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Investment traps and resilience to shocks: An experimental study of Central Asian collective water governance

Iroda Amirova[1] | **Martin Petrick**[2,3] | **Nodir Djanibekov**[3]

[1]Centre for Policy Research and Outreach (CPRO) at Westminster International University in Tashkent (WIUT), Tashkent, Uzbekistan

[2]Center for international Development and Environmental Research (ZEU), Justus Liebig University of Giessen, Giessen, Germany

[3]Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Halle (Saale), Germany

Correspondence
Martin Petrick, Center for international Development and Environmental Research (ZEU), Justus Liebig University of Giessen, Germany and Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Halle (Saale), Germany.
Email: Martin.Petrick@agrar.uni-giessen.de

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Abstract

We theoretically and empirically investigate the investments of water users in a stylized local irrigation system. We model irrigation self-management as an interdependent interaction of users in an evolutionary game and study the resilience of the irrigation system. The theoretical model implies multiple stable equilibria at different efficiency levels. Users may be trapped in a low level of collective investment or succeed by being locked in a high collective investment level, implying an irrigation system resilient against external shocks. The study seeks to empirically identify such lock-ins in experimental interactions among Central Asian farmers. Furthermore, we inquire into whether a pre-play cheap talk opportunity with peer-monitoring or sanctioning treatments influence the self-reinforcing dynamic. Our findings revealed several stable states. Among these states, there are both low and high levels of efficiency, which we measure in the size of public good. Communication among users results in higher collective investment levels. However, this does not guarantee the complete elimination of inferior conventions from best-response play. Penalties crowded out the intrinsic motivation to cooperate as they reduced collective investment in both low- and high-level equilibria. Our findings imply that institutional settings tailored to each community can improve resilience to climate-driven perturbations in water resources.

KEYWORDS
Central Asia, experiment, multiple equilibria, resilience, water management

Résumé

Nous étudions théoriquement et empiriquement les investissements des usagers de l'eau dans un système d'irrigation local stylisé. Nous modélisons l'autogestion de l'irrigation comme une interaction interdépendante des usagers dans un jeu évolutif et étudions la résilience du système d'irrigation. Le modèle théorique implique plusieurs équilibres stables à différents niveaux

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d'efficacité. Les utilisateurs peuvent être piégés dans un faible niveau d'investissement collectif ou réussir en étant enfermés dans un niveau d'investissement collectif élevé, ce qui implique un système d'irrigation résistant aux chocs externes. L'étude cherche à identifier empiriquement ces blocages dans les interactions expérimentales entre les agriculteurs d'Asie centrale. En outre, nous cherchons à savoir si une opportunité de conversation bon marché avant le jeu avec des traitements de surveillance par les pairs ou de sanction influence la dynamique d'auto-renforcement. Nos résultats ont révélé plusieurs états stables. Parmi ces États, il existe à la fois des niveaux d'efficacité faibles et élevés, que nous mesurons par la taille du bien public. La communication entre les utilisateurs se traduit par des niveaux d'investissement collectif plus élevés. Cependant, cela ne garantit pas l'élimination complète des conventions inférieures du meilleur jeu de réponse. Les pénalités ont évincé la motivation intrinsèque à coopérer car elles ont réduit l'investissement collectif dans les équilibres de bas et de haut niveau. Nos résultats impliquent que les cadres institutionnels adaptés à chaque communauté peuvent améliorer la résilience aux perturbations climatiques des ressources en eau.

MOTS CLÉS

Asie centrale, expérimentation, équilibres multiples, résilience, gestion de l'eau

1 | INTRODUCTION

Improved individual and collective water management is widely deemed necessary to enhance climate resilience and meet future water demand (Rosegrant et al., 2009). According to Ostrom and Gardner (1993), a major challenge of surface irrigation water management is that a water user who has not invested in the infrastructure cannot be prevented from enjoying its benefits. At the same time, water extraction by one user will diminish another user's access to the common water resource. In such a social dilemma, individually rational actions carry external effects on other actors, thus leading to the degradation of the common resource and resulting in Hardin's (1968) "tragedy of the commons." This, in turn, translates into mid-term maladaptation of irrigation systems to climate-driven water scarcity. A better understanding of how institutions can promote and sustain cooperative decision-making in water management, which is the goal of the current study, can thus contribute new insights towards improved climate resilience.

In the following, we embed the concept of resilience in an evolutionary game of water infrastructure investment. Moreover, we empirically confirm the existence of resilient cooperation equilibria using a novel set of behavioural data collected among water users in Central Asia (CA). Finally, we show how this resilience is affected by both communication and penalty treatments included in the behavioural experiments, concluding that communication induces higher investment levels.

The present study considers the creation of irrigation infrastructure as a potential social dilemma. We analyse this dilemma both theoretically and empirically. In the theoretical section, we develop a noncooperative game to represent water users' decision-making in irrigation management. We add multiple iterations and multiple players and incorporate the logic of dynamic evolutionary game theory. In this way, we derive testable hypotheses on the dynamics of user interaction. In the evolutionary irrigation investment game, initial conditions determine whether the interaction will converge to a high- or low-level investment convention. In other words, the interactions are subject to lock-ins, which make the high-level convention resilient to shocks. We then ask whether communication and penalty treatments can overcome such investment traps and attain resilience in water governance. These peer-monitoring and sanctioning arrangements reflect the notions of self-governance and exogenous top-down rules, respectively (Amirova et al., 2019).

This study is based on the concepts of the supergame and peer monitoring in smaller groups in Taylor (1987), multiple equilibria in water governance in Madani (2010), and the assessment of multiple equilibria by using autoregressive modelling in Barret and Constas (2014) and Naschold (2012). However, we are the first to integrate the theoretical arguments of Taylor (1987) and Madani (2010) into the experimental approach of Cárdenas et al. (2011) and apply them to the CA setting.

So far, the experimental literature on collective water governance has focused on the *determinants of cooperation*. Cárdenas et al. (2011) were the first to develop and conduct irrigation games with Colombian and Kenyan common pool resource users. They attributed the observed variation in cooperative behaviour to the users' country of origin. Colombian users were more cooperative than Kenyans, and the communication treatment was more effective in Colombia than in Kenya. Similarly, Amirova et al. (2019) found that water users in Kazakhstan cooperated more than in Uzbekistan. However, the communication treatment in Uzbekistan was more effective than in Kazakhstan. Baerlein et al. (2015) revealed that Kyrgyz irrigation users performed better in terms of rules compliance, distribution, and equity in a self-governance setting. Roßner and Zikos (2018) found that homogenous farmers with similar land sizes in Uzbekistan were more cooperative than groups with heterogeneous land endowments. Otto and Wechsung (2014) show that the power asymmetry along the irrigation channel drove infrastructure investment and water withdrawal among water users in northern China. Javaid and Falk (2015) simulate traditional authorities and legal pluralism in Pakistan and claim that these very institutions explain the equal sharing norms that prevailed in their experiments. Janssen et al. (2012), in an experimental study of Colombian and Thai farmers, state that head-end users act as "stationary bandits." These players extract more than an equal share of a common pool resource but leave sufficient resources for the tail-end users to maintain their contributions to the public infrastructure.

In contrast to this previous literature, the present study explores the *dynamic stability of water user interaction* by theoretically deriving and empirically testing hypotheses about the resilience of such interaction from an evolutionary model of irrigation investment. By using field experimental data described in Amirova et al. (2019), the current study uses nonparametric local regression methods to graphically analyse the experimental data. It thus provides novel insight into the processes of cooperation or noncooperation in irrigation water management. Amirova et al. (2019) explore why cooperation happens among water users in Kazakhstan and Uzbekistan subject to short-term layers of information and long-term cultural determinants. Here we show how cooperation or noncooperation occurs and can be locked in at one or another convention. Rather than focusing on the determinants of cooperation, we trace the inherent dynamics of reaching different cooperative equilibria.

Our findings thus enable us to evaluate the institutional capacity for resilient water governance. Our evolutionary model identifies intrinsic attributes of water governance arrangements that determine their dynamic performance under shocks such as climate change. For example, the communication treatment, representing self-governance, increased the resilience capacity. On the other hand, the penalty treatments, representing an exogenous coordination mechanism, harmed the resilience capacity of water users. This insight is crucial for CA irrigated areas, where rural welfare depends on agriculture. The analysis sheds light on the reasons behind vicious circles of underinvestment in CA water infrastructure. Abdullayev et al. (2009) holds the top-down imposition of water user associations (WUA) responsible for their ineffectiveness and the emergence of alternative informalities in the Fergana Valley. Similarly, Veldwisch and Mollinga (2013) claim that WUA in Uzbekistan are more accountable to the state rather than to their members because the state uses them to monitor and regulate "state-ordered" agricultural production. Meanwhile, Yakubov (2012) asserts that due to the mix of different WUA approaches and models, both the CA governments and international donors lack clarity in understanding which models do or do not work. By using experimental data, our study is among the first to explain both theoretically and empirically how top-down initiatives weaken self-governance. Similarly, the findings improve our understanding of how endogenous rule setting enhances the chances of escaping low-investment traps. This, in turn, helps to illustrate the significance of bottom-up WUA in resilient water decentralization.

The next section models collective investment in irrigation infrastructure. After that, section 3 presents the logic of multiple dynamic equilibria and integrates the interplay of stylized institutional arrangements with the self-reinforcing investment traps into the model. Section 4 summarizes the main hypotheses of the study. Section 5 elaborates on nonparametric graphical analysis, based on which the results of the analysis are presented in section 6.

2 | MODELLING COLLECTIVE INVESTMENT IN IRRIGATION INFRASTRUCTURE

We model the investment decisions of water users in irrigation infrastructure in a highly stylized game setting.

Investing or abstaining from the investment are the strategies available to each player (see Amirova, 2019 for more details). In the real world, most of the interesting public goods provision dilemmas, including irrigation interactions, involve more than two actors. N-person games, therefore, could produce more practically relevant insights. We thus model water users' interactions by using a population composed of N farmers who interact in pairs to engage in irrigation investment activities. We simultaneously introduce *repetition* (of the same game), *retaliation* (tit-for-tat preferences), and *replication* (of the norms of successful players) to the N-person prisoners' dilemma (PD). We show how the interactions reach multiple equilibria of both mutual defection (abstaining) and mutual cooperation. Our modelling strategy follows evolutionary game theory modified from classical game theory to account for people's limited cognitive capacities (Bowles, 2004; Dixit & Skeath, 2004). Table 1 illustrates this extension of the game with repetition, retaliation (tit for tat), and replication, where a, b, c, and d are the payoffs, with the following conditional values $a > b > c > d$.

TABLE 1 Payoff of iterative, multi-farmer irrigation investment interaction with retaliation preference possibility

	Tit for tat	Abstain
Tit for tat	$\frac{b}{\rho}; \frac{b}{\rho}$	$d + (1-\rho)\frac{c}{\rho};$ $a + (1-\rho)\frac{c}{\rho};$
Abstain	$a + (1-\rho)\frac{c}{\rho};$ $d + (1-\rho)\frac{c}{\rho}$	$\frac{c}{\rho}; \frac{c}{\rho}$

Note: $a > b > c > d$; $\rho \in [0;1]$; assumption: N-person population of farmers endowed with two strategies.
Source: Adopted from Bowles (2004:242).

We assume, for simplicity, that the N-person population of farmers is endowed with two strategies only. One is tit for tat, that is, the player with such a trait will cooperate in the initial period and in all subsequent periods will do what the counterpart did in the preceding period of interaction. The second strategy is unconditionally abstaining from investment. The probability that the interaction will terminate is denoted by ρ. The range of ρ varies between 0 (game will repeat and resemble assurance game, with two Nash solutions) and 1 (game will terminate). We ignore the players' discount rates.[1]

We normalize the size of the farmers' population and denote the fraction of farmers who are of the retaliating (playing the tit-for-tat strategy) type with τ. Consequently, $(1-\tau)$ is the fraction of the farmers' population who are unconditionally abstaining. The expected payoffs for tit for tat and unconditional abstaining players are denoted with π^{T} and π^{A}, respectively, such as:

$$\pi^{\mathrm{T}} = \tau\frac{b}{\rho} + (1-\tau)\left\{d + \frac{(1-\rho)c}{\rho}\right\} \tag{1}$$

$$\pi^{\mathrm{A}} = \tau\left\{a + \frac{(1-\rho)c}{\rho}\right\} + (1-\tau)\frac{c}{\rho} \tag{2}$$

By Equations 1 and 2, we get τ^*, that is, the interior equilibrium share of tit-for-tat playing farmers:

$$\tau^* = \frac{c-d}{2c-a-d+(b-c)/\rho} \tag{3}$$

Figure 1 (solid lines) illustrates (1), (2), and (3). The distribution of chosen strategies varies within the population. While analysing the change in a single period ($\Delta\tau$),

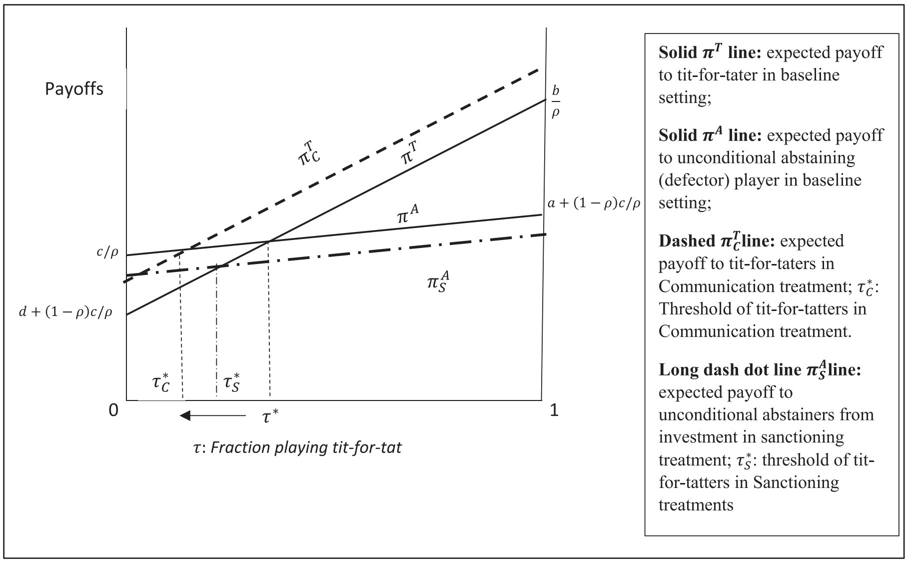

FIGURE 1 Expected payoff to strategies (traits). Role of conditional cooperation

we follow the assumption of monotonic updating of the individual strategies. This, in turn, implies that $\Delta\tau$ takes the signs of $(\pi^{\mathrm{T}} - \pi^{\mathrm{A}})$ as presented in Bowles (2004:409).

The situation in Figure 1 is subject to positive feedback as the payoff to either strategy is increasing the number of people taking the same action. Initial conditions produce persistent “lock-in” effects and lead the population into multiple equilibria or “traps” as in Figure 1. In such traps (absorbing stationary states at $\tau = 0$ and $\tau = 1$), small deviations in strategies ($\Delta\tau$) are not sufficient to shift the interaction from one state to another, unless $\Delta\tau > \tau^*$ or $\Delta\tau > 1 - \tau^*$ respectively. The steady states are self-correcting. However, the multiple stable equilibria can still be displaced through exogenous shocks, mutations, and non-best-response play (Bowles, 2004:12).

The resilience concept is an inbuilt notion of the evolutionary model. We adopt Barrett and Constas' (2014) definition of resilience as a population's ability to return to the high-payoff equilibrium after a shock. The time path of investment in irrigation infrastructure can be nonlinear and uncertain. In this way, water governance resilience emphasizes the stochastic dynamic nature of public good generation.

Achieving a cooperative outcome in smaller groups is more realistic than in bigger groups. Taylor (1987:105) explains the size effect on peer monitoring, as it is a major enabling factor for players to sustain conditionally cooperative interactions. With increasing group size, however, it becomes a tedious task for the interactors to engage in mutual monitoring. Consequently, in groups of intermediate size, positive and negative sanctioning mechanisms could be essential to facilitate the self-reinforcing cooperative outcome.

Communication may provide the players with trust and hence reputation-building opportunities. Communication among players enables them to be conditionally cooperative, which then increases the proportion of tit-for-tatters in the population. This effect of communication, through its peer-monitoring specification, is reflected in Figure 2 by an upward shift in the expected payoff for tit for tat denoted with $\pi_{\mathrm{C}}^{\mathrm{T}}$. The basin of attraction for the cooperative convention is increased $\left(\tau_{\mathrm{C}}^* < \tau^*\right)$.

Sanctions, on the other hand, diminish the payoffs for unconditional defectors. The long dash-dot line in Figure 1 (denoted with $\pi_{\mathrm{S}}^{\mathrm{A}}$) conveys this notion by shifting down the expected payoff of unconditional abstaining $\left(\pi_{\mathrm{S}}^{\mathrm{A}} < \pi^{\mathrm{A}}\right)$. This shift, in turn, increases the basin of attraction of the cooperative convention $\left(1 - \tau_{\mathrm{S}}^*\right) > (1 - \tau^*)$. That is, sanctioning also facilitates the cooperative convention.

Five major insights are, first, that the repetition of the one-shot PD makes cooperation possible as a best-response play of rational individuals. Second, the existence of conditional cooperators playing a tit-for-tat strategy is another factor enabling cooperation. Third, the repeated PD can end up in multiple equilibria. Fourth, the initial state of the interaction plays a key role in determining the final equilibrium (i.e., history matters). Finally, peer monitoring and sanctioning (Figure 1) may enable conditional cooperation and increase resilience, as they make the cooperative convention more attractive.

3 | GRAPHICALLY DEPICTING MULTIPLE EQUILIBRIA

3.1 | Multiple dynamic equilibria in the recursion diagram

Figure 2 presents a recursion diagram in the players' investment space, which we adopt and adjust from Carter and Barrett (2006) and Barrett and Constas (2014) to conduct our empirical analysis. The recursion function denotes the expected collective investment decision path.

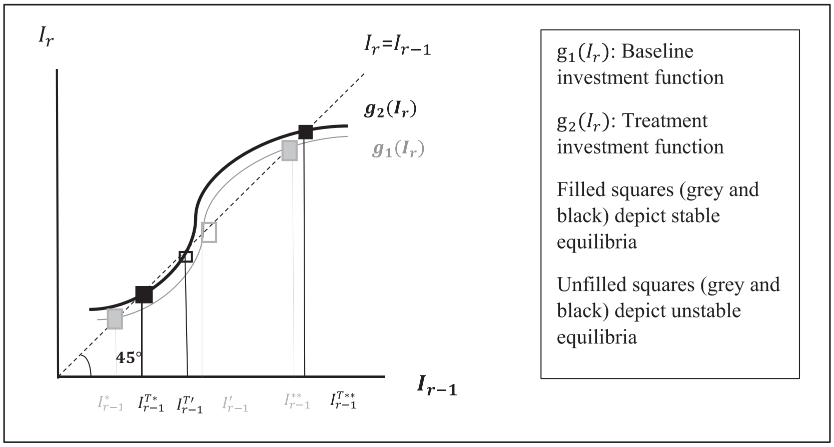

FIGURE 2 Stylized investment diagram for games' stable and unstable equilibria with treatments. *Source*: adopted from Carter and Barret (2006)

The vertical axis shows collective investment per session in the current round (I_r), and the horizontal axis illustrates collective investment per session in the previous round (I_{r-1}).

The function $g_1(I_r)$ (grey line) represents the case of multiple dynamic equilibria where the dynamic investment decision path crosses the 45-degree line several times. I'_{r-1} indicates a dynamically unstable equilibrium, that is, a collective investment threshold, also called a saddle point. If collective investment decisions are above this threshold, players can be expected to increase their collective investment decisions (i.e., more than in previous rounds) until they reach the stable equilibrium I^{**}_{r-1}.

Figure 2 illustrates interaction with two absorbing (nonergodic) investment conventions [low (defective): I^{*}_{r-1} and high (cooperative): I^{**}_{r-1}], as in Figure 1. In this model, resilience is represented by the existence of such desirable and self-stabilizing equilibria. Moreover, the distance of the favourable equilibrium to the next saddle point that will trigger a convergence to a lower-level equilibrium measures the degree of resilience. We will analyse the curvature of the recursion diagram using experimental data from a field experiment below.

3.2 | Treatments and dynamic equilibria

The deliberate introduction of non-best-response play or intentional collective action into the game could break the deterministic dependence of the outcomes on the initial state (Bowles, 2004). We consider two types of treatments: peer-monitoring enabling communication and the deployment of sanctions against defectors.

Communication gives a chance to devise agreements, even though they are nonbinding, on group interest favouring decision-making and strategies to tackle the defectors (Ostrom & Walker, 1991). In other words, the communication treatment provides the opportunity for the players to collectively decide to change the mode of play by increasing mutual trust. Given a "bad" (low-investment) equilibrium, self-organized non-best responses by players are necessary to navigate into the basin of attraction of the "good" (high-investment) equilibrium (Bowles, 2004).

Penalty treatments are also assumed to induce non-best-response play among farmers and move their interaction towards a mutually beneficial convention.

The analytical framework for both communication and penalty treatments is demonstrated in Figure 2, where the $g_1(I_r)$ (baseline) function shifts upward [$g_2(I_r) > g_1(I_r)$]. The resulting I^{T*}_{r-1}, $I^{T\prime}_{r-1}$ and I^{T**}_{r-1} respectively depict the stable low level of collective investment, an unstable threshold equilibrium, and a stable high level of collective investment for all treatments.

In the case of the communication treatment, the payoff to the retaliation strategy increases due to positive feedback. Communication and hence peer monitoring serve to increase the fraction of tit-for-tatters through the trust-building mechanism, which then increases the basin of attraction of the high-investment convention. Because penalties decrease the payoff to the abstaining strategy (as in the long dashed dot line of Figure 1), the basin of attraction of the investment strategy increases. These increases in the basin of attraction (of communication and penalty treatments) are accordingly spelled out in the upward shift of the investment path in Figure 2.

4 | KEY HYPOTHESES

According to the lock-in effect, we predict that if a game starts with a low level of joint contributions, this type of interaction will be locked in (trapped), and the interacting parties stay in a no-investment or low-joint-investment convention until the end of the game.

Hypothesis 1 (H1):. There are multiple equilibria in interactions. Among those multiple equilibria, there are low and high stable equilibria (collective investment levels) towards which the interactions move and at which the interactions can be locked in depending on the level of collective investment in the previous round.

Furthermore, building on our arguments above, we hypothesize that peer monitoring or sanctioning affect the self-reinforcing investment traps.

Hypothesis 2 (H2):. The communication treatment increases the level of cooperation compared to a baseline without treatment and makes the group interaction more resilient to shocks.

Penalties decrease the payoff to the abstaining strategy, which then increases the basin of attraction of the high-investment (cooperative) strategy (Figures 1 and 2).

Hypothesis 3 (H3):. The penalty treatment increases the level of cooperation compared to a baseline without treatment and makes the interaction more resilient. Both low-investment (defective) and high-investment (cooperative) levels are higher under penalties.

5 | DATA AND METHODS

5.1 | Experimental setting

We collected the data for the following analysis during a field experiment with water users in rural Kazakhstan and Uzbekistan in 2016. Based on experimental protocols developed by Cárdenas et al. (2011), farmers obtained an endowment to be allocated either for private consumption or to a public irrigation fund. Depending on the size of the irrigation fund, water availability and thus returns from farming for individual farmers increased. In some sessions, we allowed farmers to communicate about their allocation (“communication treatment”) or penalized them if they did not contribute (“penalty treatment”). The data include results from 235 farmers in a total of 47 sessions with 21 rounds of allocation decisions in each session. In sessions with treatments, the treatments started from round 12 onwards. We recruited the players from 12 villages of South Kazakhstan and Samarkand, out of which 120 participants were from Samarkand's 6 villages. We provided a show-up fee equivalent to 2 euro in local currency. Furthermore, the participants could earn more during the experiment, depending on their performance. Their performance, in turn, was measured in coupons. Each coupon had an exchange rate equal to 0.02 euro. More than 98% of Samarkand and 86% of South Kazakhstan players were male farmers.

Each experiment session had two stages: (a) investment and (b) water allocation. This paper focuses on the first stage of the game in which the water users decide about the construction and rehabilitation of the irrigation infrastructure as a public good.

We use data on Kazakhstan and Uzbekistan because our overall research programme investigates the conditions and effects of different reform trajectories in CA water management (Amirova et al., 2019). In this particular study it generates variation in the socioeconomic stratification of the players and their experience in water management. The field experiment kept the crucial institutional parameters constant for all players, while it referred to their everyday practice of water management. Other than in Amirova et al. (2019), the institutional differences between the two countries are of secondary interest to us here. For more details about the data and the experimental setting see Amirova et al. (2019).

5.2 | Nonparametric regression analysis

We apply nonparametric local regression to these data to investigate the dynamic properties of the collective investment choices depicted in Figure 2. Local regression is an approach to fitting curves and surfaces to data by smoothing. The fit at a particular independent variable is the value of a function fitted only to those observations in the neighbourhood of that variable (Cleveland & Loader, 1996).

With I_r the collective investment level of session s at round r, Equation 4 depicts the dynamic autoregression of a session's average investment nonparametrically for some unknown mean and variance function $g(\cdot)$, without making assumptions about the functional form of $g(\cdot)$.

$$I_r = g(I_{r-1}) + \varepsilon_r \tag{4}$$

Smoothing via local polynomials is one method among many others, and estimators fall into the category of nonparametric regression. Local polynomial regression involves fitting the response to a polynomial form of the regressor via locally weighted least squares.

In local polynomial regression, the choice of the polynomial degree and the bandwidth (how wide the local neighbourhood should be) is crucial and involves a trade-off between bias (misreporting the shape) and variance (lack of precision). A higher degree will generally produce a less biased but more variable estimate than a lower degree. It has been stated that odd-degree polynomials outperform even degrees, but ruling out even degrees is also not recommended (Cleveland & Loader, 1996). Table 2 provides a summary of the chosen polynomial degree and bandwidth to model data from baseline and treatments of irrigation game experimental sessions (see Appendix 1 and more details in Amirova, 2019).

Nonparametric techniques relax the restrictive functional form assumptions of standard regression. At the same time, we acknowledge an obvious shortcoming of this method: In the bivariate case, it cannot control for other confounding factors of current investment

TABLE 2 Polynomial degree and bandwidth values selected for smoothing analysis

	Using the eyeball method, we chose:	
Irrigation games' rounds 12–21	**Polynomial degree**	**Bandwidth**
Baseline	3	3.23
Communication	1	2.07
Low penalty	1	1.18
High penalty	2	1.65

Source: From Figure A1, Figure A2, Figure A3, Figure A4. More details are available in Amirova (2019: 156–158).

outcomes (Fan & Gijbels, 1996). Nevertheless, we believe that the inferences we get from such bivariate nonparametric regression analyses serve to check for the existence of multiple equilibria in farmers' collective investment decisions in irrigation infrastructure.

6 | RESULTS

6.1 | Overview

We analyse each game session, including baseline sessions, by dividing the observations into two stages. The first stage captures observations generated between rounds 1 and 11. The second stage captures observations generated between rounds 12 and 21, that is, the treatment rounds. We also compare the first and second stages for baseline observations. Isaac et al. (1985) explain that with more iterations of interactions, participants start to understand (learn) the rules of the game better. As a result, the interaction could move towards the convention representing narrow self-interest (low levels of collective contributions). Inter-stage comparison of the observations in baseline games allows us to capture this pure learning effect. Similarly, inter-game comparison of the second stage of the baseline with the second stage of treatment games enables us to capture treatment effect across games.

Figures 3, 4, 5, and 6 present the autoregressive nonparametric model of investment relationship for baseline, communication, low-penalty, and high-penalty irrigation games, respectively. Figures 3, 4, 5, and 6 are empirical representations of the stylized diagram illustrated in Figure 2.

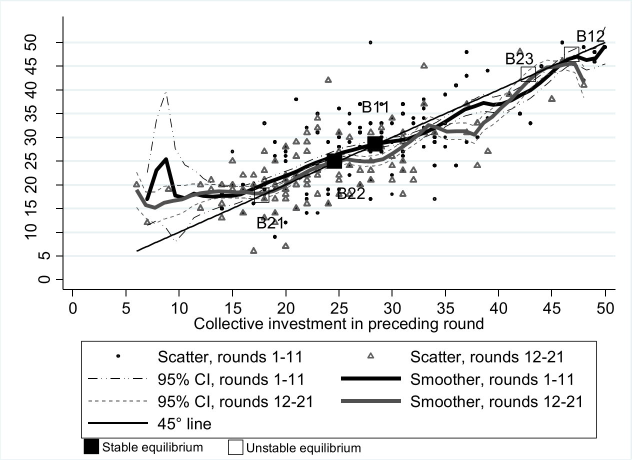

FIGURE 3 Collective investment outcomes in baseline game

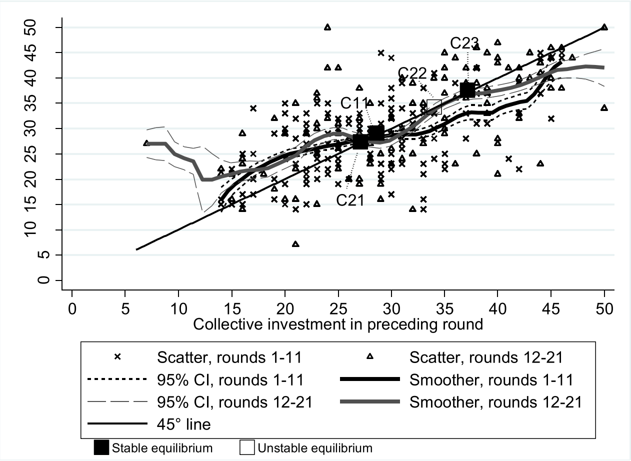

FIGURE 4 Collective investment outcomes in the communication game

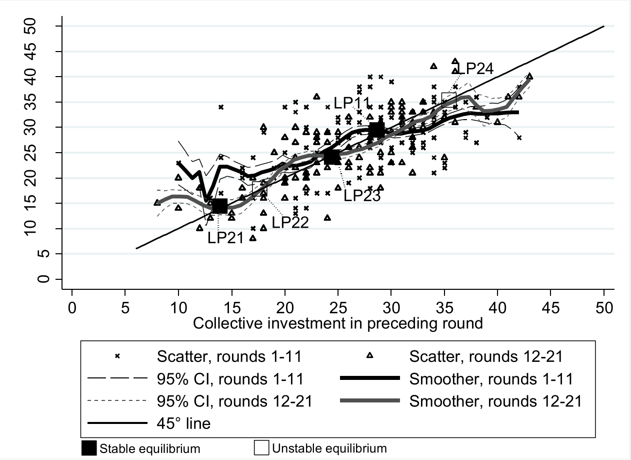

FIGURE 5 Collective investment outcomes in the low-penalty game

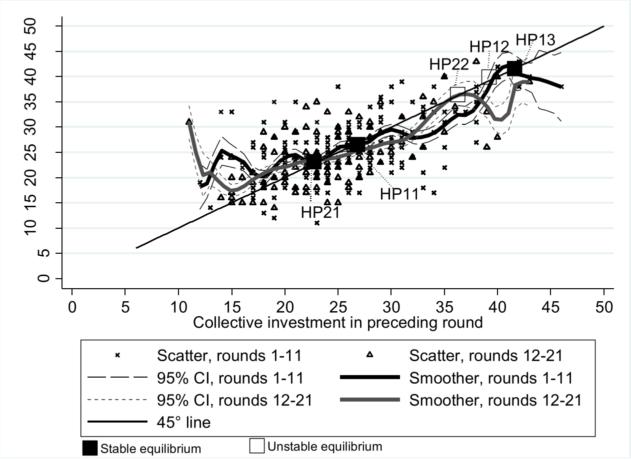

FIGURE 6 Collective investment outcome in the high-penalty game

6.2 | Baseline: H1

The baseline game demonstrates that there are multiple equilibria (at B11, B12, B21, B22, and B23) in the investment decision path. Among those equilibria, some are stable (B11, B22), and some are unstable (B12, B21, B23). Equilibria B11 (in the first half) and B22 (in the second half of the baseline game), denoted with filled squares, depict situations of lock-in in the baseline setting. Consequently, we confirm H1.

Table 3 summarizes the approximate numeric values of the denoted points of the local polynomial nonparametric regression across baseline and treatment games. In baseline games with more rounds of interactions, the equilibrium level of investment decreased from 29 to 25. This finding supports Isaac et al. (1985) regarding the learning effect, that with more iterations of interaction, people learn the setting better, and their decisions start to approach the Nash solution.

6.3 | Communication treatment: H2

We test our H2 via the graphical multiple dynamic equilibria analysis as well. Figure 4 presents the autoregressive nonparametric model of the investment relationship for communication irrigation games. We compare the number of collective coupons of investment denoted with respective alphabetical letters in the baseline as opposed to the communication game when we are comparing inter-game results. We consider collectively invested coupons in the communication game's first stage with the second stage. We can test H2 in both inter-game and intra-game context. We refer to Table 3 in these comparisons.

The value of the B22-stable equilibrium (baseline) is compared with the value of the C21-stable equilibrium (communication). As $27 > 25$, we confirm H2 in the inter-game comparison. The magnitude of cooperation in communication treatment games is higher than in baseline irrigation games. There is a clear red (scatter) dominated cloud of dots on top of the C23-equilibrium and a black-dominated one below, establishing the upward shift due to the communication treatment (Figure 4).

In intra-game comparison, the C21-equilibrium's collective coupons (27) are less than at the C11-equilibrium (29). However, there is a second stable equilibrium in the communication treatment sessions, denoted with C23. C23-convention coupons (37) are more than in the C11-equilibrium (29). Accordingly, we confirm H2 in the intra-game comparison. When farmers had the opportunity to self-organize through group deliberation and bargaining, they attained higher levels of collective

TABLE 3 Summary of local polynomial nonparametric autoregressive regressions' selected points

	Baseline					**Communication**				**Low penalty**					**High penalty**				
Points in the figures	**B11**	**B12**	**B21**	**B22**	**B23**	**C11**	**C21**	**C22**	**C23**	**LP11**	**LP21**	**LP22**	**LP23**	**LP24**	**HP11**	**HP12**	**HP13**	**HP21**	**HP22**
Approximate location (amount of collected coupons of investment)	29	47	18	25	44	29	27	34	37	29	14	18	24	35	26	40	42	23	36
Stable equilibrium (Y: Yes; N: No)	Y	N	N	Y	N	Y	Y	N	Y	Y	Y	N	Y	N	Y	N	Y	Y	N

Note: Key to equilibrium labels *Xij*: *i* is the stage of the game (stage 1: rounds 1–11; stage 2: rounds 12–21) and *j* is the position of equilibrium in ascending order from left to right (with respect to 45-degree line).

investment. We confirm the result of Amirova et al. (2019) that CA water users displayed the potential to realize endogenous cooperation and thus higher investment levels. However, just like in reality, where not all deliberations lead to better rules, not all communication opportunities have led to higher cooperation levels. Some interactions converged towards the C23-equilibrium (high), and others converged towards the C21-equilibrium (low).

In both C11 and C21, the group interaction is resilient, as both are stable equilibria. The difference in investment levels between the two is small. However, a completely new, stable equilibrium C23 with much higher investment levels emerges under communication. While the small distance to the tipping point C22 indicates that its degree of resilience is not very high, its mere existence makes the communication scenario superior to the baseline.

6.4 | Penalty treatments: H3

We hypothesized that penalties decrease the payoff to the abstaining strategy, which then increases the basin of attraction of the high-investment (cooperative) strategy. Therefore, the cooperation level in penalty games is higher than in baseline games (H3). Figure 5 presents the autoregressive nonparametric model of investment relationship for low-penalty irrigation games. It is an empirical representation version for low-penalty treatment of the stylized investment diagram illustrated in Figure 2.

In *intra-game* comparison, neither of the stable equilibria (denoted with LP21 and LP23) are more efficient than the LP11-equilibrium. Consequently, we reject H3 in this particular setting. Moreover, we reject H3 when we make an *inter-game* comparison, as both LP21- and LP24- equilibrium values of investment (14 and 24) are less than the B22-equilibrium (25) value (Table 3, Figures 3 and 5). Our finding is consistent with the findings of Andreoni and Varian (1999).

Following the results of Tenbrunsel and Messick (1999), regarding the severe versus weak sanctions' respective stronger and weaker effects on cooperative behaviour, we separately test H3 for low- and high-penalty treatments. For low penalty, we failed to confirm H3 in both inter-game and intra-game comparison. Figure 6 presents the autoregressive nonparametric model of investment relationship for high-penalty irrigation games.

In intra-game comparison, we observe that high-penalty treatment did not improve cooperation levels. Instead, as the values of the HP11- and HP13-equilibria (26 and 42, respectively) are greater than the HP21-equilibrium (23), the treatment worsened the cooperation. In other words, in the first stage, there was a possibility to converge towards a high level of collective investment because of the HP13-equilibrium (Figure 6). But when we introduced the treatment, that possibility disappeared. Accordingly, we reject H3 for high-penalty games in intra-game comparison. Our finding supports the argument about third-party induced or economic incentives' counterproductive effects on the cooperation motives of individuals (Bowles, 2008).

When we compare the high-penalty treatment with the second stage of the baseline game, we see that the B22-equilibrium amount (25) is greater than the HP21-equilibrium amount (23) of collective investment in irrigation infrastructure (Table 3). Hence, we reject H3 for high-penalty games in the inter-game comparison context as well.

To sum up, we reject H3 for low- and high-penalty treatment games based on both within-game and between-game comparisons. The treatment games also exhibit a lower resilience than the baseline, as they indicate a stronger dynamic towards lower investment levels.

7 | DISCUSSION AND CONCLUSION

Investment in irrigation infrastructure has widely been described as a social dilemma, suggesting that water users end up in a “tragedy of the commons” characterized by low investment outcomes. This has, in turn, implications for the resilience of the water sector to climate-induced water shortages. In this paper, we argue that this social dilemma may exhibit multiple equilibria, in which case the seemingly inevitable tragedy is turned into a coordination problem that may be easier to solve. We establish this possibility theoretically and provide supporting evidence from a field experiment among CA farmers.

Using these behavioural observations, we found that decisions in experiments are subject to multiple absorbing states with both inferior and superior efficiency measured in the size of the public good. This finding confirms the existence of multiple equilibria in water governance and hence serves the evidence of positive and negative feedback effects. The analysis showed how the institutions do (or do not) offer solutions to the lock-ins. In other words, these findings may explain why some water communities stay in a noncooperation trap. They shed light on which institutions provide better solutions with fewer water users trapped in low-investment conventions. Communication results in higher collective investment levels but does not guarantee the complete elimination of inferior conventions from best-response play.

Our interpretation is that the irrigation game with a communication opportunity still requires costly coordination. Which outcome, inferior or superior, will prevail depends on the ability of the players to bargain. Bargaining power originates from social status, wealth, or the ability to manipulate ideology (Ensminger, 1992). Further empirical studies highlighting the diverse political (Otto & Wechsung, 2014), biophysical (Kasymov & Hamidov, 2017), economic (Roßner & Zikos, 2018), and cultural (Amirova et al., 2019) endowments of water users explain why recent governance innovations in common pool resources in CA result or fail to result in the desired outcomes. On the other hand, penalties crowded out the intrinsic motivation to cooperate as they reduced collective investment in both low- and high-level equilibria. This finding implies that resilience to climate-driven perturbations in water resources can be improved by well-tailored institutional settings. Our arguments about the existence of inefficient lock-ins and the significance of endogenous rule devising for better cooperative outcomes may also apply to social dilemmas in other regional contexts. For example, they may explain why pasture user committees are entrapped in socially inefficient conventions (Kasymov & Thiel, 2019).

Our study replicates the experimental findings and the protocol developed by Cárdenas et al. (2011) in a CA setting and thus confirmed its strong internal validity. However, the experimental subjects were not selected randomly; treatment allocation was the only randomized action. Due to this sampling strategy and general limitations in the external validity of field experiments, our results should not be generalized out of hand. Our conclusions are preliminary and need to be further investigated, for example, using case studies or large N-studies.

The existence of multiple equilibria in the irrigation game experiments provides us with the hope that resilient cooperation in water governance can be the outcome of best-response play. However, because inferior conventions did not disappear altogether, water users are still at risk of being trapped in low investment conventions and thus vulnerable to climate-caused water shortages. A range of institutional arrangements carry the theoretical potential to coordinate the users in favour of a cooperative resilient solution. Institutional arrangements that allow user participation, give users the power to bargain, and enable endogenous rule-making may break the vicious circle of underinvestment in irrigation infrastructure and thus enhance the resilience of water governance in CA.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Iroda Amirova https://orcid.org/0000-0003-3590-6796

ENDNOTE

[1] The discount rate is a factor that discounts (discriminates) future payoffs, and the rate takes a value between 0 and 1. A zero discount rate is when the player ignores the future payoff and is determined by only the current round payoff. A discount rate equalling one implies that the player treats the next period payoffs equally to the current payoff (Dixit & Skeath, 2004: p385).

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APPENDIX 1

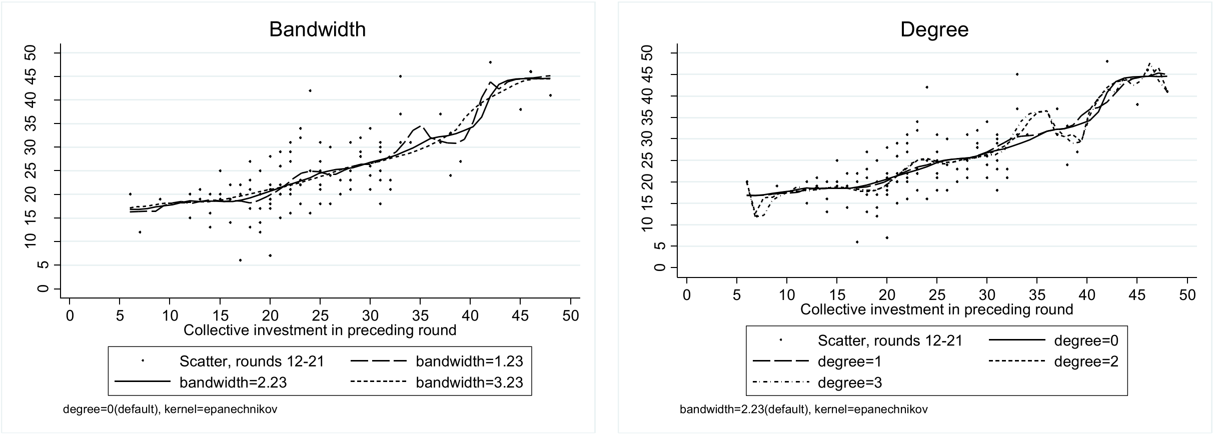

FIGURE A1 Sensitivity analyses to select bandwidth and degree, baseline

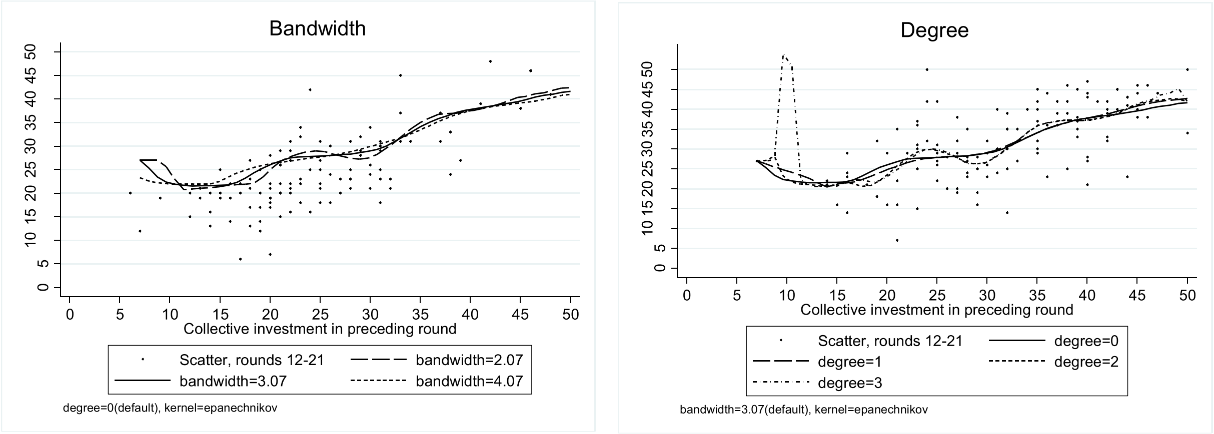

FIGURE A2 Sensitivity analyses to select bandwidth and degree, communication

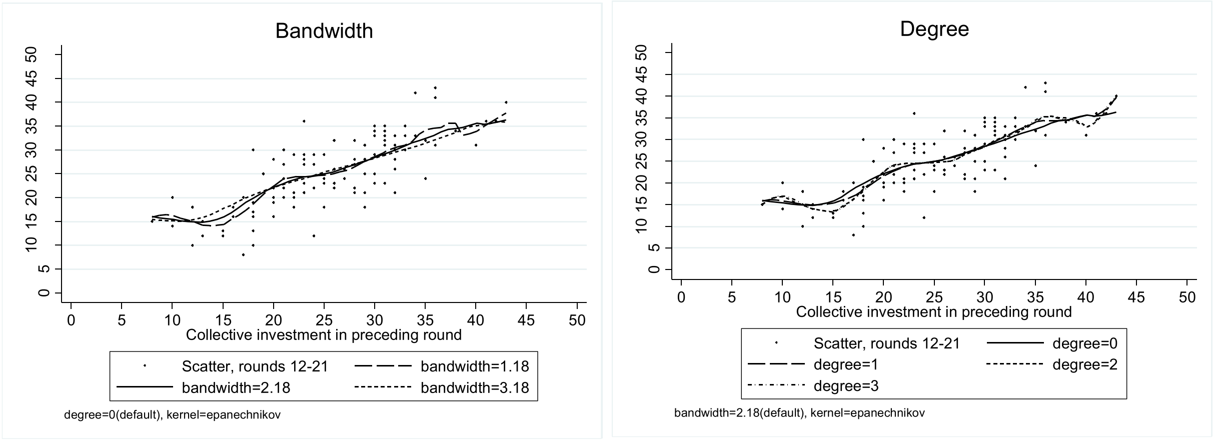

FIGURE A3 Sensitivity analyses to select bandwidth and degree, low penalty

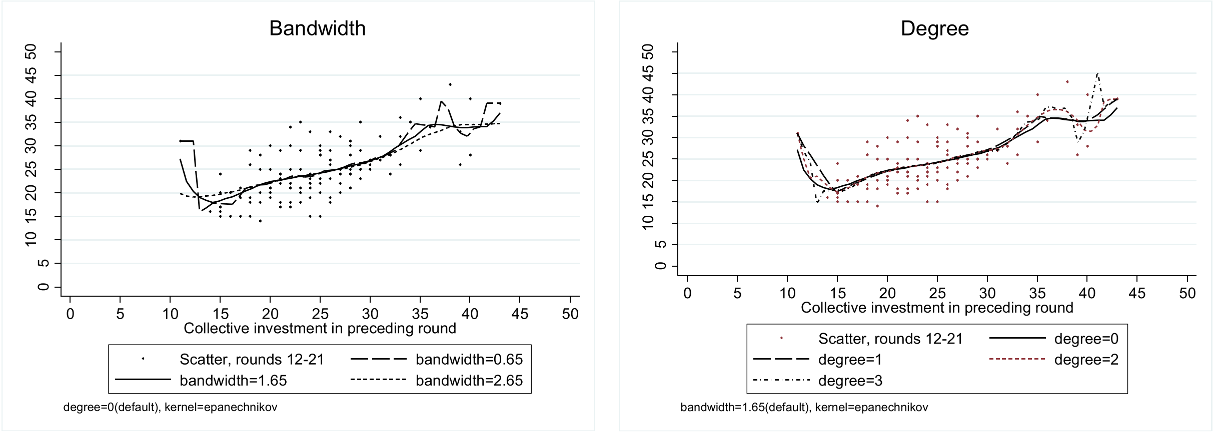

FIGURE A4 Sensitivity analyses to select bandwidth and degree, high penalty