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**Working Paper**

## Does risk communication really decrease cooperation in climate change mitigation?

Jena Economic Research Papers, No. 2017-014

**Provided in Cooperation with:**

Friedrich Schiller University Jena, Faculty of Economics and Business Administration

*Suggested Citation:* Bravo, Giangiacomo; Farjam, Mike; Nikolaychuk, Olexandr (2017) : Does risk communication really decrease cooperation in climate change mitigation?, Jena Economic Research Papers, No. 2017-014, Friedrich Schiller University Jena, Jena

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# JENA ECONOMIC RESEARCH PAPERS



# 2017 – 014

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by

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[www.jenecon.de](http://www.jenecon.de)

ISSN 1864-7057

The JENA ECONOMIC RESEARCH PAPERS is a joint publication of the Friedrich Schiller University Jena, Germany. For editorial correspondence please contact [markus.pasche@uni-jena.de](mailto:markus.pasche@uni-jena.de).

Impressum:

Friedrich Schiller University Jena  
Carl-Zeiss-Str. 3  
D-07743 Jena  
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# Does risk communication really decrease cooperation in climate change mitigation?

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## Abstract

Effective communication of risks involved in the climate change discussion is crucial and despite ambitious protection policies, the possibility of irreversible consequences actually occurring can only be diminished but never ruled out completely. We present a laboratory experiment that studies how residual risk of failure affects willingness to contribute to climate protection policies. Contrary to our initial hypothesis, we find that the contributions were higher in treatments with residual risk than in treatments without one. We interpret this as an outcome of a psychological process where residual risk puts participants into an "alarm mode", keeping their contributions high. We discuss the broad practical implications this might have on the real world communication of climate change.

*Keywords:* collective risk social dilemma, climate change mitigation, voluntary contribution, experiment, risk

*JEL:* D71, Q54, H41, D80

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## 1. Introduction

Support and design of climate policies is strongly affected by how individuals and organizations perceive risks and uncertainties and how they take these factors into account (IPCC 2014; Sterman 2008). Effective communication of climate change risks therefore presents a crucial challenge both for scientists and policy makers alike. In addition, one's mitigation behavior is directly affected by the information available as well as by framing of the problem channeled through traditional and social media (Boykoff 2011; Morton et al. 2011). In need of both clear policy goals

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and widespread behavioral change, successful climate change mitigation cannot transcend effective risk communication (Morgan et al. 2002).

From a psychological perspective, uncertainty about the future allows people to distance themselves from the reality and dangers of climate change, which in turn leads to the reduction of their willingness to adopt mitigation behavior (Budescu et al. 2009; Morton et al. 2011; Shackley and Wynne 1996). More generally, research has shown that people are less willing to cooperate in social dilemma situations presenting uncertainty or risk (Barrett and Dannenberg 2014; Dannenberg et al. 2015; Hine and Gifford 1996). However, it is crucial to distinguish between *a priori* and *residual* risk, the former referring to the consequences of an *unsuccessful* collective action — i.e., the expected harm from climate change if the currently agreed upon target of keeping the increase in the average temperature within 2°C of the pre-industrial levels is not met; and the latter referring to the risk that even a successful collective action cannot rule out — i.e., the negative consequences that climate change can still lead to even if the 2°C target is met.

The argument that *a priori* risk should necessarily reduce cooperation has recently been challenged both by theoretical models (Santos and Pacheco 2011) and experimental research (Milinski et al. 2008). Collective-risk social dilemma (CRSD) experiments allow for a particularly interesting framework to investigate the effect of *a priori* risk. CRSDs are interaction situations akin to threshold public goods games, where failure to reach the common objective results in a high probability of harm to the participants. CRSDs are designed to simulate climate change mitigation dilemmas, where failure to contain the amount of greenhouse gases in the atmosphere is forecast to harm human activities significantly. A common finding in such situations is that higher levels of *a priori* risk actually increase the likelihood of participants working together to reduce it (Dannenberg et al. 2015; Milinski et al. 2008; Tavoni et al. 2011).

To date, CRSDs have only been studied under a protocol where a group's success in reaching the common objective leads to a completely safe outcome, i.e., *without* any *residual* risk. However, this does not represent many real-world situations well, and even more so in the case of climate change mitigation where the risk can indeed be reduced by a successful collective action but never ruled out completely. Insights from psychological literature suggest that cooperation rates actually may decrease when the residual risk is greater than zero (Hine and Gifford 1996; Kahneman and Tversky 2000). In order to test this prediction, we conduct an experiment that studies how residual risk affects the willingness of participants to contribute in a CRSD situation. The intuition behind this research is

that even if countries or individuals do manage to reach some common objective — e.g., keeping the rise of the global temperature below 2°C — risks that exist in many real situations cannot be eliminated completely, and this can affect the whole process — e.g., climate change mitigation initiatives — negatively.

Despite these predictions, we find that cooperation not only does not decline in situations with residual risk but on the contrary, may even rise by the end of the game. This surprising finding suggests that the usual ways of communicating climate change risks should perhaps be reconsidered. The remainder of the paper is organized as follows. Section 2 elaborates on the rationale behind our hypotheses. Section 3 introduces the design of the experiment while Section 4 presents its outcomes. Finally, Section 5 discusses our findings and proposes directions for future research.

## 2. Problem formulation

Our general research question concerns the effect that residual risk has on the willingness to contribute in a collective action situation such as climate change mitigation. To begin with, we simplify the contribution decision under risk by reducing it to an individual decision problem. At the end of this section, however, we will relate the conclusions derived under this simplifying assumption to the literature on strategic decision making in collective action situations.

The literature on individual decision making defines a situation involving risk as a lottery with known realization probabilities of each of the possible outcomes (Kahneman and Tversky 1984). One of the main findings in this literature is that most humans are risk averse, i.e., they prefer a sure outcome over a lottery with the same expected value. Humans are even willing to pay disproportionate amounts of money to reduce the risk, and thereby accept lower expected returns.

To put this into the context of the CRSD game, the decision whether or not to invest into a climate change mitigation initiative can be seen as a choice between two lotteries: one where climate change occurs with some known *a priori* probability  $p$  and leads to the loss of the whole endowment  $E$ , and one where this probability is reduced to a *residual* level  $\pi$  at the cost  $C$  ( $\pi < p$ ). Between these two lotteries, the rational agent prefers the one with the risk level  $\pi$  as long as  $C < \frac{p-\pi}{1-\pi} \cdot E$  (see Appendix A). From this point of view, our research question can be rephrased like this: to what extent does the investment into mitigation initiatives that make the level of risk reduce from  $p$  to  $\pi$  depend on whether or not  $\pi$  is larger than zero?

Addressing this question is rather challenging for at least two reasons. First, it is impossible to come up with pairs of lotteries equivalent in all but one aspect (e.g.,  $\pi$ ) both objectively and psychologically (see Kahneman and Tversky 1972; Schmeidler 1989). Second, whether or not the risk is realized is not an outcome of an individual decision but rather depends on the behavior of a group of people all facing the same dilemma. The following paragraphs will discuss these issues separately and derive the hypotheses for our experiment.

Regarding the first issue, let us consider two pairs of lotteries  $\{p_1, 0\}$  and  $\{p_2, \pi\}$ , where the outcomes are the the same and  $p_1 = p_2 > \pi > 0$ . In this case, the two pairs differ in terms of expected gain when moving from  $p$  to  $\pi$  (henceforth simply *probability gain*). The obvious fix for the difference in probability gain would be to set  $p_2 = p_1 + \pi$ . However, we know from Prospect Theory that probabilities are not perceived objectively, that high probabilities feel different from low probabilities psychologically (Kahneman and Tversky 1972; Schmeidler 1989). In other words, even though both pairs of lotteries may objectively be the same in terms of probability gain, they may subjectively be perceived differently.

With this in mind, our goal is to separate the effect of introducing residual risk  $\pi$  from the effect of increasing *a priori* risk ( $p + \pi$ ). To do so, we compare the lottery pair  $\{p, 0\}$  to two other pairs:  $\{p, \pi\}$  and  $\{p + \pi, \pi\}$  (henceforth *baseline*, *Residual Risk 1* or RR1, and *Residual Risk 2* or RR2, respectively). The comparison between RR2 and the baseline allows us to observe the effect of introducing *residual* risk  $\pi$  while keeping the probability gain constant (by the means of increasing *a priori* risk to  $p + \pi$ ). The comparison between RR1 and the baseline on the other hand, allows us to observe the effect of introducing *residual* risk  $\pi$  while keeping *a priori* risk constant (by the means of changing the probability gain to  $p - \pi$ ). Any difference that is common to both comparisons thus can be attributed to  $\pi$ .

Knowing from Prospect Theory that small risks of losing are usually overweighted, we expect that any  $\pi > 0$  is going to discourage the participants from investing in the climate change mitigation project. For the same reason, we expect that even though the probability gain in RR2 is objectively the same as in the baseline, it will appear lower subjectively and as a consequence, the participants will invest less in RR2 than in the baseline. Since RR1 is even worse in terms of objective probability gain (and as such, also in terms of subjective probability gain), we expect that the participants in RR1 invest even less than in RR2.

Until now we have ignored the fact that the CRSD is not an individual decision problem but rather

involves a strategic interaction of six players (Milinski et al. 2008). The main difference is that in an individual decision situation the player can be certain that their investment will decrease the level of risk they are facing whereas in a strategic situation the effect of their investment depends on the decisions of others, which results in an additional layer of uncertainty. However, we have no reason to expect that the participants' assessments of this uncertainty will depend on  $p$  and  $\pi$ , and especially on the fact that  $\pi > 0$ , in any *particular* way and as such, assume that they will be just as uncertain about the decisions of others in either treatment for simplicity. Also note that previous research has shown that there is strong correlation between risk preferences in situations with human induced uncertainty and situations with purely random outcomes (Bohnet and Zeckhauser 2004; Bohnet et al. 2008; Fairley et al. 2016; Farjam 2015). As such, we expect the conclusions drawn from the analysis of the CSRD situation as an individual decision problem to hold true in the strategic context as well, which translates into the following two hypotheses:

**Hypothesis 1.** *Contributions to climate change mitigation initiatives in treatment RR2 will be lower than in the baseline.*

**Hypothesis 2.** *Contributions to climate change mitigation initiatives in treatment RR1 will be lower than in treatment RR2 and the baseline.*

### 3. Methods

Our experimental design was based on the collective-risk social dilemma framework by Milinski et al. (2008). A group of six players had 10 periods to provide a total contribution of 120 “Experimental currency units” (ECUs)<sup>1</sup> to what was referred to as a “climate protection” account. Each participant was initially endowed with 40 ECUs and could contribute  $\{0, 2, 4\}$  ECUs to the climate account in each period. All contributions were subtracted from the private endowments of the participants. In order to reach the target of 120 ECUs, on average the contribution per participant per period must be 2 ECUs. We will refer to this as the *reference contribution*. At the end of each period, the participants were informed of both contemporaneous and cumulative individual contributions of the other group members (randomly assigned aliases were used for in-game identification) as well as about the corresponding group totals.

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<sup>1</sup>We used the following conversion rate in our experiment: 3 ECUs = €1.

All contributions were non-refundable — i.e., nothing was returned to the participants even if the group target was not reached — and the participants were informed that all their contributions would be used to purchase carbon dioxide compensation certificates. At the end of the game, whether or not the group as a whole reached the common target determined the type of risk they would face: *residual* ( $\pi$ ) in case of the total contribution reaching 120 ECUs or *a priori* ( $p$ ) otherwise. At the end of game, the players would keep the remainder of their private endowment only if the uncertainty was resolved in their favor by a random draw based on the risk factor valid for their group. The actual values of  $p$  and  $\pi$  differed across the treatments:  $p = 0.7$  and  $\pi = 0.0$  in the baseline,  $p = 0.7$  and  $\pi = 0.2$  in treatment Residual Risk 1 (RR1), and  $p = 0.9$  and  $\pi = 0.2$  in treatment Residual Risk 2 (RR2). The experiment followed the protocol presented in Figure 1. First, the participants were assigned to either of the three treatments and received printed instructions similar to the ones used by Milinski et al. (2008), which included a brief explanation of the problem of global warming along with the description of the use of funds contributed to the climate account to purchase  $CO_2$  compensation certificates<sup>2</sup> (see AppendixB for the complete instructions).

Before starting the game, the participants were asked to answer a number of incentivized control questions (see AppendixC for the details). Incorrect submissions were allowed and more than 80% of the participants answered at least 6 out of 7 questions correctly. Then the game was played as described above.

Immediately after the game, the participants were presented with an incentivized Holt and Laury (2002) risk elicitation task and afterwards, with a non-incentivized environmental attitude questionnaire with items derived from the *New Environmental Paradigm* (NEP) scale (Dunlap et al. 2000). In the uncertainty resolution stage, the participant sitting at computer #1 was instructed to inspect an urn containing ten tennis balls with numbers 1 through 10 and then to draw one of them in order to resolve the uncertainty over the final outcome of the climate protection game. The same draw was used for all the three groups (i.e., treatment conditions) participating in a given session. Finally, the session concluded with a basic sociodemographic questionnaire.

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<sup>2</sup>Altogether, the participants of the experiment contributed the equivalent of USD 1185 to the climate account. These funds were used to offset 1975 metric tonnes of  $CO_2$  via the United Nations online platform for voluntary cancellation of certified emission reductions (CERs).



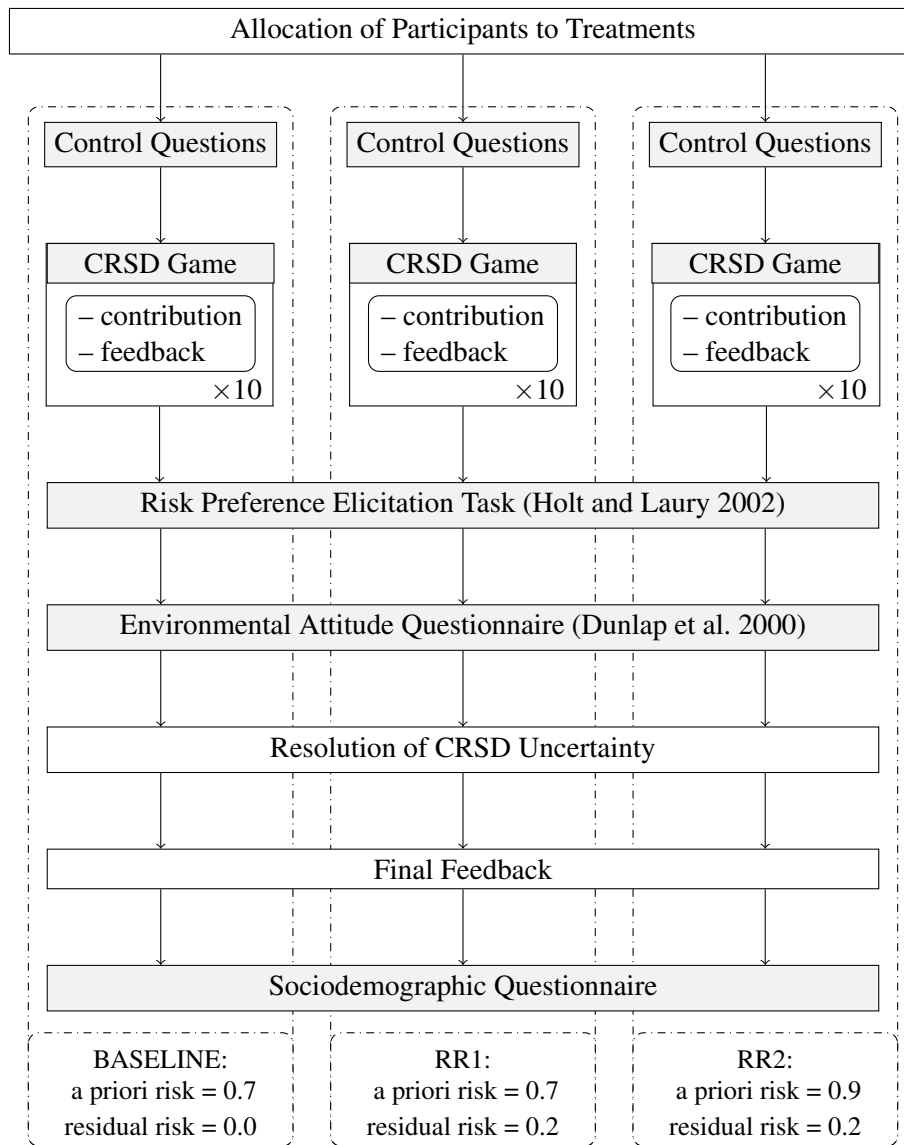


Figure 1: Experimental design overview

## 4. Results

### 4.1. Session statistics

The experiment was conducted at the Laboratory of Experimental Economics of the Friedrich Schiller University Jena (Germany) in February 2017. It was programmed in z-Tree (Fischbacher 2007) and the participants were recruited using ORSEE (Greiner 2015).

Altogether, 11 experimental sessions were concluded with a total of 186 participants (36% males).

The average age was 26 years. In terms of educational background, 48% of the participants were undergraduate students and 16% studied Economics or Business Administration. The average earnings were €10.3 (including a show-up fee of €2.5) for approximately 40 minutes spent in the laboratory.

All sessions but one involved three groups of 6 participants randomly assigned to either of the three treatments. The final session had only one group that was randomly assigned to RR2.

#### 4.2. Group-level results

The general findings are summarized in Table 1. As one can see, only 60% of the groups were successful in reaching the threshold necessary to decrease the risk of "climate change" in the baseline condition whereas an impressive 91% of them (all but one group) did so in RR2. With 80% of groups reaching the threshold, RR1 produced an intermediate result.

Treatment Condition	Threshold Reached	Average Group Contribution
Baseline ( $p = 0.7$ ; $\pi = 0.0$ )	60%	117 (sd=11.1)
RR1 ( $p = 0.7$ ; $\pi = 0.2$ )	80%	119.4 (sd=6.6)
RR2 ( $p = 0.9$ ; $\pi = 0.2$ )	91%	121.5 (sd=2.5)

Table 1: Group-level descriptive statistics. The values of  $p$  and  $\pi$  denote the levels of *a priori* and *residual* risk, respectively.

These results do not support our hypotheses that the residual risk in treatments RR1 and RR2 reduces the contributions to the climate account. The observed differences in the contributions seem to suggest quite the opposite, i.e., that the introduction of residual risk actually *increases* the average contributions. The fact that the contributions in RR1 were somewhat higher than those in the baseline suggests that this effect was even stronger than the effect of the probability gain reported by Milinski et al. (2008).

However, these group-level differences turned out not statistically significant, neither as far as the proportion of groups reaching the threshold ( $\chi^2 = 0.24$ , one-sided  $p = 0.313$  and  $\chi^2 = 1.32$ , one-sided  $p = 0.126$  for RR1 and RR2 relative to the baseline, respectively) nor as far as the total amount contributed to the climate account ( $W = 39.5$ , one-sided  $p = 0.220$  and  $W = 40.0$ , one-sided  $p = 0.145$  for RR1 and RR2 relative to the baseline, respectively). That being said, testing for treatment differences at the group level is rather inefficient, as it does not take into account variation occurring at the individual level or over time. Therefore we turn to individual-level models in the next section.

4.3. Individual-level results

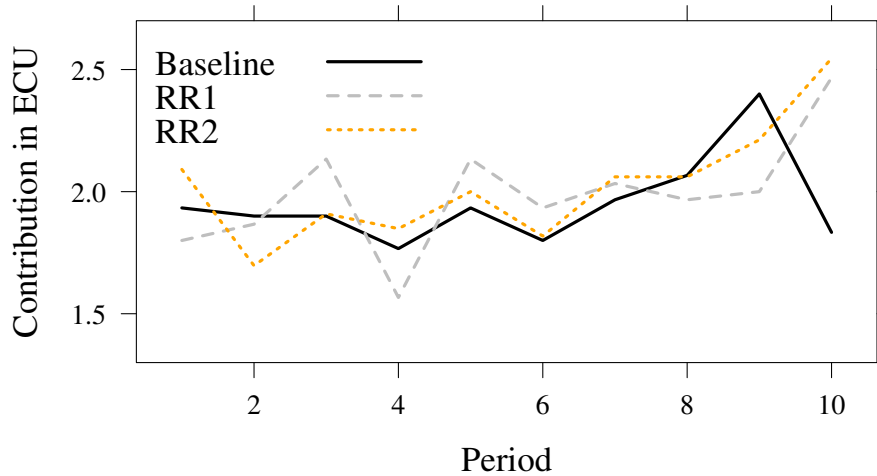


Figure 2: Average contribution in ECU per participant over time.

Figure 2 presents the average individual contributions over time. In all the treatments, the initial contributions fell short of the reference value of 2 ECUs, which if sustained would ensure reaching the threshold by the end of the game. Over time, in order to compensate for the slow start, the contributions tended to grow larger and especially so towards the end of the game, with the notable exception of the baseline.

Figure 3 provides additional insights to help better understand the group dynamics by plotting the average difference between the group total amount contributed to the climate account and the “reference” contribution scheme of 2 ECUs per period per participant. One can see varying degrees of success in keeping this difference under control across the treatments. In the baseline, the participants did not seem to realize that their contributions were too low until the very late stage whereas in RR2, they managed to reverse the initial trend of declining contributions already in the middle of the game. The RR1 groups performed worse than the baseline in the first half but better in the second half of the game.

To model the nested structure of the data we estimated a mixed effects model<sup>3</sup> as specified in equation (D.1) below. Besides the binary variables for the fixed effects of the treatments, the model

<sup>3</sup>We used the R package `lme4-1.1-13`

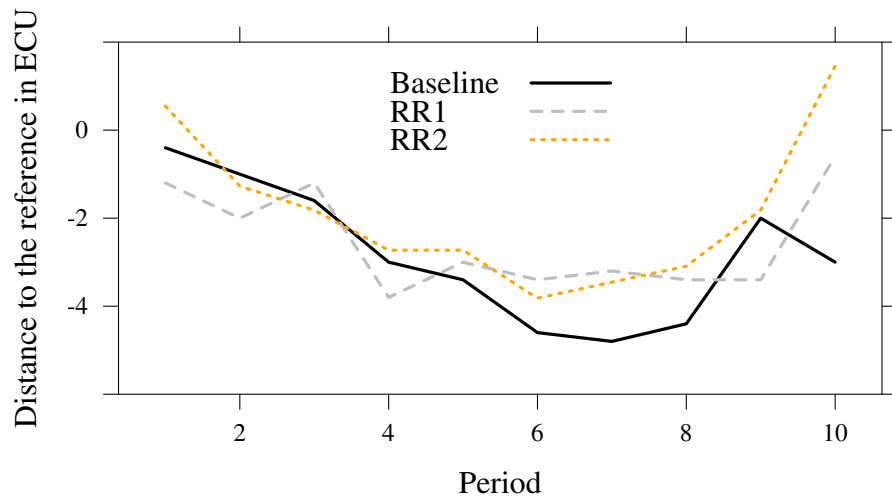


Figure 3: Difference between a climate account where every participant is contributing the reference contribution of 2 ECUs per period to the climate account and the actual ECUs in that account.

contained random effects both at the group and individual levels. Since Figure 2 suggested that most of the between-treatment variation was concentrated in the last period, a corresponding binary variable was included as an additional fixed effect (as well as its interactions with the treatment variables). Finally, we controlled for risk aversion (Holt and Laury 2002) and environmental attitude (Dunlap et al. 2000) of the participants by adding the corresponding indices to the model specification as individual fixed effects.

The coefficient estimates are summarized in Table 2. Since defining the number of degrees of freedom of the fixed effects for such model is somewhat problematic (Bates et al. 2015), all p-values were obtained using bootstrap (10K samples). We also considered a number of more complex specifications — e.g., including lagged individual and group contributions — but none of them could improve the model fit according to the AIC criterion. Those models will not be presented here.

According to the model estimation results, the last period contributions in treatments RR1 and RR2 were significantly higher than in the baseline (either p-value < 0.01), which corroborates the trends observed in the group-level data. No other significant effects were found.

A more detailed investigation of the group dynamics suggested that one group in the baseline condition could be considered an outlier as its members contributed exceptionally little during the

	$\beta$	$\sigma$	$t$	$P >  t $
Intercept	1.9646	0.051	38.47	0.00
RR1	-0.0271	0.072	-0.38	0.71
RR2	-0.0002	0.071	-0.00	1.00
LastRound	-0.1296	0.137	-0.94	0.35
RiskAv	-0.0036	0.028	-0.13	0.90
NEP	-0.0240	0.028	-0.86	0.39
LastRound $\times$ RR1	0.6593	0.193	3.41	0.00
LastRound $\times$ RR2	0.7088	0.189	3.74	0.00

Table 2: Mixed effects model of individual contribution over time as specified in equation (D.1), p-values obtained via bootstrap (10K samples).

game (Fig. 4). However, excluding this group did not qualitatively affect our results<sup>4</sup>.

#### 4.4. Distinguishing between *a priori* and residual risk

Since our experimental design was very close to the one used by Milinski et al. (2008), we expanded the analysis by including the data from their treatment with  $p = 0.9$  and  $\pi = 0.0$ . Together with our three treatments, this allowed us to employ the full factorial design — i.e.,  $2 \times 2$  levels of  $p \in \{0.7, 0.9\} \times \pi \in \{0.0, 0.2\}$  — to distinguish between the effects of *a priori* and residual risk. Comparing the average group contribution across the four treatments resulted in the following ranking: RR2 (121.5)  $\succ$  RR1 (119.4)  $\succ$  Milinski (118.2)  $\succ$  Baseline (117). This suggested that higher levels of both *a priori* and *residual* risk could lead to higher contributions. In order to test for the statistical significance of this result, we estimated the mixed effects model specified in equation (D.2) using the merged dataset. Save for absence of the individual level controls and addition of a binary variable to control for the source of the the data, the specification was identical to equation (D.1).

As one can see in Table 3, there was no significant difference between the two datasets ( $p = 0.89$ ) and the estimation results support our previous findings that both *a priori* and residual risk led to significantly higher contributions in the last period, both effects being of similar magnitudes.

<sup>4</sup>For the model estimation wouthout the outlier group, see AppendixD

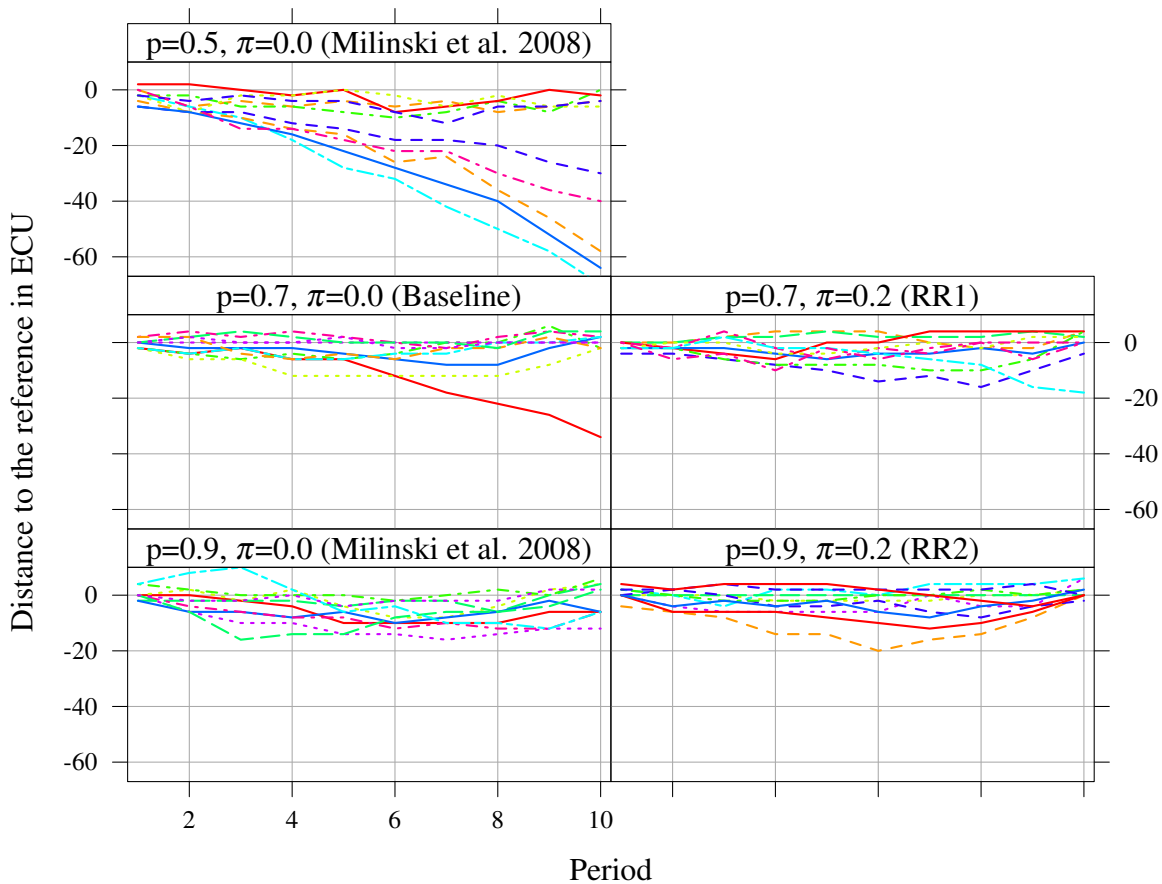


Figure 4: Difference between a climate account where every participant is contributing the reference contribution of 2 ECUs per period to the climate account and the actual ECUs in that account. Each line represents one group. Treatments with  $\{p = 0.5, \pi = 0.0\}$  and  $\{p = 0.9, \pi = 0.0\}$  are from Milinski et al. (2008). Close-ups of the last three periods are available in AppendixD.

## 5. Discussion

The purpose of this experiment was to test if introducing residual risk would reduce contributions to climate change mitigation initiatives. The results presented above did not support our initial hypotheses pointing in that direction. On the contrary, they suggested that the participants were, if anything, *more willing* to contribute to the climate account by the end of the game both in treatments RR1 and RR2, which in turn led to a higher proportion of groups reaching the threshold relative to the baseline albeit not at the statistically significant level.

	$\beta$	$\sigma$	$t$	$P >  t $
Intercept	1.9477	0.054	36.14	0.00
p=0.9	0.0002	0.073	0.00	1.00
$\pi=0.2$	0.0226	0.126	0.18	0.86
LastRound	0.0045	0.075	0.06	0.95
Milinski	-0.0142	0.103	-0.14	0.89
LastRound $\times$ p=0.9	0.3401	0.144	2.36	0.02
LastRound $\times$ $\pi=0.2$	0.3549	0.144	2.46	0.01

Table 3: Mixed effects model of individual contribution over time that distinguishes between the effects of a priori and residual risk as specified in equation (D.2), p-values obtained via bootstrap (10K samples).

To a large extent, this finding goes against what can be derived from the well established psychological literature (Kahneman and Tversky 1972; Schmeidler 1989) and perhaps even common sense as well (i.e., why would one put more effort to reach what actually can be seen as a less favorable outcome?). We would like to argue, however, that it should not be shrugged off too easily but rather considered a new hypothesis for future work. Not only was this finding robust, it also has far-reaching implications for the whole field of research on climate change mitigation initiatives where the standard paradigm is that uncertainty has a negative effect on the willingness to invest or engage in climate protection activities (e.g., Budescu et al. 2009; Shackley and Wynne 1996). We are not the first to challenge this view on the conceptual grounds (see Morton et al. (2011) for a survey approach) but to the best of our knowledge, there has been no experimental evidence to the contrary so far. Practically speaking, our results suggest that transparent communication of (residual) risks pertaining to climate protection activities, even upon their fulfillment, need not backfire but rather may increase the success rates of such initiatives.

Although this conclusion may surprise some and certainly requires further investigation, we can be fairly certain that the original hypotheses of the contributions being *negatively* affected by the introduction of residual risk were not supported by the data. Perhaps the weakest point in our line of reasoning leading to the formulation of those was the assumption that the participants' assessment of the strategic component of the uncertainty was independent of both *a priori* and *residual* risk.

Figure 4 shows that nearly every group in the baseline actually was *above* the reference contribution level right before the end of the game. However, some of them sharply reduced their contributions in the very last period, failing to reach the threshold as the result. This kind of behavior is similar to what has previously been found in the psychosocial literature where positive feedback was

demonstrated to lead to overconfidence in the participants of certain social dilemma experiments, resulting in the reduction of the contribution levels (Cremer and van Dijk 2002). This phenomenon, however, did *not* occur in our residual risk treatments. It would appear as if the very presence of residual risk helped the participants of our experiment to stay focused preventing the “overconfidence trap” and as such, sustaining their contributions at the sufficient level until the end of the game. In a similar vein, Shirado and Christakis (2017) show that a group of participants playing a coordination game can benefit from the introduction of a robot player programmed to act randomly. The authors argue that even though extra randomness makes coordination within the group more difficult objectively, it may “shake up” the human players by forcing them to rethink their current strategy and ultimately help them find a better solution to the problem at hand.

In addition, Figures 3–4 indicate that as far as the participant’s behavior over time, the game can be thought of as comprised of two distinct phases. In the first phase (roughly, the first 5 periods), the contributions were declining while in the second phase, there was a tendency to compensate for that. It could be the case that there were two opposing motives at play there. Initially, the participants could be occupied with some notion(s) of, e.g., fairness or distributive justice and as such, dissuaded from contributing by the others underperforming. As the time went by and the “deadline” loomed closer, the urgency to prevent the “catastrophe” from happening took over. In this light, residual risk could be the catalyst that makes the motives switch places faster.

Following this line of reasoning, our data would suggest that knowing that some negative consequences of climate change can no longer be avoided and that even the most optimistic IPCC scenarios cannot rule out the possibility of catastrophic outcomes (IPCC 2014), not only need not hinder willingness to contribute to mitigation initiatives but may even increase it as long as the problem is considered urgent enough.

More research is clearly needed to verify the new hypothesis of a positive relation between residual risk and willingness to contribute to the public good. In particular, it is important to have it confirmed at the group level, which implies conducting a follow-up study on a much larger scale. In addition, even though our sample was not restricted to university students only, it was clearly not representative of the general population in terms of gender, age, cultural background etc. A more diverse sample would thus be beneficial from the external validity point of view. Finally, we only considered two levels of a priori and residual risk each, which leaves room for exploration still. Despite these limitations, our hypothesis provides some important insights. If we want to avoid the



worst consequences of climate change, it is crucial that everybody is involved (Nature Editorial 2016; Ross et al. 2016), and communication plays a critical role in motivating people (Boykoff 2011; Morton et al. 2011). If confirmed, the hypothesis could result in a significant revision of how climate change should be communicated both to politicians and the general public, and we therefore believe that it deserves further investigation.

### **Acknowledgement**

We thank Manfred Milinski for making the data from Milinski et al. (2008) available to us and Alessandro Tavoni for providing us with the experimental instructions and z-Tree code of Tavoni et al. (2011). We also thank the participants of the 10th conference of the International Network of Analytical Sociologists for their useful discussion of this paper.

### **Declaration of competing interests**

Conflicts of interest: none

### **References**

- Barrett, S., Dannenberg, A., 2014. Sensitivity of collective action to uncertainty about climate tipping points. *Nature Climate Change* 4, 36–39.
- Bates, D., Mächler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67 (1), 1–48.
- Bohnet, I., Greig, F., Herrmann, B., Zeckhauser, R., 2008. Betrayal aversion: Evidence from brazil, china, oman, switzerland, turkey, and the united states. *The American Economic Review* 98 (1), 294–310.
- Bohnet, I., Zeckhauser, R., 2004. Trust, risk and betrayal. *Journal of Economic Behavior & Organization* 55 (4), 467–484.
- Boykoff, M. T., 2011. *Who Speaks for the Climate?: Making Sense of Media Reporting on Climate Change*. University Press, Cambridge.
- Budescu, D. V., Broomell, S., Por, H.-H., 2009. Improving communication of uncertainty in the reports of the intergovernmental panel on climate change. *Psychological Science* 20 (3), 299–308.
- Cremer, D. D., van Dijk, E., 2002. Reactions to group success and failure as a function of identification level: a test of the goal-transformation hypothesis in social dilemmas. *Journal of Experimental Social Psychology* 38 (5), 435–442.

- Dannenberg, A., Löschel, A., Paolacci, G., Reif, C., Tavoni, A., 2015. On the provision of public goods with probabilistic and ambiguous thresholds. *Environmental and Resource Economics* 61 (3), 365–383.
- Dunlap, R. E., Van Liere, K. D., Mertig, A. G., Jones, R. E., 2000. New trends in measuring environmental attitudes: measuring endorsement of the new ecological paradigm: a revised nep scale. *Journal of social issues* 56 (3), 425–442.
- Fairley, K., Sanfey, A., Vyrastekova, J., Weitzel, U., 2016. Trust and risk revisited. *Journal of Economic Psychology* 57, 74–85.
- Farjam, M., 2015. On whom would i want to depend; humans or nature? Tech. rep., Jena Economic Research Papers.
- Fischbacher, U., 2007. z-tree: Zurich toolbox for ready-made economic experiments. *Experimental Economics* 10 (2), 171–178.
- Greiner, B., 2015. Subject pool recruitment procedures: organizing experiments with orsee. *Journal of the Economic Science Association* 1 (1), 114–125.
- Hine, D. W., Gifford, R., 1996. Individual restraint and group efficiency in commons dilemmas: The effects of two types of environmental uncertainty1. *Journal of Applied Social Psychology* 26 (11), 993–1009.
- Holt, C. A., Laury, S. K., 2002. Risk aversion and incentive effects. *American Economic Review* 92 (5), 1644–1655.
- IPCC, 2014. *Climate Change 2014: Mitigation of Climate Change. Summary for Policymaker, working Group III Contribution to the IPCC Fifth Assessment Report.*
- Kahneman, D., Tversky, A., 1972. Subjective probability: A judgment of representativeness. *Cognitive psychology* 3 (3), 430–454.
- Kahneman, D., Tversky, A., 1984. Choices, values, and frames. *American psychologist* 39 (4), 341.
- Kahneman, D., Tversky, A. (Eds.), 2000. *Choices, Values and Frames.* Cambridge University Press / Russell Sage Foundation, Cambridge.
- Milinski, M., Sommerfeld, R. D., Krambeck, H.-J., Reed, F. A., Marotzke, J., 2008. The collective-risk social dilemma and the prevention of simulated dangerous climate change. *Proceedings of the National Academy of Sciences* 105 (7), 2291–2294.
- Morgan, M. G., Fischhoff, B., Bostrom, A., Atman, C. J., 2002. *Risk Communication: A mental models approach.* University Press, Cambridge.
- Morton, T. A., Rabinovich, A., Marshall, D., Bretschneider, P., 2011. The future that may (or may not) come: How framing changes responses to uncertainty in climate change communications. *Global Environmental Change* 21 (1), 103–109.
- Nature Editorial, 2016. The role of society in energy transitions. *Nature Climate Change* 6 (6), 539–539.
- Ross, L., Arrow, K., Cialdini, R., Diamond-Smith, N., Diamond, J., Dunne, J., Feldman, M., Horn, R., Kennedy, D., Murphy, C., Pirages, D., Smith, K., York, R., Ehrlich, P., 2016. The climate change challenge

- and barriers to the exercise of foresight intelligence. *BioScience*, biw025.
- Santos, F. C., Pacheco, J. M., 2011. Risk of collective failure provides an escape from the tragedy of the commons. *Proceedings of the National Academy of Sciences* 108 (26), 10421–10425.
- Schmeidler, D., 1989. Subjective probability and expected utility without additivity. *Econometrica: Journal of the Econometric Society* 57 (3), 571–587.
- Shackley, S., Wynne, B., 1996. Representing uncertainty in global climate change science and policy: Boundary-ordering devices and authority. *Science, Technology & Human Values* 21 (3), 275–302.
- Shirado, H., Christakis, N. A., 2017. Locally noisy autonomous agents improve global human coordination in network experiments. *Nature* 545 (7654), 370–374.
- Sterman, J. D., 2008. Risk communication on climate: Mental models and mass balance. *Science* 322, 532–533.
- Tavoni, A., Dannenberg, A., Kallis, G., Löschel, A., 2011. Inequality, communication, and the avoidance of disastrous climate change in a public goods game. *Proceedings of the National Academy of Sciences* 108 (29), 11825–11829.

### AppendixA. Lottery selection

The decision whether or not to invest into a climate change mitigation initiative can be seen as a choice between two lotteries:  $L_1$ , where climate change occurs with some known *a priori* probability  $p$  and leads to the loss of the whole endowment  $E$ ; and  $L_2$ , where this probability is reduced to a *residual* level  $\pi$  at the cost  $C$  ( $\pi < p$ ). As such, the expected utility of  $L_1$  is equal to  $(1 - p) \cdot E$  whereas the expected utility of  $L_2$  is equal to  $(1 - \pi) \cdot (E - C)$ . The rational agent will choose  $L_2$  over  $L_1$  as long as  $(1 - \pi) \cdot (E - C) > (1 - p) \cdot E$ , which is equivalent to the following condition:

$$C < \frac{p - \pi}{1 - \pi} \cdot E \quad (\text{A.1})$$

### AppendixB. Experimental instructions (translated from German)

#### Instructions

#### Welcome to the Experiment!

##### 1. General Information

You can earn money in this experiment. All transfers made during the course of the experiment will be denominated in ECU. **3 ECU correspond to 1 Euro**. For the experiment to be successful, you must not talk to the other participants or make yourself stand out in any way. Please read the following rules of the experiment carefully. If you have questions, press the red button on the computer keyboard. Press the Start button on the computer screen when you are done reading the instructions. You will then have to answer some control questions. Your answers will be checked by the computer.

##### 2. Climate Change

Below, we will present a game that simulates the climate change. The worldwide climate change is a real environmental problem faced by mankind. The majority of climate scientists expect that by the year 2100, the **average temperature** in the world is going to increase by **1.1–6.4 degrees Celsius**. It is also estimated that mankind significantly contributes to the climate change by emitting greenhouse gases, carbon dioxide ( $CO_2$ ) being the major one. Among other things,  $CO_2$  is produced as the result of burning fossil fuels such as coal, oil and natural gas as part of industrial processes or energy production as well as when using internal combustion engines in automobiles.  $CO_2$  is a global pollutant. i.e., it has the same effect on the climate regardless of the emission site.

### 3. Game Rules

Altogether, **6 players** participate in the game, i.e., 5 other players besides you. The decision problem is the same for each player. At the beginning of the experiment, an initial endowment (= **40 ECU**) will be credited to your personal account. In the course of the experiment, you can choose whether or not to invest the money from your account. In the end, what remains in your account will be paid out to you in cash. The decisions you make are anonymous. To ensure that, you will be given a pseudonym for the whole duration of the game. These pseudonyms correspond to the names of the moons in our Solar system (Ananke, Telesto, Despina, Japetus, Kallisto or Metis). Your name can be found on the bottom left of the screen.

In the course of this experiment you will play exactly **ten climate rounds**. In these rounds, you can invest in an attempt to protect the climate and lower the probability of the climate change. Among other things, dangerous climate change leads to serious economic losses, which is being simulated in this experiment. In each climate round of the game, all six players will be asked **simultaneously**:

*”How much would you like to invest into climate protection?”*

The permissible answers are 0, 2 or 4 ECU. As soon as every player has made their decision, all six decisions are displayed simultaneously. After that, all the contributions made are credited to the climate protection account (“climate account”) by the computer.

At the end of the game (that is, after exactly 10 rounds), the computer compares the climate account to the predefined amount (= **120 ECU**). This amount must be collected in order to reduce the probability of a dangerous climate change. It will be reached if **each** player pays an **average of 2 ECU** for climate protection **every** round. In that case, there would be 12 ECU paid to the climate account every round. In case the 120 ECU needed for the climate account is collected, each player receives what remains in their private account, i.e., the initial endowment of 40 ECU minus the amount paid by the player to the climate account, with a probability of {**100%** (Baseline) / **80%** (RR1 and RR2)}. If the 120 ECU is collected, the players lose the amounts in their private accounts with a probability of {**0%** (Baseline) / **20%** (RR1 and RR2)}. In case the 120 ECU needed for the climate account is **not** collected, the dangerous climate change, followed by serious economic losses, happens with a probability of {**70%** (Baseline and RR1) / **90%** (RR2)} (that is, in {7 (Baseline) / 9 (RR1 and RR2)} out 10 cases). With this probability, you lose the money remaining in your private account, and nobody gets paid out anything. With the probability of {**30%** (Baseline and RR1) /

10% (RR2)}, you keep your money and get paid out what remains in your private account after the game. The chance will be resolved in your presence. In any case, the payments will be made anonymous. Your identity will be kept secret from the other players.

4. Example

Here, you can see an example of the decisions made by the 6 players in a given round (round 6). The right panel ("Investitionen Runde 6") shows the investments made in the current round. Players Ananke, Telesto and Despina paid nothing to the climate account whereas players Japetus, Kallisto and Metis each paid 4 ECU. In total, there was 12 ECU paid this round, which was then credited to the climate account.

Investitionen		Investitionen	
Runden 1-6 insgesamt		Runde 6	
Ananke	12	Ananke	0
Telesto	12	Telesto	0
Despina	14	Despina	0
Japetus	10	Japetus	4
Kallisto	12	Kallisto	4
Metis	8	Metis	4
<b><u>Klimakonto insgesamt</u></b>	68	Gruppensumme Runde 6	12

The left panel ("Investitionen Runden 1-6 insgesamt") shows the investments made by each player throughout the first six rounds. So, players Ananke, Telesto and Kallisto each paid 12 ECU to the climate account throughout the first six rounds. Despina paid 14 ECU, Japetus paid 10 ECU and Metis paid 8 ECU throughout the first six rounds. As such, there was 68 ECU paid to the climate account throughout the first six rounds altogether. This exact information will be given to you after each climate round.

5. Use of Climate Account Money

In case the 120 ECU needed to reduce the probability of a dangerous climate change is collected, we will spend **all** the money from the climate account on the United Nations (UN) projects to support

offsetting  $CO_2$  emissions. In case the 120 ECU needed for the climate account is **not** collected, we will spend only **half** the money from the climate account to support such projects. The amount transferred by us to the United Nations will be used as a contribution to **combat climate change**. In what follows, we will briefly explain how that works.

Within the framework of the United Nations, one can choose developmental projects at [offset.climateneutralnow.org](http://offset.climateneutralnow.org). Financing a project like that allows for, e.g., buying energy efficient appliances. For each Euro donated, the website shows how many tonnes of  $CO_2$  can be spared by realizing a given project. Currently, the most efficient project is estimated at 0.5 Euro per tonne of  $CO_2$ . On March 1, 2017, we will invest the money from the climate account into the project with the best trade off between Euro and  $CO_2$ .

In summary, if the players pay, e.g., 120 ECU (40 Euro) to the climate account then approximately 120 tonnes of  $CO_2$  will be neutralized (as of this writing). This corresponds to approximately 23 return flights from Berlin to New York worth of emissions per passenger.

If you wish, you can leave your e-mail address with us at the end of the experiment and we will send you an overview of projects supported through the climate account.

### **AppendixC. Control questions**

Control questions as presented to the participants after reading the instructions (English version in italics, possible answers in parentheses).

1. Welchen Betrag muss jeder Spieler im Durchschnitt in den zehn Runden insgesamt in den Klimaschutz investieren, um die Wahrscheinlichkeit des Klimawandels zu reduzieren? (12 ECU; 20 ECU; 40 ECU; 120 ECU)  
*How much does each player have to invest in the climate account during the 10 rounds in total in order to reduce the probability of climate change? (12 ECU; 20 ECU; 40 ECU; 120 ECU)*
2. Angenommen, der notwendige Betrag von 120 ECU zur Reduzierung der Wahrscheinlichkeit des Klimawandels wurde erspielt und Sie haben dabei in den zehn Runden insgesamt 16 ECU in den Klimaschutz investiert. Wie hoch ist Ihre Auszahlung in ECU? (sicher 24 ECU; mit 80% Wahrscheinlichkeit 24 ECU, mit 20% 0 ECU; mit 80% Wahrscheinlichkeit 24, mit 20% 16 ECU; sicher 16 ECU)

*Assume that the amount of 120 ECU necessary to reduce the probability of climate change has been collected and that you have invested 16 ECU during the 10 rounds in total. How large is your final payment in ECU? (24 ECU for sure; 24 ECU with 80% chance and 0 ECU with 20%; 24 ECU with 80% chance and 16 ECU with 20%; 16 ECU for sure)*

3. In wie vielen Runden können die Spieler frei über ihre Investitionen in den Klimaschutz entscheiden? (in 3 Runden; in 5 Runden; in 7 Runden; in 10 Runden)  
*In how many rounds can the players freely decide upon their investments in climate protection? (3 rounds; 5 rounds; 7 rounds; 10 rounds)*
4. Betrachten Sie das Zahlenbeispiel, das unter Punkt 4 angegeben wurde. Wie hoch ist der Betrag auf Despinas privaten Konto nach Runde 6? (freie Antwort)  
*Take a look at the numerical example provided in paragraph 4. How large is the amount in Despina's private account after round 6? (open question)*
5. Betrachten Sie das Zahlenbeispiel, das unter Punkt 4 angegeben wurde. Wie hoch ist der Betrag auf Metis privaten Konto nach Runde 6? (freie Antwort)  
*Take a look at the numerical example provided in paragraph 4. How large is the amount in Metis' private account after round 6? (open question)*
6. Betrachten Sie erneut das Zahlenbeispiel, das unter Punkt 4 angegeben wurde. Wie viel müsste die Gruppe in den folgenden vier Runden insgesamt auf das Klimakonto einzahlen, um die Wahrscheinlichkeit des Klimawandel zu reduzieren? (12 ECU; 52 ECU; 68 ECU; 120 ECU)  
*Take another look at the numerical example provided in paragraph 4. How much would the group as a whole have to pay to the climate account in the next 4 rounds in order to reduce the probability of climate change? (12 ECU; 52 ECU; 68 ECU; 120 ECU)*
7. Angenommen, der notwendige Betrag von 120 ECU zur Reduzierung der Wahrscheinlichkeit des Klimawandels wurde nicht erspielt. Mit welcher Wahrscheinlichkeit verlieren Sie das verbliebene Geld auf Ihrem privaten Konto? (10%; 30%; 50%; 70%; 90%; 100%)  
*Assume that the amount of 120 ECU necessary to reduce the probability of climate change has not been collected. With which probability are you going to lose the money remaining in your private account? (10%; 30%; 50%; 70%; 90%; 100%)*



	$\beta$	$\sigma$	$t$	$P >  t $
Intercept	2.0150	0.051	39.20	0.00
RR1	-0.0774	0.071	-1.10	0.27
RR2	-0.0511	0.070	-0.73	0.46
LastRound	-0.0494	0.144	-0.34	0.73
RiskAv	-0.0058	0.028	-0.21	0.84
NEP	-0.0325	0.027	-1.19	0.23
LastRound $\times$ RR1	0.5790	0.196	2.95	0.00
LastRound $\times$ RR2	0.6285	0.192	3.27	0.00

Table D.4: Model (D.1) estimation results without the outlier group (in the baseline), p-values obtained via bootstrap (10K samples).

#### AppendixD. Auxiliary materials

$$\begin{aligned}
 contr_{gr,sub,period} = & \beta_0 + \beta_{RR1} \cdot RR1 + \beta_{RR2} \cdot RR2 + \beta_{LastRound} \cdot LastRound + \\
 & \beta_{LastRound \times RR1} \cdot LastRound \cdot RR1 + \beta_{LastRound \times RR2} \cdot LastRound \cdot RR2 + \\
 & \beta_{RiskAv} \cdot RiskAv_{sub} + \beta_{NEP} \cdot NEP_{sub} + \varepsilon_{gr} + \varepsilon_{sub} + \varepsilon
 \end{aligned} \tag{D.1}$$

$$\begin{aligned}
 contr_{gr,sub,period} = & \beta_0 + \beta_{p=0.9} \cdot p = 0.9 + \beta_{\pi=0.2} \cdot \pi = 0.2 + \beta_{LastRound} \cdot LastRound + \\
 & \beta_{LastRound \times p=0.9} \cdot LastRound \cdot p = 0.9 + \beta_{LastRound \times \pi=0.2} \cdot LastRound \cdot \pi = 0.2 + \\
 & \beta_{Milinski} \cdot Milinski + \varepsilon_{gr} + \varepsilon_{sub} + \varepsilon
 \end{aligned} \tag{D.2}$$

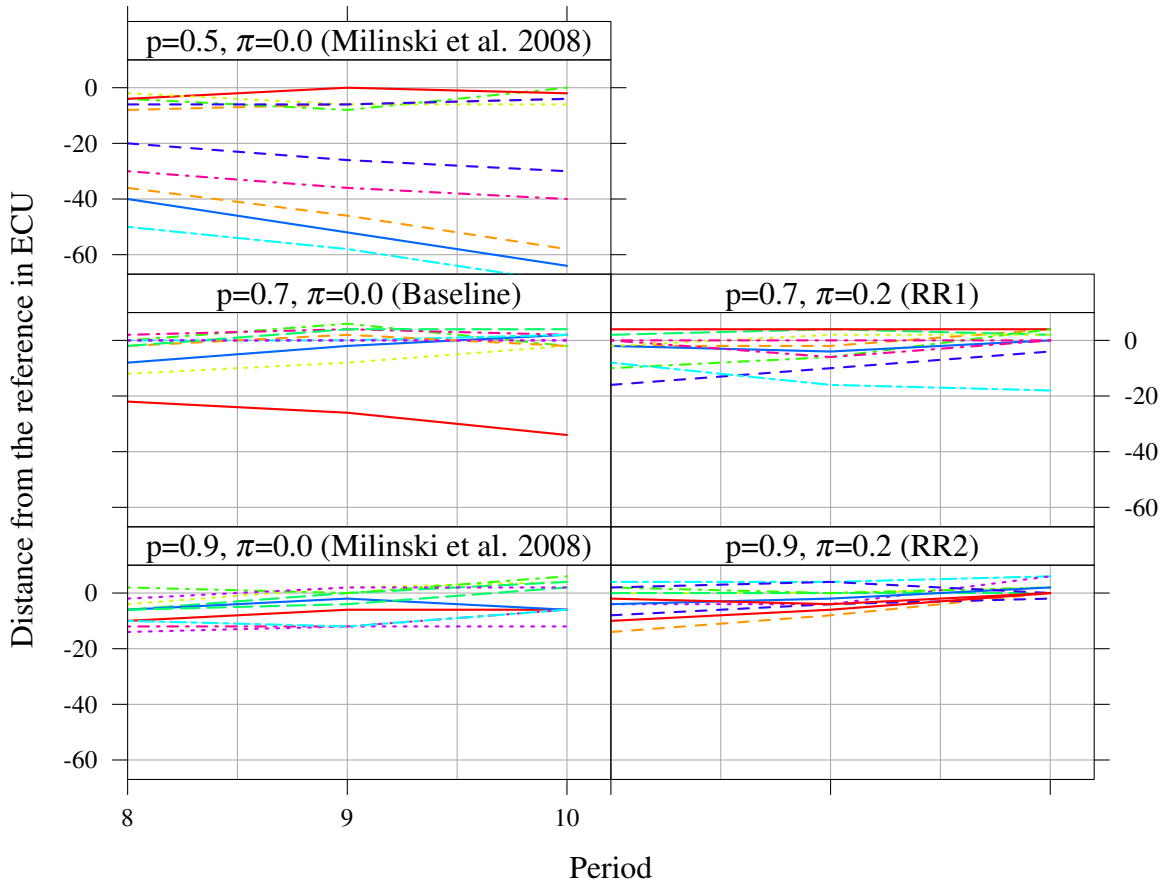


Figure D.5: Difference between a climate account where every participant is contributing the reference contribution of 2 ECUs per period to the climate account and the actual ECUs in that account. Each line represents one group. Treatments with  $\{p = 0.5, \pi = 0.0\}$  and  $\{p = 0.9, \pi = 0.0\}$  are from Milinski et al. (2008).