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Cooperation Enhances Adaptation to Environmental Uncertainty: Evidence from Irrigation Behavioral Experiments in South China

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Abstract: The world currently faces an unprecedented phase of global environmental change largely driven by the combined impact of anthropogenic climate change and environmental degradation. Adaptation to global environmental changes in natural resource management is often hindered by high levels of uncertainty related to environmental impact projections. Management strategies and policies to support adaptation measures and sustainable resource management under substantial environmental uncertainty are thus urgently needed. The paper reports results of behavioral irrigation experiments with farmers and students in the region of Hangzhou in China. The experimental design simulates a small-scale irrigation system with five parties located along an irrigation channel. The first treatment adds weather variability with a drying tendency that influences water availability in the irrigation channel. In the second treatment, the participants can select one of two adaptation options. Our results suggest that participants react with a marked delay to weather uncertainty. In addition, upstream players are more likely to adapt to uncertainty than those further downstream, and groups who show higher levels of cooperation more frequently invest in adaptation measures. Lastly, extraction inequality in earlier stages is found to constitute a key obstacle to collective adaptation.

Keywords: environmental uncertainty; behavioral experiments; adaptation; common pool resources

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1. Introduction

Common pool resource (CPR) dilemmas refer to situations where individuals have an incentive to overuse an open access natural resource at the expense of the community. Hardin (1968) argued that centralized control is necessary to avoid overexploitation and, ultimately, exhaustion of common pool resources [1]. However, abundant empirical evidence demonstrates that communities can overcome such common pool resource dilemmas and sustainably manage resources even without strong government interventions (see, e.g., [2–4]). This also applies to asymmetric common-pool resource dilemmas, which are characterized by power asymmetries between the resource users. For example, in small-scale irrigation systems, downstream water users' livelihoods depend on the water extraction behavior of upstream users. Both evidence from observational field research and case studies and findings obtained from behavioral experiments suggest that community-managed irrigation systems can lead to an efficient and environmentally sustainable use of water resources [5–11]. Members of such systems rely on collaboration to solve two interrelated coordination challenges. The first challenge is the collective construction of the necessary physical infrastructure, and the second is the equitable distribution of the resource between upstream and downstream users [11]. The impacts of climate change are changing the natural conditions of common pool resources on a global scale, though the specific local environmental effects cannot yet be reliably predicted. For example, future water availability in many places is still uncertain given the expected increase in extreme weather events [12–14]. This raises the question of how management strategies and policies for the sustainable use of natural resources should adapt to an increasing uncertainty of environmental conditions. More specifically, how does an increasing environmental uncertainty affect the viability of community managed common pool resources? Given the magnitude and pace of global environmental change, the objective of this paper is to investigate the impact of environmental uncertainty and possible adaptation pathways in the context of common-pool resource governance.

At present, it is unclear how users of asymmetric common pool resources, such as members of small-scale irrigation systems, react to an increase in environmental uncertainty [15]. A related puzzle that has received little scholarly attention to date is the adaptation to uncertainty by groups of individuals. In recent years, the need for adaptation (both of communities relying on natural resources for their livelihoods and society at large) to environmental uncertainty has grown in importance in public discourse. With the exception of Dipierri and Zikos, who carried out framed field experiments on institutional robustness and included environmental uncertainty in their experiment design, adaptation to uncertainty in the context of CPR dilemmas has not received much scholarly attention [16].

This study uses behavioral irrigation experiments with 30 farmers and 70 students in Hangzhou, China, to examine (i) whether uncertainty affects resource users' propensity to contribute to irrigation infrastructure; (ii) what factors drive an individual's investment into adaptation to uncertainty; and (iii) the factors driving a group's investment into adaptation to uncertainty. First, the paper explores the concept of uncertainty and its impact in the context of resource dilemmas based on previous research. It then continues by laying out the experimental set-up and the sampling procedures. This is followed by a discussion of the experimental results, and the paper concludes by briefly touching on possible implications for resource management.

2. Framing Uncertainty

A frequently used set of definitions of 'risk' and 'uncertainty' was established by [17]. The author uses 'risk' to refer to situations when the probability distribution of possible outcomes is known. To illustrate environmental risk, Gangadharan and Nemes use the example of the ozone layer by arguing that the relationship between depletion and the resultant health impacts such as a higher incidence of skin cancer is quite well understood [18]. In comparison, 'uncertainty' refers to future outcomes or events for which the probability distribution is entirely unknown [17]. Profound uncertainty is sometimes linked to complex natural systems. For example, it is impossible to obtain reliable estimates on the probabilities of extreme weather events due to their low frequency [19]. Uncertainty may also imply that not only is the probability distribution of different outcomes unknown but so is the range of possible outcomes. These are sometimes referred to as 'unknown unknowns' [14,20]. It can be argued that uncertainty, as opposed to risk, involves a spectrum spanning minor uncertainty about the likelihood of a known set of possible outcomes to the very ignorance about what the general nature of outcomes may look like [19].

In the context of resource dilemmas, two types of uncertainty are distinguished [21]. The first type, social uncertainty, stems from ignorance regarding the behavior of other resource users. The second type, environmental uncertainty, is linked to a lack of knowledge regarding the resource size or resource renewal [22–24]. Usually, environmental and social uncertainty are conflated, as resource users' behavior influences the availability of the resource, which, in turn, itself influences the resource users' ensuing decisions [24,25]. In the experiment presented in this paper, participants are confronted with both types of uncertainty, as they are not informed about the probability distribution of exogenously given weather outcomes (environmental uncertainty), and they are unable to anticipate the behavior of other players on which both resource generation and use depends (social uncertainty).

3. The Impact of Environmental Uncertainty on Common-Pool Resources

Research on public good provision indicates that environmental uncertainty lowers cooperation levels [18,26,27]. Results obtained from experimental work on CPR dilemmas also hint at decreases in the willingness to collaborate under natural uncertainty [22,23,27,28]. Rapoport et al. (1992), for instance, link the experimentally detected resource over-exploitation under environmental uncertainty to a participant's tendency of systematically overestimating resource availability, while [29] argue that resource users may choose to increase resource consumption despite being fully aware of impending resource exhaustion, as they speculate competing users will do the same [23,29]. Another frequently cited explanation is the outcome-desirability bias of the participants, that is, wishful thinking regarding the assumed resource size, as was demonstrated in laboratory experiments conducted by Gustafsson et al. [30,31]. In an experimental study featuring asymmetrical payoff rules, Budescu et al. observed that less advantageous ratios of payouts and resource units generated higher resource demands [32]. This implies a position-dependent responsiveness to environmental variability.

After examining the influence of differing individual characteristics on the willingness to cooperate in a CPR dilemma with varying rates of resource generation, Roch and Samuelson concluded that social-value orientation has a moderating effect on the willingness to exercise restraint when harvesting resources under uncertainty; in the experiment, non-cooperative individuals were more likely to increase resource extraction rates in conditions where resource renewal was uncertain [28]. However, the question of whether environmental uncertainty affects the degree of cooperation in asymmetric resource dilemma settings, as is the case in the irrigation dilemma, has received little scientific attention to date [15].

Probing the effects of environmental variability (which differs from environmental uncertainty insofar as the probability distribution of outcomes is a priori known), in the irrigation dilemma, did not initially provide evidence for behavioral change. After performing laboratory experiments with different weather variability treatments affecting water availability, independently of the extent to which participants contributed to resource generation, Baggio et al. claimed that environmental variability plays only a limited role in affecting resource users' behavior [15]. Pursuant to Baggio et al., the action–reaction dynamics within a community of mutually dependent members ultimately determines collaboration readiness [15]. According to the authors, the conduct of the upstream water users is the most decisive factor influencing the downstream users' willingness to collaborate. This finding tallies with results obtained by Anderies et al., who examined the effects of environmental variability in a computer-based laboratory irrigation experiment where communication among the participants was allowed [33]. It is important to point out that the irrigation experiments performed by Anderies et al. and Baggio et al. allowed participants to estimate the respective probabilities of different weather outcomes [15,33].

While there is, as shown above, some initial evidence of the effects of environmental variability on behavior in resource dilemmas, the role of environmental uncertainty in common pool resource dilemmas remains insufficiently understood. Lipshitz and Strauss identified 'suppression of uncertainty' as a common coping strategy when decision-makers are faced with ambiguous information without any known single-best option [34]. The complexity of an asymmetric natural resource dilemma can be reasonably assumed to encourage the use of such a decision-making heuristic. The recent work cited above found that the inequality and power asymmetry between members of the irrigation community mattered more than environmental variability [15]. Assuming that participants' reaction to pure environmental uncertainty is similar to their reaction to environmental variability, we hypothesize that uncertainty has only a small effect on the participants' behavior and overall levels of collective action.

Hypothesis 1 (H1). *Uncertainty does not substantially affect the investment behavior of actors involved in the irrigation dilemma.*

Adaptation can be either characterized through technology development and adoption or increased knowledge and risk-management capacities [35]. Applied to the context of the irrigation dilemma, adaptation involves the successful attempt of resource users to shield themselves against the negative effects of weather uncertainty that reduces the water available for extraction. Adaptation to uncertainty, as operationalized in this work, can be either individual or collective. The provision of collective adaptation goods often involves cross-scale interactions between private and public actors, resulting in an increase in coordinative complexity [36,37]. In some cases, adaptation measures will only yield individual benefits if the collective efforts have enough clout [36]. We therefore operationalize collective adaptation in our work as a threshold-level public good whose provision is dependent on sufficient community participation. The individual adaptation measure, on the other hand, is based on obtaining private information on environmental conditions that can be used to inform private investment decisions. Upstream water users are expected to be generally more willing to invest in any type of adaptation measure since they will be better positioned to reap the potential benefits compared to the structurally disadvantaged downstream users.

Hypothesis 2 (H2). *Upstream resource users are more likely to invest in adaptation measures than downstream users.*

Given the increased coordination requirements linked to collective adaptation, it can be expected that the general group cooperativeness will be a key determinant of adaptive capacity. Cooperative groups are defined by high levels of public contributions to maintaining irrigation infrastructure. In groups with generally higher public contribution levels, the benefits of investing in collective adaptation are seen to be higher than the expected costs. In contrast, uncooperative groups are likely to invest less in adaptation measures, as group members will expect that adaptation costs will exceed pay-offs. In summary, groups whose members collaborate well under normal conditions are expected to be more adaptable to environmental uncertainty than uncooperative groups.

Hypothesis 3 (H3). *Cooperative groups will invest more frequently in adaptation measures.*

4. Research Methods

4.1. Experimental Design

To investigate the above hypotheses, a baseline public good game simulating a small-scale asymmetric irrigation system with five players located along an irrigation channel originally proposed by Cardenas et al. and Janssen et al. is extended by two more stages [5,8,38]. Firstly, an environmental uncertainty treatment is added (with a probability distribution unknown to participants) that influences resource availability independently of the group's behavior. Secondly, participants have the choice of investing in two adaptation options that can reduce uncertainty.

The experiment is designed for groups consisting of five players (A–E) holding land plots of equal size that are positioned along an irrigation channel with individual A furthest upstream and individual E at the most downstream position, as shown in Figure 1. The experiment was divided into three discrete stages with 10 rounds each. Before the experiment commenced, two to three trial rounds were played to familiarize participants with the procedure.

4.1.1. Stage 1: Baseline Game

After receiving a labor endowment of 10 tokens at the beginning of each round, group members independently decided how much they wanted to invest in the public fund aimed at maintaining irrigation infrastructure. Based on a pay-off structure used by Janssen et al., the total amount of water varied as a function of the total investment in channel maintenance made by all players (Table 1) [38]. After the players made their public contributions, they were told the total investment volume and the corresponding quantity of water flowing through the channel. As Stage I of the experiment did not consider weather fluctuations, the water availability was calculated using the baseline data shown in Table 1 (second column). Subsequently, each player in the upstream–downstream sequence decided on the amount of water to extract. The sequential water access represents the power asymmetry between upstream and downstream participants. That said, upstream players' water availability was also dependent on the investments made by the downstream players [8]. Players were only told about the amount available during their turn, that is, not the individual extraction levels of their upstream peers. For example, if 100 units of water were available in the beginning of the harvest cycle and player A decided to extract 20 units, player B learned that they could still use 80 units. This procedure was continued until player E withdrew those water units that players A to D had left in the channel. Analogous to the original design proposed by Cardenas et al., members were not allowed to communicate with one another [5]. The total earnings per round were based on the number of water units that each participant withdrew plus the number of tokens they did not invest. At the end of the game, this total was converted into local currency. To allow for better comparability of the results with previous studies, participants in the experiment were told how many rounds they would be playing.

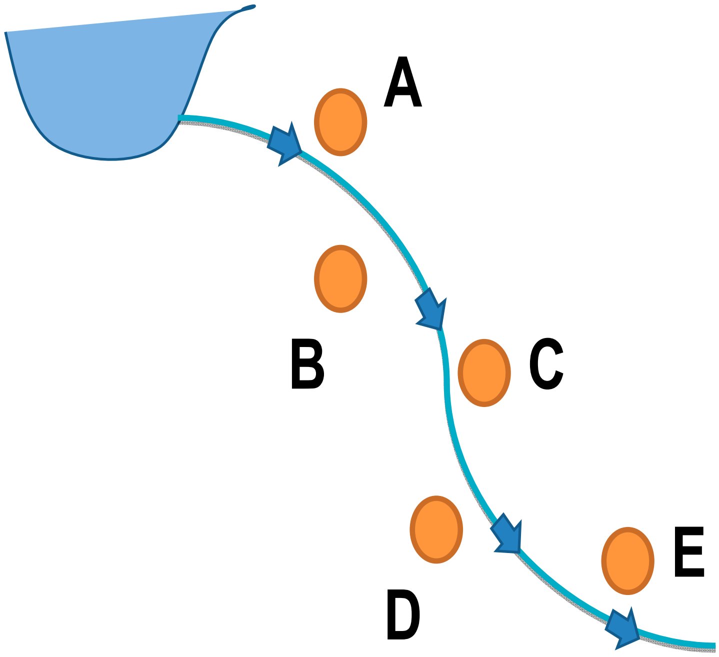

Figure 1. Location of players (A–E) along an irrigation channel (adapted from [39]).

Table 1. Available water quantity according to total investments.

Total Group Investment	Dry Weather	Baseline	Wet Weather
0–10	0	0	0
11–15	2	5	8
16–20	8	20	32
21–25	16	40	64
26–30	24	60	96
31–35	30	75	120
36–40	34	85	136
41–45	38	95	152
46–50	40	100	160

4.1.2. Stage II: Weather Uncertainty

While maintaining the basic game arrangement, some modifications were made in the subsequent stages. In Stage II, rainfall variability was introduced. This influenced the level of water in the channel independent of total group investment. During rounds with wet or dry weather, water availability was either reduced or increased by 60% compared to that expected under normal (baseline) conditions (see Table 1). Participants only found out about the weather conditions in each round after they had made their investment decisions. The associated water availability was calculated using the data for the respective weather scenarios presented in Table 1. To simulate a general drying tendency, five out of ten rounds were dry, with increasing frequency towards the end of the stage. Two out of ten rounds were characterized by humid weather, while the remaining three rounds were normal. In total, there were three different weather sequences that were randomly assigned to the groups. Each weather scenario differed in the order of weather types assigned to each round.

In Stage I (without uncertainty), water availability always corresponded to 'baseline' values (Column 2), whereas in Stages II and III (with uncertainty), water availability per round was dependent on the respective weather scenario.

4.1.3. Stage III: Adaptation to Uncertainty

In Stage III, players were given two different adaptation options to protect themselves against weather variability. Before investing in the irrigation infrastructure, players were given the option to (i) purchase weather information for the following round (individual adaptation option) or (ii) invest in a water pump (collective adaptation option) or do both. Each option came at an extra cost of one token that was subtracted from the initial allocation.

If a player chose to purchase weather information (option (i)), the experimenter privately communicated to him or her the weather details of the following round. Weather information was shared by showing small cards featuring distinct symbols for dry, wet, and normal rounds. Players who did not opt for the seasonal weather forecast were shown a blank card to prevent those who had purchased such information from being identified.

Option (ii) was conceptualized as an additional step-level public good game. Experiment participants were told that the regional government would assist with the construction of a water pump if there was enough community support. The framing of the water pump as a government-supported collective adaptation option corresponded well to local mental models of Chinese irrigation farmers and was easily understood by both farmers and students (see, e.g., [40,41]). If at least three group members decided to contribute to this option, the pump became operative for one round. When two or fewer participants selected this adaptation choice, the pump did not become operational, and no refund of the invested token was paid to reflect coordination costs. In the event of dry weather, an operational pump ensured that water availability was equivalent to levels that could be expected under normal (baseline) weather for any given group investment.

Players were also permitted to invest in both options. As in the previous stages, players had to decide independently from one another as no communication was permitted. The adaptation options did not remove all uncertainty. Participants were informed that each adaptation option failed with a probability of 0.166.

4.2. Sampling Procedures

The experiments were carried out in October and November 2017 with 20 groups of 5 individuals each, overall involving 100 participants. The participants included students and farmers. Students are usually recruited in behavioral experiments (c.f. [42]), and farmers were included since they have real-life experience in managing natural resources including water and irrigation channels. Previous experiments have shown that farmer groups in behavioral experiments display different decision-making dynamics to student groups (c.f. [39]). The experiments were conducted in 10 sessions lasting between 1 and

1.5 h each with at least 5 (one group) and a maximum of 15 (three groups) participating at a time. Seventy students (fourteen groups) were recruited at Zhejiang University on the Zijingang Campus in the provincial capital of Hangzhou. Students were recruited through announcements in popular university online forums and flyers handed out in the library and in front of the local canteen. Students who signed up to participate in the experiments were enrolled in a broad range of subjects and majors, most of which were not related to agriculture or irrigation. The groups made up of students were unbalanced in terms of gender; about 34% were male with an overall average age of 21 years (minimum age 17; maximum age 30).

In order to understand the extent to which decisions of resource users differ from students, the experiment was, as mentioned above, also conducted with 30 farmers split into 6 groups. Farmers were recruited in the village of Wusicun located around 40 km from the city center of Hangzhou. The visit of the research team was organized by a representative from the municipal administration. This contact helped ensure that those farmers interested in taking part in the experiment were present at the agreed place and point of time. The experiment took place in the conference room of the local town hall, in two sessions with three groups each. In terms of gender, farmers were more balanced; women and men each made up half of all participants with an average age of 45 years (minimum age 21; maximum age 70).

To be able to capture possible behavioral impacts of individual differences related to participants' readiness to take risks and trust others, the observations for these variables were measured on a Likert scale by asking participants from both student and farmer groups to fill out a post-experiment questionnaire. On average, farmers appeared to be both slightly more inclined to trust others and to take risks. Both higher individual readiness to take risks and propensity to trust are likely to be reflected in higher individual contributions to the public irrigation fund.

In addition to differences in personal traits, socio-cultural values and institutions have been found to influence the behavior of subjects participating in behavioral experiments (see, e.g., [43–45]). Understanding the prevalent cultural norms and values that characterize the study region may help contextualize results emerging from this study. One such cultural dimension (based on Hofstede's cultural dimensions framework) might be individualism vs. collectivism [46]. Societies with high levels of collectivism demonstrate closely integrated ties and tend to value collective benefits more than individual success. Relatively high levels of collectivism are present in the study area, which may be reflected in a tendency of participants to engage in cooperative, pro-social behavior regardless of the level at which they extract resources. This may particularly apply to farmer groups that may have stronger ties between them than loosely connected members of the much more diverse student groups.

Upon arrival at the experiment venue, participants were randomly assigned to a group and were seated in three separate table rows, each of which represented a group. To inhibit verbal and non-verbal communication, the students were physically separated from one another by large cardboard boxes or desktop computers. This was not necessary in the sessions with the farmers as the hall size allowed for sufficient distance between group members (farmers sat in rows facing the back of their more upstream peers). As soon as all participants, who had registered for a session, arrived in the room, they were read and handed out experiment instructions and decision sheets to mark choices with a pen. Since part of the experiment was also carried out in the field, pen and paper were used instead of a computer-based implementation [47].

Each group was allocated two experimenters. A 'runner' circulated to record participant decisions such as contributions to the public fund and water extraction. This was then passed on to an analyst who calculated the level of water in the channel and recorded who decided to invest in the pump or the forecast using an Excel macro. In every round, the analyst communicated water availability and information relevant to the adaptation option back to the runner who would then inform the group. After completing the experiment, participants were paid the 'show-up' fee together with their individual earnings. Each student participant received a show-up fee of CNY 10 while each unit was worth CNY 0.15. At the time the research was conducted (October and November 2017), 1 Chinese Yuan Renminbi (CNY) corresponded to around EUR 0.13. Average payout corresponded roughly to local earnings (per two hours). To motivate farmers to participate and stay until the end, the show-up fee was CNY 80, while each unit earned was rewarded with CNY 0.13. Payouts ranged between CNY 30.7 and CNY 93.55 for students and CNY 93.55 and CNY 204 for farmers. Average payout amounted to CNY 63.7 and CNY 135.6, respectively.

We analyzed the behavior of the experiment participants at both the group and the individual decision level. The individual decisions were analyzed using a random-slope multilevel mixed effects regression model. Decisions at the individual level were treated as repeated measures nested within experiment groups. To analyze how groups and resource users adapted to uncertainty in Stage III of the experiment, multivariate logistic models were employed due to the binary nature of the variables of interest in Stage III. In addition, for analyses only targeting the group level, linear regression models were used.

5. Results

The section is organized as follows. First, key variables influencing individual contributions to the irrigation fund across all stages are examined to test whether the results are in line with results from earlier studies on the irrigation dilemma. Second, the impact of uncertainty on individual decision-making was examined in order to test H1. Subsequently, the key drivers linked to adaptation decisions both at individual level and at group level were investigated to test H2 and H3.

5.1. Key Variables Influencing Individual Investment Behavior

Table 2 presents the results of a regression analysis of key variables influencing individual contributions (investments) to the public fund. The coefficients reveal whether the variables positively or negatively affect contributions and whether they are significant. Models I to III are limited to Stage I observations (rounds 1–10). Model I includes decisions by both upstream and downstream players; Model II only considers decisions by upstream players (positions A, B, and C); and Model III includes only those of downstream ones (positions D and E). Model IV encompasses all experimental stages with a total of 2900 observations. The 100 observations of the first round are not included due to the introduction of time lags for investment and water extraction volumes. The lag for investment is introduced to account for serial correlation in between rounds and path dependency. Following the example of earlier experiments on social dilemmas such as the ultimatum game and the irrigation dilemma, the Equal-Share Ratio (ESR) is included to measure how individuals react to inequality in the distribution of irrigation water [15,48]. The ESR is defined by the quantity of water an individual extracts in a given round divided by their equitable share. The equitable share in round t is computed by dividing the initial amount of water generated in round r by five. As mentioned above, other explanatory individual-level variables, including risk-taking preferences and propensity to trust, were included in the regression analyses below.

Since the values of the regression coefficients for 'position' decrease towards the tail end of the channel, Model I suggests that individuals located further downstream invested less in the public infrastructure than those situated more upstream. The further downstream, the stronger and more significant the effect becomes. This finding is well in line with earlier works [5,15,39,49]. Farmer groups tend to show higher investment levels than student groups. This will be discussed at a later stage.

Investment levels in the preceding round are positively related to high investments in the current round (ß = 0.45) with high significance ($p < 0.001$). High investments in the preceding round also indirectly point to high water withdrawals and to inertia-driven persistence in investment levels. Furthermore, risk propensity (ß = 0.22) was found to have a significant impact at the 1% level in line with expectations; that is, higher readiness to take risks is, ceteris paribus, reflected in higher investments. By contrast, higher readiness to trust others does not seem to have a sizable impact on the players' willingness to cooperate. As other individual-level variables of gender and age neither increased model fit nor proved to be significant, they were excluded from the models.

Table 2. Regression results of Stages I–III.

Investments	Stage I All players (I)	Stage I Upstream (II)	Stage I Downstream (III)	Stages I–III All Players (IV)
Intercept	2.98 *** (0.74)	3.21 *** (0.97)	2.93 ** (0.98)	3.25 *** (0.70)
Student	−0.50 (0.41)	0.27 (0.53)	−1.75 ** (0.54)	−0.43 (0.33)
Position B	−0.52 (0.37)	−0.63 (0.36)		−0.63 (0.37)
Position C	−0.98 * (0.38)	−1.04 ** (0.38)		−0.91 * (0.38)
Position D	−1.15 ** (0.39)			−1.39 *** (0.39)
Position E	−2.19 *** (0.40)		−0.84 * (0.34)	−2.66 *** (0.39)
Stage 2				−0.44 *** (0.09)
Stage 3				−1.20 *** (0.11)
Round	−0.03 (0.02)	0.02(0.03)	−0.06 (0.03)	
Risk propensity	0.22 *** (0.06)	0.28 ** (0.10)	0.08 (0.09)	0.20 ** (0.06)
Trust	0.06 (0.09)	−0.09 (0.12)	0.08 (0.14)	−0.04 (0.09)
Investment t-1	0.45 *** (0.03)	0.34 *** (0.04)	0.46 *** (0.05)	0.33 *** (0.02)
Extraction t-1	0.00 (0.01)			0.01 (0.01)
ESR t-1		0.01 (0.15)	0.97 ** (0.32)	
Group investment t-1				0.03 *** (0.01)
AIC	3696.71	2163.66	1423.57	12,181.16
BIC	3763.94	2214.82	1466.00	12,276.72
Log Likelihood	−1834.35	−1069.83	−700.78	−6074.58
Num. obs.	900	525	350	2900

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Addressing Models II (positions A, B, and C only) and III (positions D and E) allows us to look more closely at upstream–downstream dynamics. In line with theoretical expectations and previous experimental studies, the models demonstrate that the behavior of head-end individuals decisively shapes their downstream peers' willingness to invest in the public fund (and thus determine the success or failure of the irrigation community) for two reasons [5,15,39]. The first indication that tail-enders *reacted* to head-enders' conduct is shown in results from diverging coefficients regarding the ESR (ß = 0.01 vs. ß = 0.97). This is not significant for upstream individuals, but it matters significantly for irrigation stakeholders at positions D and E; the larger their share of water extraction in the preceding round, the higher their contribution in the current round (ß = 0.46). The second indication stems from differing coefficients and significance levels of risk propensity. This *only* influences contributions significantly ($p < 0.01$) at upstream positions. This is likely because head-enders' behavior determined reactions of downstream players. Tail-enders' risk attitudes did not make a significant difference as they acted according to the actions taken at upstream locations rather than their risk preferences. In other words, downstream participants passively reacted to whether head-enders exercised self-restraint by leaving a sizable share of water in the channel.

Model IV spanning all 30 rounds largely confirms results obtained in Model I. Group behavior, operationalized as group investments in the preceding round, also played a highly significant ($p = 0.001$) role. Regardless of the position, it appears that collaborative efforts by the individual were in part conditional on general cooperation levels of the group. Once again, results are largely in line with earlier research (e.g., [15,39]). It is noteworthy that within Stage I (see Models I–II), investments in the public infrastructure did not decline significantly. However, individual contributions fell in later stages of the game with the coefficients for Stage II (ß = −0.44) and Stage III (ß = −1.2) being both negative and significant at the 0.001 level.

To summarize, three core patterns can be identified from the above models. First, downstream players contributed less than upstream players to channel maintenance. Second, investments declined as the experiment progressed, and third, downstream players' propensity to invest hinged on upstream players' inclination to leave sufficient water in the channel. As these results are backed by earlier research, we can be somewhat confident that evidence obtained to investigate our research questions can be judged to be satisfactorily robust. In the following, the impact of uncertainty on the willingness to collaborate in the irrigation dilemma are discussed.

5.2. Impact of Uncertainty on Investment Behavior

To find out whether uncertainty had a discernible effect on individuals' contributions, multi-level random slope regression analyses focusing on Stage II (see Table 3 below) were run. To be able to compare the relative strengths of the different influencing factors, regression coefficients were standardized. As shown in the analysis below, the dependent variable was operationalized as individual investment. As previously reported, trust was non-significant and therefore excluded from the analyses. To account for the upstream–downstream dynamics prevailing in Stage I, the ESR was added to all models. Models were also complemented by the average group investment in Stage I to control for group-specific path dependencies. Model I includes different weather outcomes that lagged by one round. Model II additionally incorporates the cumulative effect of successive dry- or wet-weather periods using dummy variables. To increase robustness and model fit in Models III to V, random slopes were added for all explanatory weather variables. This enabled the inclusion of the reasonable assumption that uncertainty might affect each individual in a different way. A log-likelihood test with non-standardized models of the same specification revealed that introducing random slopes significantly improves model fit. To address possible concerns of multicollinearity, model IV includes just one dummy for long-term weather tendencies.

Table 3. Standardized regression results of Stage II.

Investments in Stage II	Weather Lags (I)	Cumulative Weather (II)	Cumulative Weather (III)	Cumulative Weather (IV)
Intercept	−0.08 (0.05)	−0.11 * (0.06)	−0.12 (0.07)	−0.12 (0.06)
Student	0.06 (0.06)	0.06 (0.05)	0.04 (0.07)	0.04 (0.06)
Position B	0.14 (0.09)	0.14 (0.09)	0.24 * (0.11)	0.22 * (0.10)
Position C	0.04 (0.08)	0.04 (0.08)	0.06 (0.11)	0.04 (0.10)
Position D	0.02 (0.09)	0.02 (0.09)	−0.00 (0.11)	0.01 (0.11)

Table 3. *Cont.*

Investments in Stage II	Weather Lags (I)	Cumulative Weather (II)	Cumulative Weather (III)	Cumulative Weather (IV)
Position E	−0.44 *** (0.09)	−0.44 *** (0.10)	−0.60 *** (0.12)	−0.55 *** (0.11)
Risk propensity	0.13 ** (0.05)	0.13 ** (0.05)	0.13 * (0.06)	0.13 * (0.05)
Round	−0.05(0.03)	0.02 (0.04)	0.02 (0.03)	0.03 (0.03)
Investment t-1	0.28 *** (0.03)	0.28 *** (0.03)	0.07 * (0.03)	0.14 *** (0.03)
Extraction t-1	0.03 (0.03)	0.03 (0.03)	0.04 (0.02)	0.05 * (0.02)
Average group inv. In stage I	0.25 *** (0.05)	0.26 *** (0.05)	0.34 *** (0.06)	0.31 *** (0.06)
Average ESR in stage I	0.21 *** (0.06)	0.21 *** (0.06)	0.26 *** (0.07)	0.25 ** (0.07)
Dry weather t-1	−0.01 (0.02)	0.00 (0.02)	0.01 (0.02)	0.01 (0.02)
Wet weather t-1	−0.08 ** (0.03)	−0.05 (0.03)	−0.03 (0.03)	−0.05 (0.03)
Previous 2 rounds dry		−0.00 (0.03)	−0.01 (0.03)	
2 wet rounds within preceding 3 rounds		0.03 (0.04)	−0.01 (0.04)	
3 dry rounds within preceding 4 rounds		−0.12 *** (0.03)	−0.11 ** (0.04)	−0.10 ** (0.04)
AIC	1517.89	1525.68	1486.88	1474.04
BIC	1599.53	1621.72	1654.96	1604.74
Log Likelihood	−741.94	−742.84	−708.44	−710.04
Num. obs.	900	900	900	900

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

In all of the above models, the average ESR was highly significant, underlining the importance of relative extraction levels for an individual's willingness to collaborate. What is more, in all models except Model V, the average group investment in stage I was highly significant, highlighting the group-specific path dependence of investment dynamics. Put differently, high cooperation levels in stage I translated to higher individual investments in Stage II.

In Model I, the coefficient for dry weather t-1 is non-significant (ß = −0.01). Dry weather in the preceding round does not seem to induce a reduction in investments in the current round. The coefficient for wet weather in the preceding round is significant at the 1% level, indicating that individuals lowered their investments after a wet round. Compared to other variables, however, this effect is rather weak. In Model II, rolling averages are added to account for the cumulative impact of weather variability, which significantly improves model fit. According to Model II, wet weather in the preceding round has no impact on player's behavior. Individuals decreased their contributions only after three out of four of the preceding rounds were characterized by drought conditions at a significance level of 0.1%. Compared to the variables ESR (ß = 0.21), group investment in stage I (ß = 0.26) and position D (ß = −0.44), cumulative drought (ß = −0.12) played a lesser role in determining individual investments. Considering that both t-1 weather lags and 'two preceding rounds dry' (see Table 3) fail to reach the threshold of significance, results suggest that participants' reaction to uncertainty comes with a delay.

Inserting random slopes for weather-related variables in Model III greatly improves Model fit as reflected by the change in log likelihood values from −742.84 to −708.44. The dummy for 'three dry rounds within preceding four rounds' remains negative and significant at around the same relative strength (ß = −0.11), although at a lower confidence level of $p < 0.01$. To address concerns of multicollinearity, two dummy variables for short-term weather tendencies in Model IV are omitted and only the weather lags as well as the dummy for the long-term drying tendency are kept. Again, the small but notable effect of the long-term drying tendency is confirmed ($p < 0.01$). As in Models II and III, weather lags prove insignificant while both significance level and strength of variables relating to group cooperativeness and the average ESR remain stable. Although the above results do suggest that players decrease their investments in a delayed reaction to uncertainty, one should be cautious not to overstate the strength of this effect. Relative equality in extractions and general cooperation levels as well as the players' locations influence participants' decisions to a much greater extent than increasing drought conditions. Hypothesis 1, positing that uncertainty does not substantially affect the investment behavior of actors involved in the irrigation dilemma, thus receives support.

5.3. Drivers Influencing Players' Behavior to Invest in Adaptation

The models below, as shown in Table 4, examine the variables that influence individual investments in the irrigation pump adaptation option. Model I includes control variables, actor group, and position. Model II adds group dynamics such as the average group investment and ESR in Stages I and II, along with weather variables. In Model III, dummies are added to indicate whether individuals purchased seasonal weather information in the same round and whether a pump had been operational in the previous round. Models IV and V distinguish between upstream and downstream individuals.

It can be hypothesized that downstream players are less likely to engage in adaptation. According to Model I, individuals at location E invested less often in the irrigation pump, lending some support to the hypothesis.

After adding the average ESR in Stages I and II to Model II and the 'investment t-1' lag, the variable position E no longer passes the significance threshold. This may be in part due to the ESR being a proxy for position as upstream players are consistently found to extract more water than downstream ones. High investments in the preceding round significantly raised the probability of investing in a pump in the current round (ß = 0.14). Moreover, higher investments in the preceding round are associated with higher harvests, which might be expected to increase players' readiness to invest in the pump. In line with intuition, high group investments in Stages I and II incentivized individuals to select the collective adaptation option (ß = 0.14). Members of these more cooperative groups probably saw a higher potential impact of the collective adaptation option due to the prospect of higher resource flows with a successful pump installation.

In Model III, an individual's readiness to continue to engage in the adaptation of the pump seems to have been positively influenced by the installation of a water pump in the preceding round. Furthermore, individuals who spent a token on the seasonal weather forecast were significantly less likely to simultaneously dedicate a share of their resources to the collective adaptation option.

In Models IV and V, up- and downstream irrigators are examined separately. The only variable that was found to be significant regarding tail-enders is the average ESR (ß = 2.52, $p < 0.05$) during the first stages of the experiment. The expectation of water withdrawal based on past experience seems to have been a decisive factor. When only including upstream individuals in the analysis, the positive effect emerging from a pump that was successfully established in the preceding round grows in strength. Risk propensity is significant when considering all individuals as in Models I and III (as opposed to in Models II, IV, and V), whereas participants' inclination to trust others matters only for upstream players. The deliberations of upstream individuals on whether or not to adopt also seems to have been driven by their inclination to trust their peers. That said, caution is advisable as the role of both risk and trust reach the significance threshold only by a small margin.

Table 4. Logistic regression results for individual investments in pump adaptation.

Pump Investments	All Players (I)	All Players (II)	All Players (III)	Upstream (IV)	Downstream (V)
Intercept	3.51 *	−3.98	−6.68 **	−2.40	−1.63
	(1.45)	(2.05)	(2.41)	(2.22)	(2.88)
Position B	−0.14	0.26	0.19	0.04	
	(0.58)	(0.56)	(0.67)	(0.62)	
Position C	0.19	0.65	0.85	0.73	
	(0.59)	(0.60)	(0.72)	(0.67)	
Position D	−0.83	0.02	0.15		
	(0.62)	(0.68)	(0.81)		
Position E	−1.79 **	−0.52	−1.56		−1.21
	(0.64)	(0.74)	(0.92)		(0.75)
Round	−0.12 ***	−0.07 *	−0.02	0.01	−0.04
	(0.03)	(0.04)	(0.05)	(0.06)	(0.09)
Student	−1.96 *	−1.03	−0.87	−0.48	−2.77 *
	(0.77)	(0.60)	(0.63)	(0.62)	(1.08)
Risk propensity	0.24 *	0.18	0.27 *	0.23	0.25
	(0.10)	(0.09)	(0.11)	(0.16)	(0.16)
Trust	−0.26	−0.18	−0.21	−0.45 *	−0.04
	(0.16)	(0.14)	(0.16)	(0.19)	(0.25)
Investment t-1		0.16 ***	0.13 *	0.14 *	0.21
		(0.04)	(0.05)	(0.05)	(0.11)
Avg. group inv. In Stages I and II		0.14 **	0.17 ***		
		(0.04)	(0.05)		
Avg. ESR in Stages I and II		0.52	0.67	0.19	2.52 *
		(0.32)	(0.38)	(0.37)	(1.22)
Wet weather t-1		0.93 **	0.62	1.28 *	−1.07
		(0.36)	(0.43)	(0.52)	(0.82)
Dry weather t-1		0.67 **	0.63 *	0.94 **	−0.02
		(0.25)	(0.28)	(0.34)	(0.48)
Forecast purchase			−1.17 ***	−0.85 **	−1.08
			(0.30)	(0.33)	(0.70)
Pump installed t-1			0.69 *	1.31 **	−0.37
			(0.34)	(0.46)	(0.61)
Investment in pump t -1				0.54	0.80
				(0.35)	(0.52)
AIC	897.96	872.35	724.41	499.78	240.91
BIC	951.94	950.88	810.85	568.45	299.21
Log Likelihood	−437.98	−420.18	−344.20	−233.89	−105.46
Num. obs.	1000	1000	900	540	360

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Another interesting observation concerns the variable ‘round’. It is significant and negative *only as long as* the dummy indicating whether a pump was installed in the preceding round is not included, suggesting that investments in collective adaptation decline less over time if groups manage to set up pumps. Under otherwise equal conditions, an individual’s readiness to invest in the pump seems to decrease with every further round. This could indicate that the first rounds of Stage III represented a critical juncture in determining whether individuals had enough faith in the collective adaptation. If a pump was installed in the beginning of Stage III, the feasibility of adaptation was signaled to the individuals willing to support collective adaptation, thereby triggering a virtuous cycle of pump investments and positive reinforcement behavior. In contrast, failed initial investments could discourage individuals from choosing the pump adaptation option later during the stage. Hence, irrespective of other relevant parameters such as group cooperativeness and position, readiness to back collective adaptation might be dependent on tipping points.

If we do not compare position A to every other position but instead just discriminate between more up- and downstream positions (see Table 5), the hypothesized upstream–

downstream decline regarding the willingness to invest either in the irrigation pump or weather forecast is confirmed.

Table 5. Individual investments in adaptation measures.

	Y = Contribution to Pump (I)	**Y = Forecast Purchase (II)**
(Intercept)	−4.46 * (2.23)	−0.31 (2.95)
Position	−0.47 ** (0.18)	−0.87 ** (0.27)
Round	−0.01 (0.05)	−0.14 ** (0.05)
Student	−0.94 (0.60)	0.25 (0.84)
Risk propensity	0.24 * (0.11)	0.22 (0.18)
Trust	−0.18 (0.16)	−0.16 (0.25)
Investment t-1	0.15 ** (0.05)	−0.11 * (0.05)
Avg. group inv. In Stages I and II	0.15 ** (0.05)	0.22 *** (0.06)
Wet weather t-1	0.67 (0.42)	−0.79 (0.43)
Dry weather t-1	0.65 * (0.28)	0.05 (0.27)
Pump investment		−1.37 *** (0.32)
Forecast purchase	−1.11 *** (0.30)	
Forecast purchase t-1		
Pump installed t-1	0.72 * (0.34)	−0.08 (0.36)
AIC	727.46	788.38
BIC	794.70	855.62
Log Likelihood	−349.73	−380.19
Num. obs.	900	900
Num. groups: id	100	100
Num. groups: group	20	20

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

In Model I above, position (β = −0.47) is significant at the 5% level, indicating that the further downstream players were located along the irrigation channel, the less likely they were to invest in the pump adaptation option. As Model II suggests, these core findings are also applicable to the weather forecast adaptation option. Upstream players purchased seasonal weather information more often than tail-enders, and players of more cooperative groups were more likely to obtain this information than those of uncooperative ones. This is plausible as taking adaptation measures in general is only attractive if a group member's earnings under baseline conditions can be expected to be higher than if he or she did not contribute at all.

Recapitulating the main findings, the hypothesis that *upstream players are more likely to invest in collective adaptation* receives moderate support. Second, general group cooperativeness had a positive impact on players' willingness to purchase adaptation options. Third, upstream participants with higher propensity to trust others were more likely to invest in the collective adaptation option.

5.4. Adaptation at the Group Level

Next, the third hypothesis that *cooperative groups invest more frequently in collective adaptation measures* was tested. Table 6 presents standardized results from linear regression analyses that were performed at the group level (y = the number of total investments into the irrigation pump). To check for differences between the student and farmer groups, the analyses for each group were run separately. Model I and Model II analyze the student population only. In Model II, a dummy indicating whether a pump is installed in the preceding round is added. Model III covers farmers' decisions alone. Model IV includes both populations.

Table 6. Group level regression results (Group investments in pump).

Y = Total Group Investments in Pump	Students (I)	Students (II)	Farmers (III)	All (IV)
(Intercept)	0.20 (0.13)	0.46 *** (0.13)	−0.02 (0.11)	0.36 *** (0.07)
Student				−0.56 *** (0.05)
Round	−0.27 ** (0.09)	−0.10 (0.13)	−0.13 (0.09)	−0.03 (0.06)
Average trust	0.01 (0.09)	−0.02 (0.08)	0.03 (0.07)	0.04 (0.05)
Average risk	−0.17 * (0.08)	−0.06 (0.07)	0.43 *** (0.06)	0.06 (0.05)
Preceding round dry	0.05 (0.10)	0.14 (0.08)	0.07 (0.06)	0.10 * (0.04)
Preceding round wet	0.14 (0.14)	0.18 (0.13)	0.01 (0.11)	0.13 (0.07)
Preceding 2 rounds dry	0.16 (0.10)	0.04 (0.10)	0.01 (0.07)	−0.01 (0.05)
3 in prec. 4 rounds dry	0.14 (0.09)	0.07 (0.10)	0.07 (0.08)	0.02 (0.05)
Avg. group investment stage II	0.65 *** (0.11)	0.36 ** (0.11)	0.40 *** (0.10)	0.20 *** (0.06)
Total forecast purchases	−0.41 *** (0.09)	−0.26 ** (0.09)	0.43 *** (0.08)	0.08 (0.05)
Pump mounted t-1		0.63 *** (0.10)	−0.00 (0.07)	0.33 *** (0.05)
R^2	0.34	0.51	0.91	0.81
Adj. R^2	0.30	0.47	0.89	0.80
Num. obs.	140	126	54	180
RMSE	0.84	0.70	0.33	0.45

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Model I demonstrates that group cooperation in early rounds, here proxied by the average group investment in Stage II, was a critical factor (β = 0.65, $p < 0.001$) in determining whether groups managed to set up a pump, supporting Hypothesis 3, which states that *cooperative groups invest more frequently in collective adaptation measures*. It is worth mentioning that as the experiment progressed, the student groups gradually reduced their collective adaptation efforts. This is reflected in the negative coefficient for round (β = −0.27, $p < 0.01$). Additionally, the more that group participants opted for the individual adaptation option, the less likely they were to choose to purchase the pump. This reflects findings derived from individual analyses. Counterintuitively, the coefficient for risk is slightly negative and significant (β = −0.17, $p < 0.05$), which might be due to multicollinearity. With only 30% of variation explained, the goodness-of-fit of this model is rather weak. This could be due to unobserved group characteristics that the chosen variables fail to account for.

Introducing a dummy for a pump installment in the preceding round (model II) strongly increases goodness-of-fit to 47%. Still significant at the 0.01% level, group cooperation (β = 0.36) in Stage II is confirmed as an important driver of group investments in pumps, while the variables 'average risk' and 'round' are no longer significant. The coefficient representing negative implications of the frequency of forecast acquisitions for group adaptation also retained significance (β = −0.26, $p < 0.01$). Interestingly, the strongest effect (β = −0.63, $p < 0.001$) can be attributed to the dummy of whether a pump was operational in the preceding period. This might suggest the presence of a tipping point critical for adaptation. Successful collective action by students to install a pump at an early point in Stage III translated into higher chances of another collective pump investment. In contrast, collective adaptation efforts declined with every round in which there was no pump installed. This mirrors results obtained in the context of individual decision analysis and might suggest the existence of a path-dependent adaptation trajectory.

A quite different behavior could be observed among farmer groups (Model III). The regression results suggest that pump investments were not influenced by pump installations in the preceding round. To some extent, this might be explained by the observation that farmers were generally more likely to collectively adapt as shown in Model IV. Actor type was the most decisive factor determining the number of pump investments a group made in any round. This is illustrated by a strong negative and highly significant coefficient (β = −0.56, $p < 0.001$) for 'student'. Farmer groups consistently showed higher levels of pump investments. Actor-specific behavioral differences are thus among the factors driving adaptation. In contrast to student groups, for farmers, the number of times seasonal weather information was purchased had a positive and significant (β = 0.43, $p < 0.001$) impact on pump investments per round. Farmers who opted for one adaptation option were likely to also choose the other. Furthermore, and again in contrast to student groups, average risk propensity significantly (β = 0.43, $p < 0.001$) affected the inclination of farmer groups to make investments into collective adaptation.

Despite these differences, farmer and student groups share one critical commonality. Average Stage II group investments played a highly significant and positive role (β = 0.40, $p < 0.001$) of similar magnitude in determining the number of pump investments per round. More elevated levels of contributions into the public fund led to more investments into the collective adaptation option. This finding is also validated by Model IV with the related coefficient retaining significance (β = 0.20, $p < 0.005$). Given the robustness of the effect across actors and model specifications, support for Hypothesis 3, stating that *more cooperative groups invest more frequently in collective adaptation*, is confirmed.

5.5. Drivers for High Contribution Levels in Stage III

Models I and II (Table 7) examine group investments in Stage III. Model I includes adaptation variables (e.g., whether a pump was mounted in the previous round). We first discuss the drivers enabling high contribution levels through Stage III before looking in more detail at the determinants facilitating pump investments. Examining Stage III in Model I (without adaptation options) shows that students invested considerably less than farmers (β = −0.20, $p < 0.001$). The model also detected a downward tendency regarding contributions towards the end of the experiment (β = −0.27, $p < 0.05$). There was no significant influence of weather variables. Factors concerning group dynamics are found to be among the most relevant. More equal water extractions in the preceding stages and a high cooperation level in the preceding round had a positive and significant impact on group investments. This suggests initial support for our hypothesis.

Model II complements Model I with adaptation variables such as the total number of pump investments per group and round, the total number of seasonal weather information purchases, and a dummy for whether a pump was installed in the preceding round. Adding Stage III variables improves model fit to a significant extent. Groups characterized by more equal water extractions in the preceding Stages I and II (β = −0.22, $p < 0.001$) managed to maintain higher contributions to the public fund. A fair distribution of water resources could be interpreted as an indispensable prerequisite for the willingness to invest in adaptation. More pump investments per round were associated with substantially higher contributions (β = 0.36, $p < 0.001$), as players investing in the pump were found to hike up their contributions (see previous section). Likewise, a previously installed pump positively influenced group contributions (β = 0.17, $p < 0.05$) (Table 7), which tallies well with individual-level results. A previously installed pump seems to be supportive of a virtuous cycle of cooperation, pump investments, and consequently higher resource levels. We suggest that there could be a tipping point driving adaptation trajectories.

Table 7. Group-level regression results (group investments in channel maintenance).

Group Investments in Stage III	**(I)**	**(II)**
(Intercept)	0.52 (0.33)	0.56 (0.30)
Student	−0.20 ** (0.07)	0.01 (0.09)
Round	−0.12 * (0.06)	−0.14 (0.08)
Average Trust	−0.06 (0.06)	−0.07 (0.06)
Average Risk	0.03 (0.06)	0.02 (0.06)
Dry t-1	0.06 (0.06)	0.04 (0.06)
Wet t-1	−0.02 (0.09)	−0.08 (0.09)
2 in prec. 3 rounds wet	0.42 (0.33)	0.54 (0.30)
Preceding 2 rounds dry	0.10 (0.06)	0.07 (0.07)
3 in prec. 4 rounds dry	−0.03 (0.06)	−0.03 (0.07)
Group investment t-1	0.55 *** (0.06)	0.38 *** (0.07)
Avg. Gini in stages I + II	−0.17 ** (0.06)	−0.22 *** (0.06)
Total forecast purchases		−0.10 (0.07)
Total pump investments		0.36 *** (0.10)
Pump mounted t-1		0.17 * (0.07)
R^2	0.62	0.71
Adj. R^2	0.59	0.68
Num. obs.	200	180
RMSE	0.64	0.57

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

6. Discussion

Our results show that individuals do not significantly react to short-term weather fluctuations and only slightly adjust their contributions downwards after the frequency of dry weather spells reaches a certain threshold. General cooperation levels driven by extraction inequality are more influential in determining participants' commitment to collective action than uncertainty or drought. In addition, the investment and water abstraction decisions of both upstream and downstream positions are found to be among the most crucial determinants affecting readiness to contribute to the collective pool resource. The mechanism of unequal resource harvests driving down levels of collective action and the importance of relative positioning have been demonstrated before [5,7,38]. Our results also conform with behavioral experiments conducted without the addition of uncertainty and adaptation treatments.

Our findings largely confirm the results of previous investigations carried out in the context of an asymmetric resource dilemma that includes resource variability. Although Baggio et al. and Anderies et al. found a small significant effect of variability, they concluded that this is secondary to upstream–downstream dynamics, i.e., extraction inequality and positional asymmetry, in influencing an individual's investment behavior [15,33]. Research subjects confronted with pure uncertainty do not behave in a different way when compared to an experimental setup in which available resources vary with an a priori known probability distribution, as investigated by Baggio et al. [15]. Our findings may therefore support the suggestion that individuals do not necessarily distinguish between risk and uncertainty when faced with complex decisions (c.f. [50]).

Our results are also well aligned with the conjecture made by Lipshitz et al. that in complex situations without an a priori knowable single best option, uncertainty may be systematically suppressed [34]. Considering our findings related to the asymmetric irrigation dilemma, participants seem to base decisions on whether to partake in collective action, mainly on observations of group-member behavior. Mutual interdependence can be seen, even under uncertainty, as the key component influencing future resource-collection opportunities.

Apart from the preponderance of observed group-member behavior and the concomitant suppression of uncertainty, wishful thinking might also explain the observed reluctance of experiment participants to reduce investments in the face of gradually dwindling water extractions. Wishful thinking, reflected in the tacit assumption that after several rounds featuring dry weather, wet weather would surely return, is in accordance with human propensity to judge preferable outcomes as being more likely [51]. By contrast, other CPR studies, where uncertainty was related to resource size, demonstrated that wishful thinking may lead to excessive harvesting and thus to a collapse of collective action (c.f. [23,31]). Hence, our findings suggest that the degree to which collective action is affected by uncertainty is likely to be conditional on the specific social dilemma type as was first hypothesized by Wit and Wilke [24].

Contrary to results from earlier research on CPR dilemmas (see for example [52,53]), our results further suggest that uncertainty in Stage II does not lead to rising levels of extraction inequality, implying that upstream individuals refrain from withdrawing relatively higher shares. An ANOVA test comparing levels of extraction inequality (Gini) in Stages I and II could not detect significant differences (F(1,2) = 1.207, $p = 0.74$). In fact, extraction inequality appears to decrease in farmer groups. The observation that overall inequality levels remain stable or even decrease in the case of farmer groups might have been due to the nature of the CPR 'irrigation water' that needs to be actively generated in a collaborative effort by mutually dependent system members.

Upstream individuals, the first to benefit from high resource flows, were generally more likely to contribute to the collective adaptation option. The probability of an individual choosing adaptation options was raised by their being part of a more cooperative group. Both farmer and student groups who showed relatively high levels of contributions in the preceding stages exhibited relatively high total pump investments. Our results demonstrate that relatively high group investments, i.e., high levels of cooperation, were driven by relatively low levels of water collection inequality (reflected in relative restraint by upstream players). This result supports the suggestion of previous studies that indicate that there is an important link between resource distribution equality and the level of group cooperation [11,33,54]. Inequality is probably related to greater conflict and less social cohesion within groups (c.f. [55]). Dipierri and Zikos point out that in CPR dilemmas with environmental uncertainty, effective conflict-resolution mechanisms can help deal with environmental uncertainty [16]. More generally, this study identifies the importance of extraction inequality in influencing participants' readiness for collective action in support of adaptation. This links well to research emphasizing the need for adequately including disadvantaged farmers when reforming common-pool resource governance [56].

The experiment's results also show that student groups were less inclined towards collective adaptation but were more often drawn to seasonal weather information. For students, the effect of social learning could have played an important part in their decision-making process; when a pump was successfully mounted during the first rounds, the chances of further pump installations grew significantly as students gained confidence in the general feasibility of collective adaptation. Due to the growing frequency of dry rounds in Stages II and III of the experiment, the effectiveness of collective action considerably declined without sufficient investment in the collective adaptation option. Individuals who were still maintaining public infrastructure under conditions of non-adaptation incurred sizable losses. Almost two-thirds of the student groups often earned considerably lower revenues than would have been the case if all group members had reduced their investments to zero. Among student groups, more frequent purchases of the seasonal weather information also led to both lower pump investments and fewer maintenance contributions given the dominance of dry-weather predictions. As maintenance contributions decreased, so did incentives for collective adaptation. This suggests that adaptation trajectories may be strongly path-dependent and depend on tipping points (c.f. [57]).

Interestingly, indications of a tipping-point-dependent adaptation trajectory could only be identified among student groups; farmers more often backed the collective adaptation option. In fact, farmer groups generally showed higher levels of collective action under otherwise similar conditions. In contrast to the farmers, students preferred the individual adaptation option, and their behavior generally seemed closer to that of a rational actor. Diverging collaboration rates between farmers and students are not a new phenomenon; field experiments carried out in Columbia and Thailand also concluded that groups of farmers were more cooperative when compared to those of students [5,7]. Indeed, a large body of behavioral research indicates that university students show lower levels of cooperative or pro-social behaviors than other subject pools [58–60].

Apart from behavioral variability across subject types, evidence from experimental research has repeatedly pointed to the significance of contextual and socio-cultural factors for modulating collective action in CPR dilemmas [43,45,61]. Higher cooperation levels that were observed in the case of farmers may thus also be partly ascribed to the Chinese cultural context. which is, as discussed before, characterized by collectivist attitudes. Anecdotal evidence supports this interpretation. Several farmers have indicated that their behavior was not primarily driven by personal gain but rather the pursuit of the public interest. Although the study did not primarily focus on the role of socio-cultural factors, its results are well aligned with research highlighting the importance of considering local cultural and social norms when designing and implementing interventions to improve access to common-pool resources such as water (see for example [62]). Similar studies in other cultural contexts would be required to arrive at a more systematic understanding of the relative importance of socio-cultural factors in shaping participants' behavior vis à vis structural elements characterizing the resource dilemma at hand.

7. Conclusions

This research shows (i) that uncertainty influences contribution levels with a marked delay; (ii) that upstream players are more likely to engage in adaptation than downstream ones; and (iii) that groups who show higher levels of cooperation more frequently invest in adaptation measures. This work also confirms the pre-eminent significance of the resource extraction behavior of privileged water users in shaping general group cooperativeness. It thus seems that the responsibility for creating favorable conditions for collective adaptation rests on the shoulders of upstream players. This is a robust finding that holds for both farmer and student experiment participants. More uneven withdrawals decrease incentives for downstream players to contribute to the public maintenance fund, driving down total group investments and resulting in lower overall efficiency of the system. Low levels of group investments, in turn, result in lower levels of adaptation to uncertainty. Within the limits of this experiment, extraction inequality can thus be argued to constrain collective adaptation prospects by making cooperation less likely. More research is required to verify whether the role of distributional inequality in influencing adaptation pathways is equally important in other CPR contexts beyond the asymmetric irrigation dilemma.

To conclude, the results of this research concur with existing evidence that reciprocity is a powerful determinant of human and societal cooperation. Amid a backdrop of rapid environmental changes, this implies that actors with more economic clout should consider equity aspects to inspire less well-placed stakeholders to contribute to the efforts of maintaining global or local commons. However, privileged actors are often unaware of the importance of their role as feedback loops are much more complex and less transparent in reality than in the highly simplified irrigation dilemma used in this work. Sensitizing privileged resource users to their decisive role in enabling collaboration and collective action appears to be a reasonable step in increasing chances of successful group adaptation.

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