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Resource Scarcity and Cooperation

Evidence from an Irrigation System in Western China

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Resource Scarcity and Cooperation: Evidence from an Irrigation System in Western China

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Abstract

This study examines the impact of long-term exposure to resource scarcity on farmers' cooperation. A historical irrigation water quota system in western China provides an opportunity to measure exogenous variation of water scarcity within an otherwise homogeneous region. We use the ratio of the arable land to the irrigation water quota of each village as our measure of water scarcity. Moreover, we use survey questions to measure collective actions in irrigation activities and we use a public goods game to measure cooperation norms in rural communities. We find that irrigation water scarcity not only induces better irrigation management practices and outcomes, but also fosters a stronger cooperation norm.

Keywords: water scarcity, irrigation, cooperation, public goods game, China

JEL Codes: C92, C93, Q15, Q25

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Resource Scarcity and Cooperation: Evidence from an Irrigation System in Western China

Zihan Nie and Xiaojun Yang *

1. Introduction

The literature on the impact of resource scarcity on people's behavior is mixed. Resource scarcity can be related to more competition, more conflicts, and less cooperation. Long-term exposure to resource scarcity can induce anti-social behavior and incite conflicts (Prediger, Vollan, and Herrmann, 2014), while resource abundance tends to reduce conflicts and wars (Brunnschweiler and Bulte, 2009). Short-term resource scarcity caused by negative climate and economic shocks can incite conflicts as well (Miguel, Satyanath, and Sergenti, 2004; Burke, Hsiang, and Miguel, 2015; Maystadt and Ecker, 2014). In experimental settings, artificially created scarcity can also undermine cooperative behavior (Pfaff et al., 2015; Blanco, Lopez, and Villamayor-Tomas, 2015; Gatiso, Vollan, and Nuppenau, 2015).

Yet, resource scarcity may promote cooperation if people perceive incentives to use the resources efficiently in order to maximize the welfare of the group. In experimental settings, people have refrained, at least to some extent, from over-appropriating when facing increasing scarcity and potential depletion of resources (Oses-Eraso, Udina, and Viladrich-Grau, 2008; Oses-Eraso and Viladrich-Grau, 2007; Lindahl, Crepin, and Schill, 2016). In field settings, several studies suggest that (perceived) resource scarcity is associated with better resource management (Araral, 2009; Wang, Chen, and Araral, 2016; Ito, 2012; Brooks, 2010).

Another strand of literature highlights the influence of behavioral experience on social norms. Bowles (1998) identifies "task performing effects": when people work together toward a common goal, it can foster cooperation. Empirically, Carpenter and

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Seki (2011) and Gneezy, Leibbrandt, and List (2016) find that differences in work organizations affect such preferences. For instance, fishermen who work closely together are more cooperative than those who operate more individually. Attanasio, Polania-Reyes, and Pellerano (2015) find that regular meetings can improve cooperation.

This study aims to link these strands of literature and investigate how resource scarcity affects cooperation in rural communities. Specifically, we focus on water scarcity and examine the effect of water scarcity on cooperation in the context of a gravity irrigation system in western China. Following literature on irrigation management (e.g., Araral, 2009; Bardhan, 1993, 2000; Ito, 2012; Wang, Chen, and Araral, 2016), we expect to see a positive effect of irrigation water scarcity on collective irrigation management activities. More importantly, following the "task performance effect" logic that collective action fosters cooperative norms, we expect that communities with scarcer irrigation water have stronger norms of cooperation. We build a simple model of irrigation agriculture with endogenous norm formation to illustrate the coevolution of collective irrigation management behavior and the norm of cooperation and to evaluate how water scarcity affects both. We form our hypothesis based on the comparative statics of the long-term equilibrium.

Instead of artificially manipulating scarcity in experimental settings (e.g., Pfaff et al., 2015), we measure water scarcity in the field, using a unique irrigation water quota system in western China. Under the quota system, the amount of water allocated to each village was based on the irrigated land areas self-reported by the village before the construction of the reservoir and canals in the 1960s. Villages that reported larger irrigated land areas got more irrigation water, but also had to undertake more workload in the construction of the reservoir and canals. The tradeoff between the benefits (more irrigation water) and costs (more labor input in canal construction) resulted in differences in the relative size of reported irrigation areas compared with the actual arable land areas, which created variations in water scarcity across villages in later agricultural activities. We use these variations as our measure of real life water scarcity. In addition, we collected rich information about farmers' irrigation management activities and used a lab-in-the-field public good experiment to measure the norm of cooperation.

We find that water scarcity improves irrigation management in terms of both the irrigation-related activities and their outcomes; people living in more water-scarce villages are more likely to coordinate in crop choices, more likely to keep local canals clean, and have higher self-reported quality of canals. More importantly, we find that the impact of water scarcity goes beyond irrigation-related activities. People in villages with a higher level of water scarcity also make significantly higher contributions in the public goods game. This result suggests that water scarcity also strengthens the norm of cooperation among rural communities.

This study contributes to three strands of literature. First, it contributes to the emerging literature on the impact of contextual factors on the formation of social preferences and norms. An emerging strand of studies has investigated how, among other factors, market institutions (Bowles, 1998), political regimes (Brosig-Koch et al., 2011; Kuhn, 2013; Heineck and Sussmuth, 2013), production technologies (Leibbrandt, Gneezy, and List, 2013; Alesina, Giuliano, and Nunn, 2013; Talhelm et al., 2014), workplace organization (Carpenter and Seki, 2011; Gneezy, Leibbrandt, and List, 2016) and even prenatal exposure to stressful environments (Duchoslav, 2017; Cecchi and Duchoslav, 2018) shape social preferences and norms. This study examines the role of resource scarcity in promoting the cooperative norm. While many studies manipulate resource scarcity using experimental methods (Pfaff et al., 2015; Blanco, Lopez, and Villamayor-Tomas, 2015; Gatiso, Vollan, and Nuppenau, 2015) or focus on negative shocks on resource availability (Cassar, Healy, and Von Kessler, 2017), few have examined the effect of relatively long-term resource scarcity on cooperation. Hazarika, Jha, and Sarangi (2015) also measure the historical resource scarcity, but they investigate how resource scarcity affects the culture of gender inequality. Prediger, Vollan, and Herrmann (2014) conduct a survey with pastoralists in Namibia, find that resource scarcity increases anti-social behaviors, and "identify long-term exposure to greater scarcity as a source of individual conflict behavior" (p. 3). On the contrary, our study finds that greater water scarcity increases cooperation among individuals in an irrigation system. This finding suggests that while long-term exposure to resource scarcity can invoke potential conflicts, it is not always the case. In different settings (in our case, irrigation water in a gravity irrigation system), resource scarcity could foster and improve cooperation among individual users.

Second, this study contributes to the literature regarding the impact of the gravity irrigation system on cooperation. As it requires large-scale investment and collective efforts to build, maintain, and use a gravity irrigation system, irrigation per se is an institutional arrangement that could have a profound impact on people's preferences and social norms and, thus, on their societies. Tsusaka et al. (2015) find that the introduction of gravity irrigation increases farmers' altruism and cooperation in a short period of time. von Carnap (2017) identifies irrigation agricultural practices as a determinant of social capital in India and finds that different types of irrigation affect social capital formation differently. Bentzen, Kaarsen, and Wingender (2017) find that irrigation makes societies less likely to be ruled under democracy at the subnational level; people in areas with higher irrigation potential hold lower opinions of democracy, as the large investment required to build an irrigation system favors elite monopolization of water and, thus, political power. Our study shows that such impacts are not limited to comparisons between people or society with and without irrigation; within a gravity irrigation system, the intensity of the irrigation institution (through collective irrigation management due to water scarcity) also affects the norm of cooperation among farmers.

Lastly, our research also speaks to the literature on common pool resource (CPR) management. Several studies have linked CPR management with public goods provision (Botelho et al., 2015; Solstad and Brekke, 2011), where they find that allowing resource users to contribute to a public good with their gains from the resource could help to mitigate the over-extraction problems. Our study provides a different link between resource extraction and public goods, where the effort of appropriating resources itself is a public good. If resource appropriation requires collective actions, as in the case of gravity irrigation, it could help foster a norm of cooperation, which could spill over to practices in environmental and resource management.

The rest of this paper is organized as follows: Section 2 provides a simple model to illustrate how water scarcity could affect the norm of cooperation; Section 3 describes our empirical strategy and the data; Section 4 presents empirical results; and Section 5 concludes the paper.

2. A Model with Endogenous Norm Formation

In this section, we build a simple model of endogenous norm formation in the context of a gravity irrigation system to demonstrate how water scarcity affects the evolution of the norm of cooperation within rural communities through the demand for collective actions.

Assume a rural community where agricultural production relies on irrigation and the irrigation water (W) available to the community is exogenously determined. For simplicity, we assume that the agricultural output q_i is a C-D production function of two inputs, private labor input (l_i) and irrigation service (A): $q_i = {l_i}^{\alpha} A^{\beta}$, $\alpha, \beta \in (0,1)$.[1] The irrigation service A can be interpreted as irrigation water use efficiency, which is a public good that is shared by every member of the community. We assume that water use efficiency $A = A(G, W)$ is a function of irrigation water (W) and the collective efforts on irrigation management (G) from the community on irrigation-related

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[1] The C-D production function form implies that a certain level of collection effort is optimal for each individual farmer despite free-riding incentives. This assumption suits the case of gravity irrigation, as something has to be done if anyone wants to get any water.

activities such as maintenance and coordination in farming decisions. For a community with exogenously given W, A is determined by the collective effort *G* and thus we can consider *G* as a public good as well. Collective effort $G = \sum_{i=1}^{N} g_i$ is the sum of the individual effort on irrigation management of all *N* households in the community. It is reasonable to assume that *A* is concave to *G* and *W*: $A_1 = \frac{\partial A}{\partial G} > 0$, $A_2 = \frac{\partial A}{\partial W} > 0$, $A_{11} = \frac{\partial^2 A}{\partial G^2} \leq 0$ and $A_{22} = \frac{\partial^2 A}{\partial W^2} \leq 0$. Furthermore, we assume that, at least when the total amount of irrigation water falls in a certain range $W \in \left(\underline{W}, \overline{W}\right)$, where water is moderately scarce, the marginal efficiency gain from additional collective effort is decreasing with *W*: $A_{12} = \frac{\partial^2 A}{\partial G \partial W}$ <0, as implied in Ito (2012). Individual farmers have to decide how to divide their fixed labor endowment (*E*) into private farming (l_i) and providing irrigation service (g_i): $l_i + g_i = E$.

We further assume that farmers not only gain utility from material outputs from agricultural production, but also care about (complying with) a social norm regarding public goods provision. This social norm defines the appropriate contributions to public goods in the community. At any moment, the norm is acknowledged by everyone and applies to everyone. Failing to conform to this norm would result in costs such as reputation loss or psychological discomfort. Contributions that exceed the norm may also benefit people (e.g., by building better reputation). We assume the utility from (not) conforming to the norm takes the form of $R(\Delta g_i, r_i) = r_i f(\Delta g_i)$, which depends on the gap ($\Delta g_i = g_i - g^N$) between individual contribution (g_i) and the norm (g^N) and individuals' sensitivity to the norm (r_i), where $r_i \in [0, r^{max}]$. We further assume that $R(\Delta g_i, r_i)$ has the following properties: $R(0, r_i) = 0$, $f' > 0$, $f'' < 0$. These properties mean there is no utility gain or loss when people exactly match the norm; there is utility gain when own contributions exceed the norm and utility loss when own contributions fall short of the norm; and the marginal utility loss from falling short of the norm is larger than the marginal utility gain from exceeding the norm.

For simplicity, we assume farmers have a linear utility function $u_i = q_i + R_i$, where q_i is agricultural output and R_i is the utility related to the social norm. Then, farmer *i* faces the following maximization problem:

$$\max_{l_i, g_i} u_i = {l_i}^{\alpha} A^{\beta} + r_i f(\Delta g_i),,$$

$$\text{s.t. } l_i \geq 0,\ g_i \geq 0 \text{ and } l_i + g_i = E.$$

Proposition 1: In the short term, when the social norm on public goods provision g^N is given, individual's optimal public goods provision $\widetilde{g_i}$ is increasing with social norm g^N, increasing with sensitivity to social norm r_i, and decreasing with water resource *W*.

Proof: see Appendix.

So far, we treat the norm of appropriate public goods contribution g^N as given for individual decision making. However, social norms also evolve. For simplicity, we assume that norms evolve in a "naive" way, in that people in a community form and adjust the norm of appropriate public goods provision according to the average contribution observed in the previous period: $g_{t+1}^N = \int_0^{r^{max}} \widetilde{g_{i,t}}\, h(r_i) dr_i$. $h(r_i)$ is the probability density function of r_i.

Proposition 2: The long-term equilibrium level of social norm $\widehat{g_t^N}$ is decreasing with water resource W.

Proof: see Appendix.

Thus, in the long term, people living in villages with a higher level of water scarcity have better cooperation in public goods provision and higher social norms regarding public goods provision. How do these predictions translate into behavior in the abstract setting of a linear public goods game?

Proposition 3: If people follow decision-making heuristics (Tversky and Kahneman, 1974) or a rule of thumb that carries the established norms to other situations, such as a public goods game, given individual sensitivity to the norm r_i, we should observe that people in villages with a higher level of water scarcity (smaller W) contribute more to the public goods than people in villages with a lower level of water scarcity.

Proof: see Appendix.

The simple model above illustrates how water scarcity affects cooperation in public goods provision through endogenous norm formation. A higher level of water scarcity increases the marginal payoff contribution to irrigation service, which, in turn, fosters a cooperative norm. Then, guided by the more cooperative norm, people tend to have higher contribution in settings beyond agricultural and irrigation activities, such as in a public goods game. At the long-term equilibrium, the predictions of the model give us testable hypotheses about the relationships among water scarcity, irrigation management, and the norm of cooperation. Water scarcity is expected to improve both irrigation management and the norm of cooperation in rural communities.

3. Empirical Strategy and Data

3.1. Study Site: Irrigation Water Quota System in Minle

We carried out our study in the Hongshui River Irrigation District in Minle County, Zhangye City, Gansu Province in northwestern China. Minle County is an oasis located in the northern foothills of the Qilian Mountains and lies in the middle of the

Hexi corridor, which is characterized by a semi-arid climate and a long history of irrigation agriculture.[2] Agriculture in Minle depends heavily on irrigation and water is the main constraint on agricultural production. The traditional and main source of irrigation water is surface water from local rivers. Hongshui River is the largest of the five major rivers in Minle County. The Hongshui River Irrigation District is the largest irrigation district in the county and one of the "large irrigation districts" at the national level. We choose to focus on only one irrigation district in one county in order to eliminate potential confounding factors such as different geo-climate conditions, different socio-economic histories, different irrigation cultures and traditions, and different local regulations and policies.

The distinctive feature of the irrigation practices in this area is the water quota system. The Hongshui River Irrigation District was the first to adopt the water quota system. The irrigation water quota system in the Hongshui River Irrigation District was first introduced in 1966 when facing the construction of the new irrigation canals and the reservoir. Villages that would benefit from the new canal system were asked to report their irrigated land areas. These self-reported irrigated land areas were then used as the sole criterion for the allocation of both irrigation water and the workload of irrigation infrastructure construction and maintenance across villages. Villages that reported larger irrigated land areas would receive more irrigation water, but also had to undertake a larger obligation in the irrigation infrastructure construction and maintenance. These self-reported irrigated areas became the measure of water quota and are called "*pan ding pei shui mian ji*", or "determined water allocation areas". We will refer to these self-reported irrigated areas as "irrigation water quota" or "water quota" in the rest of the paper.

Because the availability of irrigation water was tied to labor input obligations, when reporting the irrigated area, villages had to balance between the benefits (more irrigation water) and costs (more labor input in canal construction rather than on their own land). Such trade-offs resulted in differences between irrigation water quota and the actual land size across villages. Villages that received relatively more water quota suffered less from water scarcity in later years and vice versa, which created variations in the relative water scarcity across villages. In this study, we take advantage of these historically formed variations in water scarcity to examine the impact of water scarcity on cooperation.

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[2] Zhang et al. (2013) provide a detailed introduction to the socio-economic and geo-climatic background of Minle County.

3.2 Measuring Water Scarcity

Measuring water scarcity is crucial to our empirical analysis. The level of scarcity depends on the demand for water as compared to the supply of water. Therefore, we define our water scarcity indicator based on the ratio of the potential demand for water to the accessible irrigation water supply of each village:

$$Scarcity = \frac{Village\ arable\ land\ areas}{Village\ irrigation\ water\ quota}.$$

The irrigation water quota of each village, shown in the denominator, determines the supply of irrigation water, while arable land area in each village, shown in the numerator, reflects the potential demand for water.[3] The ratio represents how much arable land one unit of water quota has to irrigate.[4] Water is scarcer when the ratio is larger. We adjust the water quota and land size to any changes that have occurred since the land reform to capture the initial state of water scarcity.[5] We believe that this ratio can largely capture the differences in water scarcity between villages over a relatively long time.

Note that our measure of water scarcity only refers to surface water, while groundwater availability could affect the validity of our scarcity measure. However, the groundwater is not an important issue for two reasons. First, while we focus on long-term exposure to water scarcity in this study, the use of groundwater is a recent phenomenon in Minle. The oldest well in our sample villages was dug in 1987, the second oldest one was dug in 1998, and there were only five wells before 2009. The boom of well digging occurred in 2011 and 2012, and 58% of the wells were dug in

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[3] We use the potential demand for water (represented by arable land of each village) instead of actual demand measures, such as sown area and crop portfolio, because the actual demand is likely to be endogenous to the availability of irrigation water. Using arable land size as the numerator captures long-term scarcity, which is the focus of this study, better than using actual water demand measures in 2015.

[4] The ratio is used to compare the level of water scarcity among villages within the Hongshui River Irrigation District. It is not an indicator that is comparable to water stress level in other regions. When comparing Minle with the rest of Gansu or China, we believe the extent of irrigation water scarcity can be seen as "moderate". Water is scarce in the sense that water is the single most binding constraint to local agricultural production. However, we regard water in Minle as not being very scarce because irrigation agriculture in Minle is still very active and Minle and neighboring areas have been famous for their irrigation agriculture throughout history.

[5] Changes in the water quota have been rare. Only six out of the 26 villages in our sample reported that they had a change in village water quota, and these changes were small. The most recent change was in 1997. There have been no changes in the arable land areas of our sampled villages since the land reform in 1981. This is probably because our study site is the central part of the irrigation district and has been fully reclaimed. Expansion of arable land happened mostly in marginal areas of the irrigation district. We do not mean to extrapolate this trend outside of our sample.

these two years.[6] Access to groundwater does not affect the initial differences in water scarcity; if anything, the use of groundwater could be the result of initial water scarcity. Second, despite the increasing access to groundwater in recent years, groundwater is still not an important source for agricultural irrigation (Zhang et al., 2013). The cost of pumping groundwater out of the deep wells is much higher than that of surface water. Most importantly, groundwater salinity is much higher than surface water salinity, making groundwater harmful to yields and soil fertility. Therefore, groundwater is only used as a complement to surface water. Irrigation water scarcity is mainly driven by access to surface water.

Our water scarcity measure based on the irrigation water quota system has several merits. First, the shocks and uncertainty in water supply affect all villages simultaneously in the same direction. However, in the water quota system, when there is more water available, each water quota unit gets more water, while when less water is available, each unit gets less water, and thus the relative scarcity across villages, represented by the size of the scarcity ratio, is not affected. Therefore, although the literature has shown that uncertainty in the size of resources could affect people's behavior (e.g. Aflaki, 2013), our measure of water scarcity is not confounded by the variations and uncertainty in water supply. Second, because the quota system sets the maximum amount of water that a village can use, the water use of one village within its quota does not affect how much water other villages can use.[7] Because the water quota of each village and the time of irrigation are public knowledge in the whole irrigation district and because irrigation can be easily controlled by the sluices on the main canal, the chances of stealing water from other villages are very low. Inter-village competition over water is very unlikely and, thus, cannot affect people's preferences and norms formed within their villages. Third, because the amount of water that each quota unit represents is set by the local irrigation district administration, water use today does not affect the stock of water resource and, hence, the water flow tomorrow, provided that the irrigation district administration allocates water reasonably. Therefore, the typical intertemporal tradeoff between today's consumption and the future's consumption, the dynamics between resource stock and flow, and the externality of an individual's extraction in a common pool resource scenario play little role in determining famers' behaviors in our case. This helps rule out the endogeneity of resource scarcity due to

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[6] There are a total of 90 wells in the 26 villages, but we only have the information on which year they were dug for 79 wells. Two villages only reported when their first wells were dug (in 2002 and 2011).

[7] Traditionally, water quotas were not transferable. The market for water quota reform was only established after a water rights reform pilot project, Building a Water-saving Society in Zhangye in 2002. Yet, water rights transactions have been rare despite the existence of the market (Zhang et al., 2009). This study focuses on the effect of historical water scarcity. This recent event should not affect our analysis. If anything, recent water rights transactions could be the consequence of historical water scarcity.

past extraction. These features greatly simplify our analysis and enable us to focus on the impact of water scarcity itself.

It is crucial that the variations in our water scarcity measure are exogenous to people's social preferences and social norms of cooperation. There are three important aspects that support our claim. First, the water quota of each village was not decided by the people we interviewed, but by the older generation. Even the oldest person in our sample (age 66) was a teenager in 1966 when the water quota was determined. They might have been involved in the later construction of the canals and the reservoir, but they were certainly not involved in deciding how much irrigated land should be reported to the county authority. We can safely say that the irrigation water quota and, hence, the degree of water scarcity was imposed upon them, rather than determined by them. Second, unlike in many common pool resource settings where a more cooperative community could better preserve its resource stock and alleviate resource scarcity, the water quota system limits this channel of endogeneity, because current water flow is not directly affected by individuals' or communities' water use in the past. Third, migration across villages has been rare. Cross-village migration could affect our identification strategy in two ways. On the one hand, cross-village migrants would have experienced different levels of water scarcity, which would jeopardize our water scarcity ratio as a measure of exposure to water scarcity. On the other hand, if people migrate among villages as a response to water scarcity, it raises a potential selection bias issue. However, the Chinese *hukou* system[8] largely ties people to where they were born, especially for rural residents. Migration due to insufficient water was thus unlikely. Marriage has been a legitimate reason for inter-village migration, but it is much more common for women than for men. In our all-male sample, only four out of the 312 subjects were not born in the village in which they lived at the time of the survey. Therefore, cross-village migration is not an important issue for our study.

However, there is still one potential source of endogeneity that we cannot rule out: the intergenerational transmission of social preferences or norms. If the older generations were more pro-social and, thus, were willing to contribute more to the public projects in exchange for more water or if they formed a more cooperative culture or social norm through working together on the public projects, their pro-social preferences or cooperative norms could be transmitted to the younger generations. Then, either the current water scarcity in terms of irrigation water quota is the result of certain social preferences, or both the scarcity and the social preferences are results of

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[8] *Hukou* is the household registration system in China.

some omitted factors. Yet, as we will discuss later, even if such endogeneity exists, it does not jeopardize our main findings.

3.3 Measuring Irrigation Management

The most straightforward measure of effort in irrigation management activities is the actual labor or monetary contribution to irrigation-related collective activities. For instance, Ito (2012) uses the household labor contribution to irrigation management as the measure of collective actions of farmers. However, such labor or monetary contributions are quite noisy, because current contributions could be affected by the contributions in the past. For example, a large investment in upgrading a canal system in the past could lead to less maintenance effort now. Unfortunately, we only have one-year cross-sectional data with a relatively small sample size, which is not enough to smooth such noise. Alternatively, we turn to irrigation-related activities that are carried out more frequently and bear fewer long-term implications. Specifically, as summarized in Table 1, we mainly focus on two aspects: coordination in farming and keeping the canal clean. Farming coordination can improve irrigation efficiency because the same type of crops planted closely together can be irrigated at one time when water is most needed, which thus reduces the water loss from multiple rounds of irrigation. Coordination in farming includes two dummy variables: whether a farmer coordinates with other farmers about crop portfolios and whether a farmer discusses what to grow with farmers who have neighboring plots. Cleaning canals is major canal maintenance work every year and keeping the canals clean can help ease the job for everyone and improve irrigation efficiency. Keeping the canals clean includes three dummy variables: whether people dump trash in the canal, whether they stop other villagers from doing so, and whether they stop strangers from dumping trash in the canal. In addition, we expect that better irrigation management is reflected in its outcomes. We use the self-reported canal quality to measure the outcomes of collective irrigation management. The indicator is a five-point scale self-evaluation on the quality of the third-, fourth-, and fifth-tier canals.[9] If water scarcity motivates farmers to invest more in maintaining and renovating canals, such efforts are expected to result in higher canal quality. We expect that a higher level of water scarcity leads to better irrigation canal quality.

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[9] The irrigation canal network in the Hongshui River District typically has five tiers. The first-tier canal is the main canal that connects directly to the reservoir. The second-tier canals are the branches of the first-tier canal and they carry irrigation water to multiple villages. Both of these higher-level canals are governed by higher levels of administration and are not directly involved in village-level irrigation. Thus, we did not include them in the questions on canal quality. From the third tier down, canals are more directly involved in village irrigation. The third-, fourth-, and fifth-tier canals together are often referred as the “end level canal network (*Mo Ji Qu Xi*)”. They are the canals that directly irrigate the fields and are often shared and maintained by a group of farmers.

Table 1. Indicators of farmers' effort on irrigation-related collective activities

Variable	Survey question	Indicator	Mean (SD)	N
A: Coordination in farming				
Crop structure decide	How did you decide what crops to grow in 2015?	Dummy variable: 0, decide on their own; 1, decide through coordination	0.42 (0.49)	297
Crop discuss	Do you discuss with neighboring farmers about which crop to grow every year before sowing?	Dummy variable: 1, discuss; 0, don't discuss	0.83 (0.38)	311
B: Keeping the canal clean				
Throw trash	Do people dump trash in the canal?	Dummy variable converted: 1, never or rarely; 0, often	0.73 (0.45)	310
Stop villager	If you see another villager dump trash in the canal, will you stop him?	Dummy variable, converted from 1-5 scale: 1, probably or definitely will stop him; 0, otherwise	0.91 (0.29)	312
Stop stranger	If you see a stranger dump trash in the canal, will you stop him?	Dummy variable, converted from 1-5 scale: 1, probably or definitely will stop him; 0, otherwise	0.95 (0.21)	312
C: Self-reported canal quality				
Canal quality: third tier	How is the condition of the third-tier canal?	1-5 scale: 1 as the worst condition and 5 as the best	3.38 (1.37)	281
Canal quality: fourth tier	How is the condition of the fourth-tier canal?	1-5 scale: 1 as the worst condition and 5 as the best	2.50 (1.26)	216
Canal quality: fifth tier	How is the condition of the fifth-tier canal?	1-5 scale: 1 as the worst condition and 5 as the best	1.89 (1.23)	219

Note: calculated by the authors using the household survey data.

3.4 Measuring Cooperation: A Public Goods Game

To measure the more general inclination of cooperation beyond agriculture- or irrigation related activities, we conduct a lab-in-the-field experiment. In the abstract and anonymous setting of a public goods game, there is no incentive for a self-interested person to contribute. Thus, contribution behavior in a public goods game can be used as a measure of the norm of cooperation in rural communities. Specifically, we use a repeated linear public goods game to measure cooperation.[10] We briefly summarize the game design here.

Subjects are randomly divided into three-person groups at the beginning of each round. Each subject receives an initial endowment of 10 *Yuan* in each round.[11] They are asked to decide how much to keep in a personal account and how much to contribute to a group account. The payoff function is described as follow:

$$\pi_i = 10 - g_i + 0.5 \sum_{j=1}^{3} g_j,$$

where π_i is subject i's payoff and g_i is his contribution to the group account. The amount of the group account equals the sum of the contributions from the three subjects in the same group. The marginal payoff of the group account is 0.5, offering monetary incentives to free ride. After subjects made their contribution decisions, they were informed about the total group contribution and their individual payoffs before proceeding to the next round. The public goods game lasted for five rounds. Subjects were randomly distributed into three-person groups at the beginning of each round.

We use the subjects' contributions to the group account as our measure of cooperation in each village. Specifically, we use both the average contributions over the five rounds and the contributions in the first round as our key dependent variables.

We conducted the experiment and a household survey in January 2016. The experiment was computerized and programmed with z-Tree (Fischbacher, 2007). We created a lab environment with tablets and cardboard boxes in the conference rooms of village administration buildings. We turned cardboard boxes into small cubicles with tablets inside so that subjects could make their decisions independently and anonymously. Communication among subjects was not allowed. Subjects received oral instructions from the experimenters at the beginning of the experiment and were asked to answer practice questions on paper. The practice questions aimed to test whether the participants understood how to calculate the payoff from the contributions. The experiment only proceeded when all subjects were able to correctly answer the practice questions. In addition to the experiment, all subjects participated in a household survey.

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[10] This standard public goods game is part of a three-stage public goods game design. After this stage of the five-round public goods game, subjects were asked about their preferences between a punishment and a reward institution. Then, they were randomly assigned to one of the institutions for another five rounds of a public goods game with punishment or reward. In addition, subjects also played a simple risk game and three binary-choice dictator games. The whole experiment lasted 60-90 minutes, and the average payment to subjects was 166 *Yuan*.

[11] At the time of the experiment, 1 USD = 6.58 *Yuan*.

3.5 Subject Pool

We randomly selected 26 villages in the Hongshui River Irrigation District in Minle County and selected 12 men from each village as our experimental subjects and survey respondents. We chose male-only subjects for several reasons. Men are usually household decision-makers and represent the family in most community events.[12] More importantly, compared to women, men are more exposed to irrigation activities and water scarcity than are women, because men are traditionally more involved in agricultural production and irrigation-related activities. Men are also much less likely than women to migrate across villages, so that issues related to cross-village migration are avoided. Moreover, most middle-aged women in Minle County have little education and had trouble understanding the setup of the experiment in our pilots.[13] Therefore, we limited the subjects to males.

Our target age range was from 40 to 65 years old. We set this age range because we want to target the people who have engaged in irrigation activities and been exposed to irrigation water scarcity for a relatively long period. We exclude older men because they were adults when the water quota system was established and they might have been influenced by the experience of canal and reservoir construction; they might even have played a role in determining the water quota. We exclude younger generations because they have been less exposed to water scarcity and less engaged in agricultural activities.

The summary statistics of individual and household characteristics of the subjects are presented in Table 2. The vast majority of our subjects are household heads. The average age is 51 years old.[14] The average educational level is quite low (primary school education). All subjects are ethnic Han. Only two subjects reported having urban hukou, while the rest have rural hukou. The subjects on average spent more than 8 months in the village in 2015. Thirty-nine percent of the subjects were employed in off-farm jobs in 2015. The average gross household income per capita is 22,060 *Yuan*. For the village characteristics, 35% of the sampled villages have non-farming enterprises and the average share of local off-farm labor is 19%. As the key variable for our study,

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[12] It has been found that women on average have lower bargaining power than their husbands in the context of rural China (Bulte, Tu, and List, 2015; Yang and Carlsson, 2016).

[13] Thirty-nine percent of the wives of our subjects never received any formal school education and only 7% received education higher than elementary school, while the corresponding figures for our male subjects are 3% and 57%.

[14] Although we targeted people from 40-65 years of age, in the process of survey implementation, there were actually two men younger than 40 years old (35 and 37 years old) and two men older than 65 years old (66 years old) included in our sample. However, we do not believe this is a serious issue and this does not affect our main results.

we can see that the water scarcity ratio is 1.38 with moderate variations (ranging from 1 to 2.02; coefficient of variation is 20%).

Table 2. Summary statistics of individual, household, and village characteristics

Variable name	Mean	SD	Min	Max	N
Individual characteristics					
Household head (dummy)	0.97	0.16	0	1	312
Age	51.4	4.96	35	66	312
Years of schooling	6.63	2.62	0	15	312
Ethnic dummy (han=1)	1	0	1	1	312
Hukou dummy (rural=1)	0.99	0.08	0	1	312
Off-farm job dummy (have any=1)	0.39	0.49	0	1	312
Time at home in 2015 (month)	8.24	3.45	1	12	312
Household characteristics					
Number of siblings	4.07	1.97	0	11	312
Majority Family name dummy (yes=1)	0.83	0.38	0	1	312
Household size (person)	4.09	1.35	1	8	312
Farm size (mu)	18.36	10.94	2.5	72	312
Gross income per capita (1000 Yuan)	22.06	56.23	0.06	753.41	312
Village characteristics					
Village arable land size (mu)	4959	2265	1500	11200	312
Distance to town seat (km)	5.17	2.58	1	11	312
Distance to county seat (km)	13.79	99.51	0	40	312
Village enterprise dummy	0.35	0.48	0	1	312
Share of local nonfarm labor (%)	19.01	11.54	0.75	50.61	312
Village water quota (mu)	3807	1708	1064	9520	312
Water scarcity (ratio)	1.38	0.28	1	2.02	312

Note: calculated by the authors using the household survey data.

3.6 Empirical Model

To empirically test our hypothesis, the model in Section 2 implies a dynamic structural model. However, because we only have one-year cross-sectional data and we are mainly interested in the long-term impacts of resource scarcity, not the dynamic relationship between irrigation management activities and the social norm, we estimate the impact of water scarcity on irrigation management and contributions in the public goods game (PGG) separately using the following reduced-form models:

$$IrriM_{ij} = \alpha_0 + \alpha_1 Scarcity_j + \alpha_2 X_{ij} + \alpha_3 V_j + \epsilon_{ij};$$

$$Coop_{ij} = \beta_0 + \beta_1 Scarcity_j + \beta_2 X_{ij} + \beta_3 V_j + \varepsilon_{ij},$$

where $IrriM_{ij}$ stands for irrigation management indicators and $Coop_{ij}$ represents the contributions in PGG of subject i in village j; $Scarcity_j$ is the water scarcity indicator for village j; X_{ij} is individual and household characteristics of subject i in village j; V_j represents characteristics of village j; and ϵ_{ij} and ε_{ij} are the village-clustered error terms. Specifically, individual and household characteristics X include age, years of schooling, contracted land size, number of siblings, household size, and a dummy variable for having an apartment in town as an indicator for wealth. Village characteristics V include logarithmic arable land size, distance to town seat, distance to county seat, dummy for having non-farming enterprises in the village, and percentage of off-farm labor. We choose these explanatory variables based on literature that identifies factors that could affect collective actions (Araral, 2009; Wang, Chen, and Araral, 2016).

The coefficients of water scarcity indicators, α_1 and β_1, are the key parameters in which we are interested. Our model predicts that the level of water scarcity is positively associated with both irrigation management and contributions in the public goods game. Thus, we expect to find positive α_1 and β_1 in all model specifications. We vary the estimation methods according to the different data structures of dependent variables and the detailed estimation strategies will be discussed in the results section. Since our key explanatory variable is at the village level and contributions in the PGG are likely to be correlated within an experimental session, especially for the average contributions, we cluster the standard errors at the village level for all estimations. Moreover, because the number of clusters (villages) in this study is not large (26), we also use wild cluster bootstrap suggested by Cameron, Gelbach, and Miller (2008) and the score bootstrap developed by Kline and Santos (2012) to calculate p-values robust to few clusters for the key water scarcity indicators.[15]

4. Results

4.1 Water Scarcity and Irrigation Management

First, we test whether the higher level of water scarcity leads to better cooperation in irrigation management. Table 3 displays the probit regressions results of the effect of water scarcity on farming coordination and canal maintenance.[16] Consistent with our expectation, the results show that the coefficients of water scarcity indicators all have positive signs, although only three of them are statistically

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[15] The bootstraps are performed using the Stata command *boottest* developed by Roodman (2018) with 100,000 replications.

[16] We reported estimated coefficients as we are more interested in the direction of the effect, rather than the size of the effect. Because many of the dependent variables are dummy variables converted from subjective attitudes, the size of the marginal effects here carries little economic meaning. The same applies to the ordered probit regressions in Table 4.

significant. We also build an index variable by adding up these five dummy variables and the ordinary least squares (OLS) regression results are shown in the last column of Table 3. The results are consistent with the previous probit results. Water scarcity induces better irrigation management.

Better irrigation management should also be reflected in its outcomes. Therefore, we further look at whether villages with a higher level of water scarcity have higher quality canals. Because the self-reported canal quality is on a 1-5 scale, we report the ordered probit regression results in Table 4. We find positive effects of water scarcity on the quality of fourth- and fifth-tier canals. As the fourth-tier canals and fifth-tier canals are shared and managed by local farmers as local public goods, these results are consistent support for our previous argument.[17] Yet, we do not find a significant effect on the third-tier canal quality. This is probably because the investment to improve third-tier canal quality is quite large, so that it is often beyond the reach of the villages and must rely more on investment from higher authorities. To sum up, we do find that water scarcity increases farmers' efforts in collective irrigation management, in both irrigation management activities and their outcomes.

Table 3. Water scarcity and irrigation management

	(1) Crop structure decide	(2) Crop discuss	(3) Throw trash	(4) Stop villager	(5) Stop stranger	(6) Irri management index
Water scarcity	0.509*	0.211	0.732**	0.242	1.341**	0.621***
	(0.295)	(0.383)	(0.311)	(0.554)	(0.615)	(0.181)
	[0.21]	[0.62]	[0.02]**	[0.65]	[0.02]**	[0.02]**
Age	-0.00477	-0.0285*	0.00242	0.0174	0.0119	-0.00420
	(0.0143)	(0.0163)	(0.0144)	(0.0230)	(0.0260)	(0.0102)
Years of schooling	-0.0129	0.00464	-0.0207	0.0786**	-0.0600	-0.00175
	(0.0317)	(0.0440)	(0.0301)	(0.0360)	(0.0615)	(0.0267)
Contracted land (mu)	-0.0106	-0.00282	-0.0134	-0.00228	-0.00878	-0.0108**
	(0.00772)	(0.00783)	(0.00971)	(0.00929)	(0.0120)	(0.00449)
Number of siblings	0.0312	0.0700	-0.0246	0.0661	0.0429	0.0329
	(0.0402)	(0.0491)	(0.0478)	(0.0452)	(0.0633)	(0.0357)
Household size	-0.00942	0.0946	0.0124	0.177**	0.0189	0.0520
	(0.0740)	(0.0650)	(0.0475)	(0.0737)	(0.0629)	(0.0378)
Wealth: Have an apartment	0.377	0.940**	-0.137	0.385	-0.0878	0.339**
	(0.250)	(0.466)	(0.262)	(0.426)	(0.398)	(0.129)
ln(village arable land)	0.0724	0.348*	0.0238	-0.198	0.0910	0.137
	(0.184)	(0.203)	(0.234)	(0.333)	(0.279)	(0.128)

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[17] Almost all fourth- and fifth-tier canals are shared by farmers and they maintain these canals together. In our survey data, 210 out of 215 households reported sharing fourth-tier canals with others and maintaining the canals together; similarly, 205 out of 220 households reported sharing fifth-tier canals and 203 out of 221 households reported maintaining fifth-tier canals together with others.

Village enterprise dummy	0.166	-0.101	-0.356**	-0.184	0.0181	-0.139
	(0.148)	(0.199)	(0.179)	(0.253)	(0.242)	(0.128)
Share of off-farm labor in village	1.602**	1.517*	-0.792	-0.876	-1.912**	0.428
	(0.646)	(0.779)	(0.565)	(0.809)	(0.926)	(0.366)
Distance to town seat	0.109***	-0.00593	0.00407	0.0531	0.0711	0.0554**
	(0.0261)	(0.0393)	(0.0254)	(0.0482)	(0.0506)	(0.0214)
Distance to county seat	0.00110	0.00455	-0.00819	0.00389	0.00242	-0.000939
	(0.00771)	(0.0120)	(0.00937)	(0.0134)	(0.0135)	(0.00758)
Constant	-2.090	-1.736	0.0990	0.283	-1.129	1.568
	(1.547)	(1.993)	(2.213)	(2.718)	(2.406)	(1.108)
Observations	297	311	310	312	312	294
Pseudo R^2 (adjusted R^2)	0.074	0.075	0.038	0.077	0.086	0.052

Note: Probit regression of behavior in and attitude toward irrigation related activities in columns (1) – (5) and OLS results in column (6). Dependent variables in column (1) – (5) are dummy variables: *crop decide* equals 1 if there is coordination in determining crop structure; *crop discuss*, 1 if there is discussion with neighbors about what to grow on which land parcel; *throw trash*, 1 if one reports people never or rarely throw trash in the irrigation canal; *stop village*, 1 if he claims he would probably or definitely stop a villager from throwing trash in the canal; *stop village*, 1 if he claims he would probably or definitely stop a stranger from throwing trash in the canal. The dependent variable in column (6) is an index variable that equals the sum of the dummy variables used in columns (1) – (5). Robust standard errors in the parentheses are adjusted for clustering at village level. P-value obtained from score bootstrap with 100,000 replications for the water scarcity indicator are reported in the brackets. ***, **, and * stand for significance level 1%, 5%, and 10%, respectively.

Table 4. Water scarcity and self-reported canal quality

	(1) Third tier canal quality	(2) Fourth tier canal quality	(3) Fifth tier canal quality
Water scarcity	0.145	0.855**	0.709*
	(0.341)	(0.432)	(0.363)
	[0.672]	[0.05]*	[0.07]*
Age	-0.0117	-0.0169	0.0218
	(0.0110)	(0.0135)	(0.0190)
Years of schooling	-0.0107	-0.0306	-0.0396
	(0.0356)	(0.0337)	(0.0290)
Contracted land (mu)	-0.00323	0.0207**	0.0136
	(0.00903)	(0.0103)	(0.0117)
Number of siblings	-0.00390	0.000798	-0.0298
	(0.0306)	(0.0350)	(0.0422)
Household size	-0.0280	-0.0625	-0.00940
	(0.0519)	(0.0613)	(0.0679)
Wealth: Have an apartment	0.240	0.473*	0.114
	(0.215)	(0.261)	(0.234)
ln(village arable land)	-0.110	-0.494	-0.0930
	(0.344)	(0.367)	(0.246)
Dummy for enterprise in village	-0.260	0.147	0.0789
	(0.275)	(0.338)	(0.222)
Share of non-farm labor in village	-0.660	-1.195	-0.377
	(0.677)	(0.958)	(0.710)
Distance to town seat	0.0304	0.0951**	0.0229
	(0.0295)	(0.0397)	(0.0370)
Distance to county seat	-0.000351	0.0315*	0.0123
	(0.0121)	(0.0174)	(0.0139)
Observations	281	216	219
Pseudo R^2	0.011	0.057	0.032

Note: Ordered probit regression results for self-reported canal quality. Canal quality variables are 1-5 scale variables, where 1 stands for the worst quality and 5 is the best quality. We asked each villager about the quality of the canals that irrigate their lands. Not all households use all three tiers of canals to irrigate their lands, which leads to a large number of missing values in the sample, especially for the fourth- and fifth-tier canals. Robust standard errors in the parentheses are adjusted for clusters at village level. P-value obtained from score bootstrap with 100,000 replications for the water scarcity indicator are reported in the brackets. ***, **, and * stand for significance level 1%, 5%, and 10%, respectively.

4.2 Water Scarcity and Contributions in the Public Goods Game

So far, we have shown that water scarcity improves irrigation management activities and their outcomes in terms of canal quality. This is consistent with existing literature on the determinants of collective action in irrigation. However, we are more interested in whether the effect of water scarcity goes beyond agriculture- or irrigation-related activities and shapes the norms of cooperation within rural communities. As predicted by our model following related literature such as Gneezy, Leibbrandt, and List (2016), we expect to find a positive effect of water scarcity on cooperation (i.e., higher contributions in the public goods game).

We first show the relationship between the water scarcity indicator and the contributions in Figures 1A and 1B. Despite large variations in individual contribution at different degrees of water scarcity, we can see that water scarcity and cooperation are positively correlated (the fitted line in red).

Figure 1A. The relationship between the water scarcity indicator and the average contributions in the public goods game (PGG)

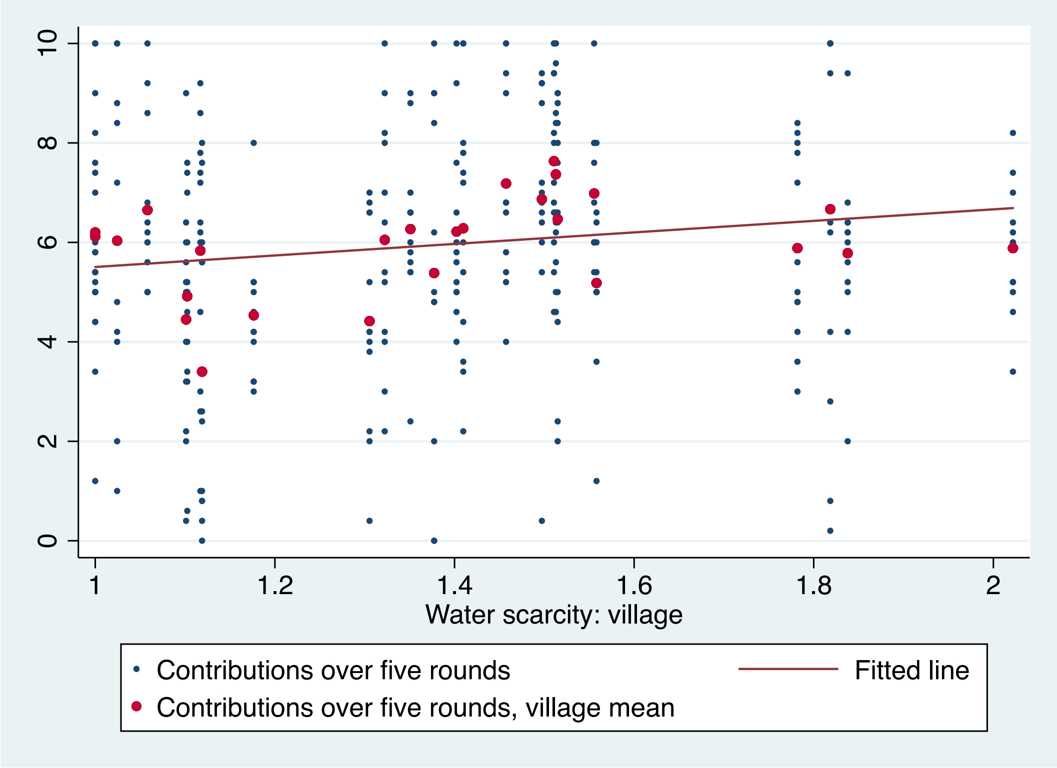
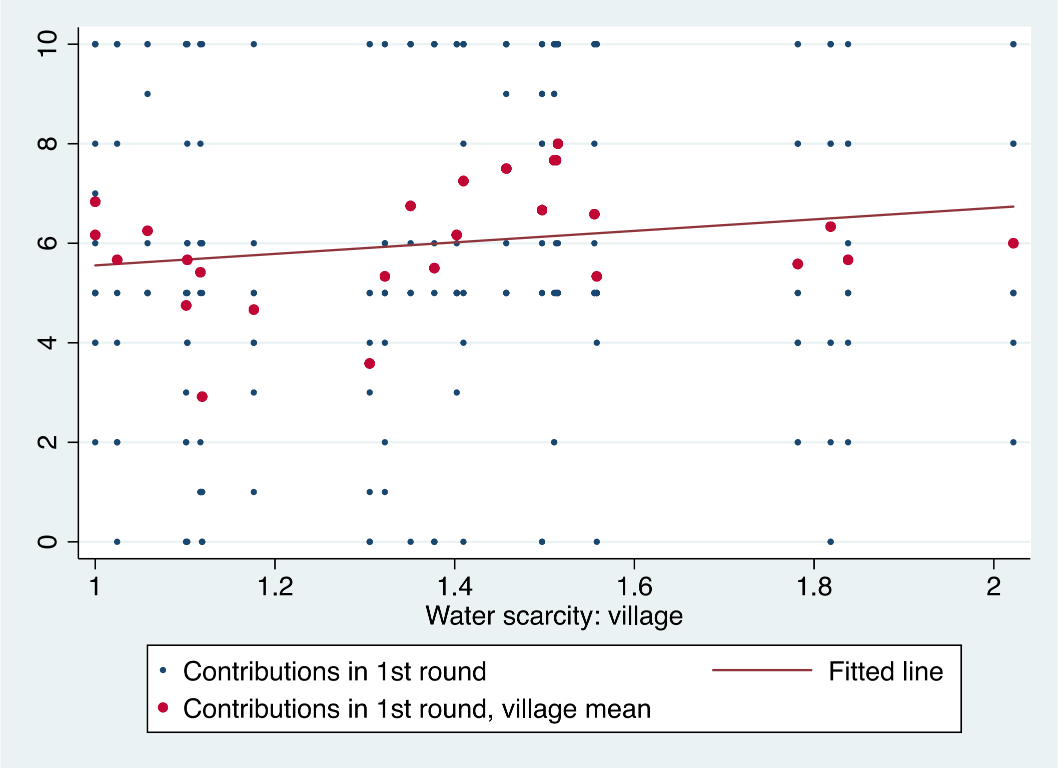


Figure 1B. The relationship between the water scarcity indicator and the contributions in the first round of the public goods game (PGG)



We then formally test the relationship between water scarcity and contributions in the public goods game, using both average contributions over the five rounds and contributions in the first round as dependent variables. The main OLS regression results are reported in Table 5.[18] Columns (1) - (3) in Table 5 use average contribution over the five rounds in the PGG as the dependent variable and columns (4) - (6) use the contributions in the first round in the PGG as the dependent variable. The results show a positive effect of the degree of water scarcity on the contributions in the PGG. Only including the water scarcity indicator in columns (1) and (4) confirms the relations in previous figures. Including individual and household characteristics does not affect the size of the coefficients of the water scarcity, but reduces the significant level to the borderline level, probably because we introduce many irrelevant variations. The effects are larger and more significant after we include village characteristics as additional explanatory variables in columns (3) and (6), while the coefficients of other characteristics are consistent with our expectations. Based on the size of the coefficients in columns (3) and (6), one standard deviation increase in the water scarcity indicator

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[18] Because contributions in the game are limited to between 0 and 10, the dependent variables are censored at both ends. We also perform tobit regressions with the same model specifications and the results are very similar. For simplicity of interpretation, we only show OLS results here; tobit regression results are available upon request.

could increase the average contributions by 0.42 Yuan, about a 7% increase from the mean, and increase the contributions in the first round by 0.54 Yuan, about a 9% increase from the mean.

Table 5. Water scarcity and contributions in the public goods game

	(1) Average Contribution	(2) Average Contribution	(3) Average Contribution	(4) Contribution in 1st round	(5) Contribution in 1st round	(6) Contribution in 1st round
Water scarcity	1.159*	1.046	1.527**	1.156*	1.220	1.953**
	(0.613)	(0.656)	(0.658)	(0.677)	(0.737)	(0.737)
	[0.05]*	[0.10]	[0.03]**	[0.08]*	[0.08]*	[0.01]**
Age		0.000118	0.00200		-0.0236	-0.0231
		(0.0351)	(0.0332)		(0.0395)	(0.0361)
Years of schooling		0.0310	0.0480		0.0820	0.107*
		(0.0473)	(0.0483)		(0.0504)	(0.0524)
Contracted land (mu)		-0.00476	-0.00311		-0.0228	-0.0222
		(0.0117)	(0.0120)		(0.0160)	(0.0158)
Number of siblings		-0.121*	-0.135**		-0.134	-0.153*
		(0.0647)	(0.0648)		(0.0811)	(0.0801)
Household size		0.178	0.185		0.273*	0.276*
		(0.121)	(0.125)		(0.149)	(0.154)
Wealth: Have an apartment		-0.646	-0.580		-0.434	-0.326
		(0.520)	(0.510)		(0.618)	(0.616)
ln(village arable land)			-0.857**			-1.099**
			(0.388)			(0.444)
Dummy for enterprise in village			0.307			0.410
			(0.356)			(0.417)
Share of non-farm labor in village			-0.0218			-0.696
			(1.441)			(1.385)
Distance to town seat			0.0415			0.0756
			(0.0701)			(0.0871)
Distance to county seat			-0.0166			-0.0428**
			(0.0165)			(0.0190)
Constant	4.346***	4.205*	10.44**	4.399***	4.869**	13.14***
	(0.910)	(2.212)	(3.894)	(1.004)	(2.286)	(3.576)
Observations	312	312	312	312	312	312
Pseudo R^2	0.015	0.023	0.042	0.007	0.020	0.051

Note: OLS regression results for self-reported canal quality. The dependent variable in columns (1) – (3) is the average contribution over five rounds and the dependent variable in columns (4) – (6) is the contribution in the first round. Robust standard errors in the parentheses are adjusted for clustering at village level. P-value obtained from wild cluster bootstrap with 100,000 replications for the water scarcity indicator are reported in the brackets. ***, **, and * stand for significance level 1%, 5%, and 10%, respectively.

Table 6A. Water scarcity and average contribution over five rounds in the public goods game

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Water scarcity	1.312**	1.457**	-6.836	1.949**	0.665	1.312*	1.954**	1.045	1.043
	(0.576)	(0.608)	(5.835)	(0.911)	(0.672)	(0.647)	(0.919)	(0.698)	(0.755)
	[0.03]**	[0.03]**	[0.24]	[0.06]	[0.38]	[0.06]*	[0.05]*	[0.21]	[0.26]
No. of wells in vill (per 1000 ha)	-0.302								
	(0.239)								
Household groundwater access dummy	0.241								
	(0.403)								
Water scarcity, household		0.101							
		(0.273)							
Age*water scarcity			0.163						
			(0.112)						
			[0.13]						
Not farming 2015						-2.128			
						(1.382)			
Not farming*water scarcity						1.732			
						(1.044)			
						[0.14]			
Off-farm job							1.680		
							(1.817)		
Off-farm job* water scarcity							-1.305		
							(1.255)		
							[0.33]		
Zone dummies								Yes	
Constant	11.07**	10.34**	22.35**	6.620	12.21	10.68**	10.23**	9.628**	5.805
	(4.188)	(3.875)	(8.708)	(4.978)	(8.021)	(3.872)	(3.774)	(4.030)	(5.488)
Observations	312	311	312	175	137	312	312	312	264
Adjusted R^2	0.083	0.080	0.086	0.126	0.081	0.084	0.084	0.084	0.051

Note: OLS regression results of the effect of water scarcity on average contribution over the five rounds of the PGG. The coefficients of the individual and village characteristics are omitted for the sake of brevity. Individual characteristics include age, years of schooling, size of contracted land, number of siblings, household size, and dummy for having an apartment in town as a proxy for wealth. Village characteristics include natural log of village land size, dummy for having non-farm enterprises in the village, share of off-farm labor, distance to town seat, and distance to county seat. Column (4) is results for a subsample of subjects born before 1982 and Column (5) is for subjects born in 1982 and later. Column (9) excludes the four villages from Zone 3. Robust standard errors in the parentheses are adjusted for clustering at village level. P-value obtained from wild cluster bootstrap with 100,000 replications for the water scarcity indicator are reported in the brackets. ***, **, and * stand for significance level 1%, 5%, and 10%, respectively.

Table 6B. Water scarcity and the contribution in the first round in the public goods game

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Water scarcity	1.738** (0.683) [0.03]**	1.807** (0.656) [0.02]**	-11.11* (6.350) [0.12]	2.567*** (0.873) [0.01]***	0.191 (1.055) [0.88]	1.719** (0.733) [0.02]**	2.026* (0.985) [0.05]**	1.673* (0.859) [0.10]*	1.961** (0.919) [0.10]*
No. of wells in vill (per 1000 ha)	-0.336 (0.272)								
Household groundwater access dummy	0.552 (0.502)								
Water scarcity, household		0.212 (0.514)							
Age*water scarcity			0.254** (0.120) [0.07]*						
Not farming 2015						-2.994 (1.892)			
Not farming*water scarcity						2.009 (1.268) [0.12]			
Off-farm job							0.238 (2.158)		
Off-farm job* water scarcity							-0.255 (1.389) [0.86]		
Zone dummies								Yes	
Constant	14.52*** (3.974)	12.92*** (3.635)	31.74*** (10.09)	7.518 (6.627)	15.59* (8.130)	13.57*** (3.500)	13.33*** (3.474)	13.12*** (3.548)	9.976* (5.776)
Observations	312	311	312	175	137	312	312	312	264
Adjusted R^2	0.091	0.090	0.098	0.117	0.137	0.092	0.088	0.092	0.062

Note: OLS regression results of the effect of water scarcity on average contribution in the first round of the PGG. The coefficients of the individual and village characteristics are omitted for the sake of brevity. Individual characteristics include age, years of schooling, size of contracted land, number of siblings, household size, and dummy for having an apartment in town as a proxy for wealth. Village characteristics include natural log of village land size, dummy for having non-farm enterprises in the village, share of off-farm labor, distance to town seat, and distance to county seat. Column (4) is results for a subsample of subjects born before 1982 and Column (5) is for subjects born in 1982 and later. Column (9) excludes the four villages from Zone 3. Robust standard errors in the parentheses are adjusted for clustering at village level. P-value obtained from wild cluster bootstrap with 100,000 replications for the water scarcity indicator are reported in the brackets. ***, **, and * stand for significance level 1%, 5%, and 10%, respectively.

Based on the results in Table 5, we move on to test whether the results are robust to potential confounding factors and explore potential heterogeneous effects in Tables 6A and 6B. Regression specifications are the same in the two tables except for the dependent variables. The dependent variable in Table 6A is the average contribution and the dependent variable in Table 6B is the contribution in the first round. Because the results in the two tables are similar, the following analyses are about both tables if not otherwise specified.

As mentioned before, groundwater availability is another factor that might affect our identification strategy. Although we do not believe that the relatively recent availability of groundwater could have disturbed the long-term effects of water scarcity, we tested it in column (1). We include the number of wells per hundred hectares of arable land in the village and a dummy for access to groundwater at the household level to see whether the availability of groundwater affects our result. The result confirms our previous argument. Better access to groundwater may have slightly reduced contributions, but it is not statistically significant. And the significant and positive relationship between contributions in the game and water scarcity is robust to groundwater availability.

So far, we mainly measure water scarcity at the village level, because we believe that the impact of water scarcity on cooperation works through the interaction among people and shapes people's preferences at the community level rather than at the individual or household level. In column (2), we add a household-level water scarcity indicator constructed in a manner similar to the village-level indicator. The results show that household level scarcity does not affect contributions in the public goods game and only village-level water scarcity is statistically significant. This finding supports our argument that individual households cannot effectively operate irrigation by themselves and that the effect of water scarcity operates through inducing better collective irrigation management, which then fosters a more cooperative norm within the whole community.

Because we argue that a stronger norm of cooperation is formed through better collective actions, and better collective actions are induced by the higher level of water scarcity, the length of exposure to water scarcity and experience of collective actions are important for the formation and evolution of cooperative norms. We expect that people who have been exposed to water scarcity longer and have more experience in working together as a collective should hold a higher norm in term of cooperation. More importantly, before the land reform in 1981, villages in Minle were functioning as collectives to coordinate agricultural and irrigation activities and farmers had more experience in working together on public projects. Thus, we test the impact of exposure in two ways. First, we interact age with water scarcity in the model specification in column (3). We expect to find a positive coefficient for the interaction term. Second, we separate the sample into two subsamples based on their exposure to the collective era. We define the "old" generation as people who were at least 16 years old in 1981 when the land reform happened, and the rest are classified as the "young" generation. We expect to find stronger cooperative norms among the "old" generation than the "young" generation. Columns (4) and (5) in Table 5 are regression results for the "old" and "young" generations respectively. The results are consistent with our expectations. The effect of water scarcity on cooperation is stronger both in the size and significance among older subjects than among the younger subjects.

Furthermore, we test the robustness of our results to subjects' current involvement in agriculture and occupational choices. In column (6), we test whether a household's engagement in agricultural production affects the effect of water scarcity on cooperation by including a dummy variable for no farming in 2015 and its interaction term with water scarcity in the regression. In column (7), we test whether having off-farm jobs affects the impact of water scarcity on cooperation by including a dummy variable for off-farm jobs in 2015 and its interaction term with water scarcity. The results are robust and consistent. Greater water scarcity fosters stronger norms of cooperation in rural communities and the effect is persistent and not easily disturbed by short-term events.

Finally, although our study site is limited to a small area along the Hongshui River (longest driving distance between two sampled villages is about 40km), there could still be some variations in local geo-climate features such as rainfall and temperature, which could affect the demand for irrigation water and, thus, affect the relative water scarcity. Higher rainfall and lower temperature (lower evaporation) reduce water demand and, thus, mitigate irrigation water scarcity. In Minle, elevation is the key determinant of local rainfall and temperature. High elevation areas have more rainfall and lower temperature and, thus, lower demand for irrigation water than low elevation areas. If elevation is positively correlated with our irrigation water scarcity indicator, meaning villages with relatively less water quota actually have lower demand, the size of the water scarcity indicator might fail to capture even the direction of true water scarcity levels across villages. However, our water scarcity indicator is negatively correlated with elevation among the sampled villages (Pearson's correlation -0.430, p=0.028), suggesting that villages with great irrigation water scarcity also have higher water demand. This means that differences in the size of the scarcity indicator actually understate the true difference in water scarcity. Therefore, the direction of the effect of water scarcity is not affected, although we may have overestimated the size of the effect. Because agricultural land in Minle is typically divided into three zones based on elevation, we also control for the three zones in column (8) to see whether our results are robust.[19] The coefficients of the zone dummies are not statistically significant. Although the size and the significance level of the coefficients of water scarcity decrease, the coefficient for the first-round contribution is still significant. The decrease in both size and significance level is largely due to the correlation between the zone dummies and our small sample size. Another concern about local climatic differences is that water allocation may have been adjusted to meet the water demand. If each unit of water quota equals a different amount of water in different villages, our water scarcity indicator would fail to represent the true differences in water scarcity across villages. From the Hongshui River Irrigation Administration, we only know that the amounts of water allocated to each water quota unit are the same in the 22 villages in zone 1 and zone 2, but we do not have the same level of confidence for the four villages in zone 3. Thus, in column (9), we exclude those four villages in zone 3. Again, although weaker in both magnitude and significance level due to the smaller sample size, the results are similar, especially for the contribution in the first round.

Furthermore, when we compare the results in Tables 6A and 6B, we find that the effect on the contributions in the first round of the PGG is consistently larger than the effect on the average contributions over the five rounds. This finding supports our decision-making heuristic assumption that people tend to carry the existing norms to new situations – in this case, a lab-in-the-field experiment. The effect of a cooperative norm on contribution decisions should be strongest in the first round and then may be gradually eroded by the learning process during the game play.

4.3 IV Estimation Results

Although we have discussed the exogeneity of our water scarcity measure in Section 2, we cannot completely rule out potential endogeneity. Our measure could be endogenous if the water quota and thus relative water scarcity was affected by older generations' attitudes toward public goods and if such local culture, norm, or social preferences was transmitted to the younger generation. The villages that valued public

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[19] Zone 1 has an elevation ranging from 1600 to 2000 m; zone 2 ranges between 2000 and 2200 m; and zone 3 ranges between 2000 and 2200 m. In our sample, among the 26 villages, 10 are located in zone 1, 12 in zone 2, and 4 in zone 3.

goods more and thus were more willing to contribute to the canal and reservoir construction would tend to acquire more water quota than the villages that valued public goods less. This relation holds for the younger generation as well if their attitudes toward public goods are influenced by the older generation. However, if this is the case, it implies a negative relationship between water scarcity and contributions to the public goods game, which means that the OLS results in Table 5 should have underestimated the true effect of water scarcity on contributions and this endogeneity issue does not affect our main findings.

We deal with this endogeneity concern with an instrumental variable approach. We argue that, in the context of Hongshui River Irrigation District of Minle County, the geographic location of the villages could serve as an IV for the relative water scarcity. The underlying logic is that, because the reservoir was built upstream on the Hongshui River, which is to the south of all the villages in our sample, the cost of working on the construction site was lower for the villagers who lived closer to the reservoir. Therefore, villages located in the south would be more willing to contribute than those in the north and, thus, received more water quota relative to their land size and became less water scarce later on. We use latitude of each village as a proxy for villages' proximity to the reservoir and as our IV for the 2SLS regression. Because higher latitude means farther away from the reservoir, we expect to see a positive relationship between latitude and our water scarcity indicator in the first stage regression. The 2SLS results are shown in Table 7, where explanatory variables are the same as in Table 5. Similarly, we employ the 2SLS by using both average contribution over the five rounds and the contribution in the first round in PGG. The second stage regression results are shown in columns (1) and (2). Because the first stage is the same, we only report it once, in column (3).

As we can see, latitude is a strong predictor for the water scarcity ratio in the first stage regression, and it does not affect the contribution in the PGG if we include it along with the water scarcity indicator in the regression. Results from the second stage regression show that, when taking possible endogeneity of water scarcity into consideration, the effect of water scarcity on the contribution in the PGG is even stronger. Our finding that a higher level of water scarcity improves people's preference for cooperation still holds.

Table 7. Water scarcity and contribution in the public goods game, 2SLS

	(1) Second stage Av. Con.	(2) Second stage First Con.	(3) First stage Water scarcity
Water scarcity	2.833** (1.168) [0.04]**	4.029*** (1.276) [0.06]*	
Age	-0.00124 (0.0310)	-0.0283 (0.0332)	0.00321** (0.00151)
Years of schooling	0.0359 (0.0474)	0.0878* (0.0514)	0.00579* (0.00307)
Contracted land (mu)	-0.0134 (0.0151)	-0.0384** (0.0164)	0.00795*** (0.00137)
Number of siblings	-0.137** (0.0611)	-0.155** (0.0747)	-0.000444 (0.00532)
Household size	0.178 (0.120)	0.265* (0.147)	-0.00558 (0.00850)
Wealth: Have an apartment	-0.478 (0.500)	-0.165 (0.633)	-0.0558 (0.0420)
ln(village arable land)	-1.041** (0.419)	-1.392*** (0.440)	0.157** (0.0745)
Dummy for enterprise in village	0.444 (0.403)	0.629 (0.486)	-0.0540 (0.0716)
Share of non-farm labor in village	-0.449 (1.457)	-1.374 (1.612)	0.0900 (0.398)
Distance to town seat	0.0301 (0.0893)	0.0575 (0.124)	0.0107 (0.0231)
Distance to county seat	-0.0172 (0.0194)	-0.0437* (0.0251)	-0.00958** (0.00365)
latitude			1.741*** (0.392)
Constant	10.74*** (3.818)	13.62*** (3.450)	-67.24*** (15.05)
Observations	312	312	312
Adjusted R2	0.025	0.026	0.448
Test statistics			
Partial F excl. instr.			19.69
KP LM stat			5.77
KP Wald stat			21.29
Endogeneity test	1.42	2.85	

Note: 2SLS regression results for average contribution over the five rounds and the contribution in the first round. The first stage regressions for the both outcome variables are the same and, thus, we only report it once, in column (3). Robust standard errors in the parentheses are adjusted for clustering at village level. P-value obtained from wild cluster bootstrap with 100,000 replications for the water scarcity indicator are reported in the brackets. ***, **, and * stand for significance level 1%, 5%, and 10%, respectively.

4.4 Village Level Robustness Check

So far, all of the analyses use individual-level data. Because our water scarcity measure is on the village level, we also aggregate all the individual/household level information to the village level and repeat the same regressions on the village level. The results are reported in Table 8 and are similar to the results in the individual-level analyses above.

Table 8. Water scarcity and contributions in the public goods game, village level

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	OLS	OLS	2SLS	OLS	OLS	OLS	2SLS
	Av. Con.	Av. Con.	Av. Con.	Av. Con.	1st Con.	1st Con.	1st Con.	1st Con.
Water scarcity	1.159	1.656**	1.108	2.162**	1.156	1.874**	1.664	3.646**
	(0.688)	(0.765)	(1.045)	(1.078)	(0.843)	(0.869)	(1.201)	(1.462)
Age			0.0749	0.0438			0.166	0.107
			(0.158)	(0.117)			(0.182)	(0.146)
Years of schooling			-0.135	-0.237			0.0522	-0.140
			(0.298)	(0.296)			(0.342)	(0.327)
Contracted land (mu)			-0.0000873	-0.0228			-0.0445	-0.0872***
			(0.0415)	(0.0268)			(0.0477)	(0.0303)
Number of siblings			-0.0688	-0.0496			-0.175	-0.139
			(0.380)	(0.212)			(0.437)	(0.266)
Household size			1.326**	1.257***			1.370**	1.239***
			(0.534)	(0.302)			(0.613)	(0.342)
Wealth: Have an apartment			0.679	1.525			-0.0851	1.505
			(2.806)	(1.940)			(3.224)	(2.589)
ln(village arable land)		-0.816*	-1.195**	-1.193***		-1.063*	-1.411**	-1.406***
		(0.461)	(0.502)	(0.323)		(0.524)	(0.576)	(0.322)
Dummy for enterprise in village		0.272	0.138	0.146		0.322	0.327	0.342
		(0.428)	(0.472)	(0.370)		(0.486)	(0.542)	(0.419)
Share of non-farm labor in village		-0.224	-0.763	-1.015		-0.903	-1.117	-1.591
		(1.726)	(1.798)	(1.012)		(1.960)	(2.066)	(1.270)
Distance to town seat		0.0493	0.00358	0.00318		0.0809	0.0641	0.0634
		(0.0810)	(0.0830)	(0.0688)		(0.0919)	(0.0953)	(0.110)
Distance to county seat		-0.0169	-0.000301	-0.00372		-0.0408	-0.0276	-0.0341*
		(0.0224)	(0.0230)	(0.0148)		(0.0254)	(0.0264)	(0.0190)
Constant	4.346***	10.45***	6.382	7.820	4.399***	12.55***	2.773	5.477
	(0.969)	(3.638)	(8.304)	(6.327)	(1.188)	(4.129)	(9.542)	(7.987)
Observations	26	26	26	26	26	26	26	26
Adjusted R2	0.069	0.061	0.149	0.083	0.034	0.165	0.225	0.062

Note: OLS and 2SLS regression results. Columns (1) - (4) are results for average contributions over the five rounds of PGG and columns (5) - (8) are for the contributions in the first round of PGG. The explanatory variables are the same as in Table 5. IV used in the 2SLS regressions in columns (4) and (8) is latitude of the villages as used in Table 6. First stage regression results for 2SLS results are not shown in the table for simplicity and can be provided upon request. ***, **, and * stand for significance level 1%, 5%, and 10%, respectively.

5. Concluding Remarks

As the demand for natural resource has been on a constant increasing trend due to economic development and population growth, the increasing scarcity and the potential depletion of resources have become increasingly serious challenges to people's livelihood in many parts of the world. While sustainable management of resources often requires cooperation among stakeholders, it is natural to ask how resource scarcity affects people's willingness to cooperate, especially when resource scarcity is often related to competition and conflicts. In this study, we directly examine how resource scarcity affects collective action in resource management and the general willingness of cooperation in the context of a gravity irrigation system in China. We propose that scarcity could help foster cooperation under a proper institutional arrangement. We build a simple model with coevolution of irrigation management and social norms to illustrate how water scarcity affects the norm of cooperation in rural communities. We test this idea using both experimental and survey data from an irrigation district with a historical irrigation water quota system. This irrigation water quota system formed in the 1960s creates variations in the ratio of water quota to arable land area across villages. We use these variations as the measure for degree of water scarcity. We measure cooperation in irrigation management with survey questions and the general inclination of cooperation using a lab-in-the-field experiment.

We find that water scarcity improves individuals' commitment to collective irrigation management. More importantly, the effect of water scarcity goes beyond irrigation activities. Greater water scarcity also creates a stronger norm of cooperation, measured by contributions in a public goods game. This relationship between water scarcity and preference for cooperation holds even if we take potential endogeneity into consideration and, thus, this result validates the causal relationship between water scarcity and the norm of cooperation.

Our findings seem to contradict many studies on similar topics, which have found that resource scarcity often incites conflicts and competition instead of cooperation. For example, Prediger, Vollan, and Herrmann (2014) find that pastoralists in areas with lower quality grazing land are more likely to engage in anti-social behavior in an artefactual field experiment. Our explanation for this discrepancy lies in the different nature of irrigation water compared to other well-documented resources. Unlike common pool resources such as pastoral land and fisheries, which can usually be used by individuals or a small group of users, irrigation requires monetary and labor inputs at a much larger scale, which is usually beyond the reach of individuals or small groups of users. Therefore, such requirements demand collective action from local communities, and these collective actions in irrigation activities may build a norm of cooperation among local people. This feature of irrigation has been well documented in the literature (Aoyagi, Sawada, and Shoji, 2014; Bardhan, 2000; Bentzen, Kaarsen, and Wingender, 2017; Fujiie, Hayami, and Kikuchi, 2005; von Carnap, 2017). As water becomes scarcer, the value of collective action increases and farmers have incentives to work more closely with each other on the irrigation system. The stronger interdependence among the farmers then shapes a more cooperative culture, as discussed in Carpenter and Seki (2011) and Gneezy, Leibbrandt, and List (2016). Furthermore, our findings are also consistent with the literature on self-governing common pool resource management, where successful cases are often found in irrigation systems (e.g., Ostrom and Gardner, 1993; Ostrom, 1990).

Our findings also underscore the importance of institutions in shaping social norms and preferences. Irrigation is not only an agricultural technology, but also a set of institutional arrangements that requires users to act in a certain way in order to benefit from it. An irrigation system could foster cooperation as it strengthens the interdependence within the community. Thus, other technological or institutional arrangements with similar features should be expected to help build cooperation in a similar way. This finding is particularly pertinent in communities with rural development or common pool resource management projects. The crucial element of the success of these projects is farmers' voluntary participation and contribution, which is affected by local norms or cultural attitudes toward cooperation. If a project could include elements that enhance the experience or the perception of interdependence, there may be a better outcome in the long term because the project could create additional benefits from the more cooperative culture that it helps to foster.

Due to the design and scale of the data, this study also has its limitations. We rely on a historical irrigation water quota system to identify variations in water scarcity. This strategy has many merits that help isolate the impact of water scarcity on cooperation, as we described in Section 3. However, these merits of our empirical strategy and our measure of water scarcity do not come without a price. By focusing on one irrigation district in one county, we forgo the ability to test the heterogeneous impacts of water scarcity on cooperation. Our findings are confined to the context of the surface water irrigation system and would have a hard time when applied to other types of irrigation systems. von Carnap (2017) has provided a detailed discussion on how different irrigation systems have different impacts on social capital formation. Similarly, while we are able to rule out confounding factors such as water distribution rules, agricultural policies, and social-economic history, we also lose the ability to examine how these factors could interact with water scarcity. We should be cautious in generalizing our findings to other regions with different social, economic, and institutional backgrounds. Moreover, since we only have 26 villages in our sample, we do not have enough statistical power to test village-level heterogeneity effects. Studies on a larger scale are needed to answer these questions in the future.

Furthermore, our experimental design only allows us to study the inner-group cooperation. While our findings in this study emphasize the positive effects of resource scarcity on inner-group cooperation, we do not claim the same effects of resource scarcity on inter-group cooperation. People tend to act differently when interacting with people from their own group rather than with outsiders (Chen and Li, 2009) and exhibit "parochial altruism" behavior (i.e., people are kind to toward members of own group, but hostile towards outsiders; see Abbink et al., 2012; Bernhard, Fischbacher, and Fehr, 2006). The existence of threats from out-groups can increase intra-group social capital accumulation (Jennings and Sanchez-Pages, 2017). Thus, when facing greater resource scarcity and when the allocation of resources is not clearly demarcated, it is not clear how resource scarcity affects inter-group cooperation or competition. The answer to this question is beyond the scope of this study.

Another limitation of this study is that we only study the impact of water scarcity in the context of moderate water scarcity in a semi-arid area. We have to be cautious if we want to generalize the findings to different settings. When water is very scarce, the positive relationship between water scarcity and cooperation that we find in this study may not hold. The literature has recorded a curvilinear relationship between water scarcity and collective action in irrigation systems (Bardhan, 2000; Araral, 2009; Wang, Chen, and Araral, 2016). Collective action is more difficult when water is very scarce or abundant, but easier when scarcity is moderate. This means that if we apply the same analysis to a more water-scarce area, we might find the opposite relationship between scarcity and cooperation. Again, larger-scale research with a wider spectrum of scarcity is needed to fully reveal the relationship between water scarcity and cooperation. It is left for future studies.

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Appendix

Proposition 1 Proof:

Substitute $l_i = E - g_i$ and $\Delta g_i = g_i - g^N$ into the utility function and we have the following utility maximization problem:

$$\max_{0 \le g_i \le E} u_i = (E - g_i)^{\alpha} A^{\beta} + r_i f(g_i - g^N);$$

The first order condition is: $\frac{\partial u_i}{\partial g_i} = -\alpha(E - g_i)^{\alpha-1}A^{\beta} + \beta(E - g_i)^{\alpha}A^{\beta-1}A_1 + r_i f' = 0.$

Let $\widetilde{g_i}$ be the short term optimal contribution of individual farmer *i* and satisfies the first order condition:

$$r_i f'(\widetilde{g_i} - g^N) = \alpha(E - \widetilde{g_i})^{\alpha-1}A^{\beta} - \beta(E - \widetilde{g_i})^{\alpha}A^{\beta-1}A_1. \qquad (1)$$

Thus, $\widetilde{g_i}$ is a function of social norm g^N and sensitivity to norm r_i.

Taking partial derivatives of g^N on both sides of the equation (1), we have

$$r_i f''\left(\frac{\partial \widetilde{g_i}}{\partial g^N} - 1\right) = (-\alpha(\alpha-1)(E - \widetilde{g_i})^{\alpha-2}A^{\beta} + 2\alpha\beta(E - \widetilde{g_i})^{\alpha-1}A^{\beta-1}A_1 -$$

$$\beta(\beta-1)(E - \widetilde{g_i})^{\alpha}A^{\beta-2}{A_1}^2 - \beta(E - \widetilde{g_i})^{\alpha}A^{\beta-1}A_{11})\frac{\partial \widetilde{g_i}}{\partial g^N}. \qquad (2)$$

Since $\alpha, \beta \in (0,1)$, $A_1 > 0$, $A_{11} < 0$, $r_i > 0$ and $f'' < 0$, rearranging equation (2) gives us $0 < \frac{\partial \widetilde{g_i}}{\partial g^N} < 1$. Short term optimal contribution $\widetilde{g_i}$ is increasing with social norm in regard of public good provision g^N.

Taking partial derivatives of r_i on both sides of the equation (1), we have

$$f' + r_i f''\frac{\partial \widetilde{g_i}}{\partial r_i} = (-\alpha(\alpha-1)(E - \widetilde{g_i})^{\alpha-2}A^{\beta} + 2\alpha\beta(E - \widetilde{g_i})^{\alpha-1}A^{\beta-1}A_1 -$$

$$\beta(\beta-1)(E - \widetilde{g_i})^{\alpha}A^{\beta-2}{A_1}^2 - \beta(E - \widetilde{g_i})^{\alpha}A^{\beta-1}A_{11})\frac{\partial \widetilde{g_i}}{\partial r_i}. \qquad (3)$$

Rearranging equation (3) gives that $\frac{\partial \widetilde{g_\iota}}{\partial r_i} > 0$. Short term optimal contribution $\widetilde{g_\iota}$ is increasing with individuals' sensitivity to social norm r_i

Similarly, taking partial derivatives of W on both sides of the equation (1), we have

$$\left(r_i f'' + \alpha(\alpha-1)(E-\widetilde{g_\iota}\,)^{\alpha-2}A^{\beta} - 2\alpha\beta(E-\widetilde{g_\iota}\,)^{\alpha-1}A^{\beta-1}A_1 + \beta(\beta-1)(E-\widetilde{g_\iota}\,)^{\alpha}A^{\beta-2}{A_1}^2 + \beta(E-\widetilde{g_\iota}\,)^{\alpha}A^{\beta-1}A_{11}\right)\frac{\partial \widetilde{g_\iota}}{\partial W} = \alpha\beta(E-\widetilde{g_\iota}\,)^{\alpha-1}A^{\beta-1}A_2 - \beta(\beta-1)(E-\widetilde{g_\iota}\,)^{\alpha}A^{\beta-2}A_1A_2 - \beta(E-\widetilde{g_\iota}\,)^{\alpha}A^{\beta-1}A_{12}. \qquad (4)$$

Therefore, $\frac{\partial \widetilde{g_\iota}}{\partial W} < 0$. Short term optimal contribution $\widetilde{g_\iota}$ is decreasing with water resource W.

Proposition 2 Proof:

The dynamic of norm g_t^N is determined by

$$\dot{g}_{t+1}^N = g_{t+1}^N - g_t^N = \int_0^{r^{max}} \widetilde{g_{\iota,t}}\, h(r)dr - g_t^N.$$

Since $0 < \frac{\partial \widetilde{g_{\iota,t}}}{\partial g^N} < 1$, $\frac{\partial \dot{g}_{t+1}^N}{\partial g_t^N} = \int_0^{r^{max}} \frac{\partial \widetilde{g_{\iota,t}}}{\partial g^N} h(r)dr - 1 < 0$. Then, long-term equilibrium at $\dot{g}_{t+1}^N = 0$ is stable.

Let $\widehat{g_t^N}$ stand for its long-term equilibrium level of social norm within a community,

$$\widehat{g^N} = \int_0^{r^{max}} \widetilde{g_\iota}(\widehat{g^N}, W)\, h(r)dr. \qquad (5)$$

Taking partial derivatives of W on both sides of the equation (5), we have

$$\frac{\partial \widehat{g^N}}{\partial W} = \int_0^{r^{max}} \left(\frac{\partial \widetilde{g_\iota}}{\partial g^N}\frac{\partial \widehat{g^N}}{\partial W} + \frac{\partial \widetilde{g_\iota}}{\partial W}\right) h(r)dr = \frac{\partial \widehat{g^N}}{\partial W}\int_0^{r^{max}} \frac{\partial \widetilde{g_\iota}}{\partial g^N} h(r)dr + \int_0^{r^{max}} \frac{\partial \widetilde{g_\iota}}{\partial W} h(r)dr. \qquad (6)$$

Rearranging equation (6), we have

$$\frac{\partial \widehat{g^N}}{\partial W}\left(1 - \int_0^{r^{max}} \frac{\partial \widetilde{g_\iota}}{\partial g^N} h(r)dr\right) = \int_0^{r^{max}} \frac{\partial \widetilde{g_\iota}}{\partial W} h(r)dr.$$

Since $0 < \frac{\partial \widetilde{g_i}}{\partial g^N} < 1$ and $\frac{\partial \widetilde{g_i}}{\partial W} < 0$, we can easily have $\frac{\partial \widetilde{g^N}}{\partial W} < 0$.

Proposition 3 Proof:

In our linear public goods game, the payoff structure is $q_i = \alpha(E - g_i) + \beta G$, with $\alpha = 1$ and $\beta = 0.5$.

If people carry this norm to other public goods situations, such as our public goods game, then we expect farmers to maximize their utility function as follows:

$$\max_{0 \le g_i \le E} u_i = \alpha(E - g_i) + \beta G + r_i f(g_i - g^N);$$

The first order condition is: $\frac{\partial u_i}{\partial g_i} = -\alpha + \beta + r_i f'(g_i - g^N) = 0$.

Define $\Delta g_i \equiv g_i - g^N$. As $\Delta g_i \in [-g^N, E - g^N]$ and $f'' < 0, f'(E - g^N) \le f'(\Delta g_i) \le f'(-g^N)$.

Therefore, for anyone with $0 \le r_i < (\alpha - \beta)/f'(-g^N) \equiv r^L$, $\frac{\partial u_i}{\partial g_i} < 0$ and thus his optimal public goods contribution is $\widetilde{g_i} = 0$.

For anyone with $(\alpha - \beta)/f'(E - g^N) \equiv r^H < r_i \le r^{max}$, $\frac{\partial u_i}{\partial g_i} > 0$, and thus his optimal public goods contribution is $\widetilde{g_i} = E$.

For $r^L \le r_i \le r^H$, $\widetilde{g_i} = \widetilde{\Delta g_i} + g^N$ and $\widetilde{\Delta g_i}$ meets $f'\left(\widetilde{\Delta g_i}\right) = (\alpha - \beta)/r_i$. Let ${f'}^{-1}$ be the inverse function of f', $\widetilde{g_i} = \widetilde{\Delta g_i} + g^N = {f'}^{-1}((\alpha - \beta k)/r_i) + g^N$.

Therefore, individual i's optimal contribution in a public goods game is

$$\widetilde{g_i} = \begin{cases} 0 & if\ 0 \le r_i < (\alpha - \beta)/f'(-g^N) \equiv r^L \\ {f'}^{-1}((\alpha - \beta)/r_i) + g^N & if\ r^L \le r_i \le r^H \\ E & if\ (\alpha - \beta)/f'(E - g^N) \equiv r^H < r_i \le r^{max} \end{cases}$$

From the definition of r^L and r^H, we can easily have $\frac{\partial r^H}{\partial g^N} < 0$ and $\frac{\partial r^L}{\partial g^N} < 0$, thus $\frac{\partial H(r^L)}{\partial g^N} < 0$ and $\frac{\partial H(r^H)}{\partial g^N} < 0$, where $H(r)$ is the cumulative distribution function of r.

And we can also easily know that $\frac{\partial (f'^{-1}((\alpha - \beta)/r_i) + g^N)}{\partial g^N} > 0$, therefore

$$\frac{\partial \int_0^{r^{max}} \widetilde{g_\iota} h(r_i) dr_i}{\partial g^N} > 0.$$

And since we have proved that $\frac{\partial \widehat{g^N}}{\partial W} < 0$, in villages with higher level of water scarcity (thus higher $\widehat{g_t^N}$), we expect to observe higher average contribution, less people who contribute little and more people who contribute all in a public goods game.