios.*



 Similar evidence comes from looking at the correlation of each participant's choice with that of his counterpart in the preceding round. In the DPD-rep condition, participants' choices correlated *r*=.64 with their counterpart's choice in the preceding round, while in the SPD-rep condition it was only *r*=.2 and in the SPD-pre condition it was *r*=-.16.[[4]](#footnote-4)

 Further evidence for the diminished sensitivity to the social dilemma in the stochastic conditions can be seen in Figure 4, which shows the investment rates in each round, collapsing across blocks. The deterministic game shows the classic end-game effect, with investment rates dropping sharply in the final rounds. In contrast, the stochastic games don't show any end-game effects.

*Figure 4: Proportion investing against loss in each round in the repeated deterministic prisoner's dilemma (DPD-rep), repeated stochastic prisoner's dilemma (SPD-rep), and precommitted stochastic prisoner's dilemma (SPD-pre) conditions, all using environmental (E) scenarios.*



*Study 1: Discussion*

 Cooperation rates in a social dilemma are much lower when outcomes are probabilistic. However, forcing participants to precommit their choices in the probabilistic dilemma significantly reduced this gap.

 Several lines of evidence suggest that players in stochastic prisoner's dilemmas are not very responsive to their counterpart: players are less likely to mention their counterpart in stochastic games, their choices are less well correlated with their predictions of their counterparts' choices, their choices are less well correlated with their counterparts' previous choices, and they don't show the classic end-game drop-off normally seen in social dilemmas.

 It seems, then, that players in a stochastic social dilemma are subjectively playing a *probability* game more than a social dilemma. Indeed, the majority of their comments mentioned probability, but not their counterpart in the open-ended question posed at the end of the experiment. As we know from prospect theory, people tend to be risk-seeking in the domain of losses (Kahneman & Tversky, 1979). This may explain why investment rates are low in interdependent security games: investment/cooperation entails a sure loss, while non-investment/defection is a gamble.

 Building on previous literature in probability and the framing of multiple prospects, precommitment appears to be a successful, though modest, intervention for raising investment rates in stochastic social dilemmas. Presumably, those participants who play one round at a time see a 4% chance of loss as very low, and decide not to invest in protection. In contrast, those participants who must precommit their choices over a much longer time horizon may be nudged into pursuing multiple goals instead of one. In other words, they would be more likely to plan on “doing well overall” in additional to “doing well on the next round”.

 Unlike most previous literature, our game had an environmental cover story. We used this to make the scenario more interesting and understandable to participants, giving it context. However, it is possible that this framing interacted with our manipulations and influenced our results. Therefore, we did a follow-up study in which we re-tested our key manipulation -- precommitment in a stochastic prisoner’s dilemma -- with a financial frame.

*Study 2: Participants and Design Overview*

60 participants were drawn from the same pool as Study 1 and had similar demographics. Participants were randomly assigned to a SPD-rep or SPD-pre condition. These were different from the Study 1 conditions in that a purely financial cover story was used for the scenario instead of an environmental cover story.

*Study 2: Methods*

Overall, the procedure was almost exactly the same as Study 1. During the introduction, however, the participants were told to imagine being investors with a risky joint venture that earned 8,500 Rp a year. They learned they could pay 1,400 Rp for a safety measure to protect against the possibility of a large (40,000 Rp) loss, but they would only be fully protected if both counterparts invested in protection. The payoff matrix, choice options, and feedback were also all changed to use financial language rather than the environmental frame in Study 1 (the complete text of the differences can be found in the appendices).

*Study 2: Results*

As can be seen in Figure 5, the results from Study 2 replicated those of Study 1. While investment rates in the stochastic prisoner's dilemma were low (averaging 31%), precommitment raised investment rates (to an average of 45%), *t*(58)=1.71, one-tailed *p*<.05.[[5]](#footnote-5) Because there were no statistically significant differences between Study 1 and Study 2, all future analyses will group the environmental and financial frames together.

*Figure 5: Mean investment proportion in the* financially *framed repeated or precommitted stochastic prisoner's dilemma conditions (SPD-rep F and SPD-pre F) in Study 2, as compared with the* environmentally *framed stochastic prisoner's dilemma (SPD-rep E and SPD-pre E) data from Study 1.*



*Study 2: Discussion*

 Framing the stochastic social dilemmas with a purely financial (as opposed to environmental) cover story did not have a significant effect on investment rates. Perhaps this is not surprising, as both Study 1 and Study 2 offered real *financial* consequences for participant's choices, but no real environmental consequences.

 The precommitment effect observed in Study 1 was replicated in Study 2: participants who were forced to precommit their choices for 20 rounds at a time invested in protection more often than those who made their choices round by round. We hypothesize that this happens because precommitment increases the time horizon of participants, making multiple goals more salient and weightier, thereby increasing the attractiveness of investment.

Forcing participants to precommit their choices also limits their ability to interact with each other, raising possible confounds. For example, perhaps some participants are motivated to outperform their counterpart, and so avoid the sure loss of invested, but precommitment precludes dynamic comparison and so reduces this tendency, leading to higher investment rates. Furthermore, as mentioned in the introduction, blocking the feedback of counterpart’s actions reduces the cooperation rates (Faillo et al., 2013). To rule out these possible confounds and to test the alternative hypothesis involving the role of counterpart’s action feedback, we ran Study 3 in which participants played a stochastic *solo game* rather than engage in a social dilemma. As before, choices were repeated or precommitted, and we hypothesized that investment rates would be higher in the precommitment condition.

*Study 3: Participants and Design Overview*

 60 participants were recruited from the same pool as previous studies and had similar demographics. Participants played a solo stochastic game in which they had the option each round to invest in protection against the large loss. Because there was no counterpart and no dilemma, investment had a higher expected value and should have always been chosen by rational, risk-neutral individuals.

 Participants were randomly assigned to either a repeated choice (Solo-rep) or precommitted choice (Solo-pre) condition.[[6]](#footnote-6)

*Study 3: Methods*

 The procedure was the same as previous studies except that participants did not interact with a counterpart. Thus, the instructions, payoff matrix, quiz, choices, and feedback were rewritten so as to only require one player. As before, all participants knew in advance that they would play 4 blocks of 20 rounds.

 The revised payoff matrix (see Table 4) essentially asked participants to choose between the upper-left (Invest/Invest) cell or the lower right (Not-Invest/Not-Invest) cells from the SPD games in the previous studies.

*Table 4: Solo payoff matrix used in Study 3 for the solo conditions (Solo-rep and Solo-pre).*

No matter what, you will earn a base pay of 8,500 Rp each year. Here is a table summarizing the possible additional outcomes, depending on your decision (whether to invest or not) and the decision of your counterpart:

**Year**

|  |  |  |
| --- | --- | --- |
| You | INVEST | - You definitely lose **1,400 Rp**, and have a 0% chance of the large loss occurring. |
| NOT INVEST | - You have a 4% chance of losing **40,000 Rp** and a 96% chance of losing **0 Rp**. |

As in previous studies, participants in the repeated (Solo-rep) condition made choices and got feedback one round at a time, while those in the precommitted condition made twenty choices at a time and then received identical feedback.

*Study 3: Results*

 As seen in Figure 6, precommitment substantially increased investment by participants in the solo stochastic game, from 32% to 61%. Thus, twice as many participants invested when precommitting. Although the effect of precommitment appears larger in the solo game than in the social dilemma games, a 2x2 ANOVA (comparing prisoner's dilemma vs solo and repeated vs precommitted play) did not show a significant interaction between game type and precommitment, *F*(1,176)=1.5, *p*=.22. However, a t-test comparing the investment rates in SPD-pre and Solo-pre was marginally significant, *t*(88)=1.90, two-tailed *p*=.06. Overall, then, we can conclude that precommitment raises investment rates in the solo game, and *may* raise them even more in the solo game than in a stochastic social dilemma.

*Figure 6: Mean investment proportions in the repeated solo (Solo-rep) and precommitted solo (Solo-pre) games in Study 3, as compared with the stochastic prisoner's dilemma (SPD-rep and SPD-pre) data from Studies 1 and 2.*



 To further investigate the “multiple goals” explanation for the effectiveness of precommitment, we had two independent coders code whether or not each participant mentioned low probability of loss. Recall that we hypothesized that precommitment would nudge the participants to recruit a more holistic view with a focus on a good performance overall (i.e., across all rounds of the game) -- therefore, we hypothesized that participants in precommitted conditions would be less likely to mention low probability of loss. The correlation between coders was moderate, at *r*=.84. As before, when there was disagreement, we "rounded up" and considered that participant as having indeed mentioned low probability of loss.

As shown in Figure 7, participants in the precommitted conditions were less likely to mention low probability of loss, as confirmed by a chi-square test of independence, *x*2 (N=174)=6.68, *p*=.01.

*Figure 7: Mean proportion of participants mentioning "low" probability of loss in each condition, collapsing and comparing data from Studies 1, 2, and 3.*



*Study 3: Discussion*

 Clearly, forcing participants to precommit their choices increased their investment rates when there was no counterpart to interact with or consider. Therefore, it is likely that the precommitment intervention seen in Studies 1 and 2 also acted on participants' weighting of the large loss. It is worth restating that both the repeated and precommitted participants knew they would play 4 blocks of 20 rounds each -- the only difference was whether participants were forced to precommit their choices or not. Rationally, there should be no difference between the two conditions.

 Further supporting the hypothesis that precommitment influences participants’ focus on single vs. multiple goals, we observed that those in the precommitment were considering multiple rounds and therefore, much less likely to mention a low probability of loss (which would only be the case if one considers “one” round). In other words, it is likely that those who precommitted felt that the large loss was more important.

 It appeared that the precommitment manipulation was more effective for the solo games in Study 3 than for the stochastic social dilemmas of Studies 1 and 2. Partly for this reason, and partly for curiosity, we ran Study 4 to explore the effects of precommitment in a *deterministic* social dilemma. Because precommitment (as we employed it) precludes the chance for participants to dynamically interact with their counterpart, we hypothesized that it would reduce cooperation rates by transforming the repeated game into a one-shot game. With no tit-for-tat incentives, participants would cooperate less often (similar to the end game rounds of a repeated game).

*Study 4: Participants and Design Overview*

 30 participants were recruited from the same pool as previous studies and had similar demographics. Only one condition was run: a deterministic prisoner's dilemma game with precommitted choices (DPD-pre). The results of this condition would then be compared with the existing DPD-rep results from Study 1.[[7]](#footnote-7)

*Study 4: Methods*

 The procedure was identical to the DPD-rep condition in Study 1, except that participants precommitted their choices. Thus, there was only one condition and we compared the results with the DPD-rep results from Study 1.

*Study 4: Results*

 As seen in Figure 8, investment rates in the precommitted, deterministic prisoner's dilemma (DPD-pre) started out high (at 63%) but dropped rapidly over the four trial blocks (to 29%). Thus, while investment rates in the first block were equivalent to the DPD-rep data from Study 1, they diverged over time. A repeated measures ANOVA confirmed this impression. A main effect of precommitment, *F*(1,58)=31.65, *p*<.001, indicated that investment rates were lower overall in the precommitted condition than the repeated condition. A marginally significant main effect of block number, *F*(1,58)=2.78, *p*=.10, indicated that investment rates went down over time on average. However, both these main effects were qualified by a block by precommitment interaction, *F*(1,58)=19.01, *p*<.001, indicating that the effect of precommitment depended on block number, such that the difference between precommitted and repeated choices grew larger across blocks.

*Figure 8: Mean investment proportion in the precommitted deterministic prisoner's dilemma (DPD-pre) condition in Study 4, as compared with the repeated deterministic prisoner's dilemma (DPD-rep) data from Study 1.*



*Study 4: Discussion*

 Strikingly, precommitment initially has no effect on investment/cooperation in a deterministic prisoner’s dilemma, but with repeated plays it rapidly decreases investment. Why does this happen? One possibility is learning effects. Initially, participants do not fully understand the game, but soon realize that they can take advantage of the other player (or be taken advantage of) without repercussions.

 These results may help explain why precommitment is more effective in solo games (Study 3) than in stochastic social dilemmas (Studies 1 and 2): on the one hand, precommitment under uncertainty extends individuals’ time-horizon and nudges them to set more holistic goals, thereby increasing investment. However, in a stochastic social dilemma, this is tempered by the knowledge that one's counterpart may defect without repercussions. On balance, participants are more sensitive to probabilities than to their counterparts. Therefore, precommitment in the stochastic dilemmas has a positive, though modest, effect.

Another major contribution of Study 4 to the research question is understanding the susceptibility of deterministic settings to precommitment. As can be seen in Figure 9, in the deterministic setting investment rates are lower when players must precommit. On the other hand, as we observed in Study 1, precommitment will actually increase investment in stochastic social dilemmas. Therefore, combining the data across studies and running a one-way ANOVA, we found that the interaction between the game type (DPD vs. SPD) and choice type (Precommitted vs. Repeated) was significant *F*(1, 116)=27.76, *p*<.001. This interaction illustrates the buffering argument: in stochastic settings, investment rates may benefit from precommitment buffering against the adverse effect of uncertainty; while in the deterministic settings, participants may suffer from precommitment, in that each party will eventually learn that they can defect without any repercussions.

*Figure 9: Mean investment proportion in the Deterministic Prisoner's Dilemma (DPD) vs. Stochastic Prisoner's Dilemma (SPD) and Repeated vs. Precommitted choices. It can be seen that when the outcomes are uncertain, precommitment results in higher investment rates, while it is quite opposite when the outcomes are certain.*

*General Discussion/Conclusion*

 Adding uncertainty to the outcomes in social dilemmas dramatically changes the behavior of those involved. In both the present research and previous studies (Gong et al., 2009; Kunreuther et al., 2009), individuals invested at much lower rates under uncertainty than they did in a typical (deterministic) prisoner's dilemma. A number of factors showed that participants in stochastic dilemmas pay much more attention to probabilities than to their counterparts in (deterministic) prisoner's dilemmas because the game is now viewed as one of chance so participants are risk-seeking to avoid the sure loss.

 Precommitment is an intervention designed to increase the relevant time horizon and increase investment rates under uncertainty. For example, a home-owner might make different choices if buying fire-insurance monthly or annually. The chance of a fire happening next month is likely to be viewed as small so the homeowner may not invest in protection voluntarily. However, when considering an annual policy, the homeowners’ time-horizon is extended, a focus on multiple years is activated, and the same people might want to purchase insurance, or purchase a more expensive policy. If fire insurance were tied to a mortgage the homeowner might be even more interested in buying insurance since the time horizon will normally be 15 to 20 years.

 The effects of uncertainty and precommitment in social dilemmas were reliable across both environmental and financially framed scenarios. However, future studies with different scenarios (that don't necessarily involve financial payouts) might yet find domain differences. Lotz (2015) found that people cooperate more when primed with intuitive thinking (i.e., System 1) rather than reflective thinking (i.e., System 2) so a promising future direction would be to investigate whether precommitment has an impact on the type of thinking in which individuals engage when deciding whether to invest in protective measures.

 A major caveat to precommitment is that it eventually *lowers* investment in social dilemmas with deterministic outcomes. Therefore, the application of precommitment as a device to increase cooperation in real-world social dilemmas should be couched in realistic probabilities based on long time horizons to encourage individuals to undertake protective measures used with care, depending on whether outcomes are certain or probabilistic.

 One shortcoming is that the present research only used variations on one basic payoff matrix, so the robustness of the results is unknown. How would the effect of precommitment change if investment didn't completely eliminate uncertainty? Or if there were two equilibria, making it coordination rather than a dilemma?

Another fruitful avenue for future research would be imposing the uncertainty component on the counterpart, rather than on the outcomes of the game. There is an inherent uncertainty in the counterpart component in the PD games, but it can be expressed more explicitly with probabilities that the counterpart will cooperate or defect. We found that participants increase the weighting of the large loss when they are precommiting their decisions; is the same argument may be valid for counterpart uncertainty?

 Future research on social dilemmas should do more to incorporate and explore uncertainty. Real-world social dilemmas of interest, such as pandemics and climate change, involve great uncertainties in outcomes. By including this uncertainty in our theoretical models, we can hope to more effectively address the tragedy of the commons.

**References:**

Botelho, A., Dinar, A., Pinto, L. M. C., & Rapoport, A. (2014). Time and uncertainty in resource dilemmas: equilibrium solutions and experimental results. *Experimental economics, 17*(4), 649-672.

Budescu, D. V., Rapoport, A., & Suleiman, R. (1990). Resource dilemmas with environmental uncertainty and asymmetric players. *European Journal of Social Psychology, 20*(6), 475-487.

Chen, X.-P. (1996). The group-based binding pledge as a solution to public goods problems. *Organizational Behavior and Human Decision Processes, 66*(2), 192-202.

Chen, X.-P., & Komorita, S. S. (1994). The effects of communication and commitment in a public goods social dilemma. *Organizational Behavior and Human Decision Processes, 60*(3), 367-386.

De Kwaadsteniet, E. W., van Dijk, E., Wit, A., & de Cremer, D. (2006). Social dilemmas as strong versus weak situations: Social value orientations and tacit coordination under resource size uncertainty. *Journal of Experimental Social Psychology, 42*(4), 509-516.

Faillo, M., Grieco, D., & Zarri, L. (2013). Legitimate punishment, feedback, and the enforcement of cooperation. *Games and economic behavior, 77*(1), 271-283.

Furlong, E. E., & Opfer, J. E. (2008). Cognitive Constraints on How Economic Rewards Affect Cooperation. *Psychological Science, 20*(1), 11-16.

Gaudeul, A., Crosetto, P., & Riener, G. (2015). Of the stability of partnerships when individuals have outside options, or why allowing exit is inefficient.

Gong, M., Baron, J., & Kunreuther, H. C. (2009). Group cooperation under uncertainty. *Journal of Risk & Uncertainty, 39*, 251-270. doi:10.1007/s11166-009-9080-2

Gustafsson, M., Biel, A., & Gärling, T. (1999). Overharvesting of resources of unknown size. *Acta Psychologica, 103*(1), 47-64.

Heal, G., & Kunreuther, H. C. (2005). IDS Models of Airline Security. *Journal of Conflict Resolution, 49*(2), 201-217. doi:10.1177/0022002704272833

Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica, 47*, 263-291. doi:10.2307/1914185

Kerr, N. L., & Kaufman-Gilliland, C. M. (1994). Communication, commitment, and cooperation in social dilemma. *Journal of Personality and Social Psychology, 66*(3), 513.

Kunreuther, H. C., & Heal, G. (2005). Interdependencies within an organization. *Organizational encounters with risk*, 190-208.

Kunreuther, H. C., Silvasi, G., Bradlow, E. T., & Small, D. (2009). Bayesian analysis of deterministic and stochastic prisoner's dilemma games. *Judgment and Decision Making, 4*(5), 363-384.

Köke, S., Lange, A., & Nicklisch, A. (2014). Learning to Cooperate on Climate Policy Facing Uncertain Damages.

Lotz, S. (2015). Spontaneous giving under structural inequality: Intuition promotes cooperation in asymmetric social dilemmas. *PloS one, 10*(7), e0131562.

Messick, D. M., & Brewer, M. B. (1983). Solving social dilemmas: A review. *Review of personality and social psychology, 4*(1), 11-44.

Read, D., Loewenstein, G., & Rabin, M. (1999). Choice Bracketing. *Journal of Risk and Uncertainty, 19*, 171-197.

Redelmeier, D. A., & Tversky, A. (1992). On the Framing of Multiple Prospects. *Psychological Science, 3*(3), 191-193. doi:10.1111/j.1467-9280.1992.tb00025.x

Roch, S. G., & Samuelson, C. D. (1997). Effects of environmental uncertainty and social value orientation in resource dilemmas. *Organizational Behavior and Human Decision Processes, 70*(3), 221-235.

Van Lange, P. A. M., & Rusbult, C. E. (2012). Interdependence theory. In P. A. M. Van Lange, A. W. Kruglanski, & E. T. Higgins (Eds.), *Handbook of Theories of Social Psychology* (Vol. 2, pp. 251-272). Thousand Oaks, CA: Sage.

Xiao, E., & Kunreuther, H. (2016). Punishment and cooperation in stochastic social dilemmas. *Journal of Conflict Resolution, 60*(4), 670-693.

1. An important caveat to the above is that *groups* playing IDS games show the opposite pattern, investing at about 30% in a typical PD game but over 50% in a stochastic PD game. The reasons for this "reverse discontinuity effect" are complex, and beyond the scope of this paper. Interested readers are referred to Gong et al, 2009. [↑](#footnote-ref-1)
2. Although this might not seem rational, many participants precommitted to a mixed strategy such as this, and in fact gave good reasons on why in their comments at the end of the study. For example, one pre-committing participant wrote "I chose to invest almost all 20 times except for one or 2 years to make an extra bonus", while another saw it as a prediction game, writing "It was really hard to decide when to invest and when to not invest. In the end, I decided to make a random choice of investing the last 8 years for one round, not investing for another round, then every 5 years for another round, and lastly investing the first year, 10th year, and 20th year..." [↑](#footnote-ref-2)
3. In the cases of disagreement, we "rounded up" and coded participant as having mentioned their counterpart or having mentioned probability. Also, in two cases, the coders agreed that the participant's free response was not codable, and so the coding was left blank (i.e., missing data). [↑](#footnote-ref-3)
4. Note that in the SPD-pre condition there was no possibility of reacting to one's counterpart's choices. [↑](#footnote-ref-4)
5. Although the two-tailed test is only marginally significant (.09), a one-tailed test is appropriate because we had a specific, directional hypothesis based on the results of Study 1. [↑](#footnote-ref-5)
6. We did not run a solo version of the DPD game for the obvious reason that this would have entailed asking participants to simply choose between more or less money. It is safe to assume that participants would overwhelmingly prefer more money to less money. [↑](#footnote-ref-6)
7. This seemed like a more efficient use of time and resources than running yet another standard prisoner's dilemma. [↑](#footnote-ref-7)