

**Climate policies under collective risk:
A laboratory investigation on the provision of local irrigation systems**

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Abstract: Motivated by the need for governments to partner with local farmers so that modern irrigation channels can be constructed to avoid losses from drought, we model the irrigation system provision problem as a threshold public goods game of loss avoidance and focus on testing whether government subsidies, as a type of price-based intervention, increase rate of successful provision. We design an experiment with scenarios involving either high or low risk of loss, while the local government provides either no subsidy, a one-to-one matching subsidy or a lump-sum subsidy. Results show that with no subsidy, the rate of provision of the public good is below the social optimum, and this is especially the case under high risk. Subsidies substantially increase the likelihood the irrigation project is undertaken, though groups remain under-insured in relation to the social optimum. A one-to-one matching subsidy appears to be at least as effective as lump-sum grants under same budget, although the improvement in average group investment and success rates is not significant.

Keywords: Threshold public goods, Subsidies, Irrigation, Climate change, Laboratory experiment

JEL Classification: C92, H23, H41, Q15, Q54

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1 Introduction

The increasing frequency of extreme weather events has imposed new challenges to small farmers, especially in developing countries (World Bank, 2007). One example is the dominating small-scale irrigated agriculture, which is highly vulnerable to drought (Morton, 2007; Fleischer, Lichtman, & Mendelsohn, 2008; Wheeler & Von Braun, 2013). Many small-scale irrigation systems are self-governed shared resources and largely rely on farmers' ability to solve collective action problems and willingness to cooperate on the provision and maintenance of these public goods (Ostrom, 2015). However, with more opportunities outside of agriculture, farmers have a low incentive to contribute to these public goods (Cardenas et al., 2017).

In this paper, we model the local irrigation system provision problem as a threshold public goods game of collective risk avoidance. We aim to find efficient ways for governments to partner with the local farmers so that modern irrigation channels can be constructed to avoid losses from drought. Using a laboratory experiment, we explore how people make decisions in this environment to collectively insure against possible common future loss and whether different types of government subsidies, as a type of price-based intervention, increase rate of successful provision under various levels of risk of drought.

Milinski et al. (2008) first model prevention of climate change as a type of collective-risk social dilemma where the group needs to reach a collective target through individual contributions; otherwise everyone suffers individually. Experimental results suggest considerable inefficiency in providing such goods: the success rate of reaching the threshold is between 20-70 percent (Milinski et al., 2008; Tavoni, Dannenberg, Kallis, & Lösschel, 2011), which is consistent with success rates typically seen in standard threshold public goods games (Croson and Marks, 2000; Alberti and Cartwright, 2015; Cartwright and Stepanova, 2015).

Theoretical and experimental research on this topic has found that people are more likely to reach the target sum under high risk of dangerous climate change than low risk (Milinski et al., 2008), that inequality in endowment reduces success and communication increases success (Tavoni et al., 2011) and that homophily (imitation of like agents) leads to cooperation collapse because poor agents may contribute less, and thus resolution of the climate change policy problem stems from the rich compensating for the smaller contribution by the poor (Vasconcelos, Santos, Pacheco, & Levin, 2014). Another reason that cooperation fails in provision of climate public goods is the uncertainty of thresholds (Barrett, 2013). The negative effect of threshold uncertainty is particularly severe when it takes the form of ambiguity, i.e. when players are not only unaware of the value of the threshold, but also of its probability distribution (Dannenberg et al., 2015).

Researchers have explored different institutions to improve efficiency in standard threshold public goods games. Examples include providing a refund when the threshold is not met (Cadsby and Maynes, 1999; Cartwright and Stepanova, 2015), adopting a sequential contribution mechanism (Coats, Gronberg and Grosskopf, 2009), requiring a full agreement (Alberti and Cartwright, 2016), employing a punishment mechanism to eliminate all but one of the provision-

point equilibria (Andreoni and Gee, 2015) and allowing pre-play communication (Feltovich and Grossman, 2015; Palfrey, Rosenthal and Roy, 2017).

The institution we focus on here is a price-based intervention: government subsidies. Ostrom and Gardner (1993) note that historically, people believe that an external, central government is necessary to supply and organize forms of collective actions like providing irrigation works because common-pool resources will be underprovided and overused without effective institutions. In many parts of the developing world, national governments were perceived as the “owner” of all natural resources (Sawyer, 1992) and could provide considerable technical expertise, so they are the only agency that should or could invest in constructing and managing irrigation systems. As a result, large-scale governmental bureaus were established to build irrigation systems during the colonial period in many parts of Asia and Africa. From the 1950s through the 1970s, to reduce governments’ expenditures on irrigation, improve productivity and stabilize deteriorating irrigation systems, efforts to transfer irrigation management from the government to farmer groups or private organizations occurred in the USA, France and Colombia, which later also became a national strategy in most developing countries in Asia, Africa and Latin America during the 1980s or 1990s (Vermillion, 1997).¹ We thus view using government subsidies as a way to reconcile historical beliefs and recent practice in establishing public-private partnerships. In fact, government subsidies often continue in both developed and less developed countries often due to the political clout of farmers (Merrey, 1996; Vermillion, 1997).

Specifically, the local government will subsidize contributions by individuals under a certain budget, which essentially decreases the effective threshold relative to the original one. Croson and Marks (2000) show that a higher Step Return, defined as the ratio of the private value of the public good to the threshold, leads to more contributions. We thus expect providing subsidies would improve efficiency. Note that the government subsidy here is not paid for by lump sum taxes on contributors, and thus is not subject to the crowding-out effect typically documented in the public finance literature that givers, who are also taxpayers, will use their tax-financed donations as a substitute for their voluntary donations (Warr, 1982; Bernheim, 1986; Andreoni and Bergstrom, 1996; Payne, 2009). These subsidies are instead similar to leadership gifts in charitable fundraising that come from large donors (e.g. loan from development banks or tax revenue from the central government) other than the smaller donors the campaigns mainly target (in this case local farmers). While leadership gifts partially crowd out actual donations, the total amount including the gifts raised still increases (Huck and Rasul, 2011; Gong and Grundy, 2014).

¹ Chile, Peru, Mexico, Brazil, the Dominican Republic, Colombia, Haiti, Senegal, Mauritania, Niger, Zimbabwe, Tanzania, Sudan, Somalia, Madagascar, Turkey, Pakistan, India, Sri Lanka, Bangladesh, Lao PDR, Vietnam, China, Indonesia, and the Philippines are among the developing countries implementing national transfer programs (Vermillion, 1997).

We consider two types of subsidies: a one-to-one matching and a lump-sum grant under a given budget. We use a 1:1 match ratio for simplicity.² Research on these two schemes in charitable giving show mixed results. For example, Andreoni (1998) concludes that given a total budget the government can devote to the charity, it is best to spend it all as a direct lump-sum grant, while only when the government's budget is large should it consider adding (matching) subsidies. Huck and Rasul (2011) also find that charities will maximize the donations they receive by treating leadership gifts as seed money as compared with using any linear matching schemes. Gond and Grundy (2014), on the other hand, find that appropriately designed matching schemes where the match ratio is chosen to reflect the characteristics of the small donor base so as to exhaust the large donor's willingness to give always raise more money than seed money schemes. Although charitable fundraising is a type of private funding for public goods, to our knowledge there is no direct test on these two subsidy schemes in threshold public goods games.

Milinski et al. (2008) and Cardenas et al. (2017) are the two papers most closely related to ours. Our design builds on the collective-risk social dilemma framework proposed by Milinski et al. (2008) where a group of players simultaneously decide how much out of their endowments to contribute to a group account, which prevents potential personal income loss if the group contribution reaches a certain threshold. Unlike a general framing of prevention of climate change in Milinski et al. (2008), we explicitly frame the threshold public goods game as funding for an irrigation system. In addition, Milinski et al. (2008) restrict the strategy space to three choices including "free rider", "fair sharer" and "altruist", while we allow continuous contributions. Cardenas et al. (2017) frame their public goods game as irrigation problems and collect data from smallholder farmers in rice-producing communities in four developing countries. Their irrigation experiment, however, is a standard linear public goods game and they aim to understand how private and collective risks affect farmers' contributions.

In our experiment, participants are told to imagine themselves as a group of farmers in a village, and the irrigation channels which protect their crops from income have decayed over time and can hardly be used anymore. In each round of the game, each player has an endowment (all or part of) which they can either invest to an irrigation renovation fund (IRF) for the group or keep as personal income from crops. The irrigation system requires a certain amount to be renovated. If the group investment in the IRF reaches the minimum required, the renovation project is undertaken and any extra amount invested will not be returned. If the minimum amount is not met, the channels will not be renovated and the farmers who invested will receive a full refund. After that, a drought occurs with a certain probability (either high or low depending on the treatment). When the renovated irrigation system is in place, crops are protected and players receive their full income after investment no matter whether a drought occurs. However, when the system has not been renovated, players lose all income and receive 0 if a drought occurs, or receive an income equal to the endowment if a drought does not occur.

² Karlan and List (2007) run a large-scale natural field charitable giving experiment and find that the match offer increases both the revenue per solicitation and the response rate, but the specific match ratio has little impact.

We run six treatments under a 2-by-3 within subject design. One dimension of the experiment is the risk of drought, which can be either high (75%) or low (25%). The other dimension describes subsidy schemes, including no subsidy, a one-to-one matching subsidy and a lump-sum subsidy. After the public goods game, we also elicit participants' risk preferences using an Eckel-Grossman (2002) ordered lottery selection and collect survey responses.

Results show that with no subsidy, provision rate is below social optimum under high risk; provision rate under low risk is very low, which can be socially efficient. Government subsidies substantially increase the likelihood the irrigation project is undertaken, while groups are still under-insured relative to social optimum. A one-to-one matching subsidy appears to be at least as effective as lump-sum grants, though the difference is not significant.

Our paper contributes to the literature in the following ways. First, we model the irrigation system provision problem as a threshold public goods game of loss avoidance as in Milinski et al. (2008) and provide a formal theoretical framework along with its predictions. Second, we explore different government subsidy schemes on contributions under different risks of drought using an experiment framed as funding for an irrigation system. Our study thus yields important policy implications for public private partnerships (PPPs) in aiding development and creating sustainable environmental policies.

2 Theoretical framework

Milinski et al. (2008) frame prevention of climate change as a collective-risk social dilemma, i.e. a threshold public goods game of loss avoidance, where the group needs to reach a collective target through individual contributions; otherwise everyone suffers individually. In this section, we formally model this game in an irrigation system provision setting and solve for its equilibria under parameters that have different social optimum implications.

2.1 The environment

A group consists of N individuals. Each individual starts with an endowment of E and decides simultaneously and privately how much to contribute to the group account for the irrigation project and keep the rest as personal income. Continuous contributions to the group account are denoted as c_i for individual i , where $0 \leq c_i \leq E$, $i = 1, 2, \dots, N$. The threshold public good, the irrigation project, requires a cost of T , where $E < T < NE$ so that sole contribution from one individual is not adequate, but the threshold is certainly achievable given the group endowment. If the total group contribution is at least T , the irrigation system is built and the contributions that exceed T are not returned (no rebate). If the total contribution is less than T , the irrigation system is not built and contributions are returned to their contributors and turn into personal incomes (full return). After that, with probability $p \in [0, 1]$ a drought occurs, in which case individuals do not lose their personal incomes only if an irrigation system is in place. With probability $1 - p$ no drought occurs and no one suffers from any loss.

Suppose each individual i has a selfish and risk neutral utility function U_i , $i = 1, 2, \dots, N$. We further assume that individuals do not receive direct utility or disutility from making a contribution, possessing an irrigation system or suffering from a drought, but rather only care about their final personal incomes. More specifically, utility takes the following form:

$$U_i = E - c_i \quad \text{if } \sum_{i=1}^N c_i \geq T \quad (1)$$

$$U_i = \begin{cases} 0, & \text{with prob. } p \\ E, & \text{with prob. } 1 - p \end{cases} \quad \text{if } \sum_{i=1}^N c_i < T \quad (2)$$

Note that it is not always socially optimal to provide the irrigation system (right at its cost) if the probability of drought is relatively low or the cost of the system is relatively high.³ In fact, providing the public good (right at its cost) is the social optimum if and only if expected social loss when the system is not built is at least as large as the cost of the system, i.e. $pNE \geq T$. Otherwise, it is never optimal to provide the system.

2.2 Equilibria when providing the public good is the social optimum

When expected social loss without the irrigation system is at least as large as the cost of building the system, i.e. $pNE \geq T$, reaching the threshold and providing the public good is socially optimal. There exist both efficient and inefficient Nash Equilibria.⁴

Under the efficient Nash Equilibria, the group contributes exactly enough to meet the threshold and provide the public good (efficiency). It is efficient because it attains the social optimal surplus $NE - T$ in a sense that any extra contribution above the threshold is not returned and essentially wasted, and any contribution below the threshold leads to non-provision and a smaller total surplus $(1 - p)NE$. Individual contributions differ among this set of Nash Equilibria. In addition, no individual contributes more toward the public good than their expected loss when the system is not built (individual rationality). Specially, the set of efficient Nash Equilibria consists of all contribution vectors $\{c_i\}$ that satisfy the following:

$$\text{(Efficiency)} \quad \sum_{i=1}^N c_i = T \quad (3)$$

$$\text{(Individual rationality)} \quad 0 \leq c_i \leq pE, \forall i \quad (4)$$

To see (3) and (4) characterize a set of Nash Equilibria, note that no individual has the incentive to unilaterally increase her contribution because any extra contribution above the threshold is a pure waste or decrease her contribution because it reduces her utility from $E - c_i$ to $(1 - p)E$.

Under the inefficient Nash Equilibria, group contribution falls below the threshold and thus the public good is not provided (inefficiency). Recall that providing the public good here is the social optimum and non-provision is thus inefficient. At the same time, for any individual i , either she is not able or she is not willing to increase her contribution and provide the public

³ Social optimality occurs when the maximum feasible group joint surplus is attained.

⁴ We adopt the constraint names to describe the efficient and inefficient Nash Equilibria in section 3.2 from Croson and Marks (2000).

good (no deviation). The set of inefficient Nash Equilibria consists of all contribution vectors $\{c_i\}$ that satisfy the constraints below:

$$\text{(Inefficiency)} \quad \sum_{i=1}^N c_i < T \quad (5)$$

$$\text{(No deviation)} \quad T - \sum_{i=1}^N c_i \geq \min(E - c_i, pE - c_i) = pE - c_i, \forall i \quad (6)$$

No individual has a (strict) incentive to contribute less because when group contribution is below the threshold, contributions are returned anyways. From constraint (6), we know that no one can both feasibly and rationally increase contribution unilaterally to reach the threshold. It follows that (5) and (6) describe a set of Nash Equilibria.

Any contribution vectors $\{c_i\}$ that involve a group contribution above the threshold, i.e. $\sum_{i=1}^N c_i > T$, can never be Nash Equilibria because some individual can unilaterally decrease her contribution and gain more utility without changing group provision of the public good.

2.3 Equilibria when not providing the public good is the social optimum

When expected social loss without the irrigation system is less than the cost of building the system, i.e. $pNE < T$, it is not worthwhile to provide the public good and not reaching the threshold is socially optimal. Only efficient Nash Equilibria exist in this case. Under these Equilibria, total group contribution is less than the threshold so the public good is not provided (efficiency) while no one can both feasibly and rationally increase contribution unilaterally to reach the threshold (no deviation). Contribution vectors $\{c_i\}$ satisfying the two constrains below characterize these efficient Nash Equilibria:

$$\text{(Efficiency)} \quad \sum_{i=1}^N c_i < T \quad (7)$$

$$\text{(No deviation)} \quad T - \sum_{i=1}^N c_i \geq \min(E - c_i, pE - c_i) = pE - c_i, \forall i \quad (8)$$

(7) and (8) constitute a set a Nash Equilibria in the same sense as (5) and (6). The only difference is that these Equilibria are efficient here because they attain the social optimal surplus of $(1 - p)NE$, compared with a social surplus of $NE - T$ (or less) if the group makes more contribution to achieve (or exceed) the threshold.

No Nash Equilibria exist for $\sum_{i=1}^N c_i \geq T$ because any individual i rationally contributes to achieve the threshold up to the expected loss under non-provision, i.e. $c_i \leq pE$, which makes a total group contribution of $\sum_{i=1}^N c_i < pNE$. It follows from $pNE < T$ that $\sum_{i=1}^N c_i < T$, which means $\sum_{i=1}^N c_i \geq T$ can never happen under rationality.

3 Experimental design and hypotheses

3.1 Design

Each session consists of two games and a survey. To make it easier for future adoption in the field, we design the two games under paper and pencil method.

Game 1 is the threshold public goods game. We frame the game as a group of farmers in a village funding for an irrigation renovation project that protects them from possible income loss caused by drought. Each group consists of $N = 6$ players and each player begins with an endowment of $E = 20$ tokens. The irrigation project requires a minimum funding of $T = 60$ tokens.

We use a 2-by-3 within subject design, with two levels of risk of drought and three types of price-based interventions which construct a total of six scenarios (or treatments, which we explain in the next section). Each group plays all six scenarios and three consecutive rounds for each scenario. The groups stay the same throughout the session so interaction only occurs within each group. Participants are paid for six randomly chosen rounds, one from each scenario, with a conversion rate of 1 token = \$0.20. They are aware of the above rules for payment at the beginning but do not see which rounds are chosen for payment until the end of the experiment.

At the beginning of each round, players receive a new decision sheet and start with an endowment of 20 tokens. They are told or reminded of the current scenario and then decide to invest how much of their endowment to their group irrigation renovation fund simultaneously and privately.⁵ After all players submit their decision sheets, an experimenter draws one ball in front of all participants from a bingo cage, a randomization device, to determine whether drought occurs or not. The composition of the balls depends on the level of risk and is observable from outside. Experimenters then calculate each player's earnings according to her investment, whether her group investment reaches the threshold and whether drought occurs. Specifically, if the group contribution reaches or exceeds the threshold, meaning the group successfully renovates the irrigation system, each player in the group earns the full amount after their investment, i.e. 20-investment, regardless of whether drought occurs. If the group investment falls below the threshold, the irrigation system is not renovated and players in the group either earn 0 tokens if drought occurs, or 20 tokens if drought does not occur. Players see total investment of their group, whether irrigation channels in their village are renovated, whether drought occurs and their earnings for the round on the updated decision sheet. After that, a new round begins and each player receives a new decision sheet. We emphasize in the instructions that tokens cannot be carried over across rounds and they are free to change their decisions from last round.

Game 2 is an Eckel-Grossman (2002) ordered lottery selection risk preferences elicitation. We choose this risk task because it requires a relatively low cognitive load. Participants need to choose one from seven 50-50 lotteries that they would like to play. In each lottery, there is a 50% chance of receiving a low payoff and a 50% chance of receiving a high payoff. Following Cardenas and Carpenter (2013), we arrange lotteries in a circle to avoid any obvious ranking (Fig. 1). Table 1 presents the seven lotteries and their corresponding expected return, standard deviation and range of CRRA coefficient. Note that as one moves clockwise from the top right

⁵ To eliminate potential warm glow effect (warm feelings from being charitable as in Andreoni, 1990), we use the word "invest" rather than "contribute" in the experiment.

corner (choice #1: lottery 33|33, or safe choice) to the bottom left corner (choice #5: lottery 9|73), the lotteries increase in both expected return and risk, measured in terms of standard deviation. Risk averse participants choose among these five with the most risk averse ones selecting #1, and the least risk averse or risk neutral ones selecting #5 for the higher expected return. Choice #6 (lottery 6|76) has the same expected return as choice #5, but a higher risk. Choice #7 (lottery 2|78) is riskier than #6, but with a smaller expected return.⁶ Risk seeking participants choose between #6 and #7 with the more risk seeking ones willing to sacrifice some expected return for even higher risk and thus choosing #7.

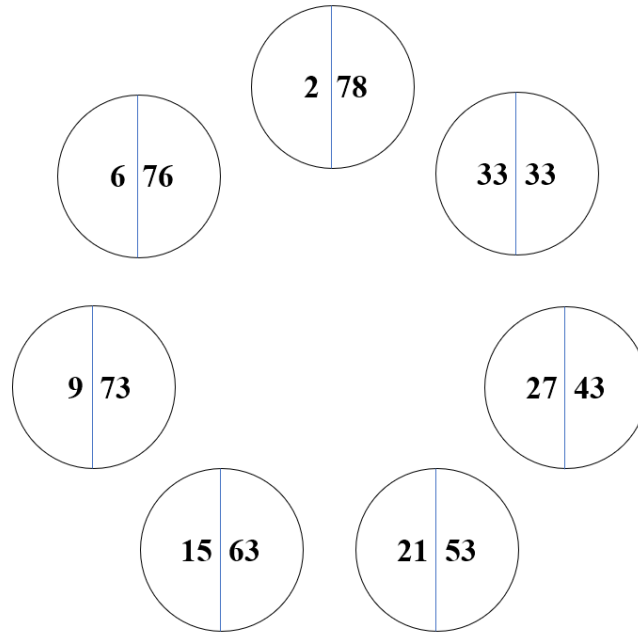


Fig.1 Lotteries presented to participants in Game 2 (in points)

Table 1 Risk elicitation in Game 2

Choice (50/50 Lottery)	Low payoff	High payoff	Expected return	Standard deviation	Implied CRRA range	Risk attitude
#1	33	33	33	0	$r > 2.20$	Risk averse
#2	27	43	35	8	$0.74 < r < 2.20$	
#3	21	53	37	16	$0.43 < r < 0.74$	
#4	15	63	39	24	$0.29 < r < 0.43$	
#5	9	73	41	32	$0 < r < 0.29$	Risk neutral
#6	6	76	41	35	$-0.23 < r < 0$	Risk loving
#7	2	78	40	38	$r < -0.23$	

⁶ While the original Eckel-Grossman (2002) design cannot differentiate between different degrees of risk-seeking behavior, we add choice #7 so that more risk seeking participants can be distinguished from those who are slightly risk seeking.

An experimenter plays in the participant’s presence her chosen lottery at the time of payment. Players receive \$0.40 for each point they earn in Game 2. Again, they know the rule of payment before they make their choice but do not know their lottery outcome until the end of the experiment.

3.2 Treatments

We run six scenarios or treatments in total, which differ in terms of the level of risk and types of price-based intervention (Table 2).

Table 2 Scenarios and parameters

Scenarios / Treatments		Subsidy scheme		
		No Subsidy ($ET = 60$)	One-to-one Matching ($ET = 30$)	Lump-sum ($ET = 30$)
Risk of drought (loss)	High ($p = 0.75$)	HNS	H121	HLS
	Low ($p = 0.25$)	LNS	L121	LLS

Notes: ET stands for effective threshold, defined as the effective amount required as contribution from individuals in the group to renovate the irrigation system.

The risk of loss can be either high (H) or low (L), where drought occurs with probability $p = 0.75$ or $p = 0.25$ respectively. Recall that an experimenter draws one ball from the bingo cage in participants’ presence in each round to determine whether drought occurs. There are eight balls in the cage, either six red and two white (high risk) or six white and two red (low risk). If the experimenter draws a red ball, drought occurs. If she draws a white ball, drought does not occur. Before each draw, the experimenter makes sure that there are eight balls in the cage and that the composition is right corresponding to the probability of drought. Each draw applies to all groups in the session.

We explore one particular type of price-based intervention: government subsidy. The three possible subsidy schemes are no subsidy (NS), one-to-one matching (121) and lump-sum (LS). Participants are told earlier in the instructions that the village government does not have sufficient funding for the renovation of irrigation channels, but it has established an irrigation renovation fund (IRF), to which farmers can voluntarily invest money. The no subsidy scheme follows the protocol described above, so the group contribution needs to reach the threshold of $T = 60$ tokens to renovate the system. Under both one-to-one matching and lump-sum scheme, the village government has funding for half of the cost needed, i.e. $0.5T = 30$ tokens, and subsidize other’s investments. The difference is that under one-to-one matching scheme, every token a player invests in the IRF will be matched with one token from the government, up to the government’s budget of 30 tokens, while under lump-sum scheme, the government provides half of the total funding required (30 tokens) to the irrigation renovation fund (IRF) upfront. Note that both one-to-one matching and lump-sum scheme essentially reduce the threshold by half to $0.5T$, which we denote as effective threshold (ET), and the two only differs in the way it is achieved. All else are the same as before.

3.3 Procedure and participants

Each session proceeds as follows. Upon arrival, all participants are randomly seated to the computer terminals. An experimenter announces there will be two games and a survey and then distributes instructions for Game 1. Instructions for Game 2 are not distributed until participants finish Game 1. Recall that in Game 1, every group plays all six scenarios, three of which have a high risk of loss and another three have a low risk of loss. We divide the six scenarios into two blocks (High risk block and Low risk block) according to its level of risk. We randomize the order of blocks across sessions, and within each block, we randomize the order of the three scenarios except that the first scenario in the first block is always the one with no subsidy. We do this to minimize the order effect, while at the same time switch from one level of risk to another only once to avoid confusion, and make sure that participants start from an easier scenario. The Game 1 instructions distributed at the beginning thus only contain information under no subsidy, and participants receive two additional instructions about one-on-one matching and lump-sum subsidy schemes before they enter the corresponding scenario for the first time in a session. We print decision sheets of different scenarios on different colored papers as well as reemphasize the scenario parameters before each new round to eliminate confusion.

We read aloud all instructions for each game. We also show the participants several figures of irrigation channels in a village to give them a concrete idea about the system and walk them through a practice round before they start the paid part of Game 1. After they finish Game 2, we direct them to a survey on the computer screen including demographic questions and thoughts regarding the experiment. Once they finish the survey, we pay them privately in cash. Their payment is the sum of earnings from Game 1 and Game 2 (converted to US\$), show-up fee and an additional amount for the survey.

We conducted 9 sessions with 12 participants (i.e. two independent groups) per session at the ICES lab at George Mason University. All participants are Mason students and no one participated in more than one session. Including a \$5 show-up fee and a \$2 for finishing the survey, participants earned an average of \$35.6 for a 2.5-hour session. We ran Game 1 and Game 2 using paper and pencil method and collected survey responses in Qualtrics. Table 3 displays summary statistics. Instructions, decision sheets and survey questions are available in the Online Appendices.

Table 3 Summary statistics

	Number of obs.	Mean	S.D.	Min	Max
Participants	108				
Male	58 (53.70%)				
Female	50 (46.30%)				
Age	108	21.44	3.18	18	35
Year of college	108				
Undergraduate	81 (75%)				
Graduate	24 (22.22%)				
Other	3 (2.78%)				
Willingness to take risks	108	2.19	0.90	1	5
Trust in others	108	3.19	1.16	1	5
Risk attitude in Game 2	108	3.14	2.06	1	7
Lottery #1	27 (25.00%)				
Lottery #2	29 (26.85%)				
Lottery #3	14 (12.96%)				
Lottery #4	13 (12.04%)				
Lottery #5	5 (4.63%)				
Lottery #6	5 (4.63%)				
Lottery #7	15 (13.89%)				
Game 1 round payoff (tokens)	1,944	12.50	7.71	0	20
Game 2 payoff (\$)	108	13.97	8.28	0.8	31.2
Total payment (\$)	108	35.58	8.77	17	56

Notes: *Willingness to take risks* is a 1-5 integer with bigger number meaning less willing to take risks; *Trust in others* is a 1-5 integer with bigger number meaning trusting less in others; *Risk attitude in Game 2* is the lottery choice the individual makes in Game 2 and is a 1-7 integer with bigger number meaning more risk seeking; *Total payment* includes the \$5 show-up fee and \$2 survey bonus.

3.4 Hypotheses

We are particularly interested in exploring whether social optimum is achieved and roles of different types of subsidies.

Table 4 presents social optimal predictions of irrigation system provision under the parameters of our design. Note that under risk neutrality, providing or not providing the system yield same social surplus under L121 and LLS. Even a slight degree of risk aversion, which is usually the case, will make providing the system and earning a sure income more socially desirable compared to a risky outcome. For LNS, the cost of building an irrigation system is much higher than the social expected loss with no protection under risk neutrality. However, if people are risk averse enough that even a small risk of loss results in a drastic reduction in utility, it is still possible that providing the public good turns into social optimum. On the other hand, risk aversion does not change social optimum in scenarios with high risk because it makes not providing the public good even less attractive. We first hypothesize that social efficiency is achieved in each scenario.

Table 4 Predictions of socially optimal irrigation system provision under risk neutrality (risk aversion)

Social optimum	No subsidy (NS)	One-to-one m. (121)	Lump-sum (LS)
Risk of loss (H)	Provide (Provide)	Provide (Provide)	Provide (Provide)
Risk of loss (L)	Not provide (Provide if risk averse enough)	Indifferent (Provide)	Indifferent (Provide)

Notes: Predictions under risk aversion are in parentheses.

Hypothesis 1 (Social Efficiency): Group investment reaches threshold and public good is provided when it is socially optimal to do so.

Recall that the one-to-one matching and lump-sum scheme only differs in the way subsidy is provided, while both essentially reduce the effective threshold by half. We thus hypothesize that these two subsidy schemes are equally effective. If players do respond more to one scheme, there must be some behavioral reasons.

Hypothesis 2 (Subsidy Effectiveness): The two subsidy schemes (121 and LS) have same effect on investment and success rate.

4 Laboratory results

4.1 Aggregate outcomes

4.1.1 Group investment

Investments of each group are depicted in Fig. 2. Overall, group investment is higher under high risk of loss compared with low risk of loss. In the LNS scenario, most groups are not risk averse enough to provide the public good and group strategies are very heterogeneous. In all other scenarios, group investments cluster around the effective threshold.

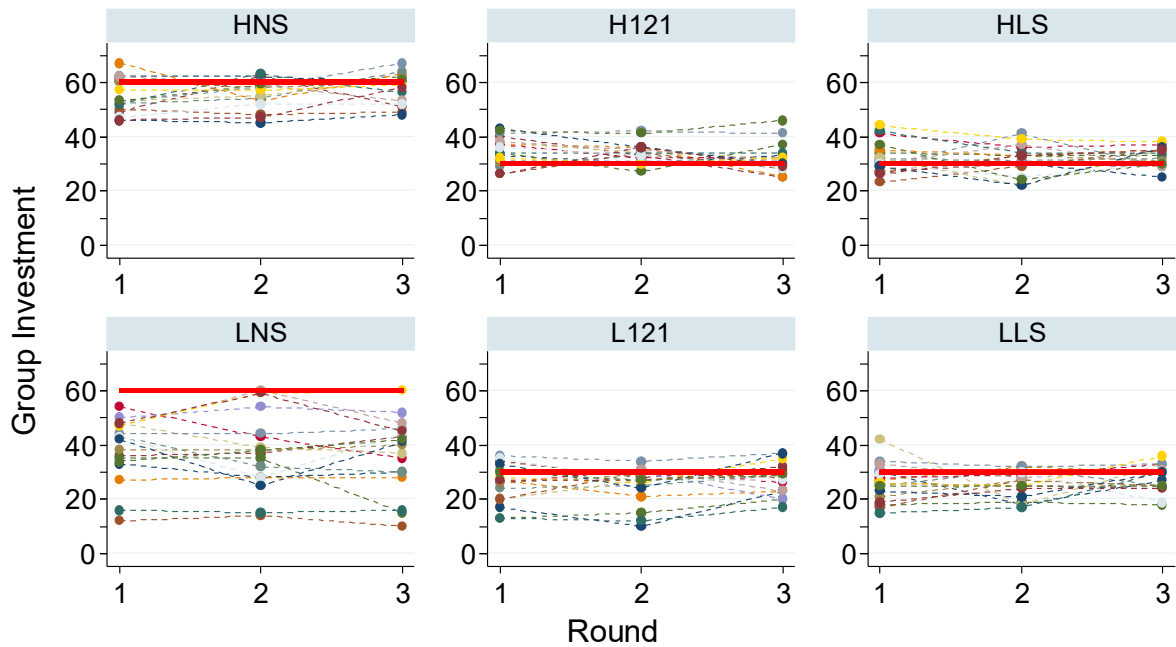


Fig. 2 Group investments by each group. Notes: Thick red lines denote the effective threshold in each scenario.

Fig.3 shows the average group investment in each round of each scenario. In terms of social efficiency, average group investment is below the effective threshold under either high or low risk when there is no subsidy. Subsidies successfully bring the average group investment above the effective threshold under high risk but fail to do so under low risk.

Hypotheses tests (t-tests, we report two-sided p-values below) comparing the observed group investments (Table 5) and the corresponding effective threshold in each scenario confirm the above trends. Under no subsidy, both group investments under high risk and low risk are significantly lower than the effective threshold (HNS: 56.39 vs. $ET = 60$, $p < 0.001$ in favor of mean < 60 ; LNS: 37.69 vs. $ET = 60$, $p < 0.001$ in favor of mean < 60). When there is subsidy under high risk, group investments reach the effective threshold under both types of subsidy (H121:33.48 vs. $ET = 30$, $p < 0.001$ in favor of mean > 30 ; HLS: 31.94 vs. $ET = 30$, $p = 0.005$ in favor of mean > 30). Under low risk, even with subsidies, group investments are still significantly below the effective threshold (L121: 26.31 vs. $ET = 30$, $p < 0.001$ in favor of mean < 30 ; LLS: 26.39 vs. $ET = 30$, $p < 0.001$ in favor of mean < 30).

Hypothesis 1 is supported only when subsidies are provided under high risk (H121 and HLS). Otherwise, group investments do not reach the effective threshold even if it is socially optimal to do so.

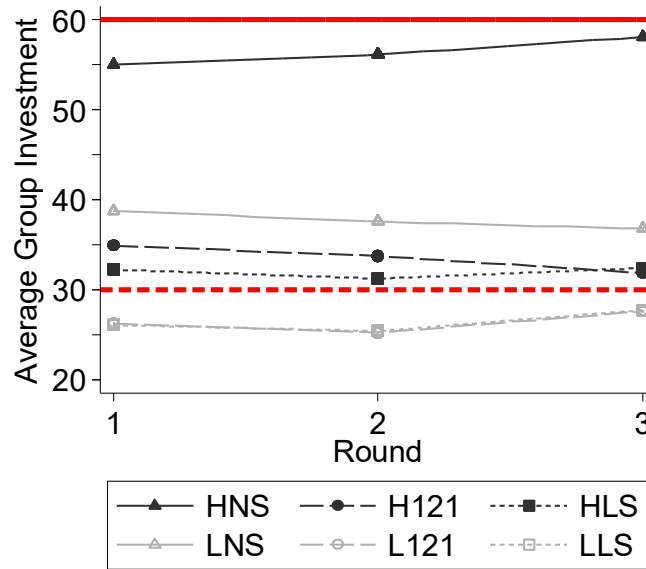


Fig. 3 Average group investment by round and scenario. Notes: Solid and dashed thick red lines denote the effective thresholds with no subsidy and with subsidy respectively.

Table 5 Average group investment by scenario

	No subsidy (NS)	One-to-one m. (121)	Lump-sum (LS)	Comparison between columns
Risk of loss (H)	56.39 (0.78)	33.48 (0.66)	31.94 (0.67)	HNS vs. H121: $p < 0.001$ HNS vs. HLS: $p < 0.001$ H121 vs. HLS: $p = 0.27$
Risk of loss (L)	37.69 (1.72)	26.31 (0.88)	26.39 (0.76)	LNS vs. L121: $p = 0.001$ LNS vs. LLS: $p = 0.001$ L121 vs. LLS: $p = 0.86$
Comparison between rows	HNS vs. LNS: $p < 0.001$	H121 vs. L121: $p < 0.001$	HLS vs. LLS: $p < 0.001$	

Notes: Group investment is the sum of investments from all players in a group. We pool groups and rounds when calculating the average group investment. Standard errors in parentheses. P-values are calculated using two-sided Wilcoxon matched-pairs signed-ranks tests.

Fig.3 also shows that average group investment is slightly higher under H121 than HLS. Participants do not respond to subsidy schemes under low risk. We compare group investments under the two types of subsidies and find no significant difference no matter whether the risk of loss is high or low (see Table 5, H121 vs. HLS: $p = 0.27$, L121 vs. LLS: $p = 0.86$, Wilcoxon signed-ranks tests). We cannot reject Hypothesis 2 that group investments are the same under one-to-one matching and lump-sum subsidy.

4.1.2 Success rates

Now we turn to what proportion of times the irrigation project is successfully undertaken. Fig. 4 shows success rates along with 95% confidence intervals in each scenario. Recall that the

theoretical prediction of social optimum is to always provide under high risk, while provision under low risk depends on risk preferences. We can see from the means and 95% CIs in Fig. 4 that success rates are significantly lower than the social optimum (100%) under high risk. Even if players are not risk averse enough to provide the public good in LNS which leads to a socially optimal provision rate of 0%, the success rates under L121 and LLS are far from the social optimum of 100% given they are on average risk averse (see the average lottery choice in Table 3).

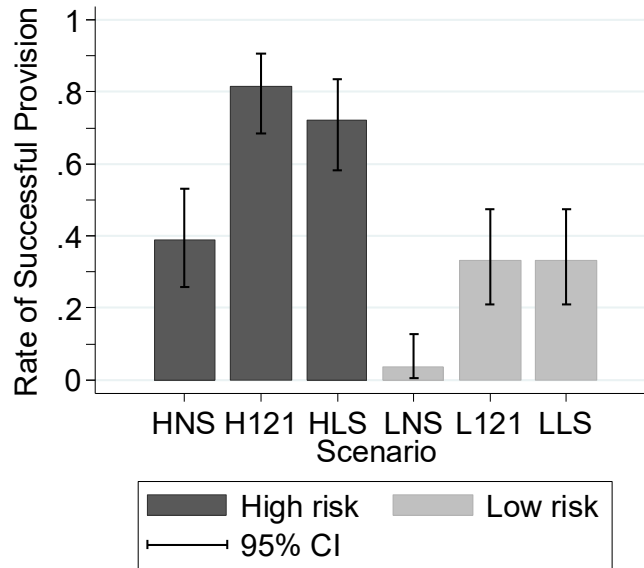


Fig. 4 Rates of successful provision in each scenario

Subsidies significantly increase success rates under either high or low risk. Table 6 reports success rates in each scenario and compares across treatments. When subsidies are present, success rates increase substantially and significantly ($p < 0.001$ for HNS vs. H121, HNS vs. HLS, LNS vs. L121, LNS vs. LLS, proportions tests), but again, the public goods are still under-provided. Results on success rates do not support Hypothesis 1 in any scenario.

Success rates under one-to-one matching are at least as high as those under lump-sum subsidy. When risk of loss is high, success rate under the former is 10 percentage points higher than under the latter, although the difference is not significant (H121 vs. HLS, $p = 0.25$, proportions test). The two types of subsidies are equally effective under low risk, which is not surprising because success rates under L121 and LLS are exactly the same in our current sample (L121 vs. LLS: $p = 1.00$). Our results on success rates support Hypothesis 2.

Table 6 Success rates in each scenario

	No subsidy (NS)	One-to-one m. (121)	Lump-sum (LS)	Comparison between columns
Risk of loss (H)	38.9% (0.07)	81.5% (0.05)	72.2% (0.06)	HNS vs. H121: $p < 0.001$ HNS vs. HLS: $p < 0.001$ H121 vs. HLS: $p = 0.25$
Risk of loss (L)	3.7% (0.03)	33.3% (0.06)	33.3% (0.06)	LNS vs. L121: $p < 0.001$ LNS vs. LLS: $p < 0.001$ L121 vs. LLS: $p = 1.00$
Comparison between rows	HNS vs. LNS: $p < 0.001$	H121 vs. L121: $p < 0.001$	HLS vs. LLS: $p < 0.001$	

Notes: Success rate is the proportion of times groups successfully provide the irrigation system in each scenario. We pool groups and rounds when calculating the success rates. Standard errors in parentheses. P-values are calculated using two-sided proportions tests.

4.2 Individual investment

The aggregate analyses above ignore any individual-specific effects. Next we explore how individuals respond to risk of loss and subsidy schemes.

Table 7 shows the OLS regression results on individual investment decisions. Model (1) shows that individual players invest about 2 tokens significantly more under high risk than low risk. When there is a subsidy, players significantly decrease their investments by about 3 tokens compared with scenarios with no subsidy. The two subsidy schemes 121 and LS are not significantly different ($F(1, 17) = 0.61$, $\text{Prob} > F = 0.45$).

Models (2) - (5) compare among the six scenarios directly under different controls. Since the coefficients of the scenario dummies do not change among the four models, we focus on model (5) with the most number of control variables. A lower risk of loss significantly decreases individual investments, especially when no subsidy is provided (a 3-token decrease from HNS to LNS). When there is subsidy, individual investment is only one token lower in low risk scenarios (H121 vs. L121, $F(1, 17) = 27.87$, $\text{Prob} > F = 0.0001$; HLS vs. LLS, $F(1, 17) = 23.62$, $\text{Prob} > F = 0.0001$). Subsidies show a crowding-out effect on individual investment. Under high risk of loss, subsidies lead to a significant 4-token decrease in individual investment and the subsidy scheme does not matter (H121 vs. HLS, $F(1, 17) = 1.67$, $\text{Prob} > F = 0.21$). Under low risk of loss, this effect is smaller (a 2-token decrease) but still significant (LNS vs. L121, $F(1, 17) = 24.85$, $\text{Prob} > F = 0.0001$; LNS vs. LLS, $F(1, 17) = 22.41$, $\text{Prob} > F = 0.0002$). Again, the two subsidy schemes show no significant difference, especially under low risk (H121 vs. HLS, $F(1, 17) = 1.67$, $\text{Prob} > F = 0.2132$; L121 vs. LLS, $F(1, 17) = 0.00$, $\text{Prob} > F = 0.9486$).

Models (3), (4) and (5) further show that although individual risk preferences, under two measurements, have a significant effect on investments that more risk averse players tend to invest more to the group account, the absolute magnitudes are small (less than 1 token). Females invest almost one token significantly more than males, while trust in others and age explains little of the investment.

Table 7 Risk of loss and subsidy schemes on individual investment

Dependent variable: Individual Investment					
	(1)	(2)	(3)	(4)	(5)
High risk of drought	1.746*** (0.247)				
One-to-one matching	-2.856*** (0.247)				
Lump-sum	-2.978*** (0.212)				
H121		-3.818*** (0.216)	-3.818*** (0.216)	-3.818*** (0.216)	-3.818*** (0.216)
HLS		-4.074*** (0.172)	-4.074*** (0.172)	-4.074*** (0.172)	-4.074*** (0.172)
LNS		-3.117*** (0.473)	-3.117*** (0.474)	-3.117*** (0.474)	-3.117*** (0.474)
L121		-5.012*** (0.329)	-5.012*** (0.329)	-5.012*** (0.329)	-5.012*** (0.329)
LLS		-5.000*** (0.197)	-5.000*** (0.197)	-5.000*** (0.197)	-5.000*** (0.197)
Risk attitude in Game 2			-0.147* (0.0752)		
Willingness to take risks				0.594*** (0.204)	0.427* (0.227)
Trust in others				-0.212 (0.176)	-0.135 (0.168)
Female					0.818** (0.310)
Age					0.0895 (0.0561)
Year of College dummies	no	no	no	no	yes
Constant	6.967*** (0.354)	9.398*** (0.178)	9.858*** (0.287)	8.777*** (0.735)	6.599*** (1.199)
No. of observations	1944	1944	1944	1944	1944
R ²	0.216	0.235	0.242	0.259	0.273

Notes: OLS regression with clustering at the group level. Standard errors in parentheses. Significant levels are indicated by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Dependent variable *Individual Investment* is the number of tokens (0-20 inclusive) invested by an individual player to the group account in each round of each scenario. Independent variables *High risk of drought* equals 1 if the scenario involves 75% probability of loss and 0 if the scenario involves 25% probability of loss; *One-to-one matching* equals 1 if a one-to-one matching subsidy is provided and 0 otherwise; *Lump-sum* equals 1 if a lump-sum subsidy is provided and 0 otherwise; *H121*, *HLS*, *LNS*, *L121* and *LLS* are dummy variables for the corresponding scenarios; *Risk attitude in Game 2* is the lottery choice the individual makes in Game 2 and is a 1-7 integer with bigger number meaning more risk seeking; *Willingness to take risks* is a 1-5 integer with bigger number meaning less willing to take risks; *Trust in others* is a 1-5 integer with bigger number meaning trusting less in others; *Female* equals 1 if the individual is a female and 0 otherwise; *Age* is the age of the individual in years; *Year of College* are dummies indicating the school year of the individual.

5 Conclusion

We design an experiment to explore how individuals contribute to a group irrigation system that prevents the whole group from possible loss caused by drought and how subsidies affect the contribution decisions. The collective-risk dilemma is framed as a threshold public goods game under either high or low risk of loss and at the same time the local government provides subsidies under either a one-to-one matching scheme or a lump-sum grant scheme in some treatments. The game has clear equilibrium and social optimum predictions, the latter of which are our focus.

We collect data in the laboratory and find that the public good is underprovided compared with the social optimum even when subsidies are present. More specifically, when the risk of loss is high which indicates the social optimum is to provide the system under risk aversion and risk neutrality, the group investments and success rates are far below the optimum when there is no subsidy; subsidies significantly increase the likelihood the irrigation project is undertaken with average group investments above the effective threshold, but the realized success rates are still significantly lower than 100%. When the risk of loss is low, slight risk aversion predicts full provision for treatments with subsidy, while the social optimum for the treatment without subsidy is towards non-provision if people are not hyper risk averse. Results show that participants are not risk averse enough to provide the public good when there is no subsidy under low risk, which can be socially efficient. Subsidies significantly increase the success rates of provision, but they perform worse under low risk than high risk because average group investments are still below the effective threshold and the realized success rates are significantly lower than those under high risk.

Individual decision data show that a lower risk of loss significantly decreases individual investments but subsidies mitigate this effect. Subsidies significantly crowd out individual investments and the crowding-out effect is greater under high risk. Nevertheless, subsidies still increase the success rates more under high risk compared with low risk.

For a same subsidy budget, the one-to-one matching scheme works at least as good as the lump-sum scheme. When the risk of loss is high, groups invest more on average and have a higher success rate under a one-to-one matching subsidy than a lump-sum subsidy, though the differences are not significant. Neither aggregate group outcomes nor individual decisions differ under the two schemes when the risk of loss is low.

The funding for an irrigation system problem in our setting, like other standard threshold public goods games, suffer from two challenges: free riding and coordination. When the social optimum is to provide the public good, individuals may want to keep their contributions at the minimum possible amount to hit the threshold. While we derive our social optimum assuming homogeneous risk preferences, individuals' actual risk attitudes differ very much from each other, which makes it even harder to coordinate. A possibility of loss amplifies the role of risk aversion and loss aversion, because some individuals may want to take advantage of large contributors who are more risk averse. Government subsidies facilitate provision by lowering the cost to provide the public good but do not address the risk-intensified coordination problem. In

this sense, a further exploration of behavioral interventions that directly speak to coordination under risk on top of government subsidies can be profitable. Finally, it is also worthwhile to do a field investigation on the irrigation provision problem with real farmers facing possible drought.

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