Fragility of the provision of local public goods to private and collective risks

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Smallholder agricultural systems, strongly dependent on water resources and investments in shared infrastructure, make a significant contribution to food security in developing countries. These communities are being increasingly integrated into the global economy and are exposed to new global climate-related risks that may affect their willingness to cooperate in community-level collective action problems. We performed field experiments on public goods with private and collective risks in 118 small-scale rice-producing communities in four countries. Our results indicate that increasing the integration of those communities with the broader economic system is associated with lower investments in public goods when facing collective risks. These findings indicate that local public good provision may be negatively affected by collective risks, especially in communities more integrated with the market economy.

framed field experiments | commons | irrigation | public goods | risk

In many developing countries around the world, food security and well-being depend on the performance of smallholder agricultural systems (1). These agricultural communities are increasingly confronted with new challenges owing to climate change and market integration (2, 3). Specifically, many communities around the world whose livelihoods depend on their local ecosystems are becoming more connected to global markets that govern prices of their inputs or outputs. This increased connectivity can affect decisions and livelihoods of smallholders in various ways, including variability in prices for purchased inputs, such as fertilizers, and for harvested products; less predictable supplies of labor because of seasonal migration to urban areas; and exposure to alternative sources of income. Meanwhile, climatic change exposes smallholders to more volatile drought and flood events and decreases predictability of the weather (3–5).

This study focused on small-scale irrigated agriculture because of its increasing importance for food production for millions of people in the developing world in the coming decades (6, 7). The productivity of irrigated agriculture depends largely on the ability of farmers to solve collective action problems related to the provision and maintenance of ecological and physical infrastructure and the distribution of water. Many small-scale irrigation systems are examples of successful self-governed shared resources (8, 9); however, most of these exemplar cases represent communities that have been relatively isolated from potential vulnerabilities associated with the outside world. Here we contribute to the understanding of the capacity of communities to govern shared resources when they are exposed to outside shocks. Specifically, we report on experiments in 118 communities across China, Colombia, Nepal, and Thailand to test how the exposure to risk in individual and group payoffs affects cooperation in a public good game.

We restricted our study to predominantly rice-producing cases, to maintain some degree of homogeneity in the biophysical context across sites and countries. In all four countries, rice production requires the creation and maintenance of public infrastructure for irrigation, an example of a classic local public good. Within this biophysical context of paddy rice production, the cases vary along a gradient from relatively isolated self-governing communities to communities increasingly integrated with different market activities and opportunities. We exploited the variation along this gradient to enhance our analysis of the fragility of cooperation in public good games facing different types of risk. The villages within and between countries may vary in various contextual factors that may influence collective action, such as property size, household size, population size of the community, trust, and education. (More details are provided in *SI Appendix, Experimental Procedures*.) We controlled for those differences in our statistical analysis. To our knowledge, no previous studies using field experiments to evaluate the impact of different types of risk on public good dilemmas have been reported to date.

Experimental Design

Our experimental design tests the roles of two specific risks faced by community members: (*i*) exposure to personal risk in earnings associated with, for example, wage labor outside the community, and (*ii*) exposure to risk in the return from shared infrastructure owing to fluctuations in revenues and costs related to volatility in prices for inputs and outputs; variations in output levels due to

Significance

Smallholder farmers make a significant contribution to food security in developing countries. Those farmer communities are experiencing new challenges owing to integration with the broader economy (increasing price volatility) and climate change (increasing frequency of extreme weather events). Our study aimed to understand how smallholder agricultural communities make collective action decisions in a public good game with different types of risks. Experiments performed in 118 small-scale rice-producing communities in China, Colombia, Nepal and Thailand show that increasing the integration of those communities with the broader economic system is associated with lower investments in public goods when facing collective risks. As such, the provision of local public goods may be negatively affected by market integration and climate change.

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floods, droughts, and pest outbreaks; or both. For example, rainfall variability impacts the whole community, and climate change may increase variability. As such, collective risk may become more important for small-scale communities in the near future. Based on our survey data, participants revealed that those risks—especially volatility of input and output prices—are perceived as threatening their communities (*SI Appendix*, Table S3).

Previous experimental work has shown that cooperation within social dilemmas can be related to risk aversion in at least two important ways. First, given the simultaneity of decisions in many social dilemmas, players are uncertain about the contribution levels of others. Thus, each player's expectations about the behavior of others is a crucial determinant of outcomes (10, 11). Second, if returns on private or public investments are uncertain (e.g., defined probabilistically), then the decision whether to forego the potential rents from free-riding becomes more complex. For these reasons, preferences regarding risk might play a significant role in social dilemma settings. Previous studies have found that the level of risk aversion in the participants has a mixed effect on the relative level of investments. Some studies found a positive effect (12), whereas others found a negative effect (13) or no effect at all (14). Studies on the effect of risk associated with the resource size in common-pool resource experiments (15) and public good experiments (16, 17) have found that risk reduces cooperation. That said, however, we are aware of no other field experimental studies that have explored the role of risk in the public vs. private returns in a public good setting along with how expectations play a critical role in shaping the decision to cooperate. Such a decision problem captures the dilemma faced by many smallholder agricultural communities. To explore this question, we visited 118 rural communities (shown as dots in Fig. 1) in different regions of Colombia, China, Nepal, and Thailand, and conducted our experiment under different conditions of risk with a total of 2,147 participants.

For each session, we recruited an average of 18.7 (median, 20) participants. The experiment was framed as an irrigation provision problem (*SI Appendix*, *Experimental Procedures*). Each player had to choose between keeping an endowment (one token) with a private return of \$8 or investing it in a group fund that provided a public good that transferred \$1 to each player for

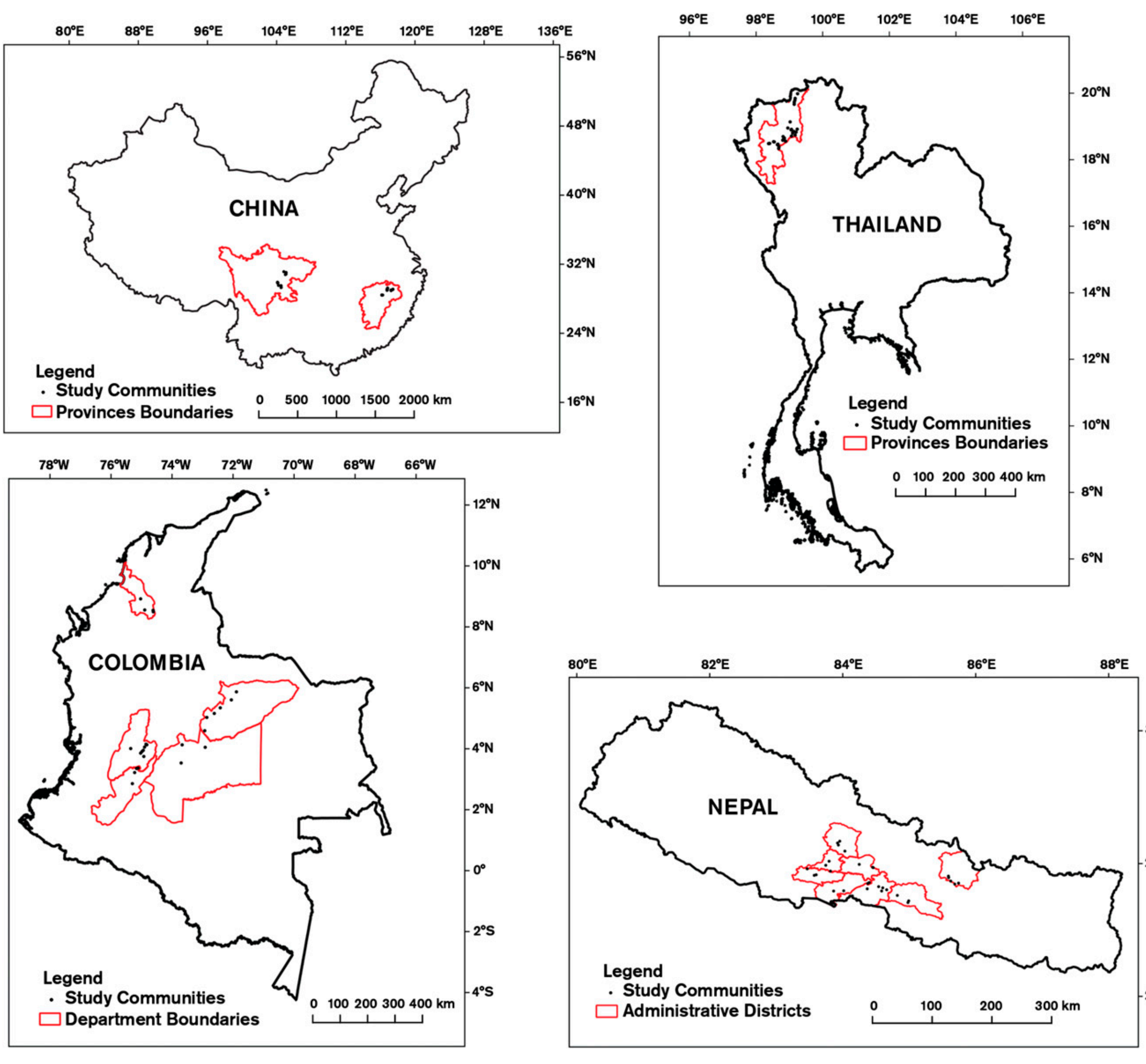

Fig. 1. Locations of the regions and communities (dots) where we conducted the field experiments and survey data collection. In clockwise order starting in the upper left corner: China, Thailand, Nepal, and Colombia.

each token invested by the group. Because the ratio of the marginal return on the public good to the return on the private option was $1/8 = 0.125$, when group size exceeded eight, the participants faced a clear social dilemma. For 20 players, full cooperation would yield \$20 for each player, whereas universal defection would leave each player with only \$8.

After a first baseline round in which players faced these incentives without any communication and with complete certainty about the returns, we then proceeded to two more rounds in which they were exposed to risks about the return on either the private or the public investment opportunities. In the Private Risk round, participants were faced with the choice of a receiving double-or-nothing return (\$16 or \$0) with a 50/50 probability if the token was kept or investing in the same public good at a sure \$1 return per token in the public account. In the Collective Risk round, participants had to decide between a sure return of \$8 if the token was kept or a double-or-nothing (\$2 or \$0) payment (50/50 probability) for each token invested in the public good by the group. In each of these three rounds, we also elicited each individual's prediction about the fraction of players that he or she expected to contribute to the group fund. At the end of these rounds, the participants were asked to make another set of incentivized decisions to elicit their preferences toward risk (18–20).

Our interest in understanding the factors that affect collective action in the context of public good provision is motivated by the challenges faced by small-scale agriculturalists. We emphasize this point because the nature of our experiments and the fact that we performed them in different countries may cause some readers to draw parallels between our work and previous various cross-cultural studies on human cooperation. For example, Henrich et al. (21) found a positive relationship between "prosociality" (e.g., altruism, fairness) and integration with the market. Our study has a very different experimental design, and the results are not comparable. The study reported by Henrich et al. (21) involves two-player and three-player experiments on altruism and fairness (dictator, ultimatum, and third-party punishment games), whereas our study involves a framed public good experiment with approximately 20 participants in the same session. In our experiment, participants knew with whom they were interacting at the moment of the experiment, in contrast to the experiments of Henrich et al., where participants did not know the identity of their counterparts. Thus, Henrich et al. tested fairness with unknown others in an abstract task, whereas we focused on public good provision in a group of community members related to familiar tasks in the context of their community activities.

Public good experiments have been performed in cross-cultural studies, such as that of Hermann et al. (22), who performed 20-round public good experiments (with and without costly sanctioning) using college-level student participants in 16 urban centers around the world. They found a huge variation, and showed that antisocial punishment is related to the strength of the rule of law in specific countries. Our study is quite different because we used one-shot public good experiments, did not include costly punishment, and focused on the effect of uncertainty. Furthermore, our experiments are framed as irrigation problems instead of an abstract public good game.

Results

Our results support the conjecture that Collective Risk leads to lower levels of cooperation compared with Private Risk across all four countries (Fig. 2). When exposed to risk in the returns on the private asset, the results were no different from those in the baseline round; however, when the public good returns were risky, a significant fraction of participants switched away from cooperation, keeping their tokens privately and thus reducing the gains from cooperation.

To avoid learning effects, no feedback was provided to participants regarding the outcomes of their decisions until after all of the experiments were performed. To control for order effects, we randomized the sessions for rounds 2 and 3; that is, in round 2, one-half of our participants faced the Private Risk treatment and the other half faced the Collective Risk treatment. A two-sample Wilcoxon rank-sum (Mann–Whitney) test of Private Risk vs. Collective Risk for the second round yielded a P value of 0.0000, with the collective risk showing a 12% lower rate of cooperation compared with that under private risk. Comparing the Private Risk and Collective Risk treatments in round 3 also yielded the same direction and statistically significant difference, with a 5% lower rate of cooperation for the Collective Risk treatment ($P = 0.0176$).

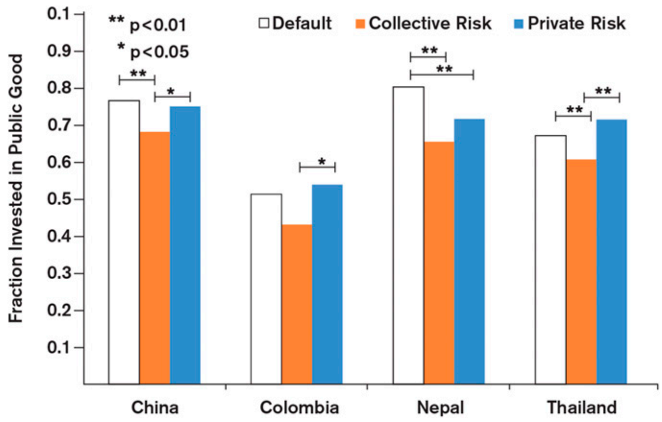

Fig. 2. Average investment levels for the three treatments for each country. * and ** represent levels of significance when we used the Wilcoxon signed-rank test (see also *SI Appendix*, Table S4).

The two unknowns—what decisions others will make and what returns the private and public assets will yield—are the reasons why cooperation is so fragile in a world in which farmers face greater risks because of exposure to global variabilities, such as market and climate forces. Experimental evidence shows that payoff stochasticity in these dilemmas can erode cooperation (23). Selfish rational individuals who are risk-neutral will not invest in the public good in any of the treatments, whereas participants who are risk-averse and rational will reduce their investment in assets with risk. We would expect the Collective Risk treatment to lead to lower levels of cooperation compared with the Private Risk treatment, owing to the difference in risk experienced for the two choices in the Private Risk and Collective Risk treatments. In the Private Risk treatment, there is risk with the return for not investing in the public good (50% probability of two different levels) and a risk when the participant invests in the public good (uncertain level of investments by others). In the Collective Risk treatment, however, there is a no risk option in which the participant does not invest in the public good, but two combined risks to determine the level of returns for the option to invest in the public good (50% probability of two levels of return from public good and uncertainty of investments by others) (*SI Appendix, Experimental Procedures*). As such, there is more risk surrounding the returns from the public good in the Collective Risk treatment.

Although we controlled for several contextual factors in deriving the general results summarized in Fig. 2 (*SI Appendix, Experimental Procedures*), we can gain a more nuanced understanding of observed variation using survey data. For example, the fraction of participants investing in the public good varied considerably across communities, ranging from 9% to 100%. The data on contextual factors gathered via our survey instrument helps clarify potential sources of this variation, as summarized in Figs. 3 and 4. This fraction is highly correlated with the participant's predictions regarding the investments of other participants, indicating that he or she is behaving as a conditional cooperator (Fig. 3*D*) [$R^2 = 0.297$; $P < 0.01$, ordinary least squares (OLS)].

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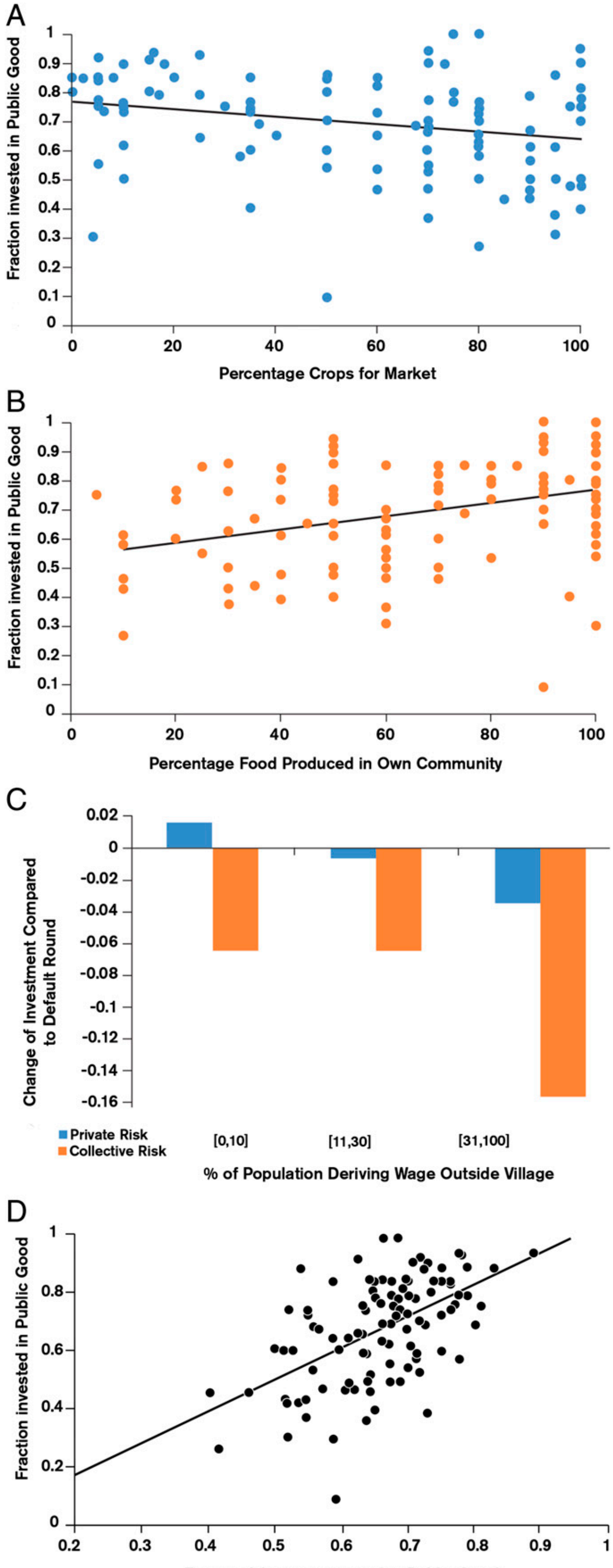

Fig. 3. Relationships using group-level data. (*A*) Relationship between investment in the public good, round 1 of the experiment, and the percentage of crops produced for the market. (*B*) Relationship between investment in the public good, round 1, and the percentage of food consumed produced in their own community. (*C*) Change in investments owing to risks for different percentages of members earning wages outside the community. (*D*) Average fraction of investment in each of the 118 communities as a function of the expressed level of expected contributions by others in the baseline round.

Regarding risk preferences, when using the aforementioned measure of risk preferences, 84.2% of our 2,147 participants showed a level of moderate to high risk aversion, and only 15.8% could be considered risk-loving. We also found that our risk-averse participants were more likely than our risk-loving players to contribute in the first baseline round ($P = 0.0479$, Wilcoxon Mann–Whitney test), in line with some previous studies (12); however, this effect did not remain significant in the subsequent rounds when we introduced variations in the uncertainty involved in the investment decisions.

We next explored how variation in economic contexts may explain differences in decisions in rounds with and without risks. Communities with a higher percentage of members who work outside the community reduced their investments in the public good more frequently in response to risk in returns from the public good (Fig. 3*C*). The finding that communities with more members involved with the outside economy opted out from investing in the public good with risk is most likely related to a lower commitment to the collective in those communities, which rely more on private income sources from outside the community. In a similar vein, the more the agricultural practices of the community were integrated with the broader economy, the lower the level of investment in the public good. As shown in Fig. 3*A*, a higher percentage of crops grown for the external market was correlated with lower investment rates in round 1 ($R^2 = 0.088$; $P < 0.01$, OLS). Moreover, Fig. 3*B* shows that consuming a higher percentage of food produced in the community was positively correlated with investment levels in the public good in round 1 ($R^2 = 0.127$; $P < 0.01$, OLS). This effect held in rounds 2 and 3 (*SI Appendix*, Table S7).

Fig. 4 shows that communities' interactions with the broader economy had significant effects on the level of cooperation after controlling for various socioeconomic factors, including education, sex, age, income, trust in other community members, size of the agricultural property, community size, household size, and risk aversion. We used multilevel regression analysis to capture the village- and country-specific effects (*SI Appendix*, Table S7). A higher percentage of food produced for consumption by the community and a lower amount of crops produced for the external market were significantly correlated with more cooperation independent of the treatment; however, reduced cooperation in the Collective Risk treatment was correlated with the percentage of community members having income outside the community.

Overall, our findings suggest that (*i*) a greater integration of small-scale agricultural communities with the global economy leads to a lower level of cooperation with community members, and (*ii*) increasing variability or uncertainty will lead to a reduction in cooperation with community members. A possible explanation for the relationship between community food self-sufficiency and cooperation might be related to social proximity among participants (24). We cannot exclude this explanation, but we did control for the size of the community (varying from 50 to more than 100,000 households; median, 426 households), and did not find that community size (a rough measure of social proximity) affected our results.

Note that less investment in the public good owing to more involvement in the broader economy does not necessarily mean that communities are less resilient to external shocks. The community members may have broader social networks that enable them to mobilize support in times of need (25, 26). In fact, market integration may increase bridging social capital at the cost of bonding social capital (27). More market integration also may provide exposure to new technologies that could lead to efficiency

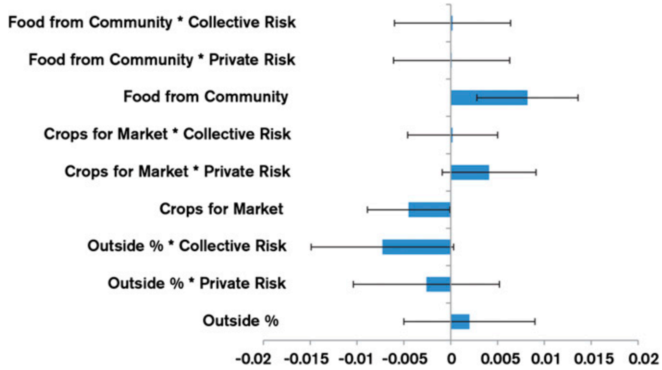

Fig. 4. Average marginal effects of key variables on the probability of investing in the public good with 95% confidence interval plots. Model includes other controls (n = 4827) (see also *SI Appendix*, Table S7).

gains. Thus, a low level of cooperation does not automatically mean a lower level of productivity or resilience. In fact, exactly how the level of cooperation affects the resilience of the system is a matter of scale. Specifically, the lower investment levels in the experiments may indicate a lower level of investment in regular agricultural production systems, which in turn may affect the agricultural productivity of the community in the long term. This is a case of robustness-vulnerability trade-offs across scales; the market may provide opportunities for the reduction of risk at the individual scale, but may increase the risk at group the level of collapsing infrastructure and with it, food production.

Conclusion

Our experiments in 118 small-scale rice-producing communities reveal differences across communities that correlate with their level of involvement with the broader economy. The more the agricultural production system is integrated with the global food chain, the less participants invest in the public good. The more people from the community have sources of income from outside the community, the less they invest in the public good when returns of the public good are risky. This effect is not seen when the return from the public good is fixed per person invested in the public good. Greater market integration may reduce investment in their own communities and as such, may reduce the productivity of their group assets for agricultural production, critical to supply-side aspects of food security. This negative effect on cooperation is clearly present when the groups face risk in the shared resource (Collective Risk), but is not found when the risk is associated with the private asset.

Small-scale agricultural systems are the last safety net for many rural people in a world that is in the midst of an intense period of market integration and may experience local impacts from climate change. Such climate change impacts may increase the collective level risk communities are facing. Our results suggest that the vulnerability of food production of those small-scale agricultural systems will increase as a result of the changes in how collective action problems are perceived and addressed. We have focused here on shared resources associated with irrigation infrastructure through the framing of the game, but other shared resources might be as critical for agricultural systems and food security. Coastal artisanal fisheries, communal water or grain storage, and shared forests for firewood are other examples in which greater uncertainties can play a role in how communities make decisions to contribute to their conservation. An extension of our research could be to replicate these experiments in these other domains and explore the replicability across contexts.

Materials and Methods

This research was approved by Arizona State University's Institutional Review Board (1210008468). Protocols are described in detail in *SI Appendix*, *Experimental Procedures*. Our experiment was conducted in 118 different rice-producing communities, including 30 communities each in China, Nepal, and Thailand and 28 communities in Colombia. In each community, we invited 20 individuals, not more than 1 adult per household, and on average 18.7 individuals accepted, for a total of 2,147 participants. Each participant signed a consent form before the start of the experiment. The experiment was framed in the context of irrigation and was performed using paper and pencil. The different one-shot public good games were performed (Baseline, Private Risk, Collective Risk) without providing feedback on the results. Subsequently, each participant performed a task to estimate risk aversion, and then completed a survey on sociodemographic variables. The experimenter script was translated and back-translated from English into each of the native languages (Chinese, Nepalese, Thai, and Spanish), and several pilot tests and debriefing sessions were conducted. Lead experimenters of the different countries were trained in human subject issues as well as the study protocol, to streamline the consistency of data collection.

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