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To mitigate or to adapt? Collective action under asymmetries in vulnerability to losses.

Esther Blanco[a*], E. Glenn Dutcher[b], Tobias Haller[a]

Abstract

Many policies addressing global climate change revolve around the implementation of mitigation and adaptation strategies. We experimentally examine subjects' choices in a climate change game where subjects are put into groups where they face a potential damage and have the choice to invest resources into mitigation, adaptation and/or productive funds. Resources allocated to mitigation reduce the probability of the loss to the entire group while adaptation investments reduce the magnitude of the loss to the investing agent and productive investments increases payoffs only for the investing agent. We explore subject's response to three treatment conditions; high damage, low damage and heterogeneous damage. Results show that subjects view mitigation and adaptation funds as substitutes in that they contribute higher levels to the adaptation fund if low levels of contributions to the mitigation fund exist, but free-ride on others by contributing to the productive fund if contributions to the mitigation fund are high enough. In particular, we find the highest level of contributions to the socially efficient mitigation fund when all subjects in a group face a high damage and the lowest level when all subjects face a low damage. When high-damage subjects are mixed with low-damage subjects, their contribution levels to the mitigation fund decline, but are still greater than those of their low-damage group members.

JEL Codes: H41, H87, C92

Key Words: Collective Action, Climate Change, Economic Experiments

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1. Introduction

"As land recedes under advancing waters, governments are faced with the costs of building defensive seawalls and relocating coastal populations — and in some extreme cases, finding new homes for entire island nation." *New York Times 2014 (1).*

The Framework Convention on Climate Change (UNFCCC) has thus far yielded only modest reductions in global emissions of greenhouse gases. The UNFCCC embraces a battery of policies, where two of the most significant are centered on mitigation and adaptation strategies. Mitigation strategies are formulated to meet the UNFCCC's objective of stabilizing greenhouse gas concentrations in the atmosphere. Efforts to reduce CO2 emissions are the paramount example of mitigation. Adaptation, on the other hand, is the use of technologies that can help increase resilience to the impacts of climate change. This includes, for example, building dikes to control sea level rise or upgrading climate control in buildings. Importantly, these two policy alternatives differ in their strategic implications. While mitigation policies benefit all countries, including those that did not choose to abate, adaptation policies are mainly private investments aiming to reduce the magnitude of the negative effects only for the investing country or region. That is, mitigation investments are a form of public good contributions and adaptation investments are a form of private insurance.

Many strides have been made in understanding basic behavior by utilizing experiments. Previous experimental research addresses the strategic nature of mitigation by focusing on a subject's trade-off between investing in a private account and investing in mitigation effort (2, 3), or on alternative forms of mitigation technologies that differ in terms of costs (4, 5). Our research departs from the previous literature along two main avenues. First, our experiments give the subjects an additional option to invest in an adaptation fund that reduces the damage that the investing agent will suffer. This gives subjects three – rather than two - investment options capturing the strategic interaction of production, mitigation and adaptation. The second main point of divergence is on the interaction of this richer strategy set with the presence of heterogeneity in potential damages. We consider environments where the agents are homogeneous in their vulnerability – either all suffer a high damage or a low damage - and compare these results to settings where the agents vary in their potential damage. Previous theoretical and experimental studies addressing the relevance of heterogeneity in the "collective-risk social dilemma" (3, 6-8) have focused on endowment asymmetry.1 In contrast, we examine the effects of damage asymmetry, capturing differences in vulnerability to a potential loss. Tackling the interaction of alternative mitigation-adaptation investments with heterogeneous damages provides new insights on why previous agreements have failed and will help inform policy makers on how to structure successful agreements in the future.

Although our paper was motivated by the climate problem, the participants in our experiment were not framed in this context, making our results equally applicable to other situations in which mitigation of a damage or adaptation to it are alternative options. For instance, these options are generally available within the framework of risk-sharing. Risk-sharing typically occurs when market-based insurance mechanisms are lacking. In these situations, a group must decide how to best deal with a potentially damaging effect. If the group pools risk, they will lessen the damage to their group. In the absence of risk sharing, individuals are left only with the option of private insurance. Other examples that illustrate the tensions between adaptation and mitigation include more modest local issues at the household level such as investment decisions on construction standards to protect from extreme climate events and energy intensity of the family. Similarly, for broader issues such as piracy or terrorism adaptation and mitigation of these threats are compatible policies.

In our experiment, subjects' payoffs are determined by a linear function where a group of n agents face the possibility of a damage occurring in the form of an expected loss of an initial endowment. Initially, the damage occurs with certainty and the size of the damage, D_i, varies by treatment. Agents have the possibility to reduce the expected value of D_i by allocating tokens either to the Mitigation Fund

[1] See also a recent theoretical contribution of endowment asymmetry in Vasconcelos et al 9.

(M-Fund) or to the Adaptation Fund (A-Fund).[2] Each token invested in the M-Fund reduces the probability of the damage occurring to all members of the group. Investment in the A-Fund reduces the size of the loss only for the investing agent. Investment in either the M- or the A-Fund has an opportunity cost, as it reduces the investment possibilities in a Productive Fund (P-Fund) that yields a positive payoff. The motivation for presenting the P-fund is to include those externally relevant investment opportunities which generate private benefits for an agent. Individuals can invest simultaneously in all three funds, however, total investment is limited by the initial endowment which is equal for all individuals.

In the experiment, subjects made choices within the same group for 20 rounds, split in two blocks of 10 rounds each. The first ten rounds are used to understand how inexperienced subjects make decisions in the game and can be used to understand how play evolves in such a setting. The second 10 rounds are used to understand how experience may change initial behavior. Individual and group behavior is studied in a repeated game setting with feedback for two main reasons. First, countries make repeated decisions about their emission (reduction) levels over time. Second, countries receive feedback on global emissions and might vary their targets depending on other countries' reduction efforts.

37 groups of 4 students took part in one of three treatments, for a total of 148 participants who played 20 rounds of the game, resulting in 2960 observations. All subjects started the experiment with 15€ and, depending on the treatment, faced in each of the 20 rounds the possibility to lose 15 Experimental Currency Units (0.75€; low damage or D_L subjects) or 25 ECUs (1.25€; high damage or D_H subjects). In the first treatment, all subjects had the same low value of D_L (the symL treatment) while in the second all had the same high value of D_H (the symH treatment). In the third treatment half of the subjects in a group had a value D_L and the other half had a value D_H (the asym treatment). The decision environment was parameterized to create a social dilemma such that individual self-interested payoff-maximizing behavior leads to a sub-optimal outcome on the group level.

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[2] The funds were neutrally labelled as A, B and C in the instructions.

For the individuals' payoff function, we chose parameter values such that each token invested in the P-Fund yields exactly 1 ECU, each one invested in the M-Fund reduces the probability of a loss occurring by 3 %, and a token invested in the A-Fund would reduce the individual size of the damage by 1.1 ECUs. The size of the damage in the three treatment conditions influences the absolute payoff, however it does not change the social dilemma framework of the model. Reaching the social optimum would require each one of the four group members to allocate 2 tokens to the P-Fund, 8 to the M-Fund, and 0 to the A-Fund. However, individual incentives to deviate from this socially optimal solution exist, since a free-riding strategy yields the highest possible individual payoff.[3]

2. Results - Overview

We start the analysis by focusing on contributions to the mitigation fund (M-fund) which is a measure of cooperative behavior. We find that average cooperative behavior between the first 10 periods and the final 10 periods is never significantly different and thus we will pool the sample going forward.[4] Panel a in Figure 1 shows that investment in the M-fund is higher in the symH than in the symL treatment in all 20 periods,[5] and pairwise comparisons confirm that these differences are statistically significant ($p<0.01$, $p<0.01$)[6]

[3] If all subjects were to free-ride, the money-maximizing solution is for an individual to contribute all of their tokens to the A-fund while the optimal could change if some group members contribute a certain amount to the M-fund. If a certain level of group contributions is reached, the money-maximizing contribution is to contribute fully to the P-fund. The potential damage determines the cross-over point for group contributions which is obviously lower for D_L subjects than D_H subjects.

[4] Specifically, in the *symL* treatment, the means in the first 10 and last 10 periods are 1.52 vs. 1.90 (*p=0.13)*, in the *symH* treatment they are 3.29 vs. 3.35 (*p=0.83*) and in the *asym* treatment, they are 2.24 vs. 2.00 (*p=0.24*).

[5] The qualitative results in Figure 1 are robust to an additional measure of cooperation capturing the percentage of subjects in each setting who contributed at least a positive amount to the M- fund, represented in Panels C and D in Figure S1 of the supporting material.

[6] Unless otherwise noted, the first p-value is the result of pairwise comparison (t-test) with clustering at the individual level to account for the obvious correlation of the repeated observations. If we instead cluster at the group level, very little changes, but we note that in many cases, the pairwise comparisons result in fewer than 30 groups and thus we are not as confident in the appropriateness of this measure. To account for this, the second p-value is the

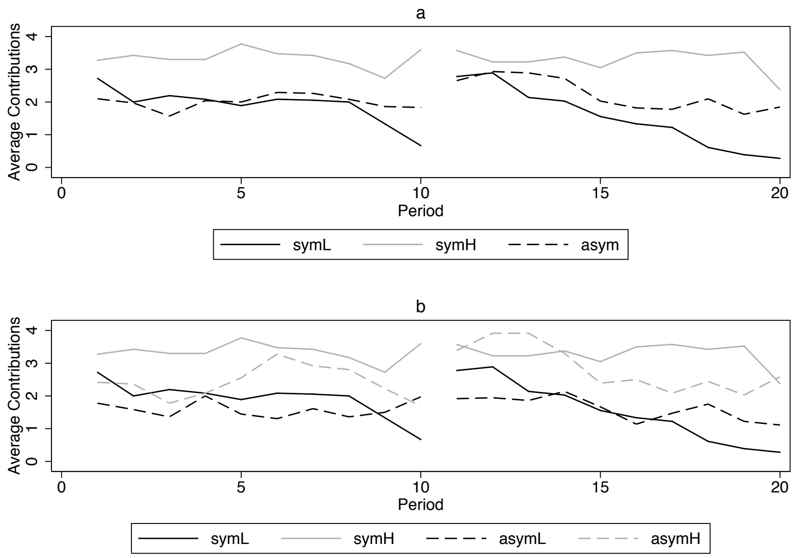

Figure 1 – Panel a shows the average individual contributions to the M-fund by treatment and Panel b shows this information by player type over all 20 periods.

Random effects GLS and marginal effects Probit, with errors clustered at the subject level to control for the repeated observations (see supporting material), confirm that the potential damage a subject faces affects his/her contributions to the M-fund. In particular, D_L subjects in the asym and symL treatments contribute significantly less to the M-fund and are about 30% less likely to contribute a positive amount relative to their D_H counterparts.

Result 1: Lower levels of potential damage lead to lower levels of mitigation investments.

Similarly, the presence of asymmetry in potential damages also leads to lower levels of investment in the M-fund and fewer subjects willing to invest in it. Pairwise comparisons show that investment in the M-fund is lower in asym than in symH ($p<0.01$, $p<0.01$) and it is not significantly different than average M-fund investments in symL ($p=0.17$, $p=0.38$). Panel b in Figure 1 disaggregates the behavior of D_H and D_L subjects in the asym treatment. As expected there are significant differences in

result of a Wilcoxon test for differences in the overall mean at the group level for all 20 periods which substantially reduces the number of observations.

behavior between subjects with different damage levels in asym. In particular, D_H subjects invest in the M-fund more than $D_L$subjects (p=0.01).[7] When comparing behavior of subjects with the same damage between symmetric and asymmetric treatments we observe that asymmetry only affects cooperation of high-damage subjects. D_H subjects in asym lessen their cooperation compared to subjects in symH (p=0.07); the cooperation levels of D_L subjects in asym is not significantly different than that of subjects in symL (p=0.77). The regression analyses in the supporting material show that the asymmetric treatment reduces the overall level of investment in the M-fund of subjects which is due to the lower level of M-fund investments of D_H subjects in asym. The regressions also show that D_H subjects in asym are about 16% less likely to contribute a positive amount to the M-fund relative to the D_H subjects in symL. Using a post-estimation Wald test, we find no difference between the cooperativeness of D_L subjects by treatment (from Model 2a, p=0.55).

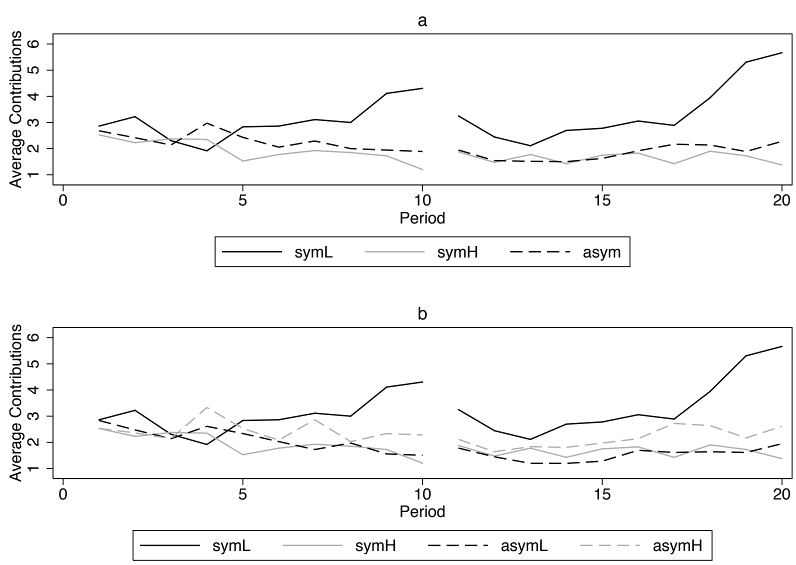

Figure 2 – Panel a shows the average individual contributions to the A-fund by treatment and Panel b shows this information by player type over all 20 periods.

[7] The results of Wilcoxon tests are not reported for these comparisons because at the group level, there is no difference since the groups were mixed in the asymmetric treatment.

Result 2: Subjects facing the potential of high damage invest less in mitigation if they are in an asymmetric group compared to if they are in a symmetric group.

Turning to contributions to the A-fund, Figure 2 presents average treatment investments in Panel a and Panel b disaggregates the behavior of D_H and D_L subjects in the asym treatment. Regression analyses in the supporting materials show that subjects in the symL treatment contribute significantly more to reduce the size of the damage they privately face than subjects in the symH treatment ($p<0.01$). Using Wald tests, we also see that subjects in the symL contribute more than the average A-investment in asym ($p=0.01$), or either of the D_L and D_H subjects in asym ($p<0.01$, $p=0.07$). In addition, there is no difference in the contributions to the A-fund by D_L and D_H subjects in asym ($p=0.31$) or between subjects in asym and symH ($p=0.33$).

Result 3: Those who suffer the lowest damage and are in symmetric groups contribute the most to the adaptation fund.

An implication of Results 2 and 3 is that when groups are not able to achieve substantial investments in the M-Fund, subjects invest more intensively in the socially inefficient A- fund to privately limit the potential damage. Thus, in symL, low (group) mitigation investments coexist with high adaptation investments. This suggests a certain degree of substitution between investments in the adaptation and mitigation funds.

Similarly, a theoretical implication of the strategic nature of the game is that if the group contributes sufficiently to the M-fund, then the group members who are acting more selfishly - D_L subjects in the asym treatment in our experiment - should invest more strongly in the P-fund; the option available to subjects which generates private gains. As group contributions to the M-fund increase for a given group, the marginal value of contributing to the A-fund decreases whereas the marginal value of the P-fund remains stable. Our regressions (see supporting material) provide support for this argument which highlight that contributions to the P-fund are higher in the asym treatment than in the symH (p=0.03) or the symL treatments (Wald test, p=0.08). This results from the behavior of the D_L subjects in the asym treatment who invested more in the P-fund than D_H subjects in the asym treatment (Wald test p=0.02) or the groups in any of the symmetric treatments; both symH treatment (p<0.01) or symL treatment (Wald test p=0.01).

Result 4: Those who suffer the lowest damage in asymmetric groups contribute more to the productive fund than any other group.

Combining Results 3 and 4, we see that when D_L subjects are in asymmetric groups, they respond to the increased investment in the M-fund by D_H subjects in their group by choosing to free-ride on mitigation by investing more in the P-fund. However, if the low-damage subjects are grouped only with others of their type who do not invest in the M-fund, they invest more in the socially inefficient A-fund to guard against private losses. Results 1-4 lead to the natural outcomes regarding payoffs seen in Table S1 in the supporting materials. Specifically, we see that D_L subjects make more than D_H subjects (p<0.1) and that the asymmetric treatment is more profitable for low-damage subjects than the symmetric treatment (*p=0.02*) and less profitable for high-damage subjects (*p<0.01*).[8]

3. Conclusions

President Obama recently pushed for non-binding commitments from partner countries for abatement of green-house gas emissions which are similar in concept to previously unenforceable agreements.9 Our results imply that such an effort could be futile. An implication of our results is that low-damage subjects would like to enter into non-binding agreements with high-damage subjects to

[8] The results for pairwise comparisons of payoffs are from a two-tailed t-test.

[9] http://mobile.nytimes.com/2014/08/27/us/politics/obama-pursuing-climate-accord-in-lieu-of-treaty.html?_r=0

subsequently free-ride on them which may explain some of the observed behavior of limited mitigation investments.

We show experimentally that the magnitude and presence of asymmetry in terms of damage of potential losses influence the substitution between mitigation, adaptation and productive strategies. This result is in line with the theoretical findings in Bayramoglu, Finus and Jacques (10) where the authors defend that "mitigation and adaptation are substitutes, adaptation will reduce equilibrium mitigation and hence may influence stability through the same channel as modest mitigation." First, by contrasting different damage magnitudes we show that although high contributions to the (group) mitigation fund are socially beneficial, low contributions to the mitigation fund in symmetric groups facing low damages leads to high contributions to the (private) adaptation fund. This is socially concerning, as investments to the adaptation fund are rather inefficient from a group perspective, since they benefit only the investing agent through a reduction of the size of losses as opposed to the mitigation fund, which reduces the probability of occurrence of losses to the whole group. Second, the asymmetry in the group composition leads to a different pattern of substitution between the funds. Low damage subjects in asymmetric groups benefit from the contributions to the (group) mitigation fund by high-damage members of the group and invest more in the (private) productive fund. This is the conventional free-riding result though in our design, we have identified a parametrically induced reason for the free-riding behavior. In our setting, a subject should free-ride on others by contributing to the production fund only after a certain level is contributed to the mitigation fund (by others). We find that this comparative static result holds.

Thus, not only is the strategy set available to subjects relevant, but also the potential damage that they and their group members suffer. The current focus of agreements such as the UNFCC is mainly backward looking: those who polluted more in the past should be the ones that reduce emissions in the future. This implies that, for example, while developing countries do not have mitigation commitments, developed countries are requested to abate based on their historical emission levels. In other words, commitments abstract from the damage levels that the different countries are expected to face. Our experimental results suggest that this omission may be an important reason why such agreements do not live up to their lofty goals.

Our results also indicate that information about the potential damages is extremely important to solving this problem. This result should be seen as support for further research in the hard sciences to understand the key elements behind climate change - along with appropriate decimation of such results - so that a country and its constituents can form an appropriate response.

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Supporting Material

1. Materials and Methods

1.1. The mitigation-adaptation game

We set up a linear model involving a group of n agents that face the possibility of a damage occurring in the form of an expected loss of an initial endowment. The initial damage occurs with certainty and the size of the damage, D_i, varies by treatment. Agents have the possibility to partially reduce the expected value of D_i by allocating tokens either to the Mitigation Fund (M-Fund) or to the Adaptation Fund (A-Fund). Each token invested in the M-Fund, denoted by m_i, reduces the *probability* (p) of the damage occurring by β for the group. Each token invested in the A-Fund, denoted by a_i, reduces the *size* of the loss by γ only for the investing agent. Investment in either the M- or the A- Fund has an opportunity cost, as it reduces the investment possibilities in a Productive Fund (P-Fund) that yields a private marginal value of α to the agent for every token, x_i, he invests in this fund. Individuals can invest simultaneously in all three funds, however, total investment is limited by the initial endowment T which is equal for all individuals. The payoff function for an agent i can be presented as:

$$\begin{cases} \pi_i = \alpha x_i - (p - \beta \sum_{i=1}^{n} m_i) \cdot (D_i - \gamma a_i) & \text{for } \sum_{i=1}^{n} m_i < \frac{p}{\beta} \\ \pi_i = \alpha x_i & \text{for } \sum_{i=1}^{n} m_i \geq \frac{p}{\beta} \end{cases}$$

s.t.

$$T = x_i + m_i + a_i$$

Given that the probability of the damage cannot be negative, it becomes zero for group mitigation equal or above $\frac{p}{\beta}$. The associated marginal incentives for investments in each of the funds follow:

$$\frac{\partial \pi_i}{\partial x_i} = \alpha \quad \text{(S1)}$$

$$\frac{\partial \pi_i}{\partial m_i} = \beta(D_i - \gamma a_i) \quad \text{(S2)}$$

$$\begin{cases} \frac{\partial \pi_i}{\partial a_i} = \gamma(p - \beta \sum_{i=1}^{4} m_i) & \text{for } \sum_{i=1}^{n} m_i < \frac{p}{\beta} \\ \frac{\partial \pi_i}{\partial a_i} = 0 & \text{for } \sum_{i=1}^{n} m_i \geq \frac{p}{\beta} \end{cases} \quad \text{(S3)}$$

Marginal incentives to invest in the P-fund are constant and equal to α. Marginal incentives for investments in the M-fund are decreasing in the investments in the A-fund while marginal incentives for investments in the A-fund are decreasing in investments in the M-fund. Thus, there exists a substitutability between investments in the M- and the A-Funds where the marginal benefit from mitigation (adaptation) decreases with the level of adaptation (mitigation). An implication is that despite investments in adaptation generate no positive externalities to the group, they indirectly influence the strategic interaction among players. This is because the higher the adaptation level by a player, the lower will be its mitigation level, and this in turn influences the mitigation decision by other players.

Given the parameters presented in Table S1, the unique symmetric Nash equilibrium for myopic self-interested payoff-maximizing players is to fully invest in adaptation. Under these parameter values, the condition $\sum_{i=1}^{n} m_i < \frac{p}{\beta} = 34$. If we allow for subjects to hold expectations that the behavior of other players is off-equilibrium, the best response for myopic self-interested payoff-maximizing agents with expected group mitigation $\sum_{i=1}^{4} m_i > 3$, is to invest all tokens in private production (P-Fund). If $\sum_{i=1}^{4} m_i \leq 3$ the best response is again for subjects to invest all tokens in adaptation.

Table S2 displays the ranking of marginal incentives to invest in each of the three funds for different ranges of expected group mitigation. Notice that marginal incentives to invest in the P-fund are always higher than for investments in the M-fund ($\frac{\partial \pi_i}{\partial x_i} > \frac{\partial \pi_i}{\partial m_i}$). This implies that for any probability of occurrence, each agent has an incentive to free-ride on mitigation efforts by others. This free-riding benefit increases with higher adaptation investments by an agent (higher investments in adaptation reduce the value of $\frac{\partial \pi_i}{\partial m_i}$).

Furthermore, comparing marginal incentives between the A- and the M-fund, requires specifying the treatment condition under consideration. For the D_L (D_H) subjects marginal incentives for investments in the M-fund are higher than marginal incentives for investments in the A-fund for expected group mitigation $\sum_{i=1}^{4} m_i \geq 20$ (10). This implies that those who face a low damage will have stronger incentives to invest in the A-fund over the M-fund for a larger set of contributions of others to the M-Fund; i.e., they are predicted to be more likely to free ride.

Also notice from equations S1-S3 that the size of the damage does not affect marginal incentives to invest in the private or the adaptation fund, but varies the incentives to invest in the mitigation fund. Ceteris paribus, incentives to mitigate are higher for D_H subjects than for D_L subjects. This should lead to more (off-equilibrium) investment in the mitigation fund by high damage subjects relative to low damage subjects.

	Abbreviation	Treatment symL	Treatment symH	Treatment asym
Damage	D_i	15	25	15&25
Initial endowment	T	10	10	10
Initial probability of loss occurance	p	1	1	1
Marginal return of investment in the private fund	α	1	1	1
Marginal return of investment in the mitigation fund	β	0.03	0.03	0.03
Marginal return of investment in the adaptation fund	γ	1.1	1.1	1.1
Number of subjects	---	36	40	72

Table S1 – Decision Settings and Parameters

D_H subjects			
Expected group investment in mitigation	$\sum_{i=1}^{4} m_i \leq 3$	$3 < \sum_{i=1}^{4} m_i \leq 20$	$\sum_{i=1}^{4} m_i \geq 20$
Rank order of marginal incentives	$\frac{\partial \pi_i}{\partial a_i} > \frac{\partial \pi_i}{\partial x_i} > \frac{\partial \pi_i}{\partial m_i}$	$\frac{\partial \pi_i}{\partial x_i} > \frac{\partial \pi_i}{\partial a_i} > \frac{\partial \pi_i}{\partial m_i}$	$\frac{\partial \pi_i}{\partial x_i} > \frac{\partial \pi_i}{\partial m_i} > \frac{\partial \pi_i}{\partial a_i}$
D_L subjects			
Expected group investment in mitigation	$\sum_{i=1}^{4} m_i \leq 3$	$3 < \sum_{i=1}^{4} m_i \leq 10$	$3 < \sum_{i=1}^{4} m_i \leq 10$
Rank order of marginal incentives	$\frac{\partial \pi_i}{\partial a_i} > \frac{\partial \pi_i}{\partial x_i} > \frac{\partial \pi_i}{\partial m_i}$	$\frac{\partial \pi_i}{\partial x_i} > \frac{\partial \pi_i}{\partial a_i} > \frac{\partial \pi_i}{\partial m_i}$	$\frac{\partial \pi_i}{\partial x_i} > \frac{\partial \pi_i}{\partial m_i} > \frac{\partial \pi_i}{\partial a_i}$

Table S2 – Rank order of marginal incentives of investments in the private, adaptation and mitigation funds.

Moving to the social optimum, group payoffs are maximized when three group members invest 8 tokens in mitigation and 2 tokens into the productive fund and one group member invests 9 tokens in mitigation and 1 token in the productive fund. This reduces the probability of the loss affecting the group to 1%, and further (integer) investments in mitigation do not increase group payoffs. Given that the probability of the loss affecting an individual is virtually zero, investments in adaptation generate negligible group and private increases in payoffs as compared to the investments in the private fund.

1.2. Experimental design

The experiment consisted of 8 sessions conducted from December 2012 to March 2013 at the University of Innsbruck. In total 148 students participated in the study who were recruited from the standard subject pool using ORSEE (1). The experiment lasted for about an hour and earned the participants an average of € 9.79. In our sample, 50% of them were female.

The procedure used for all three treatments was the same. Participants were seated randomly at computer terminals in the laboratory and were never allowed to communicate with each other. At the beginning of the experiment, subjects were anonymously assigned to a group of four players in which they remained for the entire game. At no point did we tell them who their other group members were. The instructions, including detailed examples, were formulated in a neutral language and handed to the participants prior to the start of the experiment. The experimenter read the instructions aloud to create common knowledge and answered questions privately (see instructions in section 4 of the supporting materials). The experiment was programmed and conducted with the software z-Tree (2). At the end of the experiment, tokens where converted into Euros using an exchange rate of 1 Token = 0.05 Euros.

For the first part of the experiment, the mitigation-adaptation game, participants had to choose how to allocate ten tokens to the three funds, which we labeled as A, B and C, for each of the ten rounds. In each round, all ten tokens had to be allocated. Negative or fractional allocations were not allowed, and tokens could not be carried over from one period to another. To assuage concerns of numeracy, participants could use an on-screen calculator to test the outcome of different allocations. Testing was not limited so that subjects could try different allocations as many times as they wanted before making their decision final. Once everyone had submitted his/her decision, payoffs for account A, B and C as well as the individual total payoff for this round were presented. This procedure was repeated for 20 rounds with a break after the first 10 rounds.

In the second part of the experiment, the participants were presented with a risk aversion task. Instructions were given on the screen and read out by the experimenter. Subjects were asked to choose between an Option A or Option B for 10 games. Option A yielded a payoff of € 5.00 or € 0.00 with an equal probability of 50 %. Option B yielded a payoff with certainty that was different in each of the games.

The participants were told that at the end of this part, one of the ten games would be chosen randomly to determine actual payoffs. All games could be chosen with equal probability. Once all subjects made their decisions, the individual payoff for the randomly drawn game was presented on the screen.

The third part was designed to capture the degree of loss aversion of the subjects and consisted of six lotteries. For instance, a lottery may present a subject with a 50 % chance of losing € 2 and a 50 % of winning € 6. While the winning amount was equal in all lotteries, the potential loss varied between € 2 and € 7. Subjects had to choose whether to accept or reject the particular lottery. Again, only one of the lotteries was determined randomly for actual payoffs.

In a concluding questionnaire, participants were asked to give some personal information like gender, age, which semester they were studying in and at which faculty. Once they completed this form, their individual total payoff from the previous parts was shown on the screen and paid privately in cash.

2. Additional descriptive statistics

Table S3 presents overall means of the contributions to the various accounts by type and treatment. For all but one type, about half of the tokens were contributed to the gains domain (P-Fund) and half to limit the losses (either M- or A-Fund). The exception is the D_L subjects in the asymmetric treatment, who contributed about 66% of their tokens to the P-fund. Cooperative behavior, defined as contributions to the M- fund, appears to be the highest in the D_H treatment and the lowest for the D_L subjects in the asymmetric treatment. The last column shows the payoffs. In general, we see that the D_L subjects make more than D_H subjects. We also see that D_L subjects make the most in the asymmetric treatment, which is also the treatment where the D_H subjects make the least.

	P-Fund	A-Fund	M-Fund	Payoff (in tokens)
D_L	5.05	3.23	1.71	224.07
D_H	4.88	1.80	3.32	123.21
asym	5.81	2.06	2.12	155.09
asym D_L	6.57	1.83	1.61	240.07
asym D_H	5.06	2.31	2.63	69.62

Table S3 – Average Individual Contributions and Payoff by Treatment

Figure S1 presents in Panels a and b the same information as presented in Figure 1 in the main text and in Panels c and d the percentage of subjects in each setting who contributed at least a positive amount to the mitigation M-fund. Those who did not contribute anything can be thought of as complete free-riders meaning, the higher the percentage, the lower the number of free-riders. From Panel c – showing the percentage of non-free-riders by treatment – we see that the lowest percent of free-riders is 24.5% in the symmetric treatment with D_H subjects which is substantially lower than the 53.1% in the symmetric treatment with D_L subjects ($p<0.01$)[10] and the 44.8% in the asymmetric treatment ($p<0.01$). We do not find support for differences in the rate of free-riders between the asymmetric treatment and the symmetric treatment with only D_L subjects ($p=0.15$). The results of a similar analysis for Panel d are in line with what was reported for Panel b.

[10] The reported p-value is the result of pairwise comparison (ttest) with clustering at the individual level to account for the correlation of the repeated observations.

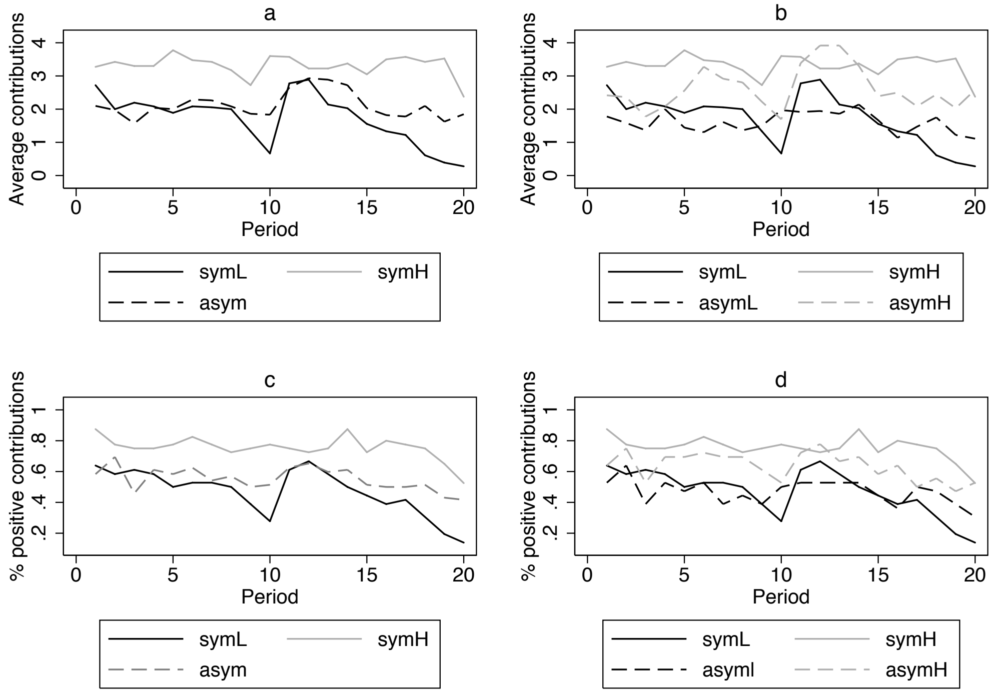

Figure S1 – The upper panels show the average individual contributions to the mitigation fund by treatment (Panel a) and Type (Panel b) over all 20 periods. The bottom panels show the percent of positive contributions to the mitigation fund by treatment (Panel c) and type (Panel d).

3. Regression analyses

Table S4 presents the results of random effects GLS (Models 1a and 2a) and a marginal effects Probit (Models 3a and 4a), with errors clustered at the subject level to control for the repeated observations. The reference group is the symH treatment.

The primary variables of interest are the dummy variables for treatments symL and asym, as well as the dummy variables for low- and high-damage subjects in the asym treatment, D_L and D_H respectively. We also include control variables for Period (continuous variable from 1 to 20), Risk Aversion and Loss Aversion (continuous variable for the number of risky choices taken when gains versus when losses were possible), Male (=1 if the subject was male), Age (a continuous variable for age), Period 10 and Period 20 (binary variables for the final periods).

	(1a)	(2a)	(3a)	(4a)
symL	-1.470***	-1.496***	-0.301***	-0.304***
	(0.328)	(0.328)	(0.062)	(0.063)
asym	-1.236***		-0.221***	
	(0.320)		(0.058)	
D_L		-1.705***		-0.291***
		(0.390)		(0.067)
D_H		-0.760**		-0.155**
		(0.371)		(0.070)
Period	-0.014	-0.014	-0.008***	-0.008***
	(0.013)	(0.012)	(0.002)	(0.002)
Risk Aversion	0.006	-0.034	-0.022	-0.028
	(0.118)	(0.126)	(0.019)	(0.0194)
Loss Aversion	0.120	0.107	0.040**	0.039**
	(0.086)	(0.085)	(0.018)	(0.018)
Male	0.021	0.137	-0.102**	-0.085*
	(0.268)	(0.287)	(0.050)	(0.051)
Age	0.070**	0.060*	0.013**	0.011*
	(0.033)	(0.034)	(0.007)	(0.006)
Period 10	-0.376**	-0.376**	-0.080**	-0.080**
	(0.173)	(0.173)	(0.035)	(0.035)
Period 20	-0.651***	-0.651***	-0.166***	-0.167***
	(0.218)	(0.218)	(0.036)	(0.037)
Constant	1.479	1.848*		
	(1.072)	(1.104)		
Observations	2,960	2,960	2,960	2,960
Number of Subjects	148	148	148	148
R-squared	0.07	0.08	0.08	0.08

Table S4: Models (1a) and (2a) are random effects GLS regressions while Models (3a) and (4a) are Probit regressions; all errors are clustered at the subject level. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Values of R-squared for the probit regressions are pseudo R-squared values.

	(1b)	(2b)	(3b)	(4b)
symL	-1.017***	-1.044***	-0.258***	-0.258***
	(0.350)	(0.351)	(0.067)	(0.068)
asym	-0.844**		-0.180***	
	(0.336)		(0.061)	
D_L		-1.373***		-0.254***
		(0.408)		(0.071)
D_H		-0.301		-0.102
		(0.376)		(0.072)
Lag Group Contributions	0.106***	0.107***	0.001***	0.011***
	(0.017)	(0.017)	(0.004)	(0.004)
Period	-0.012	-0.012	-0.007***	-0.007***
	(0.013)	(0.013)	(0.002)	(0.002)
Risk Aversion	0.000	-0.045	-0.024	-0.031
	(0.117)	(0.125)	(0.0189)	(0.020)
Loss Aversion	0.139	0.125	0.045**	0.042**
	(0.091)	(0.088)	(0.019)	(0.019)
Male	0.011	0.142	-0.106**	-0.088*
	(0.273)	(0.291)	(0.052)	(0.053)
Age	0.072**	0.060*	0.013**	0.011*
	(0.034)	(0.034)	(0.006)	(0.006)
Period 10	-0.221	-0.220	-0.066*	-0.065*
	(0.173)	(0.173)	(0.034)	(0.035)
Period 20	-0.483**	-0.482**	-0.155***	-0.155***
	(0.215)	(0.215)	(0.037)	(0.037)
Constant	0.304	0.715		
	(1.110)	(1.135)		
Observations	2,960	2,960	2,960	2,960
Number of Subjects	148	148	148	148
R-squared	0.10	0.11	0.09	0.09

Table S5: Models (1) and (2) are random effects GLS regressions while Models (3) and (4) are Probit regressions; all errors are clustered at the subject level. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Values of R-squared for the probit regressions are pseudo R-squared values.

One of the often cited drivers of behavior in Result 2 in the main text has been dubbed the "poisoning of the well". If, as others have found (e.g. 3, 4, 5), conditional cooperation plays a role in behavior in a social dilemma, a poisoning of the well in our setting could come from the overall lower group-level contributions in the asym treatment vs. the symH treatment. In other words, if subjects are conditionally cooperative, we should expect to see D_H subjects in the asymmetric treatment respond to the lower observed contributions of others by also reducing their own contributions. To test this, we add the variable Lag Group Contributions in Models 1b – 4b. These results are presented in Table S5.

As expected, we see a positive and significant sign on Lag Group Contributions in all Models. This form of conditional cooperation does not seem to be the driving force explaining the behavior of the D_L subjects in the asym treatment because of the still significant and negative coefficient in all Models. However, looking at Models 2b and 4b, we see that there is no longer a significant effect of D_H. In other words, once conditional cooperation is controlled for, there is no difference between D_H subjects in the asymmetric and symmetric settings. In sum, those who suffer higher damages are responding as if they are conditional cooperators by contributing less in the asymmetric treatment in response to lower contributions from others.

Table S6 reports regressions where the dependent variable is contributions to the A-fund (Models 5 and 6) and the P-fund (Models 7 and 8). To make comparisons easier to cooperative behavior, the regressions reported in this table use the same explanatory variables as Models 1a and 2a from Table S4. From Table S6, we see that subjects in the symL treatment contribute significantly more to the A-fund than subjects in the asymH treatment. Using Wald tests, we also see that symL subjects contribute more than the D_L subjects ($p<0.01$) and the D_H subjects ($p=0.07$). There is no difference between D_L and D_H subjects ($p=0.31$).

	A − fund		P − fund	
	(5)	(6)	(7)	(8)
symL	1.367***	1.355***	0.103	0.141
	(0.388)	(0.388)	(0.483)	(0.483)
asym	0.312		0.924**	
	(0.333)		(0.418)	
D_L		0.099		1.606***
		(0.397)		(0.521)
D_H		0.529		0.231
		(0.396)		(0.487)
Period	-0.017	-0.017	0.032**	0.032**
	(0.014)	(0.014)	(0.013)	(0.013)
Risk Aversion	0.117	0.099	-0.122	-0.064
	(0.189)	(0.192)	(0.168)	(0.179)
Loss Aversion	-0.155	-0.161	0.035	0.054
	(0.111)	(0.107)	(0.135)	(0.128)
Male	-0.666**	-0.614*	0.645	0.477
	(0.327)	(0.314)	(0.402)	(0.398)
Age	-0.023	-0.028	-0.047	-0.032
	(0.046)	(0.046)	(0.056)	(0.056)
Period 10	0.045	0.045	0.331	0.331
	(0.195)	(0.195)	(0.212)	(0.212)
Period 20	0.785***	0.785***	-0.134	-0.134
	(0.230)	(0.231)	(0.246)	(0.246)
Constant	2.803**	2.970**	5.718***	5.182***
	(1.249)	(1.274)	(1.622)	(1.644)
Observations	2,960	2,960	2,960	2,960
Number of Subjects	148	148	148	148
R-squared	0.03	0.06	0.03	0.05

Table S6: Regressions on contributions to the A-fund or the P-fund by type; all errors are clustered at the subject level. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

4. Sample Instructions

Instructions for the experiment were originally written in German. We provide a translation of the instructions for a low-damage cost type in homogenous groups. Instructions for the other treatment conditions are analogous and available upon request from the authors.

Experiment Instructions: Periods 1-10

This is an experiment on the economics of decision making. You will have the chance to earn money based on your decisions in this experiment. It is extremely important that you put away all materials including external reading material and turn off your cell phones and any other electronic devices. If you have a question, please raise your hand and I will come by and answer your question privately.

You will receive €15 for your participation, but note that should a loss occur during the experiment, the loss will be deducted from that amount, whereas a gain will be added.

In the experiment you will earn Experimental Currency Units (or ECU's). At the end of the experiment, your ECU's from all periods will be summed and converted to euros where 1 ECU = € 0.05. Today's experiment is comprised of 5 sections. The following instructions are for the first section. Prior to the start of the other sections, additional instructions will be given.

The first section is comprised of 10 periods. At the beginning of the section, you will be randomly and anonymously assigned to a group of 4 players, meaning you and other 3 participants. You will remain in this same group for the entire 10 periods. At no point will we reveal who was in each group.

In each period, each of you will be given 10 tokens. Your task is to decide how many tokens to allocate to accounts A, B and C. You can allocate anywhere from 0 to 10 tokens to each account, but the total allocated to all three must sum to 10. (Negative allocations or fractional allocations are not allowed, and tokens cannot be carried over from one period to another).

As mentioned previously, there is the possibility that you will lose ECU's each round. Your allocation decisions and the allocation decision of other members in your group can affect the size of this loss.

Earnings from Account A:

Each token allocated to account A will return to you 1 ECU.

Earnings from Account C:

Initially, 100% of the loss will occur for your group. Each token you or anyone in your group allocates to account C will reduce the percentage of this loss to *your group* by 3% until 0% is reached. If more tokens are contributed to account C than is required to reach 0%, those tokens will not be returned.

Note: Tokens you allocate to account C reduce this percentage for you and everyone in your group. Likewise, tokens allocated to account C by any of your group members reduce this percentage for you and everyone in your group.

Earnings from Account B:

Every token you allocate to account B will reduce the maximum size of the loss *you* will experience by 1.1 ECUs. Everyone in your group has a value of the maximum size of the loss equal to 15 ECUs.

Note: Tokens you allocate to account B only affect your individual payoffs. Likewise, tokens allocated by your group members to their B accounts only affect their individual payoffs.

Total Earnings

Your earnings in a round will be your earnings from account A minus the result of multiplying the percentage of the loss for your group (after accounting for allocations in account C by all members of your group) by the size of the loss for you (after accounting for your allocations in account B).

The computer program will have a calculator so you can test various scenarios.

Examples

Let's go through four examples.

Example 1: Suppose you contributed 2 tokens to account A, 4 tokens to account B and 4 tokens to account C. Also suppose that the total contributions from other members in your group into account C were the same as you meaning the total contributed to account C totals 4+4+4+4=16. With these assumptions, you would end up with

(1 ECU/token * 2 tokens) = 2 ECUs earned from account A

minus

(100% - 3% * 16 tokens) * (15 ECUs - 1.1 ECUs/token * 4 tokens)

= -5.5 ECUs earned from accounts B and C

= -3.2 total ECUs earned for that round

Example 2: If everything remained the same as above except you instead contributed 6 tokens to account A and none to account C, that would mean that others contributions to account C would total 12 tokens and you would still contribute 4 tokens to account B. You would end up with

1 ECU/token * 6 tokens = 6 ECUs earned from account A

minus

(100% - 3% * 12 tokens) * (15 ECUs - 1.1 ECUS/token * 4 tokens)

= -6.8 ECUs earnings from accounts B and C

= -0.8 total ECUs earnings for that round

Example 3: assume that as in the first example that your group's contributions remained the same and you contributed 2 tokens to account A. This time though, assume you contributed no tokens to account C and instead put the remaining tokens in account B. You would end up with

1 ECU/ token * 2 tokens = 2 ECUs earnings from account A

minus

(100% - 3%*12 tokens) * (15 ECUs - 1.1 ECUs/token * 8 tokens)

= -4.0 ECUs earnings from accounts B and C

= -2.0 total ECUs earnings for that round

Example 4: assume your group’s contributions to account C remained at 12 and your allocations to account A remained at 2. Assume you allocated no tokens to account B and thus your remaining 8 tokens will go into account C bringing the total to 20. You would end up with

1 ECU/token * 2 tokens = 2 ECUs earnings from account A

minus

(100% - 3% * 20 tokens) * (15 EUCs - 1.1 ECUs/toekn * 0)

= -6 ECUs earnings from accounts B and C

= -4 total ECUs earnings for that round

Remember, in all of the above examples, the resulting number from account C is common for everyone in your group including you.

Timing and Feedback

When the first period begins you and everyone in the experiment will make your allocation decisions in accounts A, B, and C. After you have made your decision, you must click on the "continue" button. Once everyone has clicked continue, the computer will show your earnings from accounts A, B and C and your total earnings for that round. After you are done viewing your earnings, you should click continue. Once everyone has done this, the next period will begin. This will be repeated for 10 periods.

If there are any questions, please raise your hand and we will come to you and answer them privately.

[*Before starting round 11*] You have now ended section 1 and will start section 2. The second section is comprised of 10 new periods where you will continue in the same group and all conditions are exactly the same as before.

If there are any questions, please raise your hand and we will come to you and answer them privately.

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To mitigate or to adapt? Collective action under asymmetries in vulnerability to losses

Abstract
Many policies addressing global climate change revolve around the implementation of mitigation and adaptation strategies. We experimentally examine subjects? choices in a climate change game where subjects are put into groups where they face a potential damage and have the choice to invest resources into mitigation, adaptation and/or productive funds. Resources allocated to mitigation reduce the probability of the loss to the entire group while adaptation investments reduce the magnitude of the loss to the investing agent and productive investments increases payoffs only for the investing agent. We explore subject's response to three treatment conditions; high damage, low damage and heterogeneous damage. Results show that subjects view mitigation and adaptation funds as substitutes in that they contribute higher levels to the adaptation fund if low levels of contributions to the mitigation fund exist, but free-ride on others by contributing to the productive fund if contributions to the mitigation fund are high enough. In particular, we find the highest level of contributions to the socially efficient mitigation fund when all subjects in a group face a high damage and the lowest level when all subjects face a low damage. When high-damage subjects are mixed with low-damage subjects, their contribution levels to the mitigation fund decline, but are still greater than those of their low-damage group members.

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