"Once? No. Twenty times? Sure!" Uncertainty and precommitment in 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 terrorism (shared border security), disease outbreak (eg, bird flu), or extreme weather events (e.g., from climate change). Decisions on whether to invest in protection may be made year by year, or investment may be precommitted for a number of years. We propose that precommitment increases the subjective probability of losses, thereby increasing risk aversion and increasing investment rates in inderdependent security (IDS) situations. Study 1 examined repeated, loss-framed social dilemmas, and found that although investment rates are lower under uncertainty, this can be mitigated through precommitment. Studies 2-6 investigated the processes driving the precommitment effect, by 1) isolating impacts of precommitment under uncertainty from its impacts on interactions with other people, 2) testing boundary conditions, and 3) explicitly manipulating uncertainty levels.

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

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 In many real-world social dilemmas, interdependent actors must decide whether to invest in preventive measures against catastrophic loss. For example, the United States and Canada share a huge undefended border and both must protect against terrorism. If one country does not take preventative measures, it puts the other at risk. Similarly, one country may free ride and benefit from the counter-terrorism measures of the other. Another example of interdependent security can be seen in disease control. Farmers and countries must decide whether to protect against diseases such as avian influenza or H1N1. The security of each individual depends on its neighboring actors. 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, Joireman, & Van Lange, 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) will lead to reduced cooperation rates. Other authors have also 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 research involving uncertain outcomes with interdependencies. For example, farmers investing in preventive measures against disease, fire, water contamination, etc. do not know what will happen given how much they spend. There is uncertainty both about what other people will do and about what the outcome will be even if all peoples' actions are known. The current research seeks to investigate the effect of uncertainty in the game outcomes. Although some recent 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 an emerging 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 computer security, fire protection, vaccinations, 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, 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) Thus, cooperation rates under uncertainty are up to 3 times lower.

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.

 Similarly, in real-world IDS situations of interest, 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.

The chance of a terrorist attack on a particular airline in any given year is small, and airlines might prefer to avoid the sure loss of paying for security checks. However, when considering multiple years, the chance of a terrorist attack happening sooner-or-later grows subjectively larger, and airlines may become more likely to invest in ongoing security.[[2]](#footnote-2) Faced with this kind of situation, where the natural structure of the decision outcomes are in a way that individuals will not be motivated to pursue mutually desirable outcomes, changes in the structure of the decision and outcomes, known as structural solutions, can stimulate cooperative behavior (Messick & Brewer, 1983). Precommitment can be one of those structural solutions. 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 present research set out to determine why investment rates are lower in social dilemmas with uncertainty and to test the effect of precommitment as a method to increase investment rates. 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. Therefore, precommitment, which increases the time-horizon of the players, can change the perceived “subjective” outcomes on the players’ side and their final perceived payoff matrix will be different from those who do not precommit their decisions.

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 increasing their subjective perception of the likelihood of at least one loss during this period. This may lead them to increase their investment rates. In other words, precommitment may buffer against the negative effects of uncertainty on cooperation.

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). This may explain why investment rates are typically low in IDS situations (Gong et al., 2009; Kunreuther et al., 2009). When precommitting for 20 rounds, however, the perceived likelihood of at least one loss during this time period increases and the same player may now invest in protection. 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. While precommitment doesn't reduce feedback, it reduces the ability to respond to counterpart actions, and thus one needs to consider this hypothesis. The present research tests both of these possibilities, separately and in combination, by comparing repeated vs precommited decision making about losses in the following three situations: typical prisoner's dilemma games (with certain outcomes), "solo" games with uncertain losses (but no counterpart), and IDS games with both a counterpart and uncertainty. Based on previous research showing that the presence of uncertainty has a large negative impact on investment rates in IDS (Kunreuther et al., 2009), and that group attitudes towards uncertainty have a large impact in IDS (Gong et al., 2009), we predict that positive effect of precommitment on risk perceptions (and hence investment) will outweigh the potential negative impact of precommitment on counterpart interaction and reciprocity. Furthermore, if precommitment increases initial investment rates in IDS, it has the potential to create a virtuous cycle in subsequent play where all players invest more often.

**Overview of studies:**

In the course of six studies, we test our proposed conceptual framework. 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.**

 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 2, 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 in Study 2, we eliminated the counterpart to isolate the effect of uncertainty, in Study 3, we eliminated 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 the ones in the normal deterministic prisoner's dilemma condition.**

 All the aforementioned hypothesizes are proposed under the “loss” frames, typical of previous IDS research and real-life IDS situations. However, it remains unanswered what would happen under a “gain” frame. Under the loss frame, we argue that the effect of precommitment is a result of change in the perceived risk of the options (i.e. the risk of incurring a big loss). However, this is based on the assumption that individuals are risk seeking. Under a gain frame, this is not the case as the individuals are naturally “risk-averse” (Kahneman & Tversky, 1979). Therefore, precommitment may increase the perceived likelihood of the risky gain and make people more risk-seeking in the gain frame. Thus, the effect of precommitment would be reversed between losses and gains: in the loss frame, precommitment makes people more risk averse (because the risky loss appears more likely), while in the gain frame it makes people more risk seeking (because the risky gain appears more likely).

 An alternative hypothesis comes from recent evidence that people are risk averse for both gains and losses in intertemporal contexts (Hardisty & Pfeffer, 2016). These findings suggest that precommitment would have no effect in gain frames, as people would expected to be risk averse both for repeated, one-shot gains and for gains over time. Taken together, we hypothesize:

**H4: The effect of precommitment on risky choice will be eliminated or reversed under “gain” frames.**

 We argue that the precommitment effect works through increasing the subjective probability of the big loss. Therefore, what will happen if we experimentally increase the objective probability of the loss (while reducing the size of the loss to keep the expected value constant)? Consistent with our increase in subjective probability account, we hypothesize that as the probability of the big loss increases (and the size of the loss decreases accordingly), investment in the safer option will also increase. Moreover, our account suggests that precommitment and increased probability of the big loss will not explain “independent” portions of variance in the investment decisions. Therefore, we expect the precommitment effect to become weaker as the probability of the big loss increases.

**H5a: As the probability of the big loss increases, the investment in the safer option will also increase.**

**H5b: As the probability of the big loss increases, the effect of precommitment will become weaker.**

 In the real-world, people may not always stick to their choices after they precommit. After they see how events are playing out, they may change their plans. We explore this "non-binding precommitment" structure experimentally in a solo game, with a condition in which participants precommit for 20 rounds, but see feedback one round at a time and have the option to revise their current and future choices at any time without penalty. If our theory is correct that precommitment increases investment rates because it increases the subjective probability of loss, this process should hold true even when precommitments are non-binding. Therefore, preferences for the safe option should be the same under both binding and non-binding precommitment.

**H6: Under a non-binding precommitment choice structure, individuals will invest in the safer option more than the repeated choice structure and as much as the binding precommitment structure.**

*Table 1: Summary of hypotheses, manipulations, and game types in Studies 1-6.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Hypothesis** | **Manipulation** | **Investment rates** | **Type of games** | **Studies Testing Hypothesis** |
| H1a | Uncertainty | Decrease | Stochastic compared to deterministic. | Study 1 |
| H1b | Precommitment | Increase | Stochastic compared to deterministic. | Study 1 |
| H2 | Precommitment | Increase | Stochastic “solo” games compared to deterministic “solo” games. | Studies 2,4,5, 6 |
| H3 | Precommitment | Decrease | Deterministic game with precommitment compared to deterministic with round-by-round decisions. | Study 3 |
| H4 | Frame (Gain vs. Loss) | Slightly reversed in gain frame | Stochastic “solo” game under gain and loss frames. | Study 4 |
| H5a,b | Explicit probability of large loss | Increase | Stochastic “solo” game with varying probabilities of big loss. | Study 5 |
| H6 | Non-binding precommitment | Increase | Stochastic “solo” game with non-binding precommitment  | Study 6 |

**Study 1a:**

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 a 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 1a: 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 1a: Methods*

 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. Participants' compensation depended entirely on the outcome of the experiment, as described below.

 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 in Study 1a.*

|  |  |
| --- | --- |
|  | 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 in Study 1a.*

|  |  |
| --- | --- |
|  | 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.[[3]](#footnote-3)

 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 1a: 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 good, at a correlation of *r*=.95 for mentioning the counterpart and *r*=.91 for mentioning probability.[[4]](#footnote-4)

 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.[[5]](#footnote-5)

 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.*

 *Self-report measurement of risk perception*

After playing the game, participants in the stochastic conditions estimated "the likelihood that a loss would occur at least once in 20 rounds" if no protective action were taken. The average probability estimate was 20.54%. This did not vary between the repeated and precommited conditions, *t*(58) = .63, *p* = .53. Likewise, in other studies we collected different self-report measures of risk perception, risk concern, and time horizon, and never found any differences between conditions on these measures. We will not report these self-report measures (of risk and time perception) further in the main manuscript, but they can all be found in the Web Appendix.

*Study 1a: 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 rather 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 think, "A loss will probably happen to me, so I should invest in protection." These findings are in line with our theory based on the interdependence theory and the transformation of an objective, given payoff matrix to a subjective, perceived payoff matrix (Van Lange & Rusbult, 2012). Individuals in the precommitment condition may perceive the probability of the risky loss to be higher, and this transformed subjective payoff matrix leads them to increase their investment rates.

 However, this interpretation is *not* supported by the self-report estimates of probability (neither in this study, nor in subsequent studies). It may be that the subjective probability process is unconscious, or is difficult to report on (explicit computation of cumulative probabilities is notoriously difficult for people). Of course, it is also possible that some other process drives the observed effects, such as participants becoming overwhelmed in the precommited condition and choosing the "safe" option to avoid complexity. While this "overwhelmed" idea is compelling, it cannot account for the Study 5 results, below. Therefore, we believe that the "subjective probability" theory remains the best explanation of the observed results, despite the null results in self-reports of probability perception.

 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 1b in which we re-tested our key manipulation -- precommitment in a stochastic, loss-framed prisoner’s dilemma -- with a purely financial frame and the results were replicated. The details of this study can be found in online appendix D. The effect of financial vs environmental framing was virtually non-existent; in fact the effect size of the main effect of domain framing (financial vs environmental) and the interaction of domain with precommitment both rounded to ηp2 = .00. Therefore, we collapse Studies 1a and 1b in our analyses to follow, for increased power.

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 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 2 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 2: Methods*

 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)

 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 2 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):

|  |  |  |
| --- | --- | --- |
| 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 2: Results*

 As seen in Figure 5, precommitment substantially increased investment by participants in the solo stochastic game, from 32% to 61%. Thus, participants invested roughly twice as often when precommiting. 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 5: Mean investment proportions in the repeated solo (Solo-rep) and precommitted solo (Solo-pre) games in Study 2, as compared with the stochastic prisoner's dilemma (SPD-rep and SPD-pre) data from previous studies (study 1 and the additional study in online appendix D).*



*Study 2: 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 previous studies also acted on participants' perceptions of probabilities and associated outcomes. 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 subjective probability, we observed that those in the precommitment were much less likely to mention a low probability of loss. In other words, it is likely that those who precommitted *felt* that the probability of loss was considerably higher than 4%.

 It appeared that the precommitment manipulation was more effective for the solo games in Study 2 than for the stochastic social dilemmas of previous studies. Partly for this reason, and partly for curiosity, we ran Study 3 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 defect much more often (similar to the end game rounds of a repeated game).

*Study 3: Methods*

 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)

 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 3: Results*

 As seen in Figure 7, 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 7: Mean investment proportion in the precommitted deterministic prisoner's dilemma (DPD-pre) condition in Study 3, as compared with the repeated deterministic prisoner's dilemma (DPD-rep) data from Study 1.*



*Study 3: Discussion*

 Strikingly, precommitment initially has no effect on investment/cooperation in a 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 2) than in stochastic social dilemmas (Studies 1 and Appendix D): on the one hand, precommitment under uncertainty raises subjective probabilities, 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 3 to the research question is understanding the susceptibility of deterministic settings to precommitment. As can be seen in Figure 8, 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 susceptibility/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 8: 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. Error bars show +/- 1 SE.*

*Study 4: Overview*

 All of the studies up to this point have investigated the effect of precommitment under a “loss” frame. It is illuminating to investigate the effects under a “gain” frame, too. As outlined in the introduction, the impact of precommitment on risk preferences should be eliminated or reversed for gains. We explore this possibility in Study 4. Furthermore, we rule out a confound that was present in previous studies: the repeated and precommited conditions also used different displays, with only one choice visible in the repeated condition, and 20 choices visible in the precommited condition. Therefore, we systematically varied the display of the choices to be separated or aggregated, fully crossing this with the other experimental conditions.

*Study 4: Methods*

 355 participants (63.7% female) were recruited from student pools at two large North American universities[[8]](#footnote-8). Participants played the same version of the solo game (study 2) in a 2 (choice structure: precommited versus repeated) by 2 (choice display: separate versus aggregate) by 2 (scenario frame: loss versus gain) design with incentive compatible outcomes, as in previous studies.

 *Scenario Frame*

 The procedure was same as study 2 with slight changes to the scenario so that the same cover story could be used for both the gain frame and the loss frame. We adjusted the base endowment in the gain condition (down from 8,500 Rp to 5,500 Rp) so that the expected payout in both the gain and loss conditions would the same (given a 50% choice proportion). The numeric amounts in the payoff matrix were identical between gain and loss, thus the expected values were mirrored: in the loss condition, the EV maximizing choice was to choose the certain loss, but in the gain condition, the EV maximizing choice was to choose the risky gain.

 *Choice display*

 We varied the display of the choices such that in the separate display conditions, participants saw one choice at a time, regardless of whether they were precommiting their choices or not, whereas in the aggregate display conditions, all the choices were displayed to the participants, but they either precommited their choices or did one choice at a time, depending on the choice condition to which they had been assigned. For example, participants in the separate/precommited choice condition *saw* the choices one at a time, but did not *receive feedback* until they precommited all 20 choices. On the other hand, participants in the aggregate/repeated choice saw a table of all 20 choice options but made their choices *one at a time* and received feedback right after the choice, and then they made the next choice on the same table (where they could see both past and future choices, which were grayed out so that only the current round could be chosen). Note that feedback format was identical across conditions (as in previous studies): all participants saw both round-by-round feedback and a summary table at the end of each block. At the end, the participants responded to a few demographic questions.

*Study 4: Results*

 The main effect of choice display (separated vs aggregated) was not significant *F*(1,166) = .30 , *p =* .59, nor did it interact with any other factor *F*(1,166) = .39, *p =* .54, therefore we collapse across choice display in the analyses to follow. A 2 (choice structure) by 2 (frame) by 4 repeated (blocks) ANOVA with investment proportion in each block as the DV found a main effect of precommitment on investment rates (*M*rep = .51 vs *M*pre = .59, *p* = .01), as seen in Figure 9. Also, there was a significant main effect of the scenario frame such that participants in the gain frame scenario invested more than those in the loss frame scenario (*M*loss = .44 vs. *M*gain = .67, *p* < .001). More interesting is the interaction of scenario frame and choice structure *F*(1,348) = 16.79 , *p*<.001. As seen in Figure 9, while precommitment increases investment rates in the loss frame (*M*rep = .33 vs. *M*pre = .55, *p*<.001), this effect is directionally reversed in the gain frame (*M*pre = .64 vs. *M*rep = .69, *p =* .28).

Within-subjects analysis revealed a main effect of block (the repeated measure) indicating an overall drop in investment rates over time, *F*(3, 1044) = 5.1 , *p* =.002. As seen in Figure 10, this drop was stronger in the loss frame than the gain frame *F*(3, 1044) = 8.02, *p*<.001).

*Figure 9: Mean proportion choosing the certain (no-risk) option in precommited versus repeated conditions and loss vs gain frames in Study 4. Error bars show +/- 1 SE.*

*Figure 10: Proportion choosing the certain (no-risk) option under gain and loss frames across blocks in Study 4. It can be seen that participants in the gain frame invested more in the safer option, regardless of choice structure condition they were in.*

*Study 4: Discussion*

 The effect of precommitment was replicated such that individuals who precommited their choices chose the safer option more often than those who made their choices round-by-round. However, this effect was slightly reversed for individuals considering risky gains, rather than risky losses. In other words, while precommitment makes risky losses less attractive, it makes risky gains slightly more attractive. This finding also suggests that precommitment leads to general risk aversion, for both losses and gains (consistent with intertemporal choice findings from Hardisty & Pfeffer, 2016).

 Study 4 also addressed a confound and ruled out a possible alternative explanation: the display format. We found it is not the way individuals “see” the choices (each on a separate page or all on one page) that matters, rather it is the way they “make” the choices (one at a time or all at once) that drives differences in risk preference.

*Study 5: Purpose*

 We argue that precommitment in IDS increases the subjective probability of the risky loss happening. In studies 2 and 4, we showed that when the probability of the big loss is 4%, precommitment increases the choice of the safer option. However, if we believe that an increase in subjective probabilities will result in choice of the safer option, then an increase in the actual probability of loss would also show the same pattern. At the same time, it should dilute the effect of precommitment for the very same reason: if the effect of precommitment on choices between safe and risky options is driven by increase in subjective probability, then increasing the actual probability would weaken the effect of precommitment. We test both arguments in Study 5.

*Study 5: Participants and methods*

 421 participants (43.5% female) were recruited via Amazon’s Mechanical Turk[[9]](#footnote-9). Participants played the same scenario as the loss-framed solo game in study 4 with a 2 (choice structure: Precommitted versus Repeated) by 3 (Probability of the big loss: 4% versus 20% versus 50%) between-subjects design. The amount of the large loss was adjusted between conditions (to be 40,000, 8,000, or 3,200) to keep the expected value constant. Unlike previous studies, all choices were hypothetical; participants were compensated a flat amount for participating. This explores the robustness of the precommitment effect. After making their choices, participants completed demographic measures.

*Study 5: Results*

 A 2 (choice structure:repeated vs precommited) by 3 (probability of large loss: 4 vs 20 vs 50) by 4 (question block: 1-4) repeated-measures ANOVA with proportion of safe choices as the DV revealed main effects of choice structure and probability, and an interaction, as seen in Figures 11 and 12.

 Participants who precommited their choices invested more in the safer option (*M*pre = .57) than those who made their choices round-by-round (*M*rep = .48), *F*(1,409)= 7.25, *p*<.01. Also, as the probability of big loss increased, participants invested more in the safer option *F*(2,409)= 14.32, *p*<.001. More specifically and as illustrated in Figure 11, post-hoc tests revealed that those in the 50% condition invested more (*M*50% = .63) than those in the 20% (*M*20% = .53, *p*= .01) and 4% conditions (*M*4% = .42, *p*<.001). Process Model 1 analysis revealed a marginal two-way interaction (*B*= -.07, *SE*= .04, *p* = .09). We conducted follow-up tests of choice structure effect at different levels of probability. At 4% level, precommiting choices had a significant positive effect on investment in the safer option (*B*= .16, *p*<.01, 95% CI= [.06, .26]). At 20% level the precommitment effect became weaker but was still significant (*B*= .09, *p*<.01, 95% CI= [.03, .16]). At 50% level, however, the precommitment effect became insignificant (*B*= .02, *p* *=* .64, *95% CI*= [-.08, .12]. This reduction in the effect of precommitment can be seen in Figure 11.

 The main effect of question block *F*(2.64,1080.49)= 1.51, *p*= .22 as well as its two-way interaction with the probability factor *F*(5.28,1080.49)= 1.29, *p*= .26 were not significant. But the two-way interaction of blocks with choice structure factor (*F*(2.64,1080.49)= 3.04, *p*= .03) as well as the three-way interaction (*F*(5.28,1080.49)=2.33, *p*= .04) were significant.

*Figure 11: Mean investment proportion in the safer option for precommited versus repeated choices across varying probabilities of the big loss in Study 5. Error bars show +/- 1 SE.*

*Figure 12: Investment proportion in the safer option for varying probabilities of the big loss across 4 blocks of playing the game in Study 5. Error bars show +/- 1 SE.*

*Study 5: Discussion*

 Individuals chose the safer option more often when the probability of the large loss increased (and the amount of the loss decreased accordingly). Given that all the expected values were identical among the conditions, it appears that participants risk preferences are especially sensitive to the probability of the loss occurring. This is consistent with the hypothesis that increases subjective probability under precommitment result in increased safe choices. Further evidence for this idea comes from the finding that when the objective probability was high (50%), the effect of precommitment was completely wiped out. In other words, if the objective probability is already high, precommitment cannot increase the probability any further, and it has no effect.

*Study 6: Overview*

 The purpose of this study is two-fold. First, is addresses (real-world motivated) situations in which participants may change their choices after initial commitment. Second, it further sharpens our understanding of the process underlying the precommitment effect, by testing whether it is driven mainly by the fact of being forced to consider all choices in advance, or driven by the fact that once committed, choices cannot be changed and therefore the participant cannot respond to round-by-round feedback.

*Study 6: Methods*

 We used a one-factor (Choice structure: Repeated vs. Precommited vs. Non-binding precommited) between-subjects design. Participants were 210 (48.6% female) users of Amazon’s mechanical Turk who received a fixed monetary compensation for their participation.

 The repeated and precommited conditions were the same as previous "solo game" studies. In the non-binding precommitment condition, the participants learned that they would precommit their choices, and also that they would return to the choice page after each round and have the opportunity to change their current and future choices if they wished. Then, the participants completed demographic questions.

*Study 6: Results*

 Investment in the safer option in the non-binding precommitment condition (*Mnon*= .43, *SE*= .04) was roughly as high as in the standard precommitment condition (*Mpre* = .49, *SE*= .04, *p* = .37). Investment rates in the repeated condition (*Mrep*= .30, *SE*= .04) were significantly less than those in the precommitment condition (*p* = .001) and the non-binding precommitment condition (*p* = .02). Looking over time, the "question block" repeated measure did not have a significant effect *F*(3, 621) = 2.03, *p* = .11. However, there was an unexpected interaction between choice block and choice structure *F*(6, 2.50) = 2.50, *p* = .02, reflecting the fact that the binding and non-binding precommitment conditions grew more similar over time, while the repeated condition diverged from the other two conditions over time (becoming more risk averse in later blocks).

*Study 6: Discussion*

 Study 6 replicated the effect of precommitment on the investment in safer option, even when the commitment was non-binding. This adds to the real-world applicability of our effect: we may not always be able to force people to precommit their choices, however, having them precommit their choices in a non-binding way can still increase safer choices. The non-binding precommited condition was equally flexible as the repeated condition (in that participants could make individual decisions at any given month), the mere fact that participants in the former condition precommited their choices increased risk aversion, perhaps due to greater subjective probability of loss. Thus study therefore clarifies that it is the "forward-looking" nature of precommitment, rather than the inflexibility, which drives the observed effect.

*General Discussion*

 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. As it is evident in study 2, when the counterpart is removed and the game is changed into a “solo” game, the precommitment effect still holds. On the other hand and in study 3, when uncertainty is removed and the game is changed into a DPD game, the effect of precommitment is reversed. Taken together, these suggest that the effect of precommitment in IDS works through outcome uncertainty (rather than counterpart uncertainty), increasing the subjective probability of the risky option.

 Further evidence for this argument was found in studies 4 and 5, through the discovery of two boundary conditions related to risk perceptions. In study 4, while replicating the precommitment effects under a “loss” frame, this effect was eliminated and slightly reversed under a “gain” frame. This is because participants are already “risk-averse” in the gain frame, and increased subjective probability makes the risky gain slightly more attractive (rather than less attractive).

 Study 5 replicated the effect of precommitment at the original probability (4%), with an online sample (rather than a student sample) and with hypothetical outcomes, demonstrating robustness. Furthermore, the effect of precommitment grew weaker as the objective probability of the big loss increased (20% and 50%). Those participants seeing larger probabilities of the big loss chose the safer option more, and the effect of precommitment decreased in a corresponding fashion. This suggests that experimentally increasing the objective probabilities of the big loss has the same effect as precommitment. Put another way, the fact that precommitment effect becomes weaker as the probabilities of the big loss increase rules out the possibility that these two factors work independently.

 Study 6 showed that even non-binding precommitment increases preferences for the safer option, thus demonstrating that the precommitment effect is driven by its forward-looking nature, rather than by its inflexibility. Across the six studies (plus an additional two studies in the Web Appendix), the effect of precommitment was quite robust, being demonstrated with four different sample populations (three universities and MTurk) and with both incentive-compatible and hypothetical scenarios.

 Precommitment is an intervention designed to increase the relevant time horizon, increase the subjective probability uncertain losses, and in turn increase rates of investment in protection. For example, a farmer might make different choices if buying rain insurance monthly, annually, or decadally. The chance of a severe drought happening next month is likely to be viewed as small so the farmer may not invest in protection voluntarily. However, when considering an annual or decadal policy, the chance of severe drought is subjectively larger, and the same farmer might want to purchase insurance, or purchase a more expensive policy. Insurance companies could offer financial incentives for precommitment, which could be cost effective if they lead to higher investment rates among consumers.

 Supporting evidence for this comes from research on seatbelt use: when the likelihood of being killed or injured during a single trip (~.00000025 probability of being killed, and .00001 of being injured) was communicated to individuals, it did not worry them too much. However, when the lifetime risk of death (~.01) or injury (.33) was presented to individuals, they were more likely to use seatbelts (Slovic, Fischhoff, & Lichtenstein, 1978). Also, people were more likely to purchase insurance when they were presented with the cumulative risk compared to individual repeated risks. While this research demonstrated that increasing the explicitly stated probabilities increases investment in protection, our research showed that having people precommit (without changing the explicit numbers) has a similar effect.

 The effects of uncertainty and precommitment in social dilemmas were reliable across both environmentally framed 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 without uncertainty. 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.

 While we found that non-binding precommitment was equally effective in the solo game in Study 6, the story might be different in interdependent situations, and in real life people can easily renege on interdependent commitments. While this may often result in lower investment rates in IDS situations, there are three reasons to believe that precommitment could still be an effective tool. One is that legal contracts and social pressure can enforce commitments in many situations. The second is that precommitment could be useful if it gets each player to initially commit to investment, and thus "get off on the right foot", creating a virtuous cycle of reciprocity and investment in protection. The third is that in our studies, participants in our IDS studies were more focused on the probabilities than the counterpart, so the defecting actions of the counterpart may be less detrimental in IDS than in a deterministic prisoner's dilemma. A promising area for future research would be to follow up on this finding: in stochastic social dilemmas, under what circumstances do people focus more on the "gamble", and under what circumstances do they focus more on the actions of their counterpart?

Another fruitful avenue for future research would be imposing the explicit uncertainty component on the counterpart, rather than on the outcomes of the game. There is an inherent uncertainty in the counterpart component in PD games, but it can be expressed more explicitly with probabilities that the counterpart will cooperate or defect. Just as precommitment increases the subjective likelihood of the risky loss (perhaps thinking, "One year or another, it will happen"), the same argument may hold for counterpart uncertainty ("Sooner or later, they will defect against me"), and perhaps lead to lower investment rates.

 Future research on social dilemmas should do more to incorporate and explore uncertainty. Real-world social dilemmas of interest, such as public health 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.

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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. While this account seems plausible, it stands somewhat in contrast to the typical delay discounting literature (Frederick, Loewenstein, & O'Donoghue, 2002), where increasing the time horizon *decreases* the subjective importance and probability of a single event. [↑](#footnote-ref-2)
3. 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-3)
4. 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-4)
5. Note that in the SPD-pre condition there was no possibility of reacting to the counterpart's choices. [↑](#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)
8. There was no main effect of location (ie, which university) on investment rates, nor did location interact with the precommitment manipulation in any 2, 3, or 4-way interactions. Therefore, we collapse across sample location in the following analyses. [↑](#footnote-ref-8)
9. 6 of the participants did not finish the game and therefore were excluded from the sample. [↑](#footnote-ref-9)