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Path dependencies and institutional traps in water governance – Evidence from Cambodia

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ABSTRACT

In many parts of the world, social norms of cooperation are an important element of decentralized water governance carried out by local communities. Field work in Cambodia documents that some villages have well-functioning water infrastructure and high cooperation, while others have poor infrastructure and low cooperation. We hypothesize that this outcome may be the result of an institutional trap, where initial lack of cooperation leads to poor infrastructure, water scarcity, and low revenues, undermining cooperation further in a vicious cycle. Conditional cooperation may explain why some communities can overcome such an institutional trap. We develop an agent-based model, in which users have to decide how much to contribute to water infrastructure and how much water to extract. This decision is based on economic considerations, but also reputational concerns, where own decisions are evaluated against the social norm. We find that the system features alternative stable states, depending on initial conditions. If the system has initially a functioning water system and high cooperation, prosperity can be created, which facilitates further investments in water infrastructure, fostering cooperation further. If the community features initial scarcity, cooperation is relatively costly, undermining investments in water infrastructure, leaving the community in an institutional trap.

1. Introduction

In many parts of the world, water governance is carried out by local communities (Ostrom, 1990; Lansing et al., 2017). Social norms of cooperation have been identified as key mechanisms to ensure sufficient contributions to maintain a functioning water infrastructure, and also to restrain excessive water use (Lam, 1998). Yet, most studies on self-governance of common pool resources focus on either extraction of common-pool resources (CPR) or investment in public goods (PG) provisioning, but rarely both combined. In many real-world situations, however, both problems are strongly coupled (Gardner et al., 1990). This is especially the case for an irrigation system (Tang, 1992). For example, farmers often need to collectively invest in infrastructure maintenance (PG) so that enough water (CPR) can be maintained in an irrigation system and used by community members. Studying both problems separately thus may undermine the understanding of system dynamics and how it is affected by biophysical and social attributes, but also incentive structures underlying the decisions of harvesting and investing to the infrastructure (Yu et al., 2015). Experimental evidence shows that small group of individuals can overcome the interlinked social dilemmas in an irrigation setting of unequal resource access if communication is allowed (Janssen et al., 2011b), and if the resource variability is not too high (Anderies et al., 2013). The question to what extent the coupling of social dilemmas, in particular the contribution to water infrastructure (PG) and restraining from extracting too much water (CPR), co-evolve endogenously and affects cooperation is the key contribution of this paper.

In this paper, we analyze the co-evolution of social norms of cooperation with regard to (i) investment in water infrastructure and (ii) water extraction with an agent-based model. We observe strong path-dependencies where initial scarcity and poor infrastructure makes the personal sacrifice of cooperating relatively costly. As a result, cooperation erodes, leading to an institutional trap of poor water infrastructure and low cooperation. The opposite can emerge with initial abundance, where cooperation is relatively cheap, and in the long run well-maintained infrastructure, high cooperation, and general prosperity can be observed. Previous research suggests that a system comprising of more conditional cooperators— those who try to align own behavior with the behavior of others— is more likely to be successful in managing common pool resources (Rustagi et al., 2010). This correlation is

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supported by field work carried out in Cambodia and presented here. However, establishing causality from observational data is a challenge, and our modeling work provides some insights in this regard. While conditional cooperation is typically studied in an experimental or empirical setting, formalizing it in a dynamic framework is not widely considered; but see Richter and Grasman (2013). We formalize conditional cooperation in the model through a reputational mechanism. Individuals have an intrinsic motivation to comply with social norms, and thus deviating from the social norm generates disutility due to psychological costs. Aligning one's behavior with the social norm leads to utility gains (Fehr and Schurtenberger, 2018). One of the main reasons for such psychological cost arising from non-compliance with social norms is due to an internal motivation to preserve a positive self-image or reputation in the society (Brekke et al., 2003; Fehr and Schurtenberger, 2018), which is rooted in the desire to uphold a certain self- or group-identity (Akerlof and Kranton, 2000; Brekke and Howarth, 1998). Cooperative behavior is socially desirable and thus leads to higher reputation, while selfishness (so-called defection) is socially undesirable, which thus leads to lower reputation. Reputational considerations can facilitate cooperation among different partners, especially if the social image or reputation of an individual is known within the community (Nowak and Sigmund, 1998; Milinski et al., 2002). Thus, at the heart of social norm of conditional cooperation lies the moral motive to align own behavior with social norms at large.

There are some studies that have analyzed coupled social dilemmas arising from both CPR extracting and investing to a PG before (Botelho et al., 2015; Solstad and Brekke, 2011). Solstad and Brekke (2011) model the coupled social dilemmas as a two-stage sequential game, in which income surplus from extracting a CPR in the first stage is used for buying a private good and contributing to a PG in the second stage. They find that the possibility to provide the PG serves as a collective interest and hence can help to overcome the social dilemma in CPR extracting. Their results rest on the assumption that in equilibrium, at least some individuals contribute to the public good due to the incentive structure of the game. Economic calculus will determine that the marginal (private) benefits equal the marginal (private) costs of providing the public good. Those individuals who will be richer after the first stage will contribute more as the marginal value of money decreases with wealth. This implies that there is no incentive to become richer by not cooperating in the first stage. This is also reported in irrigation experiments where asymmetric access to resource is considered. Head users in the irrigation system are better off cooperating by not taking too much water relative to the tail users, due to threat of the later not providing the investment to infrastructure maintenance (Janssen et al., 2011a; Anderies et al., 2013). Botelho et al. (2015) expand the model of Solstad and Brekke (2011) and test it in a laboratory setting. For both papers, the sequential nature of the social dilemma is salient, and so is the assumption that at least some individuals will have an incentive to contribute. In a natural setting, however, both assumptions may not be met. Also, in reality the benefit structure of water infrastructure, or PG more generally, is often nonlinear and exhibits thresholds, which is what we consider here. In the next section we present the case of water governance in Cambodia and motivate our model with stylized facts from field experiments. In section 3, the agent-based model will be presented, before presenting the results in section 4. Finally, section 5 concludes.

2. Conditional cooperation and water governance in Cambodia

In Cambodia, irrigation is a key element of water governance, as it is salient for small-scale farming, which is very prevalent in the rural areas. Such a system depends largely on collective action of farmers. In many villages, a *Farmer Water User Community* (FWUC) is present as a self-governing institution and plays a main role in regulating water sharing among farmers, as well as collecting contributions to infrastructure maintenance. The success of the FWUC in maintaining a high quality infrastructure to safeguard water availability is mixed. While in some places the water infrastructure is well-functioning, in others the infrastructure is dysfunctional, due to underlying differences in governance and institutional structure (Mak, 2017). The mutual feedbacks between individual actions and institutions lead to a complex institutional structure, best described as 'institutional bricolage' (Sakketa, 2018), where institutions are the emergent outcome of individual decisions and social interactions. In Ethiopia, field evidence suggests that the presence of conditional cooperators in the system could explain the success in commons forest management (Rustagi et al., 2010). Along the same lines, we hypothesize that the success of user communities to maintain water infrastructure could be linked to conditional cooperation. We explored this in the Kampong Chhnang province of Cambodia, where we run lab-in-the-field experiments with farmers to study conditional cooperation, followed by a survey asking participants to elaborate on their experience with resource scarcity, observed infrastructure quality, and how many users contribute to infrastructure maintenance. The study was reviewed by the Social Sciences Ethic Committee of Wageningen University and registered as a pre-analysis plan; see Richter et al. (2020). For more details on the study area, the conditional public goods game, and the complete survey, please see Schuch et al. (2021).

To measure conditional cooperation, we used the same game as Rustagi et al. (2010). In the game, subjects were endowed with 6 bills of 1000 KHR[1] and were asked to make seven decision rounds on how much to contribute to the public good, knowing what the partner contributes. Using the hierarchical cluster analysis (Fallucchi et al., 2018), the subjects can be classified into five groups: low, medium, and high unconditional cooperators, conditional cooperators, and 'other'; see Schuch et al. (2021) for implementation and experimental procedure. Subjects who are classified into the 'other' behavioral type are those whose contribution scheme does not have a clear pattern. Among these behavioral groups, we are interested in the role of conditional cooperators, who are the ones who try to match the contribution of partners.

Overall, we conducted the games in 21 villages, spread out across three communes. In total, 302 participants played the games (on average, 14 people per village), and 282 participated in the structured survey interviews. Based on the responses, we calculated per village (i) the quality of the irrigation infrastructure, (ii) the contributions to water infrastructure maintenance, (iii) experienced water scarcity, and (iv) the share of conditional cooperators. We asked participants to assess the overall quality of the water infrastructure (e.g. canal system and dam) – how well-maintained it is – in their own village on a five-point Likert scale, where 1 means very poor, and 5 is excellent. We then calculated the average score per village. Also, we asked participants how much money they paid for getting water for irrigating their rice field in their village. Regarding water scarcity, we asked how many times the household experienced irrigation water scarcity in the past 5 years. We then calculated the average reported number of water scarcity events experienced per village.

2.1. Stylized facts from field experiments

Based on the field experiments, Fig. 1 shows that the presence of conditional cooperators is positively associated with better institutional performance and less water scarcity. First, villages that are composed of more conditional cooperators have better quality of infrastructure (Fig. 1a). Second, villages that comprise a large number of conditional cooperators, have more people reporting to pay for water infrastructure maintenance (Fig. 1b). This suggests that conditional cooperation is positively correlated with institutional outcomes.

The results from the field experiments further demonstrate that conditional cooperation is positively correlated with institutional

[1] Khmer Riel. 4000 KHR is about 1 USD.

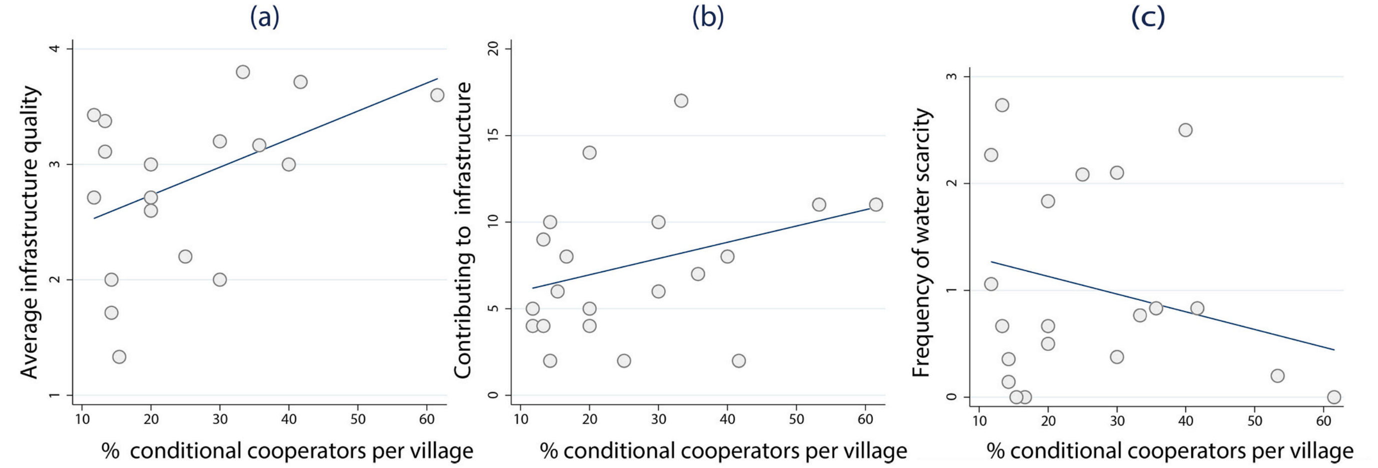

Fig. 1. Conditional cooperation and functioning of institutions across villages in the Kampong Chhnang Province, Cambodia. The institutional performance is measured in terms of (a) infrastructure quality (1 is very poor, and 5 is excellent), (b) number of people paying for water infrastructure, c) frequency of water scarcity.

performance in its role to moderate scarcity (Fig. 1c). The larger the number of conditional cooperators in the village, the less water scarcity has been experienced in the village. There are two obvious limitations to these empirical findings. First, while conditional cooperation has been measured with an experimental game, the other variables are self-reported and therefore not free of bias and error. Second, we can show correlations, but we do not infer any causality, especially because, the quality of institutions, the willingness to support those institutions, and general cooperativeness all potentially influence each other. Nevertheless, some laboratory and field experiments seem to suggest that players' decisions in the games show some degree of consistency with actual decisions in daily resource uses (Janssen and Anderies, 2011). So while our empirical results may not help to disentangle causal channels entirely, they are valuable as they can to inform our modeling work to simulate institutional dynamics 'in silico'.

3. The model

We consider a community consisting of N agents jointly extracting water as a common-pool resource (CPR), and sharing an irrigation infrastructure as a public good (PG). Water is a common-pool resource (CPR) because a unit of water extracted by an agent is not available to others and everyone has access to the water. Water availability is conditional on the state of the irrigation infrastructure. A well-maintained infrastructure can retain more water than a poorly-maintained one. Keeping the infrastructure well-maintained, however, requires the collective effort of all community members. While it is socially optimal to invest in infrastructure maintenance, doing so is individually costly, tempting self-interested individuals to free ride. After all, one can still benefit from the well-maintained infrastructure even without contributing. Similarly, restraining water extraction is collectively optimal, but requires individual sacrifices. Hence, investing in the PG and extracting from the CPR form social dilemmas. In our model, a self-image concern is the mechanism to represent conditional cooperation. Each agent faces two types of decision to be made simultaneously: water extraction and investing in infrastructure maintenance. These decisions affect individual utility in two ways. First, there are monetary consequences related to benefits and costs of agricultural practices and infrastructure investments. Second, cooperation has an effect on self-image, where high levels of cooperation give a positive self-image which translated into a utility gain, while the opposite is true for low cooperation. Cooperation levels are always evaluated against the average behavior in the community, i.e. conditional on social norms. Note that self-image is only one potential interpretation. Our model setup is also consistent with other social mechanisms that encourage cooperative behavior, such as peer pressure, or a loss of reputation. Over time, social learning ensures that successful strategies – those that give high utility – are imitated, while those that give low utility are abandoned.

3.1. Investing in water infrastructure

Agents collectively invest in the infrastructure maintenance. The investment affects water availability, which is shared by all agents in the community. Water availability *(S)* depends on collective investment (M) and water inflow into the system *(Q)* and is given by $S = \varepsilon(M)Q$, where $\varepsilon(M)$ is the infrastructure productivity as a function of the collective investment M. We define Q as a random variable with expected value μ_Q and standard deviation σ_Q, i.e. $Q \sim N(\mu_Q, {\sigma_Q}^2)$. We assume that the infrastructure productivity $\varepsilon(M)$ is a step function, as it requires a minimum level of investment μ_1 to be productive and is fully productive when μ_2 is provided (see Fig. 2). This stepwise function is also used in a similar context for characterizing irrigation infrastructure as a public good (Yu et al., 2015). Hence, the system productivity can be expressed as a function of the collective investment $M(t)$ as

$$\varepsilon(M) = \begin{cases} 0 \text{if } 0 \le M(t) \le \mu_1 \\ \dfrac{M(t) - \mu_1}{\mu_2 - \mu_1} \text{if } \mu_1 < M(t) \le \mu_2 \\ 1 \text{if } M(t). > \mu_2 \end{cases} \tag{1}$$

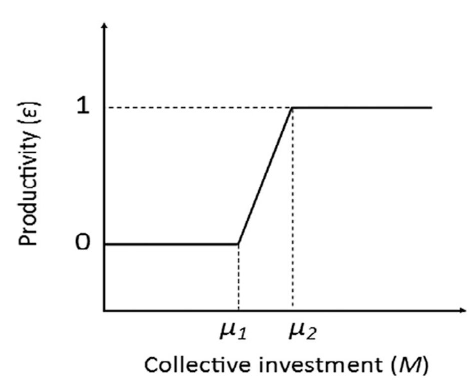

Fig. 2. The relationship between collective investment and system productivity.

3.2. Water extraction

The second decision involves water extraction for agriculture. We assume that agents use only two inputs land l_i and water w_i, for the production of a final good $f(l_i, w_i)$ which can be sold at price P. Land is private and using it incurs a cost c_1. Water is taken from a common pool and extracting it comes at a cost c_2 (e.g. pumping cost). The amount of water going to agent i is determined by the individual effort e_i relative to the aggregate effort E made by all the agents. The amount of water extracted by an agent is thus a fraction of total water availability, i.e. $w_i = (e_i/E)S$. Finally, individual investment m_i to the water infrastructure comes at cost c_3, giving the profit of agent i at time t by

$$\pi_i(t) = Pf(l_i, w_i(t)) - c_1 l_i - c_2 e_i(t) - c_3 m_i(t) \tag{2}$$

For our model, we assume that agents have fixed land endowment which is exogenously given. We also assume that the production of the final good is represented by a constant elasticity of substitution (CES) function, i.e. $f = \rho(w^\alpha + l^\alpha)^{1/\alpha}$, where ρ is a skill factor and $\alpha < 1$ measures the degree of complementarity between land and water inputs. For example, when $\alpha \to 1$, the function exhibits perfect substitutes, meaning it is possible to use either input alone to achieve the same level of output. When $\alpha \to 0$, the function exhibits some degree of substitution among inputs, i.e. it is possible to use more of one input and less of the other to obtain the same level of output. When $\alpha \to -\infty$, the function exhibits perfect complementarity among inputs, i.e. the production is possible only if all inputs are used.

3.3. Social dynamics

We assume that the self-image associated with certain behavior affects individual's utility, depending on how one's actual behavior relates to some normative benchmark what one should do. It is not entirely obvious which normative benchmark is applied in practice, and it may very well be context-dependent (Nyborg, 2018). For example, it may be the case that sometimes a Kantian principle—which assumes one should act according to rules or laws that could be hold true for everyone— is applied based on behavior that would be socially optimal if followed by all, while in other cases social norms based on observed behavior of others may be used as a moral benchmark. We try to reconcile these two different perspectives. First, we take into account that contribution to a public good and restraining from common pool extraction are perceived as an act of cooperation. Providing more to the public good (and extracting less water) than what the social norm prescribes gives a utility gain. Consequently, providing less to the public good and extracting more water than the social norm prescribes leads to a utility loss. Second, the size of the utility gain (or loss) is determined by how close behavior is to the social norm, i.e. average behavior in the community. This assumption reflects empirical evidence that normative statements about how much one should contribute to a public good tend to depend on what others do (Hauge, 2015).

Self-image is thus a function of contributions to maintenance and water extraction and investing efforts. This specification is consistent with the notion of conditional cooperation, as agents are more inclined to cooperate if others do so as well. Formally, we follow Brekke et al. (2003) by assuming that self-image is determined by the (squared) deviation from the moral benchmark. Thus, self-image $g_i(t)$ of agent i at time t can be expressed as

$$g_i(t) = \omega_1 * |\overline{e}(t) - e_i(t)| * (\overline{e}(t) - e_i(t)) + \omega_2 * |m_i(t) - \overline{m}(t)| * (m_i(t) - \overline{m}(t)) \tag{3}$$

where $\overline{e}(t)$ and $\overline{m}(t)$ give the average levels of extraction and investment efforts that can be calculated as $\overline{e}(t) = (1/N)^* \sum_{j \in N} e_j(t)$ and $\overline{m}(t) = (1/N)^* \sum_{j \in N} m_j(t)$. The parameters ω_1 and ω_2 can be considered as strength of conditional cooperation or literally as social cohesion. The overall utility of agent i is a function of economic profits $\pi_i$and self-image g_i, which are imperfect substitutes. Further, we assume that agents may also derive income and self-image from other activities, given by $\overline{\pi}$ and $\overline{g}$. The utility of agent i exhibits Cobb Douglas preferences, which can be written as

$$u_i(t) = (\overline{\pi} + \pi_i(t))^\beta (\overline{g} + g_i(t))^{1-\beta} \tag{4}$$

where β represent the preference for income compared to self-image.

Fig. 3 shows a conceptual model on the dynamic interplay between individual decisions, water availability, and social dynamics. The decisions of each agent take into consideration the economic gain as well as self-image concerns.

3.4. Strategy updating and social learning

We assume that agents revise their strategy through social learning which is facilitated through observation and imitation of other agents. A focal agent interacts with his four immediate neighbors, occupying the lattice cells in the form of a von Neumann neighborhood given by a $d \times d$ square lattice, where d is the lattice dimension. A fully-occupied lattice thus contains $N = d^2$ agents. To account for edge effects, agents that are on one side of the borders of the lattice are assumed to be the neighbors of those who are at the opposite side of the border. Each agent considers changing his strategy regarding water extraction and investment to maintenance at time step t by evaluating realized utility in the previous time step. To update his strategies, agent i compares his utility with the utility of his four immediate neighbors. Agent i identifies the strategy of the neighbor with the highest utility, and imitates it with a probability p, which is an increasing function of the utility difference $u_j(t) - u_i(t)$. We use a logistic function to model the imitation probability as follows

$$p[(e_i \to e_j) \& (m_i \to m_j)] = \frac{1}{1 + exp(-\lambda(u_j - u_i))} \tag{5}$$

where $\lambda \geq 0$ can be considered as imitation strength which measures how strongly the utility difference influences the decision of an agent to switch to a better-off strategy. $\lambda \to 0$ or $u_j = u_i$ means agent i tosses the coin to decide if he imitates the strategy of agent j. $\lambda \to +\infty$ corresponds to high imitation strength, meaning that a successful strategy is always imitated. Consequently, a small λ depicts low imitation strength, meaning that a successful strategy is less likely imitated. When updating the strategy, we also consider stochastic errors (mean of zero and standard deviation of 0.01) when imitating extraction and investment levels, resulting in a strategy that is a bit lower or higher than the copied strategy.

Table 1 presents model variables and parameters values under default conditions. For the community size, we try to match the size of the sample of our field experiment, which is around 300. However, as our model is run on a squared lattice, for convenience we consider a 20 $\times$ 20 dimension, in which the fully occupied lattice contains 400 agents. For economic parameters, we normalize the value of profit by setting the associated parameter values such that the profit of each agent (Eq. (2)) is between 0 and 1. We thus consider a unit price of $P = 1$ and a unit land of $l = 1$. Since the value of water extraction is between 0 and 1, the value of the production function (the first term in Eq. (2)) falls between 1 and 2. Thus, the cost values (c_1, c_2 and c_3) are set at 0.5 such that the values of the profit function should fall within the normalized range of 0 to 1. Likewise, for parameters associated with the self-image function (Eq. (3)), the values are set such that the function values are comparable with that of the economic function (Eq. (2)). For understanding how the model behavior changes according to various parameter values, a comprehensive sensitivity analysis was performed, as shown in Fig. 8.

4. Results

First we explore the temporal evolution of extraction and investment efforts and the general dynamics of the system. In the model, the

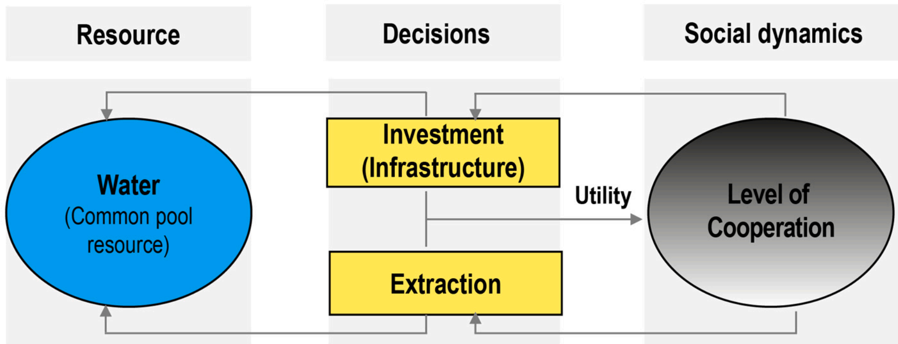

Fig. 3. A conceptual model of the key mechanisms. Agents decide how much to invest in water infrastructure (the public good) and how much water to extract (the common pool resource). The decisions affect water availability, and also profits, self-image and ultimately utility. Social learning guides the social dynamics and the emergent level of cooperation.

Table 1
Model variables and parameters at default values.

Symbols	Definition	Value
Variables		
e_i	Individual extracting effort	
m_i	Individual investment effort	
Parameters		
N	Community size	400
t	Simulation length	200
$\overline{Q}$	Mean resource inflow	100
σ_Q	Standard deviation of resource inflow	20
P	Sale price	1
l	Land size	1
c_1	Unit cost of farming per unit land	0.5
c_2	Unit cost of extraction effort	0.5
c_3	Unit cost of investment effort	0.5
ω_1, ω_2	Social pressure in relation to extraction and investment respectively	2
α	Degree of complementarity	0.5
$\overline{g}$	Exogenous reputation	0.5
$\overline{\pi}$	Exogenous profit	0.5
μ_1	Minimum investment threshold	80
μ_2	Optimum investment threshold	320
λ	Imitation strength	1

evolution of the state variables is path-dependent, giving rise to alternative stable states depending on initial conditions. Thus, we first explore under which conditions the good equilibrium of institutional prosperity emerges. Second, we turn to the question under which conditions an institutional trap may occur. Third, we analyze the model behavior without the conditional cooperation mechanism. Fourth, we analyze to escape the institutional trap and what is needed to reach the 'good' equilibrium of institutional prosperity. Finally, we investigate the sensitivity of key parameters with regard to tipping between the alternative stable states.

4.1. The good equilibrium: institutional prosperity

We simulated the model with default parameter values given in Table 1. The distributions of the investment and extraction efforts at the initial time step were modeled following a bimodal distribution or generally referred to as "Gaussian mixture distribution" to reflect the presence of different groups in the community, rather than deviation around one established norm. We also simulated our model with a normal distribution and generally found similar results. We are interested to see if a society that is largely composed of cooperative individuals initially may remain in such desirable condition over time. In our model, the condition is mimicked by having at the initial time step a large fraction of agents (80%) having high investment effort (mean investment effort of 0.8 and variance of 0.01), and only a small fraction of them (20%) exerting low investment (mean investment effort of 0.2 and variance of 0.01). Likewise, 80% of the agents have low extraction effort (mean extraction effort of 0.2 and variance of 0.01) and 20% have high extraction effort (mean extraction effort of 0.8 and variance of 0.01). Each model was run 50 times to account for stochasticity. The stochastic components of the model are mainly due to different investment and extraction efforts at the initial time step, and the strategy updating.

Over time the model reaches an equilibrium state in which agents exert relatively high investment levels (average of around 0.7) (Fig. 4a), which is slightly lower than the starting value around 0.8 for most individuals. Those high investment levels support relatively high extraction effort (Fig. 4b) (average around 0.9), which is substantially higher than the extraction at initialization (80% had an extraction level around 0.2). Due to stochasticity, we can observe that individual strategies can be out of equilibrium for some simulation runs, sometimes over prolonged periods of time (the light shading in Fig. 4a & b). Since the aggregate investment effort made by all agents is directly related to system productivity (Eq. (1)), higher investment effort means higher system productivity (Fig. 4c), which also leads to high profits (Fig. 4d).

4.2. The bad equilibrium: institutional trap

In this scenario, we look into a condition in which the society largely comprises self-interested individuals, i.e. those who are not willing to invest to the public goods but continue to extract the common-pool resource at a high rate. We are interested to see if the society that is initially in such a bad condition, would become more cooperative over time or remain trapped in this condition. In the 'bad equilibrium', at the initial time step 20% of the agents make high investment effort (mean investment effort of 0.8), while 80% of the agents have low investment effort (mean investment effort of 0.2). Also, a large number of agents (80%) exert high extraction effort (mean extraction effort of 0.8) and 20% low extraction effort (mean extraction of 0.2).

Fig. 5 shows that over time the investment effort further erodes and eventually no investments will be made (Fig. 5a). As a result, the system gets trapped in a very low-productivity state in which resource availability is close to zero (Fig. 5c). Consequently, most agents also lower their extracting effort over time (Fig. 5b), simply because it is not economically viable. Overall, profits are much lower than in the 'good equilibrium' and only some exogenous profits remain (Fig. 5d).

4.3. In the absence of self-image considerations, cooperation collapses

Our model entails a coupled social dilemma in CPR extraction and PG investment, where conditional cooperation via self-image considerations mitigates freeriding. Each agent's utility, as determined in Eq. (4),

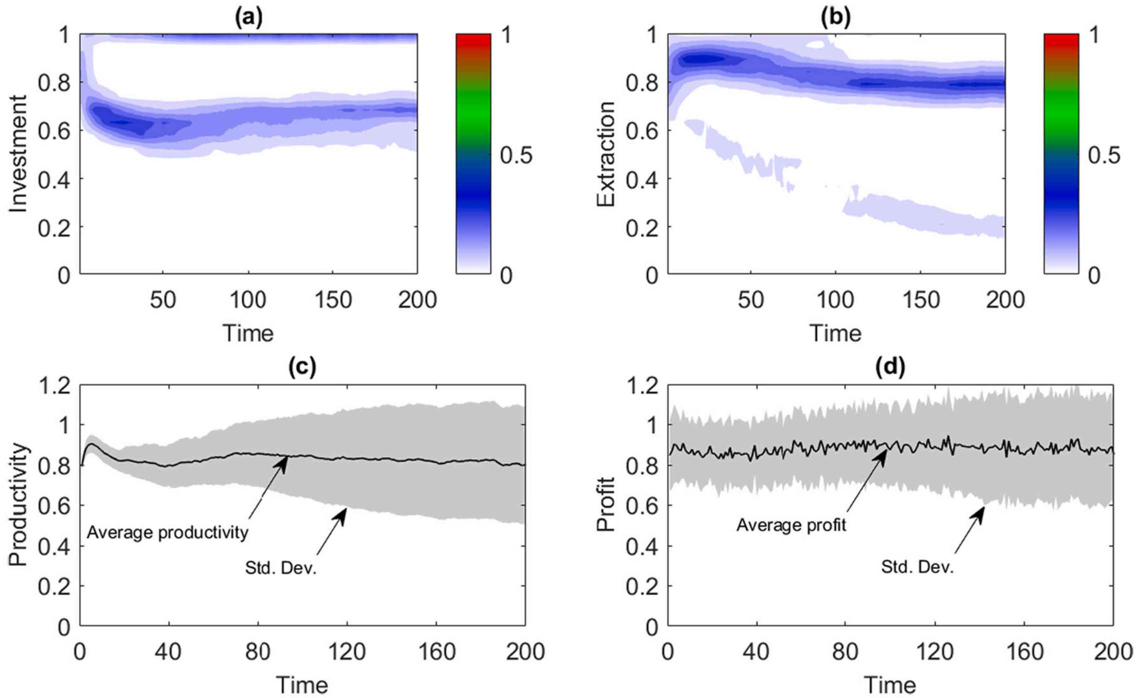

Fig. 4. Temporal evolution of extraction and investment efforts when the public good is initially in a good condition—80% of high-contribution agents and 20% of high-extraction agents at $t = 0$. X-axis stands for simulation time. Y-axis shows (a) investment level, (b) extraction level, (c) system productivity, and (d) profit. Colorbar represents the relative frequency of extraction and investment efforts among all agents at each time step over 50 repeated runs.

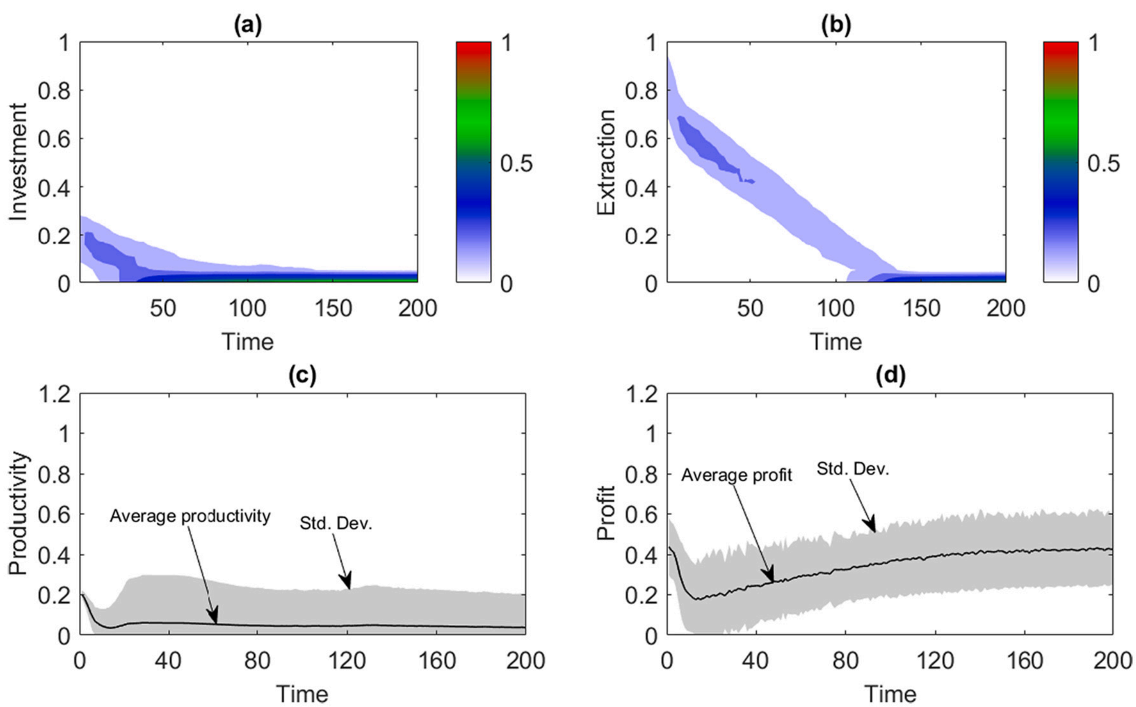

Fig. 5. Temporal evolution of extraction and investment efforts when the public good is initially in a bad condition—20% high-contribution agents and 80% high-extraction agents at $t = 0$. X-axis stands for simulation time. Y-axis stands for (a) investment level, (b) extraction level, (c) system productivity, and (d) profit. Colorbar represents the relative frequency of extraction and investment efforts among all agents at each time step over 50 repeated runs.

is the result of economic and self-image outcomes. To consider a case in which conditional cooperation is absent, the coefficients ω_1 and ω_2 were set to zero. The self-image g_i of each agent, as depicted in Eq. (3), thus becomes zero, meaning that only economic considerations remain in the utility function.

Fig. 6 illustrate the case where self-image concerns are absent. As expected, in this case cooperation collapses. The public good investment becomes largely under-provided (Fig. 6a). As a result, system productivity collapse (Fig. 6c). Under this condition any extraction effort exerted by agents is not economically viable, and extraction declines

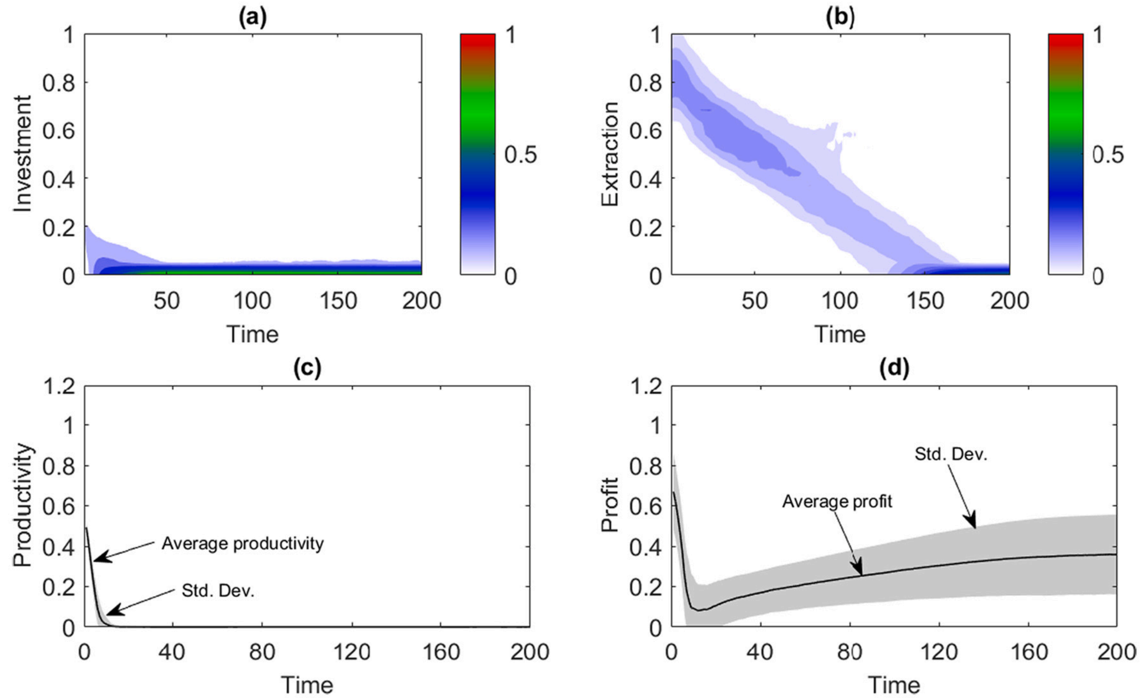

Fig. 6. Temporal evolution of extraction and investment efforts, and corresponding outcomes when the reputational mechanism is absent ($\omega_1 = 0.0$, $\omega_2 = 0.0$). All other parameters are kept at default values. X-axis stands for simulation time. Y-axis stands for (a) investment level, (b) extraction level, (c) system productivity, and (d) profit. Colorbar represents the relative frequency of extraction and investment efforts among all agents at each time step over 50 repeated runs.

over time (Fig. 6b). Some level of exogenous profit, though, remain (Fig. 6d).

4.4. Social cohesion to escape the institutional trap

We have shown earlier that if the system initially consists largely of low contributing and high extracting agents, the system remains trapped in the bad equilibrium (Fig. 5). This condition can also be considered as

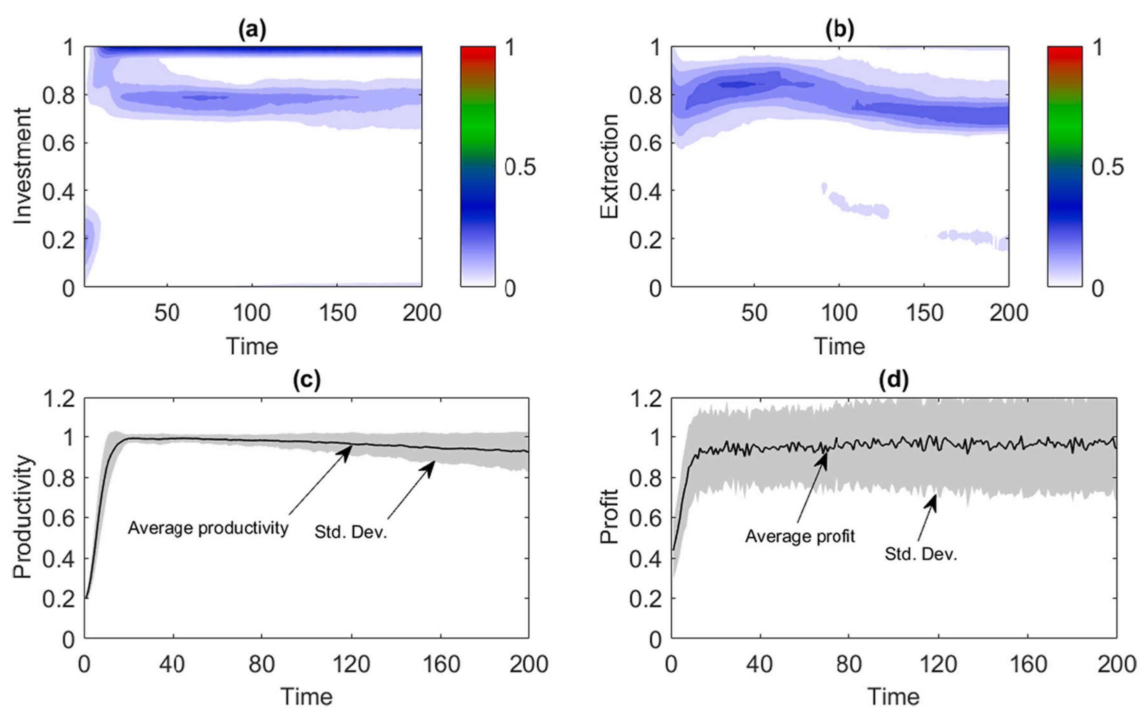

Fig. 7. Temporal evolution of extraction and investment efforts when the public good condition is initially bad (80% of low contributing agents and 80% of high-extraction agents at $t = 0$), but in the case where the strength of conditional cooperation is high ($\omega_1 = 3.0$, $\omega_2 = 3.0$). All other parameter values are kept at default values. X-axis stands for simulation time. Y-axis stands for (a) investment level, (b) extraction level, (c) system productivity, and (d) profit. Colorbar represents the relative frequency of extraction and investment efforts among all agents at each time step over 50 repeated runs.

resource scarcity condition, since the public good is largely under-provided, leading to less resource available in the system. This raises the question how the community can escape the institutional trap. Stronger social capital or social cohesion is a mechanism that comes to mind. Fig. 7 analyzes the case where the strength of conditional cooperation is high, i.e. $\omega_1 = 3$ and $\omega_2 = 3$. A high strength of conditional cooperation means agents have high tendency to align own extraction and investment decisions with what the social norm describes. Further, high strength of conditional cooperation implies strong social cohesion (Röttgers, 2016). We find that if conditional cooperation is stronger, the institutional trap can be escaped and the investments are high (Fig. 7a). As a result, system productivity is high (Fig. 7c), more resources are available, and high extraction is supported (Fig. 7b). Consequently, average profits are also high (Fig. 7d).

4.5. Tipping points between alternative stable states

We run a series of simulations to study the effects of key parameters of the model on extraction and investment efforts of agents (Fig. 8). First, we consider the role of economic costs. As cost per unit of land (c_1) increases, extraction effort slightly increases and investment goes down. There is a tipping point, above which investment collapses, and so do productivity and extraction (Fig. 8a & b). When cost of extraction effort (c_2) goes up, agents lower the extraction effort but at the same time they also lower the investment effort (Fig. 8e & f). Again, a tipping point can be observed at a critical parameter value for c_2. When the cost of investment in infrastructure (c_3) increases, investment goes down and extraction goes up (Fig. 8i & j). Beyond a critical level of c_3 the system collapses. After having analyzed the role of costs, let us now turn to social pressure. Higher social pressure in relation to extraction (ω_1) – meaning that it is socially costly to deviate one's extraction effort from the social norm – leads to lower extraction, but investment remains unchanged (Fig. 8c & d). Higher social pressure in relation to investment (ω_2) leads to both higher extraction and investment since more aggregate investment means more resource is available to be extracted (Fig. 8g & h). Again, alternative stable states can be observed. Finally, higher resource inflow leads to higher extraction and investment efforts, giving rise to alternative stable states (Fig. 8k & l).

5. Discussions and conclusion

We have developed an agent-based model, in which agents have to decide how much effort to contribute to a common water infrastructure and how much effort to extract water. This decision is based on

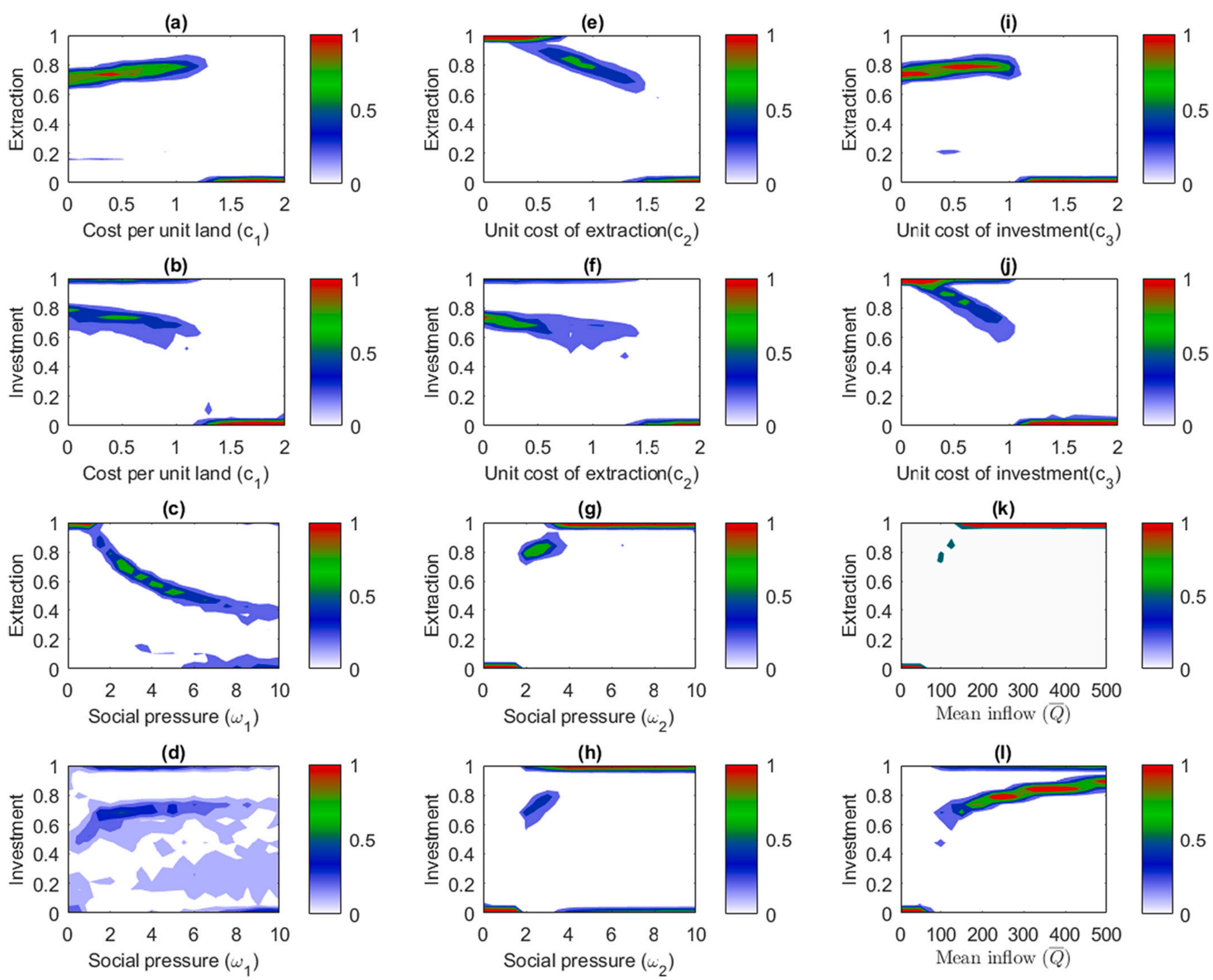

Fig. 8. One-at-a-time sensitivity plot of key model parameters against investment and extraction effort. To account for stochasticity, we run the model 50 times repeatedly for each single value of the parameters.

economic considerations, as well as reputational concerns, where the own decision is evaluated against the social norm. We find that the system features alternative stable states, depending on initial conditions. If the system has a functioning water system initially and a high level of cooperation, prosperity can be created, which facilitates investments in water infrastructure, fostering cooperation further. If the system features initial scarcity, cooperation is relatively costly, further undermining investments in water infrastructure, potentially leading to an institutional trap. If the system comprises more conditional cooperators, however, the initial scarcity condition can be mitigated. These findings are well in line with the stylized facts observed in the field. Our field experiments in Cambodia suggest that conditional cooperation is positively correlated with better institutional outcomes, and in addition, can mitigate scarcity conditions.

The results from the model establish that without reputational mechanisms – driven by conditional cooperation – self-governance will collapse (Fig. 6), and that even if the mechanism is in place, cooperation may not evolve and the system may be trapped in a situation of severe scarcity (Fig. 5). Stronger social capital can, however, facilitate an escape of the trap and facilitate cooperation under such scarcity condition (Fig. 7). In line with the field evidence the modeling results confirm that conditional cooperation could be beneficial for institutions to prosper by further facilitating cooperation under scarcity.

In the context of coupled social dilemmas arising from contributing to the public good and extracting of a common pool resource, previous studies establish that if the public good is provided, cooperative resource extracting can be achieved (Botelho et al., 2015; Solstad and Brekke, 2011). An open question is why the public good is provided by some agents in the first place if this does not align with self-interest. We offer an explanation by formalizing the notion of conditional cooperation. Inspired by the work of Rustagi et al. (2010), who show that communities consisting of more conditional cooperators are more successful in governing the forest commons, we explore this for the case of local water governance in Cambodia, using lab-in-the-field experiments. Our model results support the idea that conditional cooperation can mitigate initial scarcity and further facilitate the contribution to the public good and hence overall cooperation. Further, we show in our model that if the community is initially largely composed of low contributing agents, the system remains trapped in the regime of low contribution to the public good and thus remains trapped with poor water infrastructure.

An open question remains how heterogeneity of agents may affect sustainability outcomes. In our model, we focus on how norms of contributing to infrastructure maintenance and harvesting water co-evolve endogenously, which is complex even without considering resource heterogeneity. Though our model was not set up to specifically analyze such heterogeneity, our bimodal initial conditions (where the majority is either cooperative or not) reveal some interesting results. A community dominated by low contributing individuals translates into highly unequal distribution of payoffs, which then by imitation result in an erosion of cooperative strategies. This results in poor infrastructure, further exacerbating water scarcity, and eventually leading to a collapse of cooperation. Our interviews with community leaders in the field tend to point in the same direction. In villages that feature poor infrastructure, villagers typically have a highly heterogeneous contribution to the infrastructure maintenance (many did not contribute or contribute only partially), and varying levels of water access and extraction. In that sense, our modeling results are in line with experimental and field evidence, suggesting that the community that is composed of more conditional cooperators is more successful in irrigation water governance, and one of the reason for this is the scarcity-moderating effect of conditional cooperators. A more extensive formal analysis of how heterogeneity of agents may affect sustainability outcome would be a fruitful direction for further research. As pointed out in Poteete et al. (2010), an agent-based model allows for understanding of how different modeling outcomes pertain to various model assumptions, considering heterogeneity of agents. For example, unequal access to technology or capital almost certainly affects the evolution of sharing arrangements and ultimately also sustainability (Mirza et al., 2019; Momeni, 2021). Further, the model can also consider heterogeneous preferences of agents in terms of cooperative orientation (conditional cooperation as modeled in this study). Also, in an irrigation setting, one could potentially analyze heterogeneity in access, in the role of head users (who can access the water first) and tail users. As shown in experimental studies of social dilemmas, such heterogeneity may affect cooperation positively or negatively depending on the benefits and costs of resource harvesting by the head users relative to the tail users, and exposure to resource uncertainty (Janssen et al., 2011b; Anderies et al., 2013; Janssen et al., 2012; Janssen et al., 2011a). It seems very worthwhile to study how resource access inequality between individual users or communities would affect the co-evolution and thus emergence of social norms of water sharing and public good provisioning. Such considerations can be incorporated in an agent-based modeling setting that features two or more communities having different access to water, but depend on each other for the contribution to the shared infrastructure and thus should be the future extension of the model.

Regarding future research directions, our study also provides a fruitful avenue for formulation of hypotheses and empirical testing to understand how and when the theoretical predictions of having a good equilibrium (institutional prosperity) and bad equilibrium (institutional trap) also can be observed in the field. There are two very concrete empirical approaches one could pursue. First, one may use economic experiments to analyze whether the path dependencies observed here can be replicated in economic experiments (Diekert et al., 2020). Second, one could analyze more rigorously how social characteristics (e.g. conditional cooperation) interact with village attributes (e.g. proximity to water sources) and cause the socioeconomic outcomes (e.g. functioning water infrastructure).

Our study has two implications for researchers and practitioners. First, when evaluating the impacts of drivers that may bring about scarcity (e.g. climate change) it is important to consider that the institutional system may respond to scarcity, potentially aggravating or moderating scarcity. We have shown here that social capital in general, and conditional cooperation in particular are important mechanisms to be considered. Second, our study cautions against considering coupled social dilemmas, such as common pool resources and public goods problems in isolation, as the unfolding dynamics may be very different and could have significant implications for the long-term sustainability of social-ecological systems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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