Center for the Study of Institutional Diversity

CSID Working Paper Series

#CSID-2014-002

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February 6, 2014

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Lab Experiments on Irrigation Games Under Uncertainty

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Abstract:
Research on collective action and common pool resources is extensive. However, little work has concentrated on the effect of uncertainty in resource availability and collective action, especially in the context of asymmetric access to resources. Earlier works have demonstrated that uncertainty often leads to a reduction of collective action in the governance of shared resources. Here we assess how uncertainty in the resource availability may impact collective action. We perform a behavioral experiment of an irrigation dilemma. In this dilemma participants invest first into a public fund that generates water resources for the group, which is subsequently appropriated one participant at the time from head-end to tail-end. The amount of resource generated for the given investment level is determined by a payoff table and a stochastic event representing rainfall. Results show that access asymmetry and resulting inequalities dominate any effects from uncertainty about the resource condition. The strategic uncertainty about the decisions of other players dominates potential effects from the environmental uncertainty.

Keywords:
Asymmetry, Common-Pool Resources, Laboratory Experiment, Uncertainty

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INTRODUCTION

A challenge in managing common-pool resources, like water for irrigation, is how to prevent the free-rider problem, i.e., ensuring the individual users of a resource all contribute to the allocation and maintenance of the resource–that some don't take advantage of the effort of others. Collective action is thus especially challenging in systems that are naturally prone to asymmetries (such as irrigation systems) due to heterogeneity caused by biophysical contexts that favors free riders (Anderies et al. 2011). A key feature in many of these systems lies in the coupled interactions between the natural processes of the environment and the decisions of the resource users (Anderies et al. 2004), as well as feedback processes, which can stabilize a system and make it more resilient to perturbations in conditions or increase the system's sensitivity to disturbances (Zhou and Doyle 1998, Rodriguez 2003). Research on collective action has shown that risk and uncertainty can reduce collective action (Walker and Gardner 1992, Gangadharan and Nemes 2009). In line with definitions for "risk" and "uncertainty" established by Knight (1921) and used by Gangadharan and Nemes (2009), we use "uncertainty" to describe situations in which the probability of different outcomes in future events are not known and "risk" to describe situations in which the probabilities of different outcomes in future events are known. Likewise, two forms of uncertainty in collective action can be distinguished: strategic uncertainty, which addresses how other group members will act and environmental uncertainty, which concerns how the environmental resource will act (Messick et al. 1988).

One typical example of a collective action problem in an asymmetric setting where uncertainty in the resource may play a fundamental role is the upstream vs. downstream dilemma found in some irrigation systems. In irrigation systems, the upstream appropriators need the contributions of the downstream appropriators in constructing and maintaining the infrastructure, while the downstream appropriators need the upstream appropriators to allow water to flow to their fields. This asymmetry in access is thus given by the biophysical conditions of the resource examined, and not solely by the social and cultural environment. There are numerous examples of successful governance (Ostrom and Gardner 1993, Cifdaloz et al. 2010) of such systems despite the upstream vs. downstream dilemma. However, it is not clear how environmental uncertainty affects collective actions on such asymmetric systems. Recent studies show a U-shape relationship between resource uncertainty and collective action (Dinar et al. 2010) while Rapaport et al. (1992) found in common pool resource experiments that when environmental or resource uncertainty increased, participants overexploited the resource, mainly because of biases in estimating resource availability or "wishful thinking." Further, previous studies have found that resource uncertainty can reduce cooperation (Wit and Wilke 1998, Döll 2002, Au 2004).

We analyze the impact of resource uncertainty by performing a series of laboratory experiments. We thus assess how cooperation (measured in our game as level of investment in maintaining the irrigation infrastructure) is influenced by uncertainty and other control variables (such as trust and risk aversion) that are thought to be important drivers of collective action success or failure. We hypothesize that the uncertainty caused by rainfall variability would lead to lower investments in maintaining the infrastructure. Trust between group members has also been found to correlate strongly with cooperation (Fischbacher et al. 2001, Janssen and Rollins 2012), and we hypothesize that higher levels of trust will correspond with higher levels of investment. Our surprising result is that resource uncertainty and trust are not the dominant factors in determining levels of collective action. The defining characteristic in the outcome of this experiment is the access inequality that arises in the asymmetric structure of the situation. Uncertainty is only significant in the first two rounds after the uncertainty level changes in the game, and trust is only significant in the first round, before the actual behaviors of the group members and the level of share equality becomes evident. In other words, in the experiments we performed, strategic uncertainty over how other group members will act outweighs environmental uncertainty.

EXPERIMENT DESIGN

This experiment is structured as an irrigation management game with five participants (see Appendix 2 for the experiment protocol.) These five participants are randomly allocated to positions A, B, C, D, and E, where A is the upstream participant, and E the downstream participant. The participants keep the same position during the duration of the whole experiment. The experiment mimics the provision of infrastructure and the distribution of water that small-scale irrigation systems require (Cifdaloz et al. 2010, Janssen et al. 2012). At the beginning of each round, each participant receives an endowment of ten tokens, which they can invest in the irrigation infrastructure or keep for themselves. Each token is worth five cents. The total investment of the five participants defines the state of the irrigation system. Table 1 shows the amount of water that can flow through the irrigation system based on the total investment.

Table 1. Water production as a function of units invested in the public infrastructure. The table includes a default production function (medium), as well as a production function during a dry round (low), and an affluent round (high).

Total units invested by all players	Water available (low)	Water available (medium)	Water available (high)
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

In the second half of the round, each participant—in sequential turns from upstream to downstream—decides how much water to extract from the available water. Available water is the total water produced by the group minus the water already extracted by those before in the sequence. Each token extracted in the second stage has a monetary value for the participant that is equal to the value of each unit of water kept (not invested) in the first stage. Figure 1 provides a graphical representation of the experiment stages described.

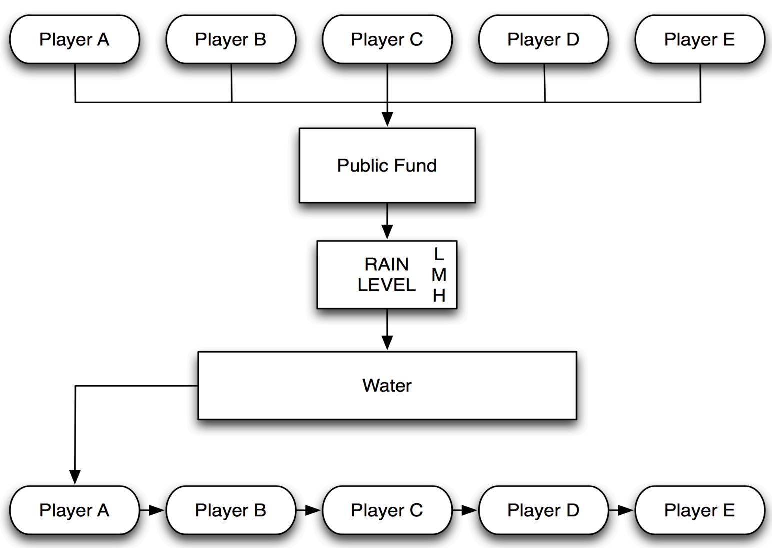

Figure 1. Flowchart of one experiment round.

The session consists of one practice round to demonstrate the game's procedures and fifteen decision rounds played for money, split into three five-round Treatment Periods. Each of the three periods apply different amounts of environmental uncertainty. We distinguish between low, medium, and high productivity rounds, representing dry, standard, and affluent conditions. The low productivity condition has 60% lower productivity compared to the medium productivity condition for the same level of investment, while the high productivity condition has a 60% increase of productivity over the medium. We also distinguish between three levels of uncertainty: 1) no uncertainty—rainfall level is fixed at the medium level production function in Table 1; 2) low uncertainty—randomly determined use of the low (1/6 probability), medium (2/3 probability) or high (1/6 probability) production functions from Table 1; and 3) high uncertainty—randomly determined, 1/3 probability, for each of the three possible production functions from Table 1.

We define three treatments with different sequences of the type of uncertainty in the experiment session (Table 2.) This is done to test the effect of different levels of uncertainty and control for any learning effects.

Table 2. Treatment designs

	# of groups	Treatment Period 1 Rounds 1-5	Treatment Period 2 Rounds 6-10	Treatment Period 3 Rounds 11-15
Treatment 1	6	No Uncertainty	Low Uncertainty	High Uncertainty
Treatment 2	5	No Uncertainty	High Uncertainty	Low Uncertainty
Treatment 3	5	Low Uncertainty	High Uncertainty	No Uncertainty

According to theory, behavior is expected to be limited by selfish rationality on one hand, and by the search for social optimum on the other. Thus we will expect actors to invest 0 tokens if they behave according to selfish rational actors (0 being the Nash Equilibrium.) On the other hand, if actors search for the social optimum, they will try to reach the maximum production by the group as a whole (or reaching a total group investment of 46 tokens in our specific case.)

Besides the results from participating in one of the treatments of the experiment, we collect information from each participant on risk aversion using the standard risk aversion exercise from Holt and Laury (2002) (provided in Appendix 2) and estimates on trust using the Trust Game from Berg et al. (1995) (also Appendix 2.) If participants are risk neutral—i.e., they show no preference between options with equal expected payoffs but differing levels of risk—we expect uncertainty not to have any role to play in the decision making process, and thus, we would expect uncertainty not to affect collective action. We expect trust to be a significant factor in how participants choose to invest in the public infrastructure, and higher measures of trust from the Trust Game will correspond with higher levels of investment in the irrigation game. Finally we collect some additional information, like demographic information, via an individual survey (Appendix 2.)

DATA COLLECTION & ANALYSIS

Data used in the analysis of collective action in an asymmetric setting under uncertainty is derived from six sessions of experiments performed during Spring 2012 with undergraduate students at Arizona State University. The data set consists of 16 groups consisting of 5 individuals who recorded their decisions for 15 rounds, resulting in 1,200 observations (summary statistics provided in Appendix 1.)

We measure cooperation by the level of investment in the public infrastructure. In other words, our dependent variable is the number of tokens invested by the participants into the public fund to generate the water resource. We analyzed both individual decisions and group aggregate results. The individual investment decisions were regressed using hierarchical models with cluster robust errors and groups as the clustering variable. Suitability of the hierarchical model compared to OLS is supported by the Likelihood Ratio test with $p < 0.001$. The group aggregate results were regressed with OLS and robust errors.

Table 3 reports the independent variables chosen to describe the drivers theorized to affect collective action. Trust is measured by the normalized scores representing the amount of money sent to another participant in the Trust Game. Risk is assessed by the number of low-risk choices in the Risk Aversion Game, and its scores are centered at 0, which represents risk neutrality. Uncertainty levels are given in terms of the probability of the water production function. In order to explore time effects on uncertainty, we use the Period Round number within each Treatment Period by clustering the game round numbers (See Figure 2.) This means within each five-round Treatment Period of the game—1-5, 6-10, and 11-15—the Period Round number is 1-5, and resets back to 1 at the beginning of the next uncertainty treatment. This measure indicates whether the fresh change from a new uncertainty regime relates to any changes in behavior.

The Equal-Share Ratio (ESR) and Net Gains are used in the individual decisions model, while the gini coefficient of water appropriation is used for inequality in the group aggregate model. ESR is calculated by the formula:

$$ESR = \frac{E_i}{R_t \div 5} - 1 \quad (1)$$

where E_i is the actual extraction decision by Participant, R_t is the total Resource quantity available at the beginning of the Extraction phase, and the 1 unit is subtracted from the score to rebalance it so 0 represents share equality. When the Equal-Share Ratio is less than 0, the participant extracted less than an equitable share, when it is greater than 0, they extracted more than an equitable share. The Net Gain is the participants' net profit in the previous round, calculated:

$$Net\ Gain = E_i - I_i \tag{2}$$

where E_i is participant's Extraction decision and I_i is participant's Investment decision. All variables are averaged across all positions within each group for the group-aggregate models.

Table 3. Definition of the independent variables used in analysis.

Variable	Definition	Value
Round	Game round	[1, 15]
Position	Participant's position in group	{A=1, B=2, C=3, D=4, E=5}
Uncertainty	Rainfall uncertainty level	{None = 0, Low = 1, High = 2}
Rainfall*	Rainfall level	{Low = 0, Medium = 1, High = 2}
Equal-Share Ratio (ESR)*	Ratio of the water share received against an equal share between all group members	[0, n]
Net Gain*	The amount appropriated less the amount invested	[0, n]
Appropriation gini coefficient*	Indicator of share inequality in water appropriations	[0, 1]
Trust	The participant's decision from the Trust Game, normalized	[0, 1]
Risk Aversion	The participant's score from the Risk Aversion game, centered around 0	[-0.6, 1]
Female	Dummy variable: Is participant female?	[0, 1]

* variables are measured from the previous round

RESULTS

Tables 4 and 5 report results stemming from the hierarchical models where individual and group investments are considered as the dependent variable, respectively. We report five different model specifications at the individual level and three at the group level in order to assess how trust, uncertainty, risk aversion and extraction patterns (ESR and Net Gain) influence investments into the public fund. The models are ordered by AIC (from the worst to the best.) The first result worth mentioning is that uncertainty seems to play only a marginal role in determining the level of investment at the individual level, while it is significant at the group-level. In both cases, uncertainty corresponds with an increased investment level. To explore whether uncertainty only has an effect at the beginning of each treatment phase—the participants may respond differently immediately after the uncertainty level changes—we interact Uncertainty with the Period Round, the round number within each treatment period (See Table 6.) Uncertainty has a significant positive effect on investments for the first two rounds after the uncertainty level changes.

Trust and Risk Aversion are not significant at the individual-level, but at the group-level they are significant and behave according to the literature (trust increases investment levels and the more risk averse one is, the less the group will invest.) The individual-level results, surprising if confronted with previous literature, may be due to the fact that while trust and risk aversion have a role to play in the beginning of the experiment (i.e., in the first round), the effect of how much we trust becomes secondary to the observed behavior of our "neighbors" or individuals in our group. This is supported by the results in the first round compared to rounds 2-15 (See Table 7.) Net gains show a similar discrepancy between the individual-level and group-level results. At the group level, increased gains correspond with higher investments, as would be expected. The

Table 4. Regression results, individual investments.

	Model 1	Model 2	Model 3	Model 4	Model 5
Round	-0.084**	-0.072**	-0.083**	-0.079**	-0.067**
Position	-0.831***	-0.857***	-0.672***	-0.790***	-0.182
Uncertainty	0.206*	0.196	0.221*	0.209	0.193*
Rainfall	-0.036	0.043	0.455***	0.367***	0.620***
Trust	0.084	0.008	0.169	0.254	0.442
Risk Aversion	0.332	0.151	-0.058	0.199	0.336
Female	-0.898	-0.989*	-0.963*	-1.007**	-0.897**
Net Gain		-0.006	-0.068***		
Net Gain x Position 1				-0.094***	-0.049**
Net Gain x Position 2				-0.081***	-0.068***
Net Gain x Position 3				-0.011	-0.082***
Net Gain x Position 4				-0.026	-0.155***
Net Gain x Position 5				-0.045	-0.180***
ESR			1.064***	0.997***	
ESR x Position 1					0.157
ESR x Position 2					0.450
ESR x Position 3					1.915***
ESR x Position 4					4.401***
ESR x Position 5					4.383***
(Constant)	9.296***	9.427***	8.808***	9.102***	7.647***
N	1,120	1,075	1,075	1,075	1,075
LL	-2974.736	-2646.796	-2630.804	-2619.537	-2558.477
AIC	5969.472	5315.592	5285.607	5269.074	5156.954

Significance at the 1%, 5%, and 10% are denoted by ***, **, and *, respectively. Significance level derived from cluster robust errors.

Table 5. Regression results, group average investments.

	Model 6	Model 7	Model 8
Round	-0.084**	-0.098***	-0.092***
Uncertainty	0.206	0.260**	0.259**
Rainfall	-0.004	-0.199	-0.199
Trust	0.947	1.502***	1.424***
Risk Aversion	-6.691***	-4.666***	-4.395***
Female	-0.146	-0.096	0.004
Net Gain		0.506***	0.495***
Appropriation gini			-0.362
(Constant)	7.231***	3.416***	3.674***
N	224	224	224
R^2	0.113	0.665	0.666
AIC	937.177	721.116	722.244

Significance at the 1%, 5%, and 10% are denoted by ***, **, and *, respectively. Significance level derived from robust standard errors.

Table 6. Uncertainty effects by Treatment Period Round

	Individual	Group
Round	-0.057	-0.082***
Position	-0.185	
Uncertainty x Period Round 1	0.301***	0.370***
Uncertainty x Period Round 2	0.314**	0.356**
Uncertainty x Period Round 3	0.083	0.181
Uncertainty x Period Round 4	0.077	0.181
Uncertainty x Period Round 5	0.055	0.096
Rainfall	0.667***	-0.158
Trust	0.445	1.425***
Risk Aversion	0.333	-4.400***
Female	-0.895**	0.003
Net Gain		0.495***
Net Gain x Position 1	-0.049***	
Net Gain x Position 2	-0.068***	
Net Gain x Position 3	-0.083***	
Net Gain x Position 4	-0.154***	
Net Gain x Position 5	-0.179***	
ESR		-0.361
ESR x Position 1	0.156	
ESR x Position 2	0.452	
ESR x Position 3	1.918***	
ESR x Position 4	4.405***	
ESR x Position 5	4.372***	
(Constant)	7.543***	3.573***
N	1,075	224
LL	-2556.685	-350.595
AIC	5143.370	727.190

individual-level results however show a negative correlation—increased gains relate with decreased investments. Model 4 shows this unexpected result may also be a positional effect—the head-enders reduce their investments slightly when their net gains increase, an attempt to increase their net gains further. Share inequality, measured by ESR at the individual-level and the Appropriation gini coefficient at the group-level, seems to be the key determinant of investment levels. Further, if we break down the Equal Share Ratio by position, while we find that the first two positions do not rely on share equality, from position three onward, the ability to extract an equitable amount of resources dramatically increases investment in the next round.

Other results are as to be expected, position (i.e., precedence in appropriation of resource) significantly reduces levels of investment. Participants invest less the further downstream they are positioned. We considered the possibility that amount of rainfall in the previous round might affect investment decisions in the subsequent round—that high rainfall might influence participants to invest more heavily and low rainfall might lead to lower investment. We find increased rainfall in the previous round does lead to increased investment, although the effect is not significant throughout all the specifications. Women tend to invest less than men.

CONCLUSION

In this paper we explore the effects of uncertainty on cooperation in an asymmetric irrigation dilemma. Many small-scale irrigation systems around the world face the dual problem of collectively constructing the needed infrastructure for the common-pool resource and how to effectively and equitably share that resource. The upstream farmers possess privileged access to the water in the system, but they are also dependent on the contributions of the downstream farmers to build and maintain the infrastructure that carries the needed water. These systems also experience environmental variability that creates extra uncertainties for the farmers, complicating the cooperative dilemma they face.

We find that resource uncertainty is only significant at the beginning of each treatment period, when the uncertainty level changes, potentially a form of "wishful thinking" or overestimation of the potential effects of a new uncertainty regime (Rapaport et al. 1992). The amount of rainfall received does have an effect, so that higher rainfall in the previous round does correspond with larger subsequent investments. Higher trust can correspond with higher investment levels at the group level, while at the individual level it is limited to the first round. At least at the group-level, more risk aversion corresponds with lower investment.

Inequality and asymmetry are the main factors explaining cooperation levels in our experiment. Previous studies have found that cooperation is lower in asymmetric dilemmas than symmetric (Ahn et al. 2007, Beckenkamp et al. 2007). Where an individual is located in the system is highly significant for their willingness to contribute, and the tail-enders are highly dependent on the head-enders to maintain share equality. The primary uncertainty that affects their income opportunities is strategic uncertainty—the decisions the other group members will make (Messick et al. 1988). For head-enders, their privileged access to the resource ensures they can mitigate their exposure to environmental uncertainty, at the expense of the tail-enders. Their primary uncertainty is over the willingness of tail-enders to contribute to the public infrastructure. For tail-enders, their dependence on head-enders to not over-exploit the resource is a larger problem than whether the round is a light- or heavy-rainfall period. The level of share equality they experience is the primary driver for their willingness to invest.

ACKNOWLEDGEMENTS

We acknowledge financial support by the National Science Foundation, grant numbers SES-0748632 and BCS-1115054.

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Appendix 1.pdfAppendix 2.pdf