האוניברסיטה העברית בירושלים

The Hebrew University of Jerusalem

המחלקה לכלכלת סביבה וניהול

Department of Environmental Economics and Management

המרכז למחקר בכלכלה חקלאית

The Center for Agricultural Economic Research

Discussion Paper No. 1.16

Management of Water Resources in Adversity: The Role of Social Norms

by

Uday Kumar Jammalamadaka and Ariel Dinar

Papers by members of the Department can be found in their home sites:

מאמרים של חברי המחלקה נמצאים גם באתרי הבית שלהם:

http://departments.agri.huji.ac.il/economics/index.html

P.O. Box 12, Rehovot 76100, Israel

ת.ד. 12, רחובות 76100

Management of Water Resources in Adversity: The Role of Social Norms

Uday Kumar Jammalamadaka[1] and Ariel Dinar[2]

Abstract

We develop a framework that quantifies the effect of social norms on the efficient functioning of institutions and thereby their impact on effectiveness of reforms for sustaining common pool water resources under conditions of scarcity. We derive theoretical solutions and provide numerical simulations that provide evidence for performance of a group of farmers that use a common pool resource (reservoir, or aquifer) under norms and no norms, with reference to the existing institutional setting considered in the theoretical model. The theoretical results suggest that under no trade institution and norm adherence water users will always use less water then under no norms, and with possible inter-group trade norm-adhering water users would replace excess extraction with increased trade rates. Simulation results for the no-trade case suggest that with higher marginal utility values from adherence, the resource is sustained for significantly longer periods. [141 words]

JEL Codes: D62, D71, Q25

Keywords: Institutions, Social Norms, Water Scarcity, Common Pool Resources, Agriculture.

Acknowledgement: co-funding for the research leading to this paper was provided by the Water Science and Policy Center, University of California, Riverside. Ariel Dinar would like to thank the Lady Davis Trust and the Center for Agricultural Economics Research at the Department of Environmental Economics and Management, the Hebrew University of Jerusalem, Israel, for support and hospitality during the stage of finalizing of this paper.

---

[1] Uday Kumar Jammalamadaka was a PhD Candidate at the Department of Economics, University of California, Riverside, USA during the research leading to this paper.

[2] Ariel Dinar is a Professor of Environmental Economics and Policy, School of Public Policy, University of California, Riverside.

Management of Water Resources in Adversity: The Role of Social Norms

Introduction

Impact of climate change on water resources, and indirectly on agricultural production, has decreased agricultural incomes and led to increased instances of social unrest. The UNWWAP (2006) report attributes the water scarcity in many countries to the inefficiency of existing water resource allocation institutions. Such inefficiency can be attributed to continuous changes in user values/norms, structural transformations in society and environment, climatic anomalies, and other exogenous shifts, along with population growth and political and institutional reforms.

The literature on institutional economics recognizes the role of 'belief structures' and 'collective learning' processes as the basis for development of institutions in the water sector. For any successful reform to address management of water resources in adversity, institutional reforms have to be complementary to the existing belief systems and the social norms, which dictate institutional interactions/functioning. Acceptance of solutions to water scarcity would largely depend on the existing political interests, communal bargaining power and other social-politico-legal factors (Iglesias et al., 2007; Ostrom and Ostrom, 1972).

However, the existing literature in this field has not yet quantified the interaction of social norms with water institutions, especially under drought situation.[3] Dinar and Jammalamadaka (2013) demonstrate in a very simplistic framework the relationship between water scarcity and institutions and the role of social norms in functioning institutions. They provide a comprehensive review of that literature. Among several of the studies they review, one can realize the role of norms influencing individual and community decision-making. For example, Shivakoti et al. (2002) refer to norms of communal maintenance based on land size or per household contribution in farmer-managed systems. Seasonal maintenance and upgrade of existing infrastructure, especially before

[3]Norms dictate the way individuals interact with each other or with the existing social institutions. World Bank's CommGAP (2009) report explains that norms are the beliefs, both real and perceived, regarding expected behavior in specific contexts, especially under conditions of uncertainty. While social institutions are the existing social regulations across societies, social norms are the socially (real and perceived) valid actions (and reactions) in any given situation. The norms would thus dictate how individual economic agents would communicate and react to changes in the existing infrastructure, climatic factors or externally-imposed reforms given the existing institutions in their respective societies.

monsoon season results in efficient flow of water and availability of water to all farmers within the water system boundaries. They also find that the norm of ensuring resource sustainability by limiting extraction of the resource through using strong monitoring and sanctioning rules leads to only limited sustainable extraction. Another norm that Shivakoti et al. (2002) identify is the political favoritism and/or condoning rent-seeking behavior. This norm allows water user associations and user committees to manage irrigation systems in agency-managed irrigation systems that are assigned based on political criterion and not on the basis of involvement in resource use. This leads to non-equitable power structure and water distribution, which in turn leads to breakdown of the system due to lack of user participation and profit-maximizing exploitation of the resource. It may also lead to conflict between upstream and downstream users. Tail-end users would stop maintenance efforts leading to system leakages and subsequent decrease in coverage and agricultural output reduction. Anjal (2005) finds that caste-based allocation rules, or rules based on inter-societal differences and not based on highest marginal value for the water leads to inefficient use of water. In the same way, Shivakoti et al. (2002) find that norms of seniority in promotions and political favor seeking in the water bureaucracy will lead to lack of proper monitoring and penalties, which results in over extraction at system head and no irrigation water available for tail-end users.

With such qualitative evidence the goal of this paper is to set up a framework to quantify the effect of social norms on the efficient functioning of institutions and thereby the impact of social norms on effectiveness of water institutions (physical, legal, social and political) to manage water resources under conditions of scarcity (e.g. drought). We start with a review of relevant literature from the field of institutional economics, experimental economics, and economics of social norms. We then set the foundation for an analytical framework that will allow us demonstrate the role of social norms in sustaining common pool resources, such as water, under scarcity. We provide a numerical example that simulates the performance of a group of farmers that use a village-level common pool resource (reservoir, or aquifer water) under norms and no norms, with reference to the village-level institutional setting considered in the theoretical model. We then conclude with several generalizations that could extend the framework to other communal common pool resources, such as forests and grazing land.

Previous Work

We categorize previous work on social norms into studies covering institutional economics frameworks, studies of social norms and the interactions between the two, and field studies.

Institutional Economics Studies

North (1990) summarizes institutions as rules that a society operates by. The sharing of benefits and rules of interactions for economic and social agents is determined by their respective bargaining power within the structure of such institutions. Ingram et al. (1984) define institutions as legal, political and administrative structures and processes by which public policy is designed and evaluated, including distribution of benefits and costs and rules for conflict resolution mechanisms. Institutions serve as the mechanism that reduces the uncertainty of societal activities by delineating the privileges, capabilities, responsibilities and opportunities available to individuals/organizations in formal or informal terms (Bromley, 1989).

The existing institutional economics literature in the water sector is predominantly concentrated on the estimation of opportunity cost and/or transaction cost of institutional reforms. However, Oswald (1992) and Saleth and Dinar (2004) provide a different perspective. They recognize the institutional dynamics induced by endogenous (water scarcity, performance deterioration and financial non-viability) and exogenous (macro economic crisis, political reform, natural calamities and technological progress) factors. Therefore the response to any water crisis (such as drought) needs to be instituted at multiple levels to target both types of factors.

Social Norms Studies

The Economic literature on Social Norms is an amalgamation of laboratory experiments on focus groups, case studies of (failed and) existing common resource systems, and theoretical economics literature. They attempt to identify factors, which cause socio-economic systems to collapse in some cases and persist, despite adversity, in other cases. While the collapse of socio-economic systems are easily explained by the exploitation of resources by 'rational economic agents', the sustainable use of common resource systems on the other hand confounds the belief of self-interested economic behavior. The extensive literature using the case study technique (Cordell and McKean, 1982; Somanathan, 1991; Ostrom, 2002; Acheson, 1993) in existing Common Pool Resources (CPR) attributes this to the presence of path dependent institutions and social norms, which regulate the self-interest behavior of involved economic agents, and commitment to monitoring and sanctioning norm-violating behavior. This literature also observes that 'common resource' systems collapse when the existing institutions/norms cannot regulate the socio-economic behavior of agents any longer, due to the lack of sanctions or monitoring effort. The cause of the systemic breakdown varies across the case studies and could not be narrowed down (Bromley and Feeny, 1992) as the observed sustainable use by communities differed in characteristics

Why are social norms important in the provision of public good resources? "Water used in irrigated agriculture has symbolic power as well underpinning respected and familiar livelihoods. Science has little leverage over symbols, yet symbols have extraordinary social and political significance" (Toope et al., 2003:2). In the public good scenario, traditional economic theory predicts that rational agents maximizing their utilities will not contribute to the provision of a public good. Economic theory also depicts little benefit from external interventions in the provision of public goods when rules have to be externally enforced to ensure cooperation and maximize social objectives (or even to achieve long-term self-interest (Ostrom 2000). Competitive market experiments have yielded results close to the predictions of consumer (economic) theory, assuming rational economic agents. On the other hand public good experiments (Schmidt et al., 2001; Cain, 1998; Frohlich and Oppenheimer, 1996; Botelho et al., 2014, 2015) yielded starkly different results from the predictions above, with greater rounds of experimentation leading to greater (sum and individual) contributions. Also, Ostrom (2000) documents the existence evidence of self-organized monitoring and sanctioning systems across societies, which ensure protection of community resources, protection against risk and prevention of free riding. These results can only be explained by incorporating social norms into the utility function of agents in standard consumer theory. Social norms (shared understanding about actions that are obligatory, permitted or forbidden) guide these findings through self/communal punishment for the violation of norms, which the individuals and the society accepted. Agents who value social norms have intrinsic preferences for payoffs as well as the compliance with social norms (reciprocity, fairness and trust) influencing their choice of utility maximizing behavior instead of profit maximizing behavior. Toope et al. (2003) substantiate the observed behavior: Village-level committees well versed in traditional methods of water management, mainly allocation, may not be open to any form of centralized direction, however scientifically appropriate. Farmers' associations will work hard to promote the perceived interests of their membership, even when it conflicts with comprehensive policy initiatives. They also speculate that in traditional societies where water is revered as a sacred entity[4], policy interventions that focus

[4] With religious or cultural relevance. Many underdeveloped economies are agrarian/pastoral in nature, and recognize their water resources as source of life or even as living sacred entities.

upon markets of water, treating water as just a market commodity, are likely to be strongly resisted. Therefore in less-developed countries, with primarily non-market water institititions, it would be more efficient for planners to exploit the existing institutions, social norms and beliefs; or at least account for them, to achieve successful interventions.

For stakeholders to accept proposed water reforms, the social and political interests have to be satisfied. To this end reforms would have to recognize the existing social norms and assimilate them to better address the social needs. Under drought conditions, placation of social groups is more important for the acceptance of reforms in water management. Bowles and Reyes (2012) caution that 'Social Preferences' obfuscate the intended effects of incentives or sanctions introduced to target social behavior or outcomes. The intended effects may get crowded in or crowded out based on strength of pre-existing 'Social Preferences' besides agents' concern for own benefit. The policy makers may need to strengthen or reduce the policy initiatives, to achieve desired outcomes, based on the direction social preferences shift the effects of interventions. Policy makers must consider understanding of social mechanisms indispensible, to achieving desired outcomes.

The experimental economics literature has thus been able to isolate the most important features of communities essential for sustainable resource use. But, the experiments by themselves are not sufficient to provide the critical values in which these factors are required. So, while the existence of agents willing to bear the transaction costs or sanction other agents (at a cost to themselves) is recognized by the experimental economics literature; it is not able to specify either the required proportion of sanctions or the minimum number of willing punishers (who monitor and impose sanctions on other agents violating the rules). The experimental economics literature is also unable to estimate the critical factors in terms of the numbers of people adhering to the norms, the amount of sanctions, and the effects of uncertainty.

One major problem with the case study and experimental economics framework is their inability to predict how the system would react to a crisis (such as drought). The meager theoretical work that exists in this field attempts to bridge this gap by estimating the impact structural parameters have on the system and how it would react to uncertainty. The institutional framework literature assumes that social norms are embedded in the existing and proposed institutional framework (Hotimsky et al., 2006), to which Poirier and Loe (2010) assume away the effect social norms have on the transmission of external interventions through the system. Most theoretical work on social norms introduced game theory frameworks to explain the sustainable use of common resources (Fehr and Schmidt, 1999; Sethi and Somanathan, 1996; Bowles, 1998).

The theoretical literature on role of social norms in sustaining CPR use can be broadly divided into three categories: (a) Role of benefits from adherence and sanctions for violation of norms (e.g., Sethi and Somanathan, 1996; Oses-Eraso et al., 2007; Noailly et al., 2005), which analyzes the effects of benefits from adherence and sanctions for violation of norms on agent behavior in the evolutionary game theory setting. (b) Role of self-sacrificing agents (e.g., Ostrom, 2000; Fehr and Gachter, 2000; Sethi and Somanathan 2003, 2004; and Oses-Eraso et al. 2011), which describes the role of 'Willing Punishers' and 'reciprocators', which may impose transaction costs for monitoring and punishing on the agents themselves. The presence of such patrons significantly reduces the CPR extraction by members with a strategy of high resource-exploitation, also increasing the chances of CPR sustainability. And (c) Role of differences in the source of scarcity (e.g., Oses-Eraso et al. 2008; Ranjan, 2010; Rustagi et al., 2010; Ingram et al., 1984; List, 2006; Glaeser et al., 2000), which concludes that societies with large initial stocks will demonstrate limited willingness to reduce exploitation of resource whereas societies with initial scarcity are more sensitive to resource availability in their actual resource use. Given the same levels of scarcity; societies with higher resource exploitation leading to human-induced scarcity, tend to exploit the resource more due to feedback effects to future periods. These approaches distinguish between agent behaviors in response to existing environmental scarcity and human-induced scarcity, which may strengthen or counteract each other, given the level of social capital in the community.

Ostrom (2000) hinges upon the existence of agents in public good resources that are willing to contribute and cooperate and agents willing to spend in order to punish violators. The contribution of cooperating[5] agents is conditional on existence of sufficient number of agents willing to reciprocate in contributions and build trust. The tolerance of contributors for free riding by other agents is limited and differing. 'Willing Punishers' are essential to the continuance of collective action to provide the public good in the community/economy. For communal management the water source should be excludable and to some degree non-rival. Ostrom and Ostrom (1972) identify the important factors for communal use of a water resource as (a) jointness of use, (b)

[5] Ostrom calls these agents conditional cooperators, as their adherence to the norm is conditional upon simultaneous adherence of the norm by at least a critical number of agents.

insulation from external claim to the resource, (c) stability and transferability of user rights over time and space, (d) conflict resolution mechanism and (e) common burden of costs and adversity. If over repeated interactions a subset of agents is willing to punish violators the emergence of social norms in the context of resource use would thereafter ensure that individual agents use of the public good would not harm the community. But such social norms will only survive until the agents continue to believe in (i) a social expectation of norm compliance from him/her and (ii) positive feedback from norm adherence or penalty for norm volition. If the agent believes that any volition will lead to either guilt and remorse or social ostracism and censure his/her actions would not violate the norm despite lack of enforcement.

Field Studies

Field studies show that public goods are more efficiently managed by communities practicing self-governance of resources than those which are externally governed (Blomquist, 1992; Wade, 1994). Bardhan (1999) finds that most communities with old irrigation systems are characterized by fair allocation systems (proportional to fees or community resource management participation), significant member participation in the process of system evolution and progressive sanctioning system. Ostrom (2008) discusses the importance of agricultural rules/norms in the traditional systems that led to efficient management of water resources as well as combating pestilence. Spiertz (1991) mentions the case study in Indonesia where introduction of modern irrigation systems management lead to greater pestilence. Bowles (2004) substantiates this in an Indian case study in Palanpur where the breakdown of traditional coordination systems has led to greater pestilence and lower crop outputs. Ostrom (2008) exploits a database of 200 irrigation systems in Nepal to compare the performance of traditional farmer managed irrigation systems (FMIS) and agency managed irrigation systems (AMIS), which impose external rules and technology. Ostrom argues that the internal valuation of social norms is correlated with the social valuation of the norm too. Rule breaking is associated with sanctions, whereas norm volition has an internal punishment through the knowledge of society. Crawford and Ostrom (2005) represent this as positive/negative parameters added to the utility functions, which represent the (individuals') returns from the compliance/non-compliance with norms. But Norms alone are not sufficient to manage irrigation systems due to the high value of water in agricultural operations (Ostrom, 2008). Formal institutions including rules and strategies are essential for sustainable management of irrigation resources.

With such volume of previous work, our paper attempts to provide an alternative explanation of why the '*Problem of the Commons'* is not seen in all CPRs. We focus on water. While most common water resources across the world are facing rapid depletion due to climate change, a few communities have managed to sustainably use, and even revive, their groundwater levels/reservoirs. We offer social norms as a possible explanation for this scenario, demonstrating the condition that would allow the community to decrease water consumption to sustainable levels, while avoiding competitive extraction.[6] This may be the reason why local management of common pool water resources (CPWRs) is successful in few communities while failing in many others. The cause and process of development of norms and rules is not explored here and can be a subject of further studies.

The Modeling Framework

Social Norms, while not a universal panacea, have played an important role in the preservation (also revival) and sustainable use of CPWRs. The few successful examples in this field are motivated by the desire of farmers/users to "sustain farm yields and household incomes … self-regulating mechanisms … and … heightened understanding of the limits of groundwater consumption, they facilitate the acceptance and adaptation of the different options to reverse groundwater overuse" (Van Steenbergen and Shah, 2002:254). Therefore our model is limited to the agricultural use of CPWR and not household consumption of water.

In the literature examining local management of CPWRs (groundwater and surface water) the CPRs described can be broadly classified into two types of systems: The first type includes systems where self-regulation of CPWRs by communities govern the maintenance of infrastructure, the recharge mechanisms and/or water extraction. The water source in this case is confined for use by the community with varying rules for access. For example, canal management (shivkoti et al. 2002), village tanks (Bardhan, 1999) and ground water management (Van Steenbergen and Shah, 2002). In these systems the existing norms limit competitive extraction. Contributions of members are utilized to maintain the infrastructure; there is no water trade in these cases.

[6] Participation and cooperation in management of CPWR by farmers is dictated by a combination of factors, including the local politics, incentives, socio-historical factors (the position of the elite vs. the other stakeholders), history of the management and maintenance of CPWR, distribution of CPWR among beneficiaries. We recognize that inclusion of only social norms is a simplification of the multiple factors involved.

The second type includes rules for limiting extractions such as the system described by Van Steenbergen and Shah (2002) in an indigenous water market, which was developed by the farmers in Salheia (East Delta), Egypt. Competitive drilling had rendered the aquifer saline, and the water extraction process costly. The community decided to limit extraction to a few wells and delivered water through a system of pipes for which water charges were paid (to recover the investment in piped infrastructure). Similar system (initial investment by external agency) was also seen in the villages of Parigi and Kosgi (India, Mahbubnagar district) where farmers with tube-wells shared water with adjacent farmers. The benefit associated with these systems are (i) provision of water to farmers who cannot afford drilling for water, and (ii) absence of competitive extraction of water (Nash equilibrium) thereby comparatively reduced extraction as the motive of recovering costs is absent.

To better model these two types of local management systems for CPWRs we have constructed our model in two steps. First, an *N* period *M* homogeneous agents model with norms for restrictive extraction of water; and second, a model with two social groups *P* and *Q* with both intra-group and inter-group water trades with transaction costs. Transaction costs can arise from information collection and searching (conducting hydro geological surveys, organizing partners), bargaining and decision-making (time and fees for legal and expert consultations) and monitoring and enforcing of existing rules.

Model components

Let U_t^i be the utility of individual agent i at period t. We assume that U is a function of profit that the agent produces and of his adherence to the social norms in effect in the village. Let Π_t^i be the profit obtained by agent i at time t. Since we model the behavior of the agents over time, we introduce β as the discount factor used by the community.

The agents in the village use water for production of agricultural crops. Let w_t^i be the water usage in the production process by agent i at time t. Water is a common property resource (CPWR) in the village. It is either stored in reservoirs (tanks) during the rainy season, or recharged to an aquifer from rain and/or snowmelt for use during the irrigation season. The amount of water stored in the reservoir or recharged to the aquifer is a common knowledge at each period t. Namely, S_t is the known stock of water at period *t*.

Water and other inputs are used to produce a set of crops. The agricultural production technology is known and is represented by the function $f^i(x, w)$. Inputs other than water that are used in the production process by agent i at period t are denoted by x_t^i. Price of output is denoted by p_f; price of water is denoted by p_w; and price of other inputs is denoted by p_x.

Since water is scarce, we assume that the village institutes a maximum water use ceiling to sustain the CPWR. This is done by assigning an individual quota to each agent, based on criteria that are acceptable in the village. The criteria can be based on farm size, on soil quality, or on historical cropping pattern in each farm. The quota is perceived by each agent, who then assigns a value associated with adherence to that social norm, which appears in the agent's utility function. Let $h_t^i = \bar{w}_t^i$-w_t^i be the measure of adherence to the social norm by agent i at period t. $h_t^i \geq 0$ means that the agent adheres to the norm (quota) and $h_t^i < 0$ means non-adherence to that norm. We should emphasize that over-extraction is not enforced by rule or by monetary penalties. The only penalty for over-extraction is the price paid for it and the disutility from the norm component due to norm violation. Violation of the norm is expected only when the disutility from violation is compensated by the utility gain from adherence.

The model allows for trade in water among the agents. Let $G_t^{i,j}$ be the gains from trade between i and j for agent i, $i \neq j$. Let T be the transaction cost of trade, assuming fixed transaction cost over time. *T* is measured in terms of cost per unit of water transferred. Net gains from trade are the difference between *G* and *T*.

We further assume, for simplicity, that the model has a single good output; that input and output prices are fixed (farmers are price takers); that the utility function, $U_t^i(\Pi_t^i, h_t^i)$, is concave in profit and in the social norm. In other words, $\frac{\partial U_t^i}{\partial \Pi_t^i} > 0$, $\frac{\partial^2 U_t^i}{\partial \Pi_t^{2i}} < 0$, $\frac{\partial U_t^i}{\partial h_t^i} > 0$, $\frac{\partial^2 U_t^i}{\partial h_t^{2i}} < 0$; that the production function is concave in water and in other inputs, namely that $\frac{\partial f_t^i}{\partial x_t^i} > 0$, $\frac{\partial^2 f_t^i}{\partial x_t^{2i}} < 0$, $\frac{\partial f_t^i}{\partial w_t^i} > 0$, $\frac{\partial^2 f_t^i}{\partial w_t^{2i}} < 0$; and that the water stock is a common community resource.

Our model treats social norm as a tangible factor affecting utility. Therefore, the agent doesn't need to be altruistic to adhere to the social norm. As suggested by Osés-Eraso and Viladrich-Grau (2011:394) "Certain norms, traditions, conventions or uses have been developed through the years to make living in common easier. Compliance with these traditions often carries a cost, however, and individuals may derive more benefit from free-riding. In most cases self-interested behavior will lead to the infringement of these conventions, while compliance will lead to the kind of cooperative behavior that has been a widespread practice in traditional societies, where it has coexisted for long periods of time with non-compliant behavior." The theory in this paper is limited to the impact a norm may have on the use of the water resource. Why agents choose to impose/adhere to certain norms despite the cost, is beyond the purview of this paper.

To summarize, the individual quotas are not sacrosanct. It can be violated as long as the utility is maximized. The model is a social planner problem at the village level and not individual maximization of utility. Finally, the social planner maximizes the group's discounted utility over a given time horizon. This forces the agent to conserve the resource and use it over time to maximize utility. Therefore, the model maximizes the community welfare, which is measured as the present value of the net revenue produced in the community agricultural production process.

N Periods M Homogeneous Agents

Our first step is a model that spans over *N* periods and includes *M* agents. It includes all attributes that have been discussed above plus some that characterize the structure of *N* periods and *M* agents. The objective is to maximize the net benefit of the entire set of *M* agents (the community) by finding the optimal allocation of water for production subject to the set of social norms in the community.

$$Max \sum_{t=1}^{N-1} \sum_{i=1}^{M} \beta^t U_t^i \left[\Pi_t^i,\ \bar{w}_t^i - w_t^i\right] + \sum_{i=1}^{M} \beta^N U_N^i \left[\Pi_N^i\right]$$

Subject to:

(1) $\sum_{t=1}^{N} \sum_{i=1}^{M} w_t^i \leq S_1$ (stock constraints)

(2) $S_{t+1} = S_t - \sum_{i=1}^{M} w_t^i\ ,\ \forall t = 1, \dots, N$ (stock dynamics)

(3) $S_N = \sum_{i=1}^{M} w_N^i$ (resource exhaustion in the last period)

The discounted utility function for the final period in the objective function has no social norm term in the preference component. Experimental game theory has provided evidence that repeated games reduce cooperation over time, and in the last period the number of contributors to social welfare declines to almost 30 percent in most cooperative games (Ostrom, 2000). This would, in most cases, eliminate the possibility of cooperation due to reduction in monitoring as well as sanctioning power by willing cooperators. The explanation for such behavior is that at the last period when the resource has depleted to a level where the social norm will have no relevance in conserving the resource we assume that the society/agent finds no more need to adhere to the norm. Therefore, the objective function is divided into two components, where the time horizon distinguishes between *N*-1 periods and the final period, *N*.

The Lagrangian of the problem is

$$L = \sum_{t=1}^{N-1}\sum_{i=1}^{M}\beta^t U_t^i\left[\Pi_t^i, \bar{w} - w_t^i\right] + \sum_{i=1}^{M}\beta^N U_N^i\left[\Pi_N^i\right] - \lambda\left(\sum_{t=1}^{N}\sum_{i=1}^{M} w_t^i - S_t\right)$$ [7]

The first order conditions (FOC) yield

(4) $\beta^t \frac{\partial U_t^i}{\partial \Pi_t^i}\frac{\partial \Pi_t^i}{\partial w_t^i} - \beta^t \frac{\partial U_t^i}{\partial h_t^i} - \lambda = 0, \ \forall t = 1, \ldots, N-1; i = 1, \ldots, M$[8]

For the N^{th} period the FOC is

(5) $\beta^N \frac{\partial U_N^i}{\partial \Pi_N^i}\frac{\partial \Pi_N^i}{\partial w_N^i} - \lambda = 0.$

The FOCs allow one to derive the inter-temporal Euler Equation

(6) $\beta^t \frac{\partial U_t^i}{\partial \Pi_t^i}\frac{\partial \Pi_t^i}{\partial w_t^i} - \beta^t \frac{\partial U_t^i}{\partial h_t^i} = \beta^N \frac{\partial U_N^i}{\partial \Pi_N^i}\frac{\partial \Pi_N^i}{\partial w_N^i}.$ [9]

The inter-agent Euler Equation for agents *j* and *k* in period *t* is:

(7) $\beta^t \frac{\partial U_t^j}{\partial \Pi_t^j}\frac{\partial \Pi_t^j}{\partial w_t^j} - \beta^t \frac{\partial U_t^j}{\partial h_t^j} = \beta^t \frac{\partial U_t^k}{\partial \Pi_t^k}\frac{\partial \Pi_t^k}{\partial w_t^k} - \beta^t \frac{\partial U_t^k}{\partial h_t^k}.$ [10]

---

[7] Explanation for the single constraint: By the stock dynamic assumption $S_2 = S_1 - \sum_{i=1}^{M} w_1^i$, and $S_3 = S_2 - \sum_{i=1}^{M} w_2^i = S_1 - \sum_{i=1}^{M} w_2^i - \sum_{i=1}^{M} w_1^i$. Therefore $S_N = S_{N-1} - \sum_{i=1}^{M} w_{N-1}^i = S_1 - \sum_{t=1}^{n-1}\sum_{i=1}^{M} w_t^i$. This means that $S_1 = S_N + \sum_{t=1}^{n-1}\sum_{i=1}^{M} w_t^i$. Combining the resource exhaustion assumption $S_N = \sum_{i=1}^{M} w_N^i$ we get $S_1 = S_N + \sum_{t=1}^{n-1}\sum_{i=1}^{M} w_t^i = \sum_{i=1}^{M} w_N^i + \cdots + \sum_{t=1}^{n-1}\sum_{i=1}^{M} w_t^i = \sum_{t=1}^{n}\sum_{i=1}^{M} w_t^i$, which is a subset of the first constraint. So, by combining the three constraints into one we can reduce the Lagrangian.

[8] In the absence of social norms this FOC becomes $\beta^t \frac{\partial U_t^i}{\partial \Pi_t^i}\frac{\partial \Pi_t^i}{\partial w_t^i} - \lambda = 0, \ \forall t = 1, \ldots, N-1; i = 1, \ldots, M.$

[9] Which in the case of no social norm will become $\beta^t \frac{\partial U_t^i}{\partial \Pi_t^i}\frac{\partial \Pi_t^i}{\partial w_t^i} = \beta^n \frac{\partial U_n^i}{\partial \Pi_n^i}\frac{\partial \Pi_n^i}{\partial w_n^i}$, implying that the loss of marginal utility with lesser water use in any period can be compensated by the increase in marginal utility in the terminal period.

[10] The inter-agent Euler equation for the N^{th} period is: $\beta^n \frac{\partial U_n^j}{\partial \Pi_n^j}\frac{\partial \Pi_n^j}{\partial w_n^j} = \beta^n \frac{\partial U_n^k}{\partial \Pi_n^k}\frac{\partial \Pi_n^k}{\partial w_n^k}.$

The inter-temporal Euler equation combined with the assumption that $\sum_{i=1}^{M} \frac{\partial U_t^i}{\partial h_t^i} > 0, \;\; \forall t = 1, \dots, \; N-1,$ leads to the conclusion that $\frac{\partial U_t^i}{\partial w_t^i}(with\ social\ norms) > \frac{\partial U_t^i}{\partial w_t^i}(without\ social\ norms), \forall t \neq N, \forall i,$

and

$w_t^i(with\ social\ norms) < w_t^i(without\ social\ norms), \forall t \neq N, \forall i.$

For the terminal N^{th} period, the Euler equation combined with the assumption that $\sum_{i=1}^{M} \frac{\partial U_t^i}{\partial h_t^i} > 0,$ leads to the conclusion that $\frac{\partial U_N^i}{\partial w_N^i}(with\ social\ norms) < \frac{\partial U_N^i}{\partial w_N^i}(without\ social\ norms), \forall i,$

which suggests that

$w_N^i(with\ social\ norms) > w_N^i(without\ social\ norms), \forall i.$

Thus, in every period except the terminal one, the utility derived from adherence to social norms would ideally decrease the usage of water. In the terminal period it leads to an increase in usage of water for every agent.

The condition $\frac{\partial U_t^i}{\partial w_t^i}(with\ social\ norms) > \frac{\partial U_t^i}{\partial w_t^i}(without\ social\ norms), \forall t \neq N, \forall i$ also requires that

(a) $\frac{\partial U_t^i}{\partial \Pi_t^i}(with\ social\ norms) > \frac{\partial U_t^i}{\partial \Pi_t^i}(without\ social\ norms)$ and $\frac{\partial \Pi_t^i}{\partial w_t^i}(with\ social\ norms) > \frac{\partial \Pi_t^i}{\partial w_t^i}(without\ social\ norms)\ \forall t \neq N, \forall i$ or if

(b) $\frac{\partial \Pi_t^i}{\partial w_t^i}(with\ social\ norms) < \frac{\partial \Pi_t^i}{\partial w_t^i}(without\ social\ norms)$ then $\frac{\partial U_t^i}{\partial \Pi_t^i}(with\ social\ norms) > \frac{\partial U_t^i}{\partial \Pi_t^i}(without\ social\ norms)$, subject to satisfying the marginal utility condition.

All findings above would imply that if marginal profit from water use is significantly lower in the presence of social norms marginal utility from profit has to be high enough that the marginal utility of water use is higher (with social norms in the utility function) so as to decrease the agent's use of water compared to the case with no value for social norm in the utility function.

And finally, if

(c) $\frac{\partial U_t^i}{\partial \Pi_t^i}(with\ social\ norms) < \frac{\partial U_t^i}{\partial \Pi_t^i}(without\ social\ norms)$ then $\frac{\partial \Pi_t^i}{\partial w_t^i}(with\ social\ norms) > \frac{\partial \Pi_t^i}{\partial w_t^i}(without\ social\ norms)$, subject to satisfying the marginal utility condition.

This would imply that marginal profit from water use has to be significantly high in the presence of social norm; if marginal utility from profit is low, such that the marginal utility of water use is higher (with social norms in the utility function) so as to decrease the agent's use of water compared to the case with no social norm.

From the inter-agent Euler equation we get $\beta^t \frac{\partial U_t^j}{\partial \Pi_t^j}\frac{\partial \Pi_t^j}{\partial \omega_t^j} - \beta^t \frac{\partial U_t^j}{\partial h_t^j} = \beta^t \frac{\partial U_t^k}{\partial \Pi_t^k}\frac{\partial \Pi_t^k}{\partial \omega_t^k} - \beta^t \frac{\partial U_t^k}{\partial h_t^k} \Longrightarrow \frac{\partial U_t^j}{\partial \omega_t^j} - \frac{\partial U_t^k}{\partial \omega_t^k} = \frac{\partial U_t^j}{\partial h_t^j} - \frac{\partial U_t^k}{\partial h_t^k}$.

Suppose that *k*'s marginal utility from norm adherence is lower than *j*'s; namely $\frac{\partial U_t^j}{\partial h_t^j} - \frac{\partial U_t^k}{\partial h_t^k} \geq 0$, which leads to the conclusion that water use by agent *j* is lower than that of agent *k*[11]. In other words, for all periods where agent *j* has higher marginal utility from norm adherence, agent *j* will use relatively less water than agent *k*.

The most important water institution at the community level, other than joint water tanks, reservoirs, or groundwater aquifer and other community infrastructure resources, is water trade. But most local water markets, over the world, have insufficient infrastructure for monitoring, information gathering and conveying the water. Therefore agents trading in water markets have to incur transaction costs in gathering information and prices for traders, and negotiating and formalizing transactions. In some parts of the world the caste status implies also certain constraints on interactions among farmer groups.

[11] As $\frac{\partial U_t^j}{\partial h_t^j} \geq \frac{\partial U_t^k}{\partial h_t^k}$

The following section introduces transaction costs in a community-trading model under two social groups and variable transaction cost of trading.

Two Social Groups, P (M1 agents) and Q (M2 agents), and Variable Transaction Costs T

The agents have three sources for obtaining irrigation water: (a) communal water source (reservoir, tank, or groundwater aquifer) up to the assigned water limit *w* or over-extraction of the resource; (b) intra-group trade between agents of group *P* only and between agents of group *Q* only); and (c) inter-group trade (between agents of group *P* and *Q*). We assume variable transaction costs, a more realistic assumption in this model. There are two groups, *P* and *Q*, of water users with *M1* and *M2* agents in each, respectively. Assuming a variable transaction cost *T*(*m*), as a function of the amount of inter-group water trade (*m*), which is shared by the two groups in ratios α and $(1-\alpha)$. The transaction cost is assumed to be equally shared among all group members: $\frac{T(m)}{M1+M2} = \frac{\alpha \cdot T(m)}{M1} + \frac{(1-\alpha)\cdot T(m)}{M2}$.

For simplicity there is no cost of water extraction in the utility function of the agents. We also assume that there are no extraction externalities.[12] The intra-group trade consists of individual trades of n_i^j for every agent *i* trading with other agent *j* $(i \neq j)$ in the group. If $n_i^j \geq 0$ agent *i* purchases water from *j*; $n_i^j \leq 0$ implies a sale; and $n_i^j = 0$ implies no transaction. In all cases $n_i^j = -n_j^i$, namely if agent *i* buys water from *j*, it is equivalent to having agent *j* selling water to agent *i*. With regards to the inter-group water trade, *m*, it will be added to the purchasing group's water stock and subtracted from the selling group's water stock. If group *P*, composed of *M1* agents maximizes its group welfare at period *t*, we get

(8) $\sum_{j\neq i}\sum_{i=2}^{M1} U^i\left[\Pi_t^i, (\bar{w}_t + n_i^j - w_t^i)\right] + \sum_{j\neq i}\sum_{i=1} U^i\left[\Pi_t^i, (\bar{w}_t + n_i^j + m - w_t^i)\right]$

Where

(9) $\Pi_t^1 = P_f f^1(x_t^1, w_t^1) - p_x x_t^1 - \frac{\alpha}{M1}T(m) - p_w' m - P_w \sum_{j\neq 1} n_1^j$, and

(10) $\Pi_t^i = P_f f^i\left(x_t^i, w_t^i\right) - p_x x_t^i - \frac{\alpha}{M1}T(m) - P_w \sum_{j\neq i}^{M1} n_i^j, \;\; \forall i \neq 1.$

[12] Developing a model with congestion externalities in water extraction will be undertaken in a future work.

We assume that only one agent from group *P* trades with one agent in group *Q*. It is also possible (empirically observed) that the water price resulting from inter-group trade is higher than price resulting from intra-group trade (e.g., Hanak and Stryjewski, 2012:31). In case of Agent *i*=1 in groups *P* and *Q*, we get $\bar{w} + m + \sum_{i \neq j} n_i^j \geq w_t^i$, where *j* belongs to the same group, would imply adherence to social norm and violation otherwise.[13] In case of all other agents, $\bar{w} + \sum_{i \neq j} n_i^j \geq w_t^i$ implies adherence (and violation of social norm otherwise) where agent *j* belongs to the same group. The constraint for utility maximization is $\sum_{i \in P} w_t^i + \sum_{i \in Q} w_t^i \leq S_t$, given the stock of water.

The Langragian for each group *P* and *Q* would be

(11) $$L^P = \sum_{i \neq j} \sum_{i=2}^{M1} U^i\left[\Pi_t^i, (\bar{w}_t + n_i^j - w_t^i)\right] + \sum_{i \neq j} \sum_{i=1} U^i\left[\Pi_t^i, (\bar{w}_t + n_i^j + m - w_t^i)\right] + \lambda \cdot \left(S_t - \sum_{i \in P} w_t^i + \sum_{i \in Q} w_t^i\right)$$

(12) $$L^Q = \sum_{i \neq j} \sum_{i=2}^{M2} U^i\left[\Pi_t^i, (\bar{w}_t + n_i^j - w_t^i)\right] + \sum_{i \neq j} \sum_{i=1} U^i\left[\Pi_t^i, (\bar{w}_t + n_i^j - m - w_t^i)\right] + \lambda \cdot \left(S_t - \sum_{i \in P} w_t^i + \sum_{i \in Q} w_t^i\right)$$

Assuming group *P* purchases water from group *Q*, the FOC for group *P* would yield

$$\frac{\partial U^1}{\partial \Pi^1}\frac{\partial \Pi^1}{\partial m} + \frac{\partial U^1}{\partial h} = 0 \quad \text{(w.r.t. inter-group water trade } m\text{)} \qquad (13)$$

Assuming group *Q* purchases water from group *P*, the FOC for group *Q* would yield

$$\frac{\partial U^1}{\partial \Pi^1}\frac{\partial \Pi^1}{\partial m} - \frac{\partial U^1}{\partial h} = 0 \quad \text{(w.r.t. inter-group water trade } m\text{)} \qquad (14)$$

And for intragroup trade

$$\frac{\partial U^i}{\partial \Pi^i}\frac{\partial \Pi^i}{\partial n_i^j} + \frac{\partial U^i}{\partial h} + \frac{\partial U^j}{\partial \Pi^j}\frac{\partial \Pi^j}{\partial n_i^j} - \frac{\partial U^j}{\partial h} = 0^{14} \quad \text{(w.r.t. intra-group water trade } n_i^j \text{ for each } i \neq j\text{)} \qquad (15)$$

$$\frac{\partial U^i}{\partial \Pi^i}\frac{\partial \Pi^i}{\partial w^i} - \frac{\partial U^i}{\partial h^i} - \lambda = 0 \quad \forall i \quad \text{(w.r.t. water use for each agent)} \qquad (16)$$

From (13) we derive the condition $\frac{\partial \Pi^1}{\partial m} = P_f f_m^1(x_t^1, w_t^1) - \frac{\alpha}{M1} T'(m) - P'_w < 0$ for group *P*. With inclusion of social norms in the utility function the agent will replace excess extraction with

[13] This cannot be a condition for utility maximization as this condition is assumed to be not imposed and even if informally imposed it cannot be completely monitored.

[14] Because $h_t^j = \bar{w}_t{}^j + n_j^i - w_t^j = \bar{w}_t{}^j - n_i^j - w_t^j$; we get $\frac{\partial h_t^j}{\partial n_i^j} = -1$

increased inter-group trade of water. Also $P_f f_m^1(x_t^1, w_t^1) < \frac{\alpha}{M1} T'(m) + P'_w$ implies that despite marginal gains in value of productivity from intra group trade being less than the marginal cost of trade, still trade would occur due to the increased marginal utility from adherence to the social norm.

From (14) we derive the condition $\frac{\partial \Pi^1}{\partial m} = P_f f_m^1(x_t^1, w_t^1) - \frac{(1-\alpha)}{M2} T'(m) + P'_w > 0$ for group *Q*. Similarly, the inter-group trade for group *Q* would take place due to the gains from trade but would have to bear the cost of the higher constraint of norm adherence.

The inter-group trade would continue until either $\frac{\partial \Pi^1}{\partial m} = P_f f_m^1(x_t^1, w_t^1) - \frac{\alpha}{M1} T'(m) - P'_w = 0$ or $\frac{\partial \Pi^1}{\partial m} = P_f f_m^1(x_t^1, w_t^1) - \frac{(1-\alpha)}{M2} T'(m) - P'_w = 0$, i.e., the trade would continue until either group does not gain any more from the trade or that the marginal utility from norm adherence reaches zero.

From (15) we can further derive the condition $\frac{\partial U^i}{\partial \Pi^i} \frac{\partial \Pi^i}{\partial n_i^j} + \frac{\partial U^j}{\partial \Pi^j} \frac{\partial \Pi^j}{\partial n_i^j} = \frac{\partial U^j}{\partial h} - \frac{\partial U^i}{\partial h}$, namely, if marginal utilities from adherence to social norm are equal for *i* and *j* we obtain $\frac{\partial U^i}{\partial \Pi^i} \frac{\partial \Pi^i}{\partial n_i^j} = -\frac{\partial U^j}{\partial \Pi^j} \frac{\partial \Pi^j}{\partial n_i^j}$.

Namely, the marginal cost of trade to agent *i* equals the marginal benefit from trade to agent *j*. If $\frac{\partial U^j}{\partial h} > \frac{\partial U^i}{\partial h}$ then $\frac{\partial U^j}{\partial n_i^j} < \frac{\partial U^i}{\partial n_i^j}$, namely, marginal utility of agent *j* from trade exceeds the marginal utility of trade for agent *i*. If $\frac{\partial U^j}{\partial h} < \frac{\partial U^i}{\partial h}$ then $\frac{\partial U^j}{\partial n_i^j} > \frac{\partial U^i}{\partial n_i^j}$, namely, marginal utility of agent i from trade exceeds the marginal utility from trade for agent *j*. Overall, whichever agent places greater value on the social norm of water conservation (based on their normative expectations) depicted by a higher marginal utility from norm adherence, they would demonstrate a higher willingness to sacrifice own production, and to trade water in order to ensure sustainability of the common resource.

Illustrative Simulations

While our analytical solution provides important behavioral and policy results, still, it is hard to compare the results for all combinations of the variables we introduced. For that purpose we develop a simplified simulation case with explicit production and behavioral functions. The objective of the simulation is to answer the following question: Given a resource stock level, how would a community use it and exhaust it over time with and without adhering to social norms?

To answer the question we employ three sets of comparative simulations. The first simulation includes a homogeneous group of farmers with no interaction among themselves with and without social norms. This simulation was implemented for *N* Periods and *M* Homogeneous Agents as in the analytical model we developed. The second set of simulations was implemented for *N* Periods and *M* homogeneous agents with heterogeneous marginal utility from norm adherence (high or low). The third set of simulations included two homogeneous groups that interact (trade water), which compares to the case of *Two Social Groups, P (M1 agents) and Q (M2 agents), and Variable Transaction Costs T* in the analytical model we developed. We introduce below several specifications to the functional forms, set and justify parameter levels, and group size and time span based on the literature. The simulation runs were conducted, using MATLAB software.

Simulation 1a: Homogeneous Group without Social Norms

The goal of the Simulation and Optimization exercise is to maximize the sum of discounted utility of the whole community over time (social planner problem). Here the utility is a monotonic transformation of the profit function

(17) $\text{Max } \sum_{t=1}^{N} \sum_{i=1}^{M} \beta^{t-1} U_t^i [\Pi_t^i]$

Subject to:

(18) $S_1 \geq \sum_{t=1}^{N} \sum_{i=1}^{M} w_t^i$, i.e. the resource S_1 can be utilized in w_t^i units only until it is exhausted.

(18.1) $w_t^i \geq 0$, the lower bound of usage is zero.

(18.2) At any period *t* the stock at the end of the period has to be non-negative i.e. $S_t \geq \sum_{i=1}^{M} w_t^i$ Where S_t is the stock of the resource at the beginning of that period.

(18.3) The profit function is $\Pi_t^i = P_f \left(A \left(w_t^i \right)^{\delta} \right) - p_w w_t^i$.

Mundlak (2001) finds that Cobb Douglas production function, while appropriate for individual level estimation, is inefficient for global scale production due to the non-inclusion of state variables. He opines that due to failure in accounting for changing techniques and inputs across groups/states/nations Cobb-Douglas production function will fail robustness tests and violate concavity assumption. But at the individual level we do not face these issues. Cobb-Douglas production function has been used in simulation literature (Ranjan, 2010; Fouka and Schlaepfer, 2014).

The Utility function is also assumed to be a Cobb Douglas function, $U\left[\Pi_t^i, \mathrm{h}_t^i\right] = Z(\Pi_t^i)^{\gamma}$. A single variable Cobb-Douglas utility function is used to account for risk aversion and avoid any bias in estimation of impact of profit on utility.

Equation (17) can be expanded to the sum of discounted value of utility for each individual (assuming a population of 100 individuals, as was used by Ranjan, 2010) over time as

(19) $\mathrm{U}_1^1[\Pi_1^1] + \beta\mathrm{U}_2^1[\Pi_2^1] + \beta^2\mathrm{U}_3^1[\Pi_3^1,] + \cdots + \beta^{\mathrm{N}-1}\mathrm{U}_\mathrm{N}^1[\Pi_\mathrm{N}^1]$

$+\ \mathrm{U}_1^2[\Pi_1^2,] + \beta\mathrm{U}_2^2[\Pi_2^2,] + \beta^2\mathrm{U}_3^2[\Pi_3^2] + \cdots + \beta^{\mathrm{N}-1}\mathrm{U}_\mathrm{N}^2[\Pi_\mathrm{N}^2]$

+…+ $\mathrm{U}_1^{100}[\Pi_1^{100}] + \beta\mathrm{U}_2^{100}[\Pi_2^{100}] + \beta^2\mathrm{U}_3^{100}[\Pi_3^{100}] + \cdots + \ \beta^{\mathrm{N}-1}\mathrm{U}_\mathrm{N}^{100}[\Pi_\mathrm{N}^{100}]$

where the first line is individual 1's discounted utility, the second line is individual 2's discounted utility, and the last line is individual 100' discounted utility; β is the discount factor. It is a function of the interest rate, *r*, i.e. $\beta = \frac{1}{1-\mathrm{r}}$.

Simulation 1b: Homogeneous Group with Social Norms

The production function, utility function, and parameters are assumed to be homogenous, as in simulation 1a. In addition the utility is derived from the profit function as well as the norm compliance[15] of the individual.

(20) $\mathrm{Max}\ \sum_{\mathrm{t}=1}^{\mathrm{N}-1}\sum_{\mathrm{i}=1}^{\mathrm{M}}\beta^{\mathrm{t}-1}\mathrm{U}_\mathrm{t}^\mathrm{i}\left[\Pi_\mathrm{t}^\mathrm{i}, \left(\mathrm{h}_\mathrm{t}^\mathrm{i}\right)\right] + \sum_{\mathrm{t}=1}^{\mathrm{N}-1}\beta^{\mathrm{N}-1}\mathrm{U}_\mathrm{N}^\mathrm{i}\left[\Pi_\mathrm{N}^\mathrm{i}\right]$

Subject to the same conditions of resource use as in simulation 1a.

The Utility function is $U\left[\Pi_t^i, \mathrm{h}_t^i\right] = \mathrm{Z}(\Pi_t^i)^{\gamma} + \mathrm{K}\cdot(\overline{w}_t^i - w_t^i)$. And the profit function is $\Pi_t^i = P_f\left(A\cdot\left(w_t^i\right)^{\delta}\right) - p_w w_t^i$.

Most of the social norm related simulation literature (Ranjan, 2010; Bardhan, 1999) assumes that utility is a monotonic transformation of the profits and do not assume any particular utility function. In our simulation a Quasi-linear Utility function is used instead of a Cobb Douglas function for multiple reasons (a) this allows the individuals to defy the norm i.e. use excess water or not save any water. (b) The linear norm component enables to account not only for the impact of

[15] The norm term is $\mathrm{h}_\mathrm{t}^\mathrm{i} = \overline{\mathrm{w}} - \mathrm{w}_\mathrm{t}^\mathrm{i}$ for all non-terminal periods and $\mathrm{h}_\mathrm{t}^\mathrm{i} = 0$ for the terminal period.

(non) adherence on the utility derived but also for the effect of the magnitude of (non) adherence on utility. (c) Quasi linearity also enables to maintain the assumption of risk aversion in the producers. (d) If the Utility function is instead assumed to strictly be a Cobb Douglas function ($U\left[\Pi_t^i, \mathrm{h}_t^i\right] = \mathrm{Z} \cdot (\Pi_t^i)^\gamma \cdot \left(\bar{w}_t^i - w_t^i\right)^{(1-\gamma)}$) and if norm adherence is zero the utility will also be zero despite substantial profits and, (e) if the norm condition is violated the norm part of the utility function will not be a real number (given the concavity condition the power of the norm adherence section of utility would be less than one and the norm value would be negative, yielding us a complex number utility value). The crops selection, crop and water prices and utility and production function in the simulation are assumed to be homogenous. The next step in the simulation would be to vary these parameters and examine the resulting changes.

Equation (18) can be expanded to the sum of discounted value of utility for each individual (assuming 100 individual population) over time as:

(21) $\mathrm{U}_1^1[\Pi_1^1, (\bar{\mathrm{w}} - \mathrm{w}_1^1)] + \beta\mathrm{U}_2^1[\Pi_2^1, (\bar{\mathrm{w}} - \mathrm{w}_2^1)] + \beta^2\mathrm{U}_3^1[\Pi_3^1, (\bar{\mathrm{w}} - \mathrm{w}_3^1)] + \cdots + \beta^{\mathrm{N}-1}\mathrm{U}_\mathrm{N}^1[\Pi_\mathrm{N}^1, (\bar{\mathrm{w}} - \mathrm{w}_\mathrm{N}^1)]$

$+ \mathrm{U}_1^2[\Pi_1^2, (\bar{\mathrm{w}} - \mathrm{w}_1^2)] + \beta\mathrm{U}_2^2[\Pi_2^2, (\bar{\mathrm{w}} - \mathrm{w}_2^2)] + \beta^2\mathrm{U}_3^2[\Pi_3^2, (\bar{\mathrm{w}} - \mathrm{w}_3^2)] + \cdots + \beta^{\mathrm{N}-1}\mathrm{U}_\mathrm{N}^2$

$+\ldots+\mathrm{U}_1^{100}[\Pi_1^{100}, (\bar{\mathrm{w}} - \mathrm{w}_1^{100})] + \beta\mathrm{U}_2^{100}[\Pi_2^{100}, (\bar{\mathrm{w}} - \mathrm{w}_2^{100})] + \beta^2\mathrm{U}_3^{100}[\Pi_3^{100}, (\bar{\mathrm{w}} - \mathrm{w}_3^{100})] + \cdots + \beta^{\mathrm{N}-1}\mathrm{U}_\mathrm{N}^{100}[\Pi_\mathrm{N}^{100}, (\bar{\mathrm{w}} - \mathrm{w}_\mathrm{N}^{100})]$

where the first line is individual 1's discounted utility, the second line is individual 2's discounted utility, and the last line is individual 100's discounted utility. All other notations are the same as in simulation 1a. The terminal period *N* is when the resource has been exhausted.

The vectors $\mathrm{w}_t^1, \mathrm{w}_t^2, \mathrm{w}_t^3, \ldots, \mathrm{w}_t^\mathrm{M}$ for every period *t*, which maximizes the objective function must satisfy two first order conditions (i.e. Euler Conditions).

(a) The inter-temporal Euler Condition: For each agent *i* at period *t* (and terminal period N): $\beta^{t-1}\frac{\partial \mathrm{U}_t^i}{\partial \Pi_t^i}\frac{\partial \Pi_t^i}{\partial \mathrm{w}_t^i} - \beta^{t-1}\frac{\partial \mathrm{U}_t^i}{\partial \mathrm{h}_t^i} = \beta^{\mathrm{N}-1}\frac{\partial \mathrm{U}_\mathrm{N}^i}{\partial \Pi_\mathrm{N}^i}\frac{\partial \Pi_\mathrm{N}^i}{\partial \mathrm{w}_\mathrm{N}^i}$.

Or for any two periods *p* and *q* for the same individual *i*: $\beta^{p-1}\frac{\partial \mathrm{U}_p^i}{\partial \Pi_p^i}\frac{\partial \Pi_p^i}{\partial \mathrm{w}_p^i} - \beta^{p-1}\frac{\partial \mathrm{U}_p^i}{\partial \mathrm{h}_p^i} = \beta^{q-1}\frac{\partial \mathrm{U}_q^i}{\partial \Pi_q^i}\frac{\partial \Pi_q^i}{\partial \mathrm{w}_q^i} - \beta^{q-1}\frac{\partial \mathrm{U}_q^i}{\partial \mathrm{h}_q^i}$.

(b) The inter-agent Euler Condition: For agents *i* and *j* at period *t*: $\beta^{t-1}\frac{\partial U_t^i}{\partial \Pi_t^i}\frac{\partial \Pi_t^i}{\partial w_t^i} - \beta^{t-1}\frac{\partial U_t^i}{\partial h_t^i} = \beta^{t-1}\frac{\partial U_t^j}{\partial \Pi_t^j}\frac{\partial \Pi_t^j}{\partial w_t^j} - \beta^{t-1}\frac{\partial U_t^j}{\partial h_t^j}$.

Simulation 2: Homogeneous Group (Production and Utility from Profit Functions) with Social Norms and Heterogeneity in Marginal Utility from Norm Adherence

Assuming the same theoretical structure as above but introducing heterogeneity in marginal utility of norm adherence, i.e., the norm coefficient parameter K (Kappa). The inter-temporal Euler Condition will remain unchanged, but the inter-agent Euler Condition at any period t will be modified to

(b)' Assuming for any two agents *i* and *j* at period *t*, $\frac{\partial U_t^i}{\partial h_t^i} > \frac{\partial U_t^j}{\partial h_t^j}$ or $K^i > K^j$ then we can derive from the above the Inter-Agent Euler Condition $\beta^{t-1}\frac{\partial U_t^i}{\partial \Pi_t^i}\frac{\partial \Pi_t^i}{\partial w_t^i} - \beta^{t-1}\frac{\partial U_t^i}{\partial h_t^i} = \beta^{t-1}\frac{\partial U_t^j}{\partial \Pi_t^j}\frac{\partial \Pi_t^j}{\partial w_t^j} - \beta^{t-1}\frac{\partial U_t^j}{\partial h_t^j}$ the condition $\frac{\partial U_t^i}{\partial \Pi_t^i}\frac{\partial \Pi_t^i}{\partial w_t^i} > \frac{\partial U_t^j}{\partial \Pi_t^j}\frac{\partial \Pi_t^j}{\partial w_t^j}$ which in turn would imply (given the concavity assumption) that $w_t^i < w_t^j$. That is, agent *i* with higher marginal utility from norm adherence would use lesser amount of water than agent *j* with a lower marginal utility from norm adherence at any period *t*.

For any two agents *i* and *j* with $\frac{\partial U_t^i}{\partial h_t^i} = \frac{\partial U_t^j}{\partial h_t^j}$, or $K^i = K^j$ the original inter-agent Euler Condition (b) will hold true at any period *t*.

For convenience the condition for norm adherence is homogenous across agents in all periods. Here the simulation-optimization was conducted for 10 agents[16]. Parameters used in the simulations are presented in Table 1. In selecting the values for the discount rate and other parameters[17] we have been guided by Ranjan (2010). The baseline value of r=0.1 yields $\beta = 0.91$. In Ranjan's paper there is no coefficient for the water usage (in the production function) or utility function. The value for these were assumed to be A=5, Z=5, and the Elasticity of the profit

[16] For convenience. The simulation can be scaled up to a larger population given sufficient computational resources.

[17] Price of Output $P_f = 1$, Price of Water $P_w = 1$, Share of water in the value of production $\delta = 0.4$, N=10.

component in the utility function was set at $\gamma = 0.4$ in our simulation. The simulations were run for 250 years.

The simulation process led to an interesting problem. As the norm of resource use in our model is static and not a function of the decreasing stock the agents in the simulation were consuming miniscule amounts of the resource until the last period (presumably infinity)[18] without completely exhausting the resource. The inter-temporal Euler Conditions were also not satisfied beyond the point where the marginal utility from profit was exceeded by the marginal utility from norm adherence. By consuming minute amounts of the resource the agents were maximizing their utility in perpetuity. To resolve this issue we imposed a 'stock lower limit' for the resource stock. When the stock reduced to this lower limit, beyond that period there was no more utility received from norm adherence. This forced the agents to terminate their optimization process and completely exhaust the resource, as is expected from rational agents in a resource use game. The resulting resource use values also satisfied the inter-temporal Euler Conditions. If a dynamic normative value (as a function of remaining stock value) was introduced in this model, we would presumably not require such a 'stock lower limit' parameter. This structure will be tested in further work.

Imposition of a stock lower limit did not lead to significant changes in the usage or in the utility values for pre-lower limit periods. Only the resource use values for periods after the lower limit of stock is achieved get adjusted. We also tested the results for various lower-limit values.[19] Again, no significant difference in usage (pre-lower limit) or utility (overall) was observed (Figure 2 and table 3). Therefore, the results (Table 2 and 4) and graphs (Figure 1 and 3) depicted below are all for 'stock lower limit'=0.3. The imposition of this stock lower limit was necessary to expedite the simulations as well as to terminate the optimization process from continuing indefinitely.

Table 1: Parameters used in the simulations.

Model	Price of Output	Price of Water	Share of Water in Value of Production	Social Norm Coefficient	Production Function Coefficient	Utility Function Coefficient for Profit	Share of Water in Value of Profit	Discounting Coefficient	Number of Agents

[18] This phenomenon was tested for 600 periods.

[19] Tested for stock lower limit values of 1, 0.5 and 0.3. See Figure 2 and Table 3 and relevant description.

Homogenous group with no social norms	1	1	$\delta = 0.4$	K=0	A=5	Z=5	γ=0.4	$\beta = 0.91$	10
Homogenous group with social Norms	1	1	$\delta = 0.4$	K=5	A=5	Z=5	γ=0.4	$\beta = 0.91$	10
Homogenous group with Social Norms and heterogeneous K	1	1	$\delta = 0.4$	$K_1 = 1$ $K_2 = 10$	A=5	Z=5	γ=0.4	$\beta = 0.91$	10

The analytical modification of simulations 3a and 3b appears in the Appendix.

Results of Simulations 1, and 2.

The results of water use in the first simulation of a homogeneous group with and without social norm are presented in Figure 1 and Table 2, and discussed below with regards to other parameters.

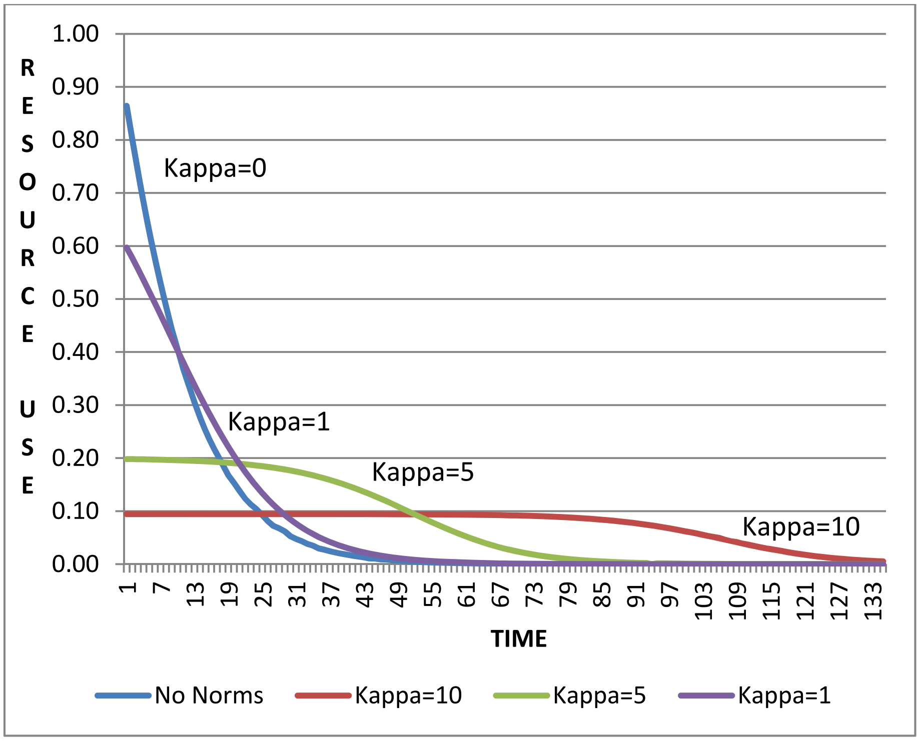


Figure 1: Normalized Water Usage of Representative Agent With and Without Social Norms for different levels of the Norm Coefficient K (the marginal utility from norm adherence).

In the case of homogenous group of agents, the simulation reveals several main differences between the cases with and without social norms. In the case with social norms agents' behavior is much more sustainable. The CPWA is depleted by the 51stth period without social norms and, by the 56th, 86th and 136th period with social norms for the cases where marginal utility from norm adherence[20]=1, 5 and 10 respectively. The utility maximizing water usage levels also satisfied the Euler conditions. The initial resource usage is significantly higher without social norms (0.864 units of water) as compared to the norm adhering case, with 0.6, 0.2 and 0.09 units of water for the 3 levels of norm adherence 1, 5, 10, respectively. Water usage drops very significantly from the initial level in the case without social norms, while it remains more stable in the case with social norms[21]. By the 18th period water usage in the case without norms is nearly equal to that of the norm adhering[22] group (0.187 units and 0.192 unit, respectively), and from thereafter, it continue to drop and reaches zero 40 years earlier than in the case with social norms (for Kappa=5). In agriculture this would mean that no norm adhering group would have higher profits and resource usage in the beginning of the simulation but within a short period their resource availability will not be sufficient, leading to lower profits and utility in the longer run and to a situation where the resource will get exhausted in a shorter period compared to the norm adhering group. The total discounted utility of the norm adhering group (Table 2) over the entire 150-year horizon simulation (1223.25) is substantially higher than that of the non-adhering group (847.81)[23]. This confirms our hypothesis that adherence to social norms would reduce the consumption of the resource (water), ensure sustained use over a longer period of time, and maximize overall utility.

Table 2: Total Discounted Utility and Time of Convergence Results of Simulations 1(a) and 1(b) for three levels of Marginal Utility from Norm Adherence ('Stock Lower Limit'=0.3)

---

[20] Measured by Kappa.

[21] With slower declines for the cases with higher marginal utility for norm. As seen in Fig.1 the resource use curves for kappa=5, 10 display flatter slopes and slower decline. Whereas for kappa=1 the slope is steeper and similar to the 'no norm' curve.

[22] Kappa=5, 1

[23] For Kappa=5. In case of Kappa =1 and 10.

Norm Status	No Norms (Baseline)	Norm K=1	Norm K=5	Norm K=10
Total Discounted Utility	847.81	909.30	1223.25	1699.70
Period of Convergence	52	57	86	136

We present in Table 2 the total discounted utility and period of convergence for the no norm case and for the cases with different levels of marginal utility from adherence to the norm (Kappa). The inclusion of norms in the utility function has considerable effect on the use of the resource without decreasing the final discounted utility of the community. The adherence to norms in fact has the effect of an overall increase in the social satisfaction levels. This is the difference between societies which adhere to the norm and those which choose to violate it. The societies which adhere to the norm possibly gain some satisfaction in this process. The societies which do not gain any satisfaction from norm adherence will choose to exploit the resource with only the profit motive in mind.

To test for the effect (if any) of variations in the parameter 'stock lower limit', we conducted simulations of the 'with norms' scenario for Kappa=1, 5 and 10 with lower limits = 1, 0.5 and 0.3. In this analysis we show that the imposed levels of lower stock limit for signaling the end of norm imposition do not have any significant impact on the outcome. Comparing the observations in Tables 2 and 3 for the same Kappa value across the three levels of 'stock lower limits' suggests that the total discounted utility and time of convergence are approximately the same in all cases. For K=5, the total discounted values are 1223.25, 1223.21 and 1223.20 and the period of convergence is 86, 86 and, 87 for the 'stock lower limits' 0.3, 0.5 and 1 respectively. There is a slightly greater divergence in the time of convergence results for K=10, namely 136, 151 and 139 for 'stock lower limits' 0.3, 0.5 and 1, respectively. But when examined visually in Figure 2 we observe that the agents' water usage largely coincides for all Kappa values, including for Kappa=10. The slight variation in convergence occurs only once the 'stock lower limit levels' are reached.

Table 3: Total Discounted Utility and Time of Convergence Results of Simulations 1(a) and 1(b) for three levels of Marginal Utility from Norm Adherence and 'Stock Lower Limit'=0.5 and 1

	K=10 stock lower limit=0.5	K=5 stock lower limit=0.5	K=1 stock lower limit=0.5	K=10 stock lower limit=1	K=5 stock lower limit=1	K=1 stock lower limit=1
Total Discounted Utility	1699.70	1223.21	909.00	1699.70	1223.20	908.66
Period of Convergence	151	86	58	139	87	58

Figure 2 is a variation of Figure 1 and it additionally plots the agents' resource usage decisions across the different values of Kappa=1, 5 and, 10, given the changes in the level of the 'stock lower limit' parameter. The kink in the penultimate periods for the agent resource usage, in the K=10, lower limit=0.5 scenario, occurs when the stock levels decline below the 'stock lower limit' of 0.5, for that particular simulation. The MATLAB simulation program automatically implemented the normless utility maximization at that point and the usage rose for the last two periods. This occurs as the agents are using the resource conservatively to (a) sustain the resource for a longer period and (b) maximize utility associated with norm adherence. Subsequently the stock was exhausted and resource use declined to zero. We can visually verify, using Figure 2, that varying the stock limit parameter for all Kappa values has little effect on usage values or convergence periods. For any Kappa value, given the variation in the 'stock lower limit' parameter, the resource usage (values) curves and their convergence points coincide. Given this observation all subsequent simulations are limited to the 'stock lower limit'=0.3 scenario.

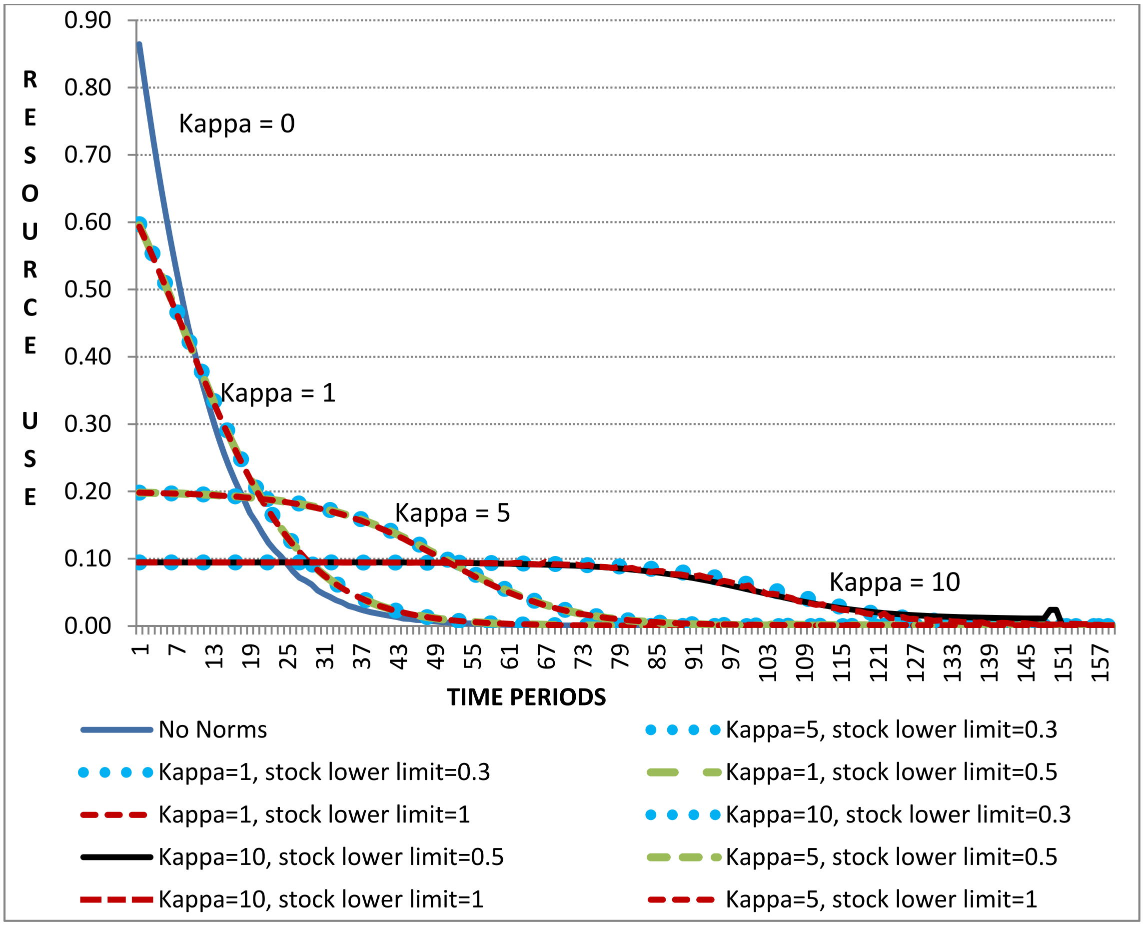


Figure 2: Normalized Water Usage of Representative Agent, with different levels of Stock Lower Limits, and Different levels of Marginal Utility from Adherence to Norms (Kappa) in Simulations 1(a) and 1(b)

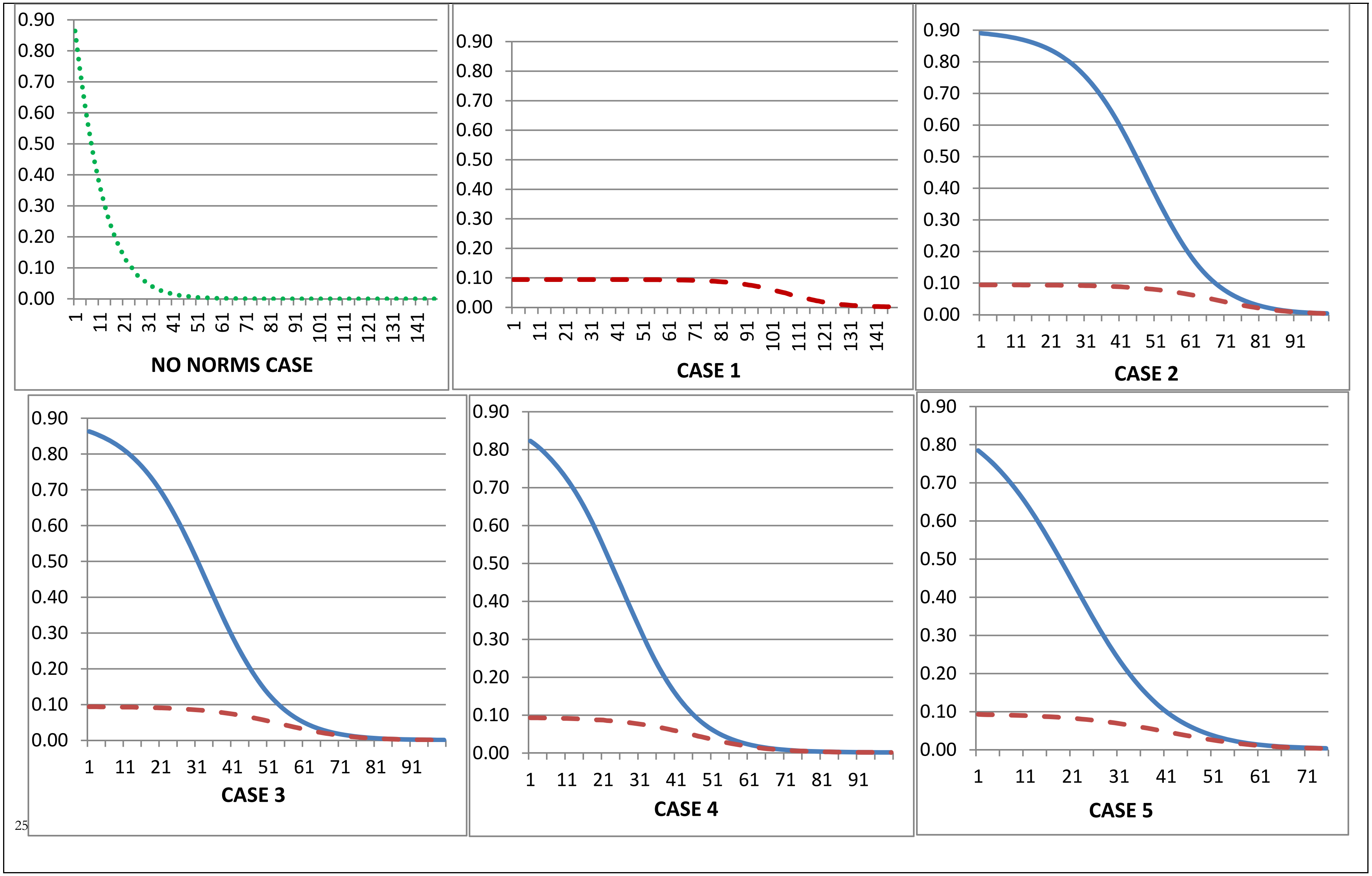
Note: Some of the lines overlap and are not seen properly in the figure.

We simulate now the impact of the distribution of agents within the group with high Kappa and low kappa on the group performance. Results of total discounted utility and of the period of convergence for the 11 case simulations are presented in Table 4. Figure 3 present the periodical values of normalized water usage for a subset of representative cases (distribution of the 10 agents across 2 groups of low value of Kappa (*K*=1) and high value of Kappa (*K*=5).

Table 4: Total Discounted Utility and Time of Convergence Resulting from the Simulation of Group with Heterogeneity in Marginal Utility from Norm Adherence (Kappa)

Case number	1	2	3	4	5	6	7	8	9	10	11
Number of Agents with Low Kappa[24]	0	1	2	3	4	5	6	7	8	9	10
Number of Agents with High Kappa	10	9	8	7	6	5	4	3	2	1	0
Total Discounted Utility	1699.7	1625.3	1550.0	1473.4	1395.5	1316.5	1236.5	1155.7	1074.1	991.94	909.3
Period of Convergence	136	98	83	78	72	67	64	62	60	58	56

[24] Where Kappa is the Marginal Utility from Norm Adherence. Low Marginal Utility of Norm adherence is Kappa =1 and High Marginal Utility of Norm Adherence implies Kappa=10.



[25]

---

[25] Note: Vertical axis measures normalized water use and horizontal axis measures periods

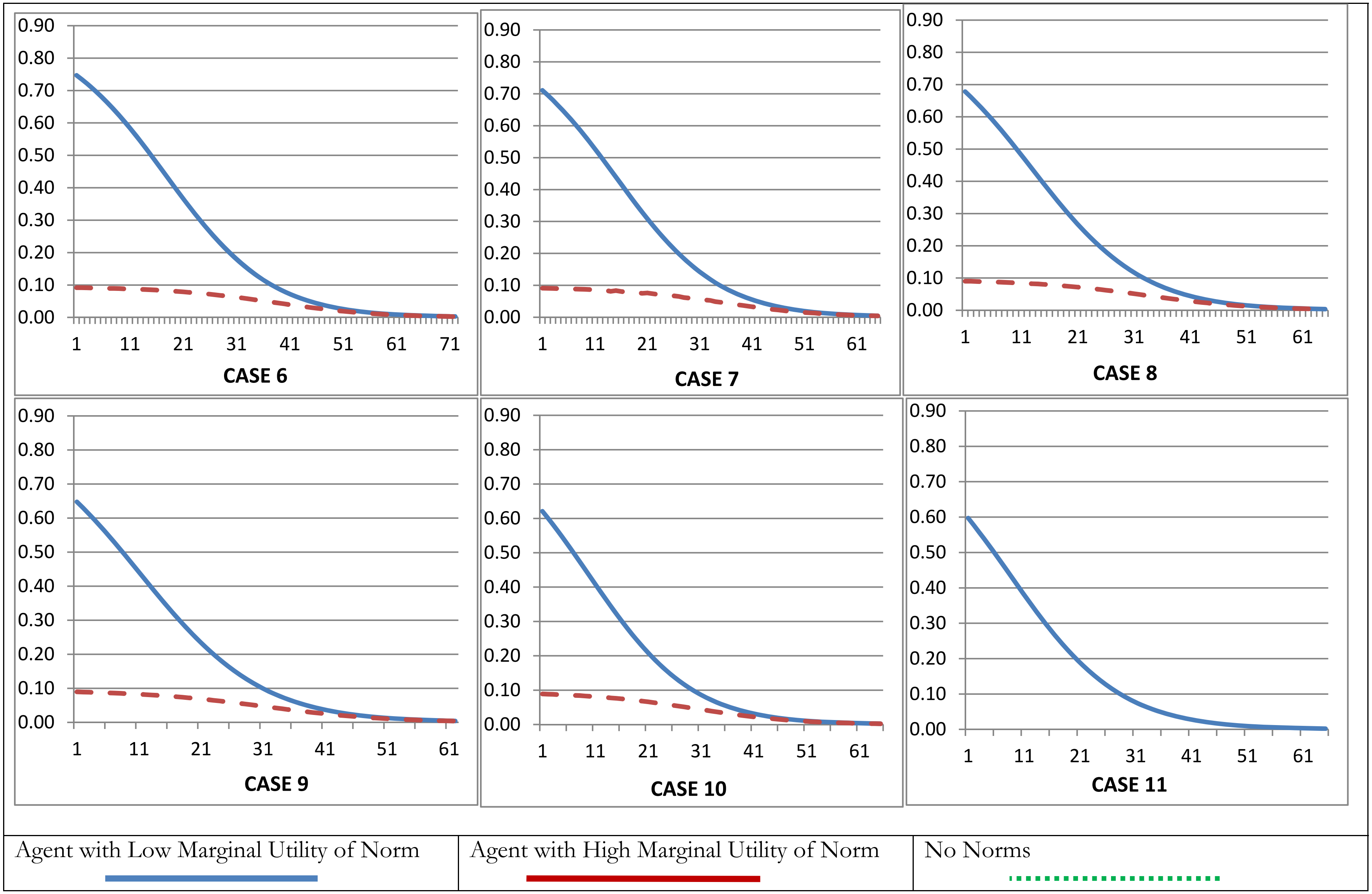


Figure 3: Normalized Water Usage by Representative Agents with Heterogeneous Marginal Utility from Adherence to Norms in Society by Proportion of Group in the Community. (Note: Vertical axis measures normalized water use and horizontal axis measures periods)

The results in Figure 3 and Table 4 suggest that as the proportion of high kappa agents increases in the community the resource is sustained longer and gets depleted less with correspondingly consistent increase in the total utility values. The marginal utility gained from the sustainable (norm adhering) use of the resource apparently is sufficient to compensate for the loss of profit as well as motivating the agents to continue to sustainably exploit the CPWR. The marginal impact on the longevity of the resource is increasing with every additional norm valuing agent added to (or transformed in) the society. But with every additional (transformed) high-norm-valuing agent in the group the magnitude/share of the low-norm-valuing agents in the exploited resource (or free ride) increases. Both the slope and intercept of the low Kappa agents' water usage curve increase as their proportion in the population. A possible implication is that the share of the profits/resource generated by exploiting the resource, for agents with a low marginal utility of norm (kappa), is inversely related to the number of violators in the society. The lesser the number of agents sharing the pool, the greater is each individual agents' share. This is a possibility in this simulation model due to three explanations: (a) The satisfaction from the decision to adhere (or not) being a subjective self-assessed valuation. As a result, for the agents who find the utility from profit significantly outweighing the perceived norms, the incentive would be to violate the norm and enjoy a greater share of the resource and the related output. (b) Though satisfaction level is autonomous, the resource use values are assigned by the central planner in this model with the goal of maximizing total social satisfaction. In each period the violating agents have relatively higher Utility levels. So the planner finds it prudent to assign greater individual resource shares to the norm violating agent. And, (c) Even in a self-deterministic scenario the simulations' structure would assign resource shares similar to the planner model due to the absence of agents willing to monetarily (or even intangibly) penalize the norm-violation (Kandori, 1992; Erasu and Grau, 2007; Fehr and Fischbacher, 2004; Ostrom, 2000; Sethi and Somanathan, 2003, 2004). Authors call such agents, who are willing to punish violators even at a marginal or substantial cost to themselves, either 'reciprocators', 'willing punishers' or 'conditional cooperators'. If a critical number exist of such agents are present in the community, purely profit seeking agents would be forced to adhere to the norms. Conversely, if there is a paucity of such agents, violators will have free reign to exploit the resource. Such conditions may force even those agents who are ambivalent and/or advocate conservative resource use, to start over-exploiting the resource. Further simulations will attempt to incorporate some of the above-mentioned features to compare results with the social planner case.

Correspondingly for the agents with a high norm coefficient the water usage curve's intercept is relatively unchanged while its slope decreases (albeit comparatively small changes) as their proportion increases in the population. Despite this decrease in water usage by a larger proportion of the population the total (social) discounted utility is correspondingly increasing (a combination of satisfaction from increased duration of profits as well as resource survival).

These observations are based on a social planner's utility maximizing model and cannot be utilized to a dynamic analysis of how the proportion of norm valuing/deriding agents evolves in this population as the self-determination of agents is essentially non-existent in a planner's model.

Conclusion

The existing literature on social norms interaction with use of common pool resources does not yet quantify such interactions, especially under resource scarce situations. This paper developed a framework that allows us to quantify the effect of social norms on the performance of existing institutions set by a group of users of a common pool resource under adversity, using water resources as an example.

We use the example of a WCPR—water reservoir that could be also an aquifer, or any other renewable natural resource, such as a forest or grazing land. We employ existing institutions that the group of users imposes on each of the members, such as quotas. We also introduce management institutions in the form of a water market that allows members to trade in their water rights. Having the social norms appear in the utility function of the individuals, allows us to derive several important theoretical results for the case of homogenous group of water users and a case with two different groups of the water users that use the water trade institution.

Our theoretical results in the case of homogenous group of users suggest that if marginal profit from water use is significantly lower in the presence of social norms marginal utility from profit has to be high enough that the marginal utility of water use is higher (with social norms in the utility function) so as to decrease the agent's use of water compared to the case with no value for social norm in the utility function. The theoretical results in the case of two distinct groups and a water trade institution suggest that overall, whichever agent places greater value on the social norm of water conservation (based on their normative expectations) depicted by a higher marginal utility from norm adherence, they would demonstrate a higher willingness to sacrifice own production, and to trade water in order to ensure sustainability of the common resource. The results from the heterogeneous group simulation suggest that the capability of free-riders to over-exploit the resource is inversely related to the number of agents (free-riders) with a low value for norm adherence.

Our simulation for the case of a homogenous group of agents allowed us also to draw conclusion with respect to the dynamics of water use and its impact on users welfare. In the case with social norms the users reveal much more sustainable extraction of the resource over time, actually doubling its life lifetime. This is reflected in initial resource usage, which is significantly higher without social norms compared to the norm adhering group. Water usage drops very significantly from the initial level in the case without social norms, while it remains more stable in the case with social norms. The total discounted utility of the norm adhering group over the entire simulation period is substantially higher than that of the non-adhering group. This confirms our hypothesis that adherence to social norms would reduce the consumption of the resource (water), ensure sustained consumption over a longer period of time, and maximize overall utility of the users.

While our model was built upon a case of WCPR, the nature of the agents exploitation of the resource, the physical growth of the resource over time, and the institutions that can be employed to manage the resource could be relevant as well for other resources such as grazing grounds and community forests, both of which have been discussed in our literature review. Once the analyst is able to identify and define the interaction between the utility from adhering to the social norms and the utility from using the resource, our model quantifies the level of resource use and the welfare derived from both resource use and adherence to the norms.

Several proposed extensions and caveats are addressed. One possible extension to our static model could include a dynamic framework with agents using grim-trigger strategy to further their agendas and the necessary evolution of the population of adhering agents as a result. We were not able to perform the simulations of the inter and intra group trade due to insufficient computing power that led to non-convergence of the model and in-ability to estimate the necessary Euler Conditions and the derived parameters of utility of the agents. While this is by itself an unfortunate outcome, we decided to present the simulation models (3a and 3b) in an appendix and to leave this issue for another paper that will include additional extensions.

References

Acheson, James, M., 1993. Capturing the commons: Legal and illegal strategies. In: Terry L. Anderson and Randy T. Simmons, editors, The Political Economy of Customs and Culture: Informal Solutions to the Commons Problem. Lanham, Rowman and Littleeld.

Anjal, Prakash, 2005. The Dark Zone: Groundwater, Irrigation, Politics and Social Power in North Gujarat, Orient Longman.

Bardhan, Pranab, 1999. Water community: An empirical analysis of cooperation on irrigation in south India. Berkeley: University of California, Department of Economics, Working Paper.

Blomquist, William, 1992. Dividing the Waters: Governing Groundwater in Southern California. ICS Press, San Francisco, California.

Botelho, A., A. Dinar, L. Pinto, A. Rapoport, 2015. Promoting Cooperation in Resource Dilemmas: Predictions and Experimental Evidence. *Journal of Behavioral and Experimental Economics*, 54:40-49.

Botelho, A., A. Dinar, L. Pinto, and A. Rapoport, 2014. Time and Uncertainty in Resource Dilemmas: Equilibrium Solutions and Experimental Results, ***Experimental Economics***, 17(4):649-672.

Bowles, S., S. Polania-Reyes, 2012. Economic Incentives and Social Preferences: Substitutes or Complements?, *Journal of Economic Literature*, 50:2, 368-425.

Bowles, Samuel, 1998. Endogenous preferences: The cultural consequences of markets and other economic institutions. *Journal of Economic Literature*, 36:75-111.

Bowles, Samuel, 2004, Microeconomics: behavior, institutions, and evolution. Russell Sage.

Bromley, Daniel W. and D. Feeny, 1992. Making the commons work: theory, practice, and policy. ICS Press, San Francisco, California.

Bromley, Daniel. W.,1989. Economic Interests and Institutions: The Conceptual Foundations of Public Policy. Basil Blackwell, New York.

Cain, Michael, 1998. An experimental investigation of motives and information in the prisoner's dilemma game. Advances in Group Processes, 15:133-160.

CommGAP, 2009. Communication for governance and accountability program technical brief. World Bank, Washington D.C..

Cordell, John, and Margaret A. McKean, 1982, Sea Tenure in Bahia, Brazil. In David Feeny A. J. Thomson, W. Bromley, Margaret McKean, Pauline Peters, Jere Gilles, Ronald Oakerson, and C Ford Runge (Eds.), Proceedings of the Conference on Common Property Resource Management April 21-26 1985, pages 183-206. ICS Press.

Crawford, Sue E. and Elinor Ostrom, 2005, A grammar of institutions. In Elinor Ostrom, editor, Understanding Institutional Diversity, pp. 137-174. Princeton University Press, Princeton, NJ.

Dinar, A. and U. Kumar Jammalamadaka, 2013. Adaptation of Irrigated Agriculture to Adversity and Variability under Conditions of Drought and likely Climate Change: Interaction between Water Institutions and Social Norms. *International Journal of Water Governance*, 1:41–64.

Fehr Ernst, and Fischbacher, Urs, 2004. Third-party punishment and social norms, *Evolution and Human Behavior,* 25:63-87

Fehr, Ernst, and Simon Gachter, 2000, Cooperation and punishment in public goods experiments. *American Economic Review*, 90(4):980-994.

Fehr. E., and Schmidt, K. M., 1999. A theory of fairness, competition, and cooperation. *The Quarterly Journal of Economics*, 114(3)817–868.

Fouka, Vasiliki, and Alain Schlaepfer, 2014. Agricultural Labor Intensity and The Origins of Work Ethics. Paper presented at the European Economic Association and Econometric Society 2014 Parallel Meetings, 25 - 29 August 2014, Toulouse, France. Accessed at http://www.eea-esem.com/EEA-ESEM/2014/m/viewpaper.asp?pid=571 on April, 12, 2015.

Frohlich, Norman and Joe A. Oppenheimer, 1996, Experiencing impartiality to invoke fairness in the npd: Some experimental results. *Public Choice*, 86:117-135.

Glaeser, E.L., Laibson, D.I., Scheinkman, J.A., & Soutter, C.L., 2000. Measuring Trust, *The Quarterly Journal of Economics*, 115(3):811-846.

Hanak, Ellen and Elizabeth Stryjewski, 2012. California's Water Market, By the Numbers: Update 2012. San Francisco: Public Policy Institute of California.

Hotimsky, S., Cobb, R., and Bold, A., 2006. Contracts or scripts? A critical review of the application of institutional theories to the study of environmental change, *Ecology and Society*, 11(1), Article 41.

Iglesias, Ana, Luis Garrote, Francisco Flores, and Marta Moneo, 2007, Challenges to manage the risk of water scarcity and climate change in the Mediterranean. Water Resources Management, 21:775-788.

Ingram, Helen M., Dean E. Mann, Gary D Weatherford, and Hanna J. Cortner, 1984. Guidelines for improved institutional analysis in water resources planning. *Water Resources Research*, 20(3):323-334.

Kandori Michihiro. 1992, Social norms and community enforcement, *The Review of Economic Studies,* 59(1):63-80.

List, John, A., 2006. The behavioralist meets the market: measuring social preferences and reputation effects in actual transactions, *Journal of Political Economics*, 114(1):1-37.

Mundlak, Yair, 2001, Production and Supply. In *Handbook of Agricultural Economics*, B. Gardner, Bruce and Gordon Rausser (Eds.), 4-77. Elsevier Science.

Noailly Joelle, Jeroen C.J.M. van den Bergh, and Cees A. Withagen. 2005. Local and global interactions in an evolutionary resource game. Working Papers 2005.78, Fondazione Eni Enrico Mattei, May.

North, Douglass C., 1990. Institutions, Institutional Change, and Economic Performance. Cambridge University Press.

Osés-Eraso, Nuria and Montserrat Viladrich-Grau, 2007. On the sustainability of common property resources, *Journal of Environmental Economics and Management*, 53(3): 393-410.

Oses-Eraso, Nuria, and Montserrat Viladrich-Grau, 2007. On the sustainability of common property resources. *Journal of Environmental Economics and Management*, 53(3):393-410.

Oses-Eraso, Nuria, and Montserrat Viladrich-Grau, 2011. The sustainability of the commons: giving and receiving. *Experimental Economics,* 14(4):458-481.

Oses-Eraso, Nuria, Frederic Udina, and Montserrat Viladrich-Grau, 2008. Environmental versus human induced scarcity in the commons: Do they trigger the same response? *Environmental & Resource Economics*, 40(4):529-550.

Ostrom Vincent, and Elinor Ostrom, 1972. Legal and political conditions of water resource development. Land Economics, 48(1):114.

Ostrom, Elinor, 2000. Collective action and the evolution of social norms. The Journal of Economic Perspectives, 14(3):137-158.

Ostrom, Elinor, 2002. In Ganesh Shivakoti and Elinor Ostrom, editors, Improving Irrigation Governance and Management in Nepal, pages 333. ICS Press, Oakland, CA.

Ostrom, Elinor, 2008. Developing a method for analyzing institutional change. In Sandra Batie and Nicholas Mercur, editors, Assessing the Evolution and Impact of Alternative Institutional Structures. Routledge Press.

Oswald, Odile, 1992. An expert system for the diagnosis of tank irrigated systems: a feasibility study. International Irrigation Management Institute, working paper no. 22, Colombo, Sri Lanka.

Poirier, Bryan A., and Robert C. de Loë, 2010. Analyzing water institutions in the 21st century: Guidelines for water researchers and professionals. Journal of Natural Resources Policy Research, 2(3).

Ranjan, Ram, 2010, Social Norms, Social Capital and the Sustainability of Small Scale Economies. *Journal of Natural Resources Policy Research*, 2(3):213-228.

Rustagi, D., Engel, S., and Kosfeld, M., 2010. Conditional cooperation and costly monitoring explain suc- cess in forest commons management. Science, 330:961–965. doi: 10.1126/science.1193649.

Saleth, Maria, R., and Ariel Dinar, 2004. The Institutional Economics of Water: A Cross-Country Analysis of Institutions and Performance. Edward Elgar.

Schmidt, David, Robert Shupp, James Walker, T.K. Ahn and Elinor Ostrom, 2001. Dilemma games: game parameters and matching protocols. *Journal of Economic Behavior & Organization*, 46:357–377.

Sethi, Rajiv, and E. Somanathan, 1996. The evolution of social norms in common property resource use. American Economic Review, 86(4):766-788.

Sethi, Rajiv, and E. Somanathan, 2003. Understanding reciprocity. Journal of Economic Behavior & Organization, 50(1):1-27.

Sethi, Rajiv, and E. Somanathan, 2004. Collective action in the commons: A theoretical framework for empirical research. Discussion Paper 04-21 June, Indian Statistical Institute, Delhi Planning Unit 7 S.J.S. Sansanwal Marg, New Delhi 110 016, India. http://www.isid.ac.in/~pu/dispapers/dp04-21.pdf.

Shivakoti, G., and Ostrom, E., 2002. Improving irrigation governance and management in Nepal. Oakland, CA: ICS Press.

Somanathan, E., 1991. Deforestation, property rights and incentives in central himalaya. *Economic and Political Weekly*, 26(4):37-46, January.

Spiertz, H.L.J., 1991. The transformation of traditional law: a tale of people's participation in irrigation management on bali. *Landscape and Urban Planning*, 20:189-196.

Toope, Stephen J., Ken Rainwater, and Tony Allan, 2003. Managing and allocating water resources: Adopting the integrated water resource management approach. In Abdulrahman S. Alsharhan and Warren W. Wood, editors, Water Resources Perspectives: Evaluation, Management and Policy, volume 50 of Developments in Water Science, pages 1-8. Elsevier,

UNWWAP. United nations world water development report. Technical report, UNESCO, 2006.

Van Steenbergen, F., and T. Shah, 2002. Rules rather than rights: Self-regulation in intensively used groundwater systems. In Intensive Use of Groundwater: Challenges and Opportunities, edited by R. Llamas, and E. Custodio, pp. 241–256, A. A. Balkema, Brookfield, VT.

Wade, Robert, 1994. Village Republics: Economic Conditions for Collective Action in South India. ICS Press, San Francisco, CA.

Auxiliary Appendix: Simulation of water trade[26]

Simulation 3a: Social Groups Model with Inter-Group and Intra-Group Trade No Social Norms and Transaction Costs.

This is an extension of the individual CPR utilization model. The population is divided into two groups *P* and *Q* with the possibility of conducting inter-groups and intra-group trade in the resource. In each period *t* the users belonging to the two groups decide their consumption and traded water quantities by solving the following langrangian problems.

(22) $L^P = \sum_{i\neq j}\sum_{i=2}^{M1}\beta^{t-1}U^i\left[\Pi_{t,}^i\right] + \sum_{i\neq j}\sum_{i=1}\beta^{t-1}U^i\left[\Pi_t^i\right] + \lambda\cdot\left(S_t - \sum_{i\in P} w_t^i + \sum_{i\in Q} w_t^i\right)$

(23) $L^Q = \sum_{i\neq j}\sum_{i=2}^{M2}\beta^{t-1}U^i\left[\Pi_{t,}^i\right] + \sum_{i\neq j}\sum_{i=1}\beta^{t-1}U^i\left[\Pi_t^i\right] + \lambda\cdot\left(S_t - \sum_{i\in P} w_t^i + \sum_{i\in Q} w_t^i\right)$

Agent 1 in each group is assigned the responsibility of conducting the inter-group trade. The profit and utility terms are modified to

***Group P*:**

For agent 1: $\Pi_t^1 = P_f\left(A(w_t^1)^{\delta 1}\right) - \frac{\alpha}{M1}T(m) - p_w'm - P_w(n_1^2 + n_1^3 + \cdots + n_1^5)$

For all other agents *i* in group P: $\Pi_t^i = P_f\left(A(w_t^1)^{\delta 1}\right) - \frac{\alpha}{M1}T(m) - P_w\left(n_i^1 + n_i^2 + \cdots + n_i^5\right)$ [27]

The utility function of each agent *i* in group P is $U\left[\Pi_t^i, \mathrm{h}_t^i\right] = \mathrm{Z}(\Pi_t^i)^\gamma$

***Group Q*:**

For agent 1: $\Pi_t^1 = P_f\left(A(w_t^1)^{\delta 2}\right) - \frac{(1-\alpha)}{M1}T(m) - p_w'm - P_w(n_1^2 + n_1^3 + \cdots + n_1^5)$

For all other agents *i* in group Q: $\Pi_t^i = P_f\left(A(w_t^1)^{\delta 2}\right) - \frac{(1-\alpha)}{M1}T(m) - P_w\left(n_i^1 + n_i^2 + \cdots + n_i^5\right)$[28]

The utility function of each agent *i* is $U\left[\Pi_t^i, \mathrm{h}_t^i\right] = \mathrm{Z}(\Pi_t^i)^\gamma$

---

[26] We were unable to produce simulation results due to non-convergence of the runs as our computational capacity was insufficient. However, the empirical model with adjustments for inter- and intra-trade is presented in this Appendix.

[27] where $\left(n_i^i = 0\right)$

[28] where $\left(n_i^i = 0\right)$

***Inter-group trade*:**

All other parameters remaining constant the share of water in productivity for group P is assumed to be $\delta 2 = 0.4$ and for group Q is assumed to be $\delta 2 = 0.6$. Assuming the higher productivity of group Q we assume they are the first movers and group P are the followers.

The Maximization Problem for group P is: given the water usage of group Q how to maximize sum of discounted utility over time. As maximizing profits are the only consideration for trade (as social norms are not part of the agents' utility functions); the inter-group trade would continue until the point the marginal profit for the agents trading on behalf of groups P and Q equal zero.

$\frac{\partial \Pi^1}{\partial m} = P_f f_m^1(w_t^1) - \frac{\alpha}{M1} T'(m) - P'_w = 0$ or $\frac{\partial \Pi^1}{\partial m} = P_f f_m^1(w_t^1) - \frac{(1-\alpha)}{M2} T'(m) - P'_w = 0,$

i.e. until neither group gains any more from trading with each other.

***Intragroup trade*:**

From the marginal conditions of intra-group trade we can derive the relation

$$\frac{\partial U^i}{\partial \Pi^i}\frac{\partial \Pi^i}{\partial n_j^i} + \frac{\partial U^j}{\partial \Pi^j}\frac{\partial \Pi^j}{\partial n_j^i} = 0 \Rightarrow \frac{\partial U^i}{\partial \Pi^i}\frac{\partial \Pi^i}{\partial n_j^i} = - \frac{\partial U^j}{\partial \Pi^j}\frac{\partial \Pi^j}{\partial n_j^i}$$

Which implies the intra-group trade will continue until the marginal cost of trade for agent i equals the marginal benefit for agent j.

Simulation 3b: Social Groups Model with Inter-Group and Intra-Group Trade, Social Norms and Transaction Costs

The modeling framework is further expanded by dividing the population into two groups *P* and *Q* with the possibility of conducting inter-groups and intra-group trade taking into account the gains from production and trade and also the additional value derived from adhering to the social norm. . In each period t the users belonging to the two groups decide their consumption and traded water quantities by solving the following Langrangian problems.

(24) $L^P = \sum_{i \neq j} \sum_{i=2}^{M1} \beta^{t-1} U^i\left[\Pi_t^i, (\overline{w}_t + n_i^j - w_t^i)\right] + \sum_{i \neq j} \sum_{i=1} \beta^{t-1} U^i\left[\Pi_t^i, (\overline{w}_t + n_i^j + m - w_t^i)\right] + \lambda \cdot \left(S_t - \sum_{i \in P} w_t^i + \sum_{i \in Q} w_t^i\right)$

(25) $L^Q = \sum_{i \neq j} \sum_{i=2}^{M2} \beta^{t-1} U^i\left[\Pi_t^i, (\overline{w}_t + n_i^j - w_t^i)\right] + \sum_{i \neq j} \sum_{i=1} \beta^{t-1} U^i\left[\Pi_t^i, (\overline{w}_t + n_i^j - m - w_t^i)\right] + \lambda \cdot \left(S_t - \sum_{i \in P} w_t^i + \sum_{i \in Q} w_t^i\right)$

Agent 1 in each group is assigned the responsibility of conducting the inter-group trade. The profit and utility terms are modified to

Group P:

For agent 1: $\Pi_t^1 = P_f\big(A(w_t^1)^{\delta 1}\big) - \frac{\alpha}{M1}T(m) - p_w' m - P_w(n_1^2 + n_1^3 + \cdots + n_1^5)$

For all other agents *i* in group P: $\Pi_t^i = P_f\big(A(w_t^1)^{\delta 1}\big) - \frac{\alpha}{M1}T(m) - P_w\big(n_i^1 + n_i^2 + \cdots + n_i^5\big)$[29].

The utility function of each agent i in group P will be $U\big[\Pi_t^i, \mathrm{h}_t^i\big] = \mathrm{Z}(\Pi_t^i)^{\gamma} + \mathrm{K}(\overline{w}_t^i + n_i^j - w_t^i)$

Group Q:

For agent 1: $\Pi_t^1 = P_f\big(A(w_t^1)^{\delta 2}\big) - \frac{(1-\alpha)}{M1}T(m) - p_w' m - P_w(n_1^2 + n_1^3 + \cdots + n_1^5)$

For all other agents *i* in group P: $\Pi_t^i = P_f\big(A(w_t^1)^{\delta 2}\big) - \frac{(1-\alpha)}{M1}T(m) - P_w\big(n_i^1 + n_i^2 + \cdots + n_i^5\big)$[30]

The utility function of each agent i in group P will be $U\big[\Pi_t^i, \mathrm{h}_t^i\big] = \mathrm{Z}(\Pi_t^i)^{\gamma} + \mathrm{K}(\overline{w}_t^i + n_i^j - w_t^i)$

Inter-group Trade:

All other parameters remaining constant the share of water in productivity for group P is assumed to be $\delta 1 = 0.4$ and for group Q is assumed to be $\delta 2 = 0.6$. Assuming a higher productivity for group Q, we also assume that they are the first movers and group P are the followers.

The Maximization Problem for group P is; given the water usage of group Q how to maximize sum of discounted utility over time.

If maximizing profits were the only consideration for trade (as in the case there was no influence of social norms on the agents); the inter-group trade would continue until the point the marginal profit for the agents trading on behalf of groups P and Q equal zero.

$\frac{\partial \Pi^1}{\partial m} = P_f f_m^1(w_t^1) - \frac{\alpha}{M1}T'(m) - P'_w = 0$ or $\frac{\partial \Pi^1}{\partial m} = P_f f_m^1(w_t^1) - \frac{(1-\alpha)}{M2}T'(m) - P'_w = 0$,

i.e. until neither group gains any more from trading with each other.

[29] where $\big(n_i^i = 0\big)$
[30] where $\big(n_i^i = 0\big)$.

But with the agent gaining positive utlity from the social norm i.e. if $\frac{\partial U^1}{\partial h} = K > 0$, the marginal condition for maximizing utility $\frac{\partial U^1}{\partial \Pi^1}\frac{\partial \Pi^1}{\partial m} + \frac{\partial U^1}{\partial h} = 0$ will lead us to infer that $\frac{\partial U^1}{\partial \Pi^1}\frac{\partial \Pi^1}{\partial m} < 0$.

By assuming the first agent of group P is a rational agent, deriving positive utility from profits i.e. $\frac{\partial U^1}{\partial \Pi^1} > 0$ we can conclude that marginal profitability of trade is negative i.e. $P_f f_m^1(w_t^1) - \frac{\alpha}{M1}T'(m) - P'_w < 0$, i.e. the marginal gains in productivity from the inter-group trade is overshadowed by its marginal cost. The only reason inter-group trade would continue is with the positive value gained from adhering to the conservation norm of the group.

Using a similar logic we can conclude that the marginal gains from inter-group trade for the first agent of group Q is positive $P_f f_m^1(w_t^1) - \frac{1-\alpha}{M2}T'(m) + P'_w > 0$[31], i.e. $P_f f_m^1(w_t^1) + P'_w > \frac{1-\alpha}{M2}T'(m)$, which implies that the marginal benefit of inter-group trade exceeds the marginal cost of inter-group trade. But this would be offset by the cost of constraints in adhering to the social norms.

Intragroup Trade:

From the marginal conditions of intra-group trade we can derive the relation

$\frac{\partial U^i}{\partial \Pi^i}\frac{\partial \Pi^i}{\partial n_j^i} + \frac{\partial U^j}{\partial \Pi^j}\frac{\partial \Pi^j}{\partial n_j^i} = \frac{\partial U^j}{\partial h} - \frac{\partial U^i}{\partial h}$= K-K =0, i.e. $\frac{\partial U^i}{\partial \Pi^i}\frac{\partial \Pi^i}{\partial n_j^i} = - \frac{\partial U^j}{\partial \Pi^j}\frac{\partial \Pi^j}{\partial n_j^i}$,

which implies the intra-group trade between agents i and j would continue until the marginal cost of trade for agent i equals the marginal benefit for agent *j*.

Simulations 3a and 3b were run with 'stock lower limit' value of 0.3 for all simulations (not presented in Table 3). However, these simulations are incomplete due to lack of computing power and thus in-ability to converge. Therefore, we could not calculate the discounted utility value nor can we test the 'Euler Conditions'. For that reason we do not present the simulations' results and will defer the work to a later stage.

[31] Whose profit function is $\Pi_t^1 = P_f f^1(w_t^1) - \frac{(1-\alpha)}{M2}T(m) + p'_w m - P_w \sum_{j\neq 1}^{50} n_1^j$.

Table 5: Parameters used in simulations 3a and 3b.

Model	Price of Output	Price of Water	Share of Water in Value of Production	Social Norm Coefficient	Production Function Coefficient	Utility Function Coefficient for Profit	Share of Water in Value of Profit	Discount Coefficient	Number of Agents
Model with 2 Groups and Trading	1	1	$\delta 1 = 0.4$ $\delta 2 = 0.6$	K=0	A=5	Z=5	γ=0.4	$\beta = 0.91$	N1=5 N2=5
Model with 2 Groups Social Norms and Trading	1	1	$\delta 1 = 0.4$ $\delta 2 = 0.6$	K=5	A=5	Z=5	γ=0.4	$\beta = 0.91$	N1=5 N2=5