UC Riverside
UC Riverside Previously Published Works

Title
Managing water resources under scarcity: the role of social norms

Permalink
https://escholarship.org/uc/item/37p3k1zf

Journal
Journal of Environmental Economics and Policy, 7(1)

ISSN
2160-6544

Authors
Jammalamadaka, Uday Kumar
Dinar, Ariel

Publication Date
2018-01-02

DOI
10.1080/21606544.2017.1342566

Peer reviewed

eScholarship.org Powered by the California Digital Library
University of California

Journal of Environmental Economics and Policy

ISSN: 2160-6544 (Print) 2160-6552 (Online) Journal homepage: https://www.tandfonline.com/loi/teep20

Managing water resources under scarcity: the role of social norms

Uday Kumar Jammalamadaka & Ariel Dinar

To cite this article: Uday Kumar Jammalamadaka & Ariel Dinar (2018) Managing water resources under scarcity: the role of social norms, Journal of Environmental Economics and Policy, 7:1, 16-40, DOI: 10.1080/21606544.2017.1342566

To link to this article: https://doi.org/10.1080/21606544.2017.1342566

Published online: 23 Jun 2017.

Submit your article to this journal

Article views: 59

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=teep20

JOURNAL OF ENVIRONMENTAL ECONOMICS AND POLICY, 2018
VOL. 7, NO. 1, 16–40
https://doi.org/10.1080/21606544.2017.1342566

UKNEE UK Network of Environmental Economists
Routledge Taylor & Francis Group

Check for updates

Managing water resources under scarcity: the role of social norms

Uday Kumar Jammalamadaka[a] and Ariel Dinar[b]

[a]Department of Economics, University of California, Riverside, CA, USA; [b]School of Public Policy, University of California, Riverside, CA, USA

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 results and use numerical simulations to provide evidence for performance of a group of farmers that use a common pool resource (reservoir or aquifer) with and without norms, with various marginal utility levels from norm adherence, and with various existing (Social Planner) institutional setting considered in the theoretical model. The theoretical results suggest that with no water trade and with norm adherence, water users will always use less water than the no norms scenario. With possible inter-group water 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 norm adherence, the resource is sustained for significantly longer periods.

ARTICLE HISTORY
Received 22 November 2016
Accepted 12 June 2017

KEYWORDS
Institutions; social norms; water scarcity; common pool resources; social choice; agriculture

1. Introduction

Impact of climate change on water resources, and indirectly on agricultural production, has decreased agricultural incomes and livelihood of communities. The UNWWAP (2006) report attributes a great deal of the water scarcity level in many countries to the inefficiency of existing water resource allocation institutions. Such inefficiency can be the result of 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 recognises the role of 'belief structures' and 'collective learning' processes as the basis for development of institutions in the water sector. To successfully address management of water resources under scarcity, institutional reforms must complement existing belief systems with 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).

Definitions and description of roles and operations of institutions have been provided in several works, including Ingram et al. (1984), Bromley (1989) and North (1990). Work in the water sector, such as Oswald (1992) and Saleth and Dinar (2004), introduce the institutional dynamics induced by endogenous (water scarcity, performance deterioration and financial failure) and exogenous (macro-economic crisis, political reform, natural calamities and technological progress) factors. Social norms could help foster community behaviour that is inductive to resource conservation and

CONTACT Ariel Dinar adinar@ucr.edu

© 2017 Journal of Environmental Economics and Policy Ltd

discourage members deviation from a collectively agreed-use strategy (Ranjan 2010). Therefore, performance of institutions in the community could be supported by the social norms. It has been documented that existing social norms can cause socio-economic systems to collapse in some cases and persist in others (Cordell and McKean 1982; Somanathan 1991; Ostrom 2002; Acheson 1993). The cause of the breakdown varies and could not be narrowed down (Bromley and Feeny 1992).

The existing literature on social norms focuses less on quantifying the interaction between social norms and water institutions, especially under water scarce situation.[1] Shivakoti and Ostrom (2002) refer to norms of communal water infrastructure maintenance based on land size or per household contribution in farmer-managed systems. They find that norms of seniority in promoting and political-favour seeking in the water bureaucracy 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. Anjal (2005) finds that the norm of caste-based allocation leads to inefficient use of water. Dinar and Jammalamadaka (2013) demonstrate in a very simplistic framework the relationship between water scarcity and institutions and the role that social norms have on functioning institutions.

Toope, Rainwater, and Allan (2003, 2) explain why social norms are important in the provision of public good resources in that water for irrigation has '… symbolic power as well as underpinning respected and familiar livelihoods. … and symbols have extraordinary social and political significance'. 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 maximise social objectives or even to achieve long-term self-interest (Ostrom 2000). Competitive market experiments 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 longer rounds of experimentation leading to greater (sum and individual) contributions.

For stakeholders to accept proposed water reforms for climate change adaptation, the social and political interests have to be satisfied. Under drought conditions, placation of social groups is more important for the acceptance of reforms in water management. Bowles and Polania-Reyes (2012) caution that 'Social Preferences' obfuscate the intended effects of incentives or sanctions introduced to target social behaviour 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.

One major problem with the case study and experimental economics frameworks is the difficulty to predict how the system would react to a crisis (such as drought). The meagre theoretical work that exists in this field attempts to bridge this gap by estimating the impact that structural variables 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, Cobb, and Bond 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 common pool resources (CPRs) 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; Osés-Eraso and Viladrich-Grau 2007; Noailly, van den Bergh, and Withagen 2005), which analyses the effects of benefits from adherence and sanctions for violation of norms on agent behaviour 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; Osés-Eraso and Viladrich-Grau 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. Osés-Eraso, Udina, and Viladrich-Grau 2008; Ranjan 2010; Rustagi, Engel, and Kosfeld 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 policies. These approaches distinguish between agent behaviors in response to existing environmental scarcity and to human-induced scarcity, which may strengthen or counteract each other, given the level of social capital in the community. In addition to the theoretically and normative studies that we reviewed, our paper is also motivated by real-world empirical works such as Ward (2000) and Rinaudo (2002) for Yemen and Pakistan, respectively. Both works show how social norms can help or deter the functioning of institutions aimed to optimise water allocation. In the case of Yemen a social norm of group control of groundwater pumping equipment has turned successful and helped sustain water level in CPR aquifers that otherwise would be depleted. In the case of Pakistan (Southern Panjab) social norms to engage in corruption regarding water allocation (Steeling, and bribing authority officers) have spread across the entire strata of the farm community in Pakistan, leading to the collapse of the existing water allocation (Warabandi) system.

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[2] 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 in providing 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 management of a water resource as (a) jointness of use, (b) 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 neither guilt and remorse or social ostracism and censure his/her actions would not violate the norm despite lack of enforcement.

Field studies show that public goods are more efficiently managed by communities that practise self-governance of resources rather than those governed top-down (Spiertz 1991; Blomquist 1992; Wade 1994; Bardhan 1999; Bowles 2004; Ostrom 2008). Ostrom (2000) 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.

The volume of previous work, while very comprehensive and persuasive, has not provided yet a clear answer to the question why the 'Problem of the Commons' is not seen in all CPRs and in all communities. It is this question that we try to address in this paper, focusing on scarce water. While most common water resources across the world are facing rapid depletion due to climate change and mal management, 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.[3] The cause and process of development of norms and rules is not explored here and can be a subject of further studies.

With such qualitative evidence the goal of this paper is to set up a framework that quantifies 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 next develop a theoretical framework that helps determine the role of social norms in sustaining CPRs, such as water, under scarcity. We derive several general results. Then, using a numerical example we simulate the performance of a group of farmers that use a village-level CPR (reservoir or aquifer water) under norms and no norms, with reference to the village-level institutional setting that were considered in the theoretical framework. We then conclude with several implications, which could be generalised to other communal CPRs, such as forests and grazing land.

2. The modelling framework

Social Norms, while not a universal panacea, have played an important role in the preservation (also revival) and sustainable use of common pool water resources (CPWRs) such as aquifers or reservoirs. There are several successful examples in this field that 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). Our model is limited to the agricultural use of CPWR and not to household consumption of water.

In the literature examining local management of CPWRs (groundwater and surface water) the CPWRs 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 (Shivakoti and Ostrom 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 utilised to maintain the infrastructure; there is no water trade in these cases.

The second system 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 extractions to a few wells and deliver 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 (Maria Saleth 2014).

To better model these two types of local management systems of CPWRs we have constructed our model in two steps. (1) a model with N periods and M homogeneous agents with norms for restrictive extraction of water; and (2) 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 (e.g. organising trade partners), bargaining and decision-making (time and fees for legal and expert consultations), and monitoring and enforcing of existing rules.

2.1. 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 from the agent's production process 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 behaviour of the agent 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. Some of these inputs are related to investments in infrastructure for measuring water flow to the individual fields. Once accounted for, such costs behave exactly as the traditional inputs used in the production process. For that reason we do not distinguish between production cost and social norms-related costs. 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 $h_t^i = \overline{w}_t^i - w_t^i$ 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 emphasise 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 adhering to 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 does not need to be altruistic to adhere to the social norm. As suggested by Osés-Eraso and Viladrich-Grau (2007):

> 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-interest 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. (394)

In doing so we follow Osés-Eraso and Viladrich-Grau (2011, 476), who found that in the presence of extraction from a common resource alongside with a reward system (even self-reward), discourages high extraction levels. This allows the utility of the individual to be appositively affected from both profits and adherence to the norms. The theory in our paper is limited, though, 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 summarise, the individual quotas are not sacrosanct. It can be violated as long as the utility is maximised. The model is a social planner problem at the village level and not individual maximisation of utility. Finally, the social planner maximises the group's discounted utility over a given time horizon. This forces the agent to conserve the resource and use it over time to maximise utility. Therefore, the model maximises the community welfare, which is measured as the present value of the net revenue produced in the community agricultural production process.

2.1.1. 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 characterise the structure of N periods and M agents. The objective is to maximise 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:

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

subject to

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

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

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

where S_t is the resource availability at year t.

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% 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 behaviour is that at the last period when the resource has been 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.

Employing the principles suggested by Hazewinkel (2001), the Lagrangian of the problem is[4]

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

The first-order conditions (FOC) yield[5]

$$\beta^t \frac{\partial U_t^i}{\partial \Pi_t^i} \frac{\partial \Pi_t^i}{\partial w_t^i} - \beta^t \frac{\partial U_t^i}{\partial h_t^i} - \lambda = 0,\ \forall t = 1,\ \cdots, N-1; i = 1,\ \cdots,\ M \tag{4}$$

which suggests that in the optimum the discounted utility from water use should be equal to the discounted utility from adherence minus the opportunity cost of the water constraint of the CPWR.

For the Nth period, the FOC is

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

The FOCs allow one to derive the inter-temporal Euler equation (Hazewinkel 2001)[6]

$$\beta^t \frac{\partial U_t^i}{\partial \Pi_t^i} \frac{\partial \Pi_t^i}{\partial w_t^i} - \beta^t \frac{\partial U_t^i}{\partial h_t^i} = \beta^N \frac{\partial U_N^i}{\partial \Pi_N^i} \frac{\partial \Pi_N^i}{\partial w_N^i}. \tag{6}$$

The inter-agent Euler equation for agents j and k in period t is[7]

$$\beta^t \frac{\partial U_t^j}{\partial \Pi_t^j} \frac{\partial \Pi_t^j}{\partial w_t^j} - \beta^t \frac{\partial U_t^j}{\partial h_t^j} = \beta^t \frac{\partial U_t^k}{\partial \Pi_t^k} \frac{\partial \Pi_t^k}{\partial w_t^k} - \beta^t \frac{\partial U_t^k}{\partial h_t^k}. \tag{7}$$

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

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

For the terminal Nth 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 $\frac{\partial U_N^i}{\partial w_N^i}(\text{with social norms}) < \frac{\partial U_N^i}{\partial w_N^i}(\text{without social norms})$, $\forall i$, which suggests that

$$w_N^i(\text{with social norms}) > w_N^i(\text{without social norms}),\ \forall i$$

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 $\frac{\partial U_t^i}{\partial w_t^i}(\text{with social norms}) > \frac{\partial U_t^i}{\partial w_t^i}(\text{without social norms})$, $\forall t \neq N$, $\forall i$ also requires[8] that

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

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

Condition (b) implies that if marginal profit from water use is significantly lower in the presence of social norms, then marginal utility from profit (with norms) has to be sufficiently large to ensure that the marginal utility of water use (with norms) is higher. This would also imply decrease in 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, so 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 $\beta^t \frac{\partial U_t^j}{\partial \Pi_t^j}\frac{\partial \Pi_t^j}{\partial \omega_t^j} - \beta^t \frac{\partial U_t^j}{\partial h_t^j} = \beta^t \frac{\partial U_t^k}{\partial \Pi_t^k}\frac{\partial \Pi_t^k}{\partial \omega_t^k} - \beta^t \frac{\partial U_t^k}{\partial h_t^k} \Rightarrow \frac{\partial U_t^j}{\partial \omega_t^j} - \frac{\partial U_t^k}{\partial \omega_t^k} = \frac{\partial U_t^j}{\partial h_t^j} - \frac{\partial U_t^k}{\partial h_t^k}$.

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.[9] In other words, for all periods where agent j has higher marginal utility from norm adherence than agent k, agent j will use relatively less water than agent k.

Introducing a water market as a community institution. 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. Tanks, reservoirs or the groundwater aquifer are governed in most cases by rules that are not obeyed by the members of the community, and in many cases (Palanisami 2009) are not functioning (silted tanks and reservoirs, and polluted or over drafted aquifers). A water market, if well operated, can amend these facilities and even improve their functioning.

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 formalising transactions. In some parts of the world the caste status implies also certain constraints on interactions among farmer groups.

Increased levels of water scarcity around the world led many countries to consider and introduce water trade arrangements with the objective of easing the pressure on producing agents and increasing social welfare. However, real world experience (e.g. Easter, Rosegrant, and Dinar 1998; Easter and Huang 2014) suggests that performance of water markets faces many challenges, especially in developing countries. A sound motivation for the analysis in our paper can be based on the mal-performance of market institutions in various countries (e.g. Chile, Oman, India, China and Pakistan). Trade in water is introduced as a possible institution to make water allocation among users more efficient. However, there are several impediments that may affect the performance of water trade, such as the mechanism of allocation of initial water rights, and the development and maintenance of appropriate infrastructure to allow efficient conveyance of water among all agents. It is the Social norms (influence of the rich on the initial allocation system and on the proximity of the conveyance infrastructure) that affect the efficient and equitable allocation of the initial water rights, and the investment in conveyance infrastructure. In the countries discussed in Easter and Huang (2014), social norms affected the efficient and equitable distribution of initial water rights (e.g. Chile, Oman), and the optimal design and implementation of infrastructure to convey water (India, China, Pakistan). Together these two impediments are responsible to unacceptable high transaction costs associated with trade, and a less-than-optimal performance of the water market.

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

2.1.2. Two social groups, P (M1 agents) and Q (M2 agents), and variable transaction costs T

There are two social groups, P and Q, of water users with $M1$ and $M2$ agents in each, respectively. 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. Assuming a variable transaction cost $T(m)$, as a function of the volume 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 water extraction externalities.[10] 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 same 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 maximises its group welfare at period t, we get

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

where

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

and

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

We assume that only one agent from group P trades with one agent from 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 $\overline{w} + m + \sum_{i\neq j} n_i^j \geq w_t^i$, where j belongs to the same group, would imply adherence to social norm and violation otherwise.[11] In case of all other agents, $\overline{w} + \sum_{i\neq j} n_i^j \geq w_t^i$ implies adherence (and violation of social norm otherwise) where agent j belongs to the same group. The constraint for utility maximisation is $\sum_{i\in P} w_t^i + \sum_{i\in Q} w_t^i \leq S_t$, given the stock of water.

The Lagrangian for each group P and Q would be

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

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

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

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

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

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

And for intragroup trade,[12]

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

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

From (13), we derive the condition $\frac{\partial \Pi^1}{\partial m} = P_f \, f_m^1\left(x_t^1, \ w_t^1\right) - \frac{\alpha}{M1} T'(m) - P'_w < 0$ for group P. With inclusion of social norms in the utility function the agent will replace excess extraction with increased inter-group trade of water. Also, $P_f f_m^1\left(x_t^1, \ w_t^1\right) < \frac{\alpha}{M1} T'(m) + P'_w$ 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 $\frac{\partial \Pi^1}{\partial m} = P_f \, f_m^1\left(x_t^1, \ w_t^1\right) - \frac{(1-\alpha)}{M2} T'(m) + P'_w > 0$ 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 $\frac{\partial \Pi^1}{\partial m} = P_f \, f_m^1\left(x_t^1, \ w_t^1\right) - \frac{\alpha}{M1} T'(m) - \ P'_w = 0$ or $\frac{\partial \Pi^1}{\partial m} = P_f \, f_m^1\left(x_t^1, \ w_t^1\right) - \frac{(1-\alpha)}{M2} T'(m) - P'_{\ w} = 0$, 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.

3. Illustrative simulations

While our analytical solution provides important behavioural and policy results, still, it is hard to compare the results for all combinations of the variables we introduced. For that reason we develop a simplified simulation case with explicit production and behavioural 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 under various existing institutions, 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 includes two homogeneous groups that interact (trade water). This set 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.

3.1. Simulation 1a: homogeneous group without social norms

The goal of the Simulation and Optimisation exercise is to maximise 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:

$$\text{Max} \sum_{t=1}^{N}\sum_{i=1}^{M}\beta^{t-1}U_t^i\left[\Pi_t^i\right], \tag{17}$$

subject to

$$S_1 \geq \sum_{t=1}^{N}\sum_{i=1}^{M} w_t^i, \tag{18}$$

i.e. the resource S_1 can be utilised 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 in the literature (Ranjan 2010; Fouka and Schlaepfer 2014).

The Utility function is also assumed to be a Cobb–Douglas function, $U\left[\Pi_t^i,\ \mathrm{h}_t^i\right] = Z\left(\Pi_t^i\right)^{\gamma}$. 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

$$\begin{aligned} &U_1^1\left[\Pi_1^1\right] + \beta U_2^1\left[\Pi_2^1\right] + \beta^2 U_3^1\left[\Pi_3^1\right] + \cdots + \beta^{N-1} U_N^1\left[\Pi_N^1\right] + \ U_1^2\left[\Pi_1^2\right] + \beta U_2^2\left[\Pi_2^2\right] \\ &\quad + \beta^2 U_3^2\left[\Pi_3^2\right] + \cdots + \beta^{N-1} U_N^2\left[\Pi_N^2\right] + \cdots + U_1^{100}\left[\Pi_1^{100}\right] + \beta U_2^{100}\left[\Pi_2^{100}\right] + \beta^2 U_3^{100}\left[\Pi_3^{100}\right] \\ &\quad + \cdots + \beta^{N-1} U_N^{100}\left[\Pi_N^{100}\right], \end{aligned} \tag{19}$$

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; β is the discount factor. It is a function of the interest rate, r, i.e. $\beta = \frac{1}{1-r}$.

3.2. Simulation 1b: homogeneous group with social norms

The production function and utility function 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[13] of the individual:

$$\text{Max} \sum_{t=1}^{N-1} \sum_{i=1}^{M} \beta^{t-1} U_t^i\left[\Pi_t^i,\ h_t^i\right] + \sum_{t=1}^{N-1} \beta^{N-1} U_N^i\left[\Pi_N^i\right] \tag{20}$$

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

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

Most of the social-norm-related simulation literature (e.g. Ranjan 2010; Bardhan 1999) assumes that utility is a monotonic transformation of the profits and does 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 (non) adherence on the utility derived but also for the effect of the magnitude of (non) adherence on utility; (c) quasi-linearity also enables maintain the assumption of risk aversion of the producers; (d) if the Utility function is instead assumed to strictly be a Cobb–Douglas function $\left(U\ \left[\Pi_t^i,\ \mathrm{h}_t^i\right] = \mathrm{Z}\cdot(\Pi_t^i)^\gamma\cdot\left(\overline{w}_t^i - w_t^i\right)^{(1-\gamma)}\right)$ 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 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 a population of 100 individuals) over time as

$$\begin{aligned} &U_1^1\left[\Pi_1^1,\ \left(\overline{w} - w_1^1\right)\right] + \beta U_2^1\left[\Pi_2^1,\ \left(\overline{w} - w_2^1\right)\right] + \beta^2 U_3^1\left[\Pi_3^1,\ \left(\overline{w} - w_3^1\right)\right] + \cdots \\ &\quad + \beta^{N-1} U_N^1\left[\Pi_N^1,\ \left(\overline{w} - w_N^1\right)\right] + U_1^2\left[\Pi_1^2,\ \left(\overline{w} - w_1^2\right)\right] + \beta U_2^2\left[\Pi_2^2,\ \left(\overline{w} - w_2^2\right)\right] \\ &\quad + \beta^2 U_3^2\left[\Pi_3^2,\ \left(\overline{w} - w_3^2\right)\right] + \cdots + \beta^{N-1} U_N^2 \ + \cdots + U_1^{100}\left[\Pi_1^{100},\ \left(\overline{w} - w_1^{100}\right)\right] \\ &\quad + \beta U_2^{100}\left[\Pi_2^{100},\ \left(\overline{w} - w_2^{100}\right)\right] + \beta^2 U_3^{100}\left[\Pi_3^{100},\ \left(\overline{w} - w_3^{100}\right)\right] + \cdots \\ &\quad +\ \beta^{N-1} U_N^{100}\left[\Pi_N^{100},\ \left(\overline{w} - w_N^{100}\right)\right], \end{aligned} \tag{21}$$

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 $w_t^1,\ w_t^2, w_t^3, \cdots,\ w_t^M$ for every period t, which maximises the objective function must satisfy two FOCs (i.e. Euler conditions).

(a) The inter-temporal Euler condition for each agent i at period t (and terminal period N) is $\beta^{t-1}\frac{\partial U_t^i}{\partial \Pi_t^i}\frac{\partial \Pi_t^i}{\partial w_t^i} - \beta^{t-1}\ \frac{\partial U_t^i}{\partial h_t^i} = \beta^{N-1}\ \frac{\partial U_N^i}{\partial \Pi_N^i}\frac{\partial \Pi_N^i}{\partial w_N^i}$.

Or for any two periods p and q for the same agent i, $\beta^{p-1}\frac{\partial U_p^i}{\partial \Pi_p^i}\frac{\partial \Pi_p^i}{\partial w_p^i} - \beta^{p-1}\ \frac{\partial U_p^i}{\partial h_p^i} = \beta^{q-1}\ \frac{\partial U_q^i}{\partial \Pi_q^i}\frac{\partial \Pi_q^i}{\partial w_q^i} - \beta^{q-1}\frac{\partial U_q^i}{\partial h_q^i}$.

(b) The inter-agent Euler condition for agents i and j at period t is

$$\beta^{t-1}\frac{\partial U_t^i}{\partial \Pi_t^i}\frac{\partial \Pi_t^i}{\partial w_t^i} - \beta^{t-1}\ \frac{\partial U_t^i}{\partial h_t^i} = \beta^{t-1}\ \frac{\partial U_t^j}{\partial \Pi_t^j}\frac{\partial \Pi_t^j}{\partial w_t^j} - \beta^{t-1}\frac{\partial U_t^j}{\partial h_t^j}$$

3.3. 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. a norm marginal utility coefficient 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-optimisation was conducted for 10 agents.[14] Parameters used in the simulations are presented in Table 1. In selecting the values for the discount rate and other parameters,[15] 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 component in the utility function was set at $\gamma = 0.4$ in our simulation. The simulations were run for 250 years.[16]

We introduced in the simulation a stock lower limit constraint to prevent the phenomena of a terminal period exhaustion of the resource.[17] 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 stock lower limit is achieved got adjusted. We also tested the results for various lower-limit values.[18] Again, no significant difference in usage (pre-lower limit) or utility (overall) was observed (Figure 2 and Table 2). Therefore, the results (Tables 3 and 4) and graphs (Figures 1 and 3) depicted below are all for 'stock lower limit' = 0.3. The imposition of this stock

Table 1. Parameters used in simulations 1 and 2.

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

Table 2. Total discounted utility and time of convergence in 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

Table 3. Total discounted utility and time of convergence in simulations 1(a) and 1(b) for three levels of marginal utility from norm adherence ('stock lower limit' = 0.3).

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

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 ($K = 1$)	0	1	2	3	4	5	6	7	8	9	10
Number of agents with high kappa ($K = 10$)	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

lower limit was necessary to expedite the simulations as well as to terminate the optimisation process from continuing indefinitely.

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

3.4. Results of simulations 1 and 2

The water use results in the first simulation of a homogeneous group with and without social norm are presented in Figure 1 and Table 3, and discussed below with regards to other parameters.

In the case of homogenous group of agents, the simulation reveals several main differences between the cases with and without social norms (Figure 1). In the case with social norms agents' behaviour is much more sustainable. The CPWA is depleted by the 51st period without social norms and, by the 56th, 86th and 136th periods with social norms for the cases where marginal utility from norm adherence (K) are 1, 5 and 10 respectively. The utility maximising water usage levels also satisfy 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

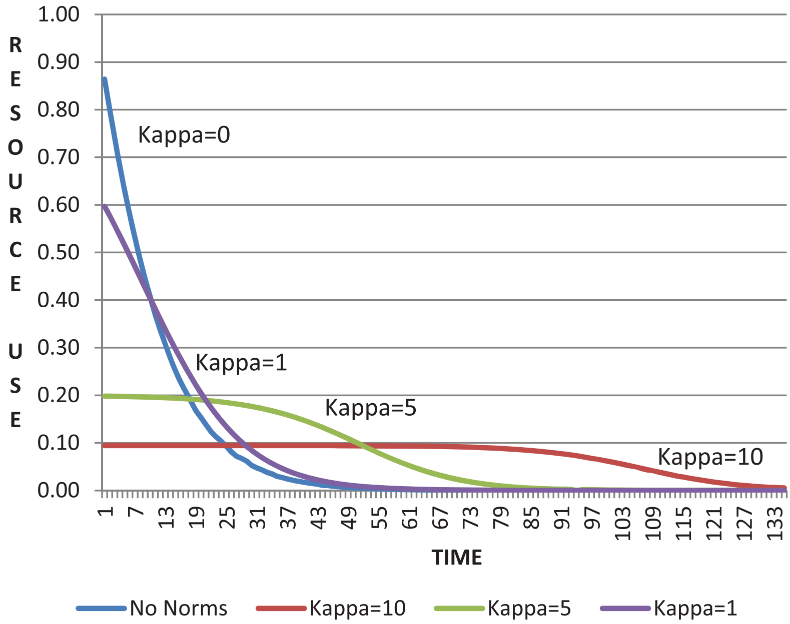

Figure 1. Normalised water usage of representative agent, with and without social norms for different levels of the norm adherence coefficient kappa.

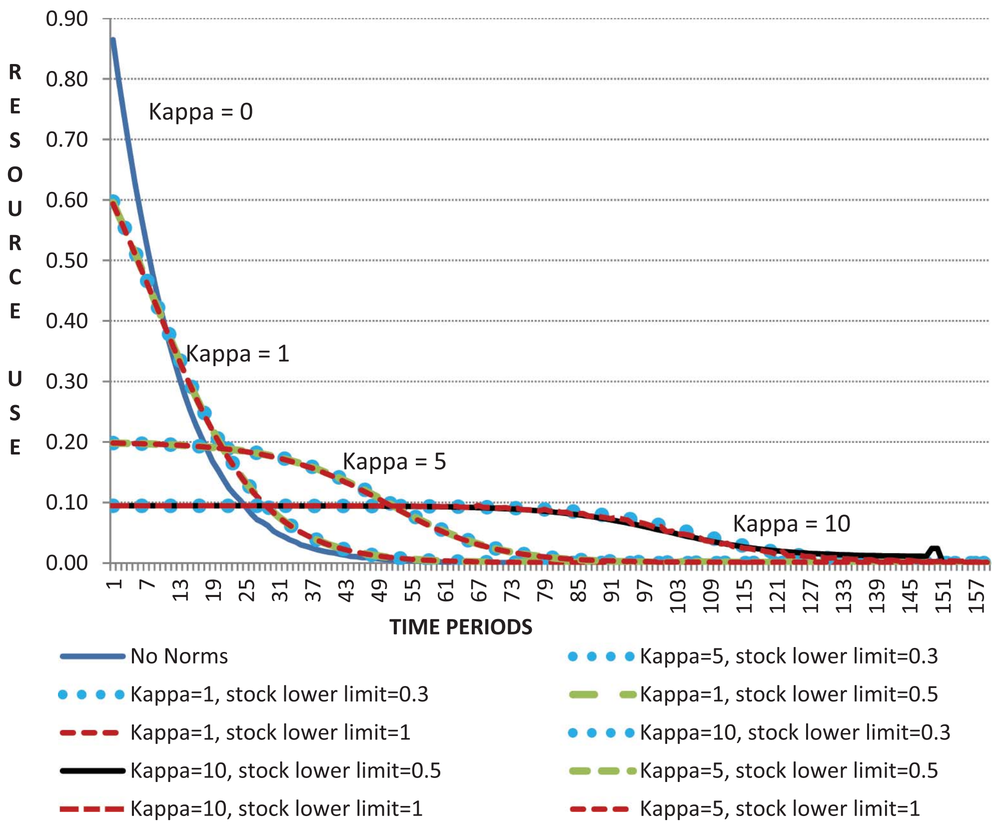

Figure 2. Normalised water usage of representative agent, with different levels of stock lower limits, and different levels of norm adherence coefficient (kappa) in simulations 1(a) and 1(b).
Note: Some of the lines overlap and are not seen properly in the figure.

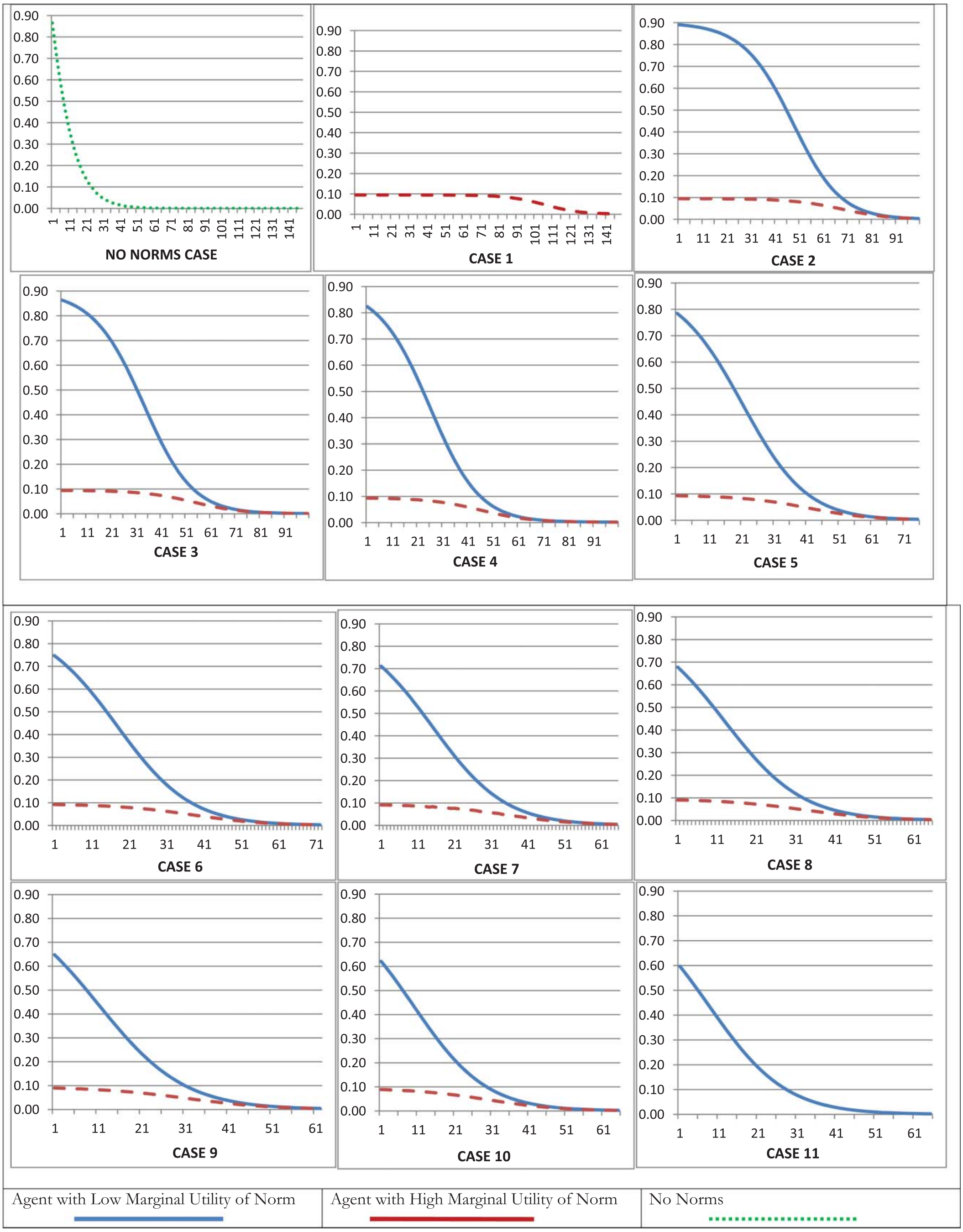

Figure 3. Normalised water usage by representative agents with heterogeneous marginal utility from adherence to norms by proportion of group in the community.
Note: Vertical axis measures normalised water use and horizontal axis measures periods.

for the three levels of norm adherence 1, 5 and 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.[19] By the 18th period, water usage in the case without norms is nearly equal to that of the norm adhering[20] group (0.187 and 0.192 units, 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. However, 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 3) over the entire 150-year horizon simulation (1223.25) is substantially higher than that of the non-adhering group (847.81).[21] 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 maximise overall utility.

We present in Table 3 the total discounted utility and the 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 on the resource use = 1, 0.5 and 0.3. In this analysis we show that the imposed levels of stock lower limit for signalling 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.

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 maximisation 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) maximise 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.

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 presents the periodical values of normalised 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 ($K = 5$).

The results in Figure 3 and Table 4 suggest that as the proportion of high Kappa 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 is 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 agent's 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 maximising 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) penalise the norm-violation (Kandori 1992; Osés-Eraso and Viladrich-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 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 K 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 maximising model and cannot be utilised 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.

4. Conclusion

This paper developed a framework that allows quantifying the effect of social norms on the performance of existing institutions set by a group of users of a CPWR under scarcity.

We employ existing institutions that a 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 quotas. The social norms being an intrinsic part of the economic agents' individual preferences (utility functions), allow us to derive several important theoretical results for the case of homogenous group of water users and for the case with two different groups of the water users that are involved in the water trade institution.

Our theoretical and simulation results, in the case of homogenous group of users, suggest that for agents with similar preferences (utility and profit functions) incorporating social norms in their preferences[22] leads to the marginal utility of water use exceeding the marginal utility of water use from the norm indifferent case; which in turn implies that water extraction will be lower for the norm adherent agent. The positive marginal utility from norm adherence is the sufficient condition for this inference. 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 individual resource share of free-riders from over-exploiting 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 the resource's accessible 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), and ensure sustained consumption over a longer period of time, because it would maximise overall discounted utility of the users.

While our model was built upon a case of CPWR, 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. Another addition would be to present simulation results of the inter- and intra-trade scenarios that were not presented here due to space limitation.

Notes

1. 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 behaviour 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.
2. 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.
3. Participation and cooperation in management of CPWR by farmers is dictated by a combination of factors, including the local politics, incentives, socio-historical factors, and distribution of CPWR endowments among beneficiaries. We recognise that inclusion of only social norms is a simplification of the multiple factors involved.
4. 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.

5. In the absence of social norms, this FOC becomes $\beta^t \frac{\partial U_t^i}{\partial \Pi_t^i}\frac{\partial \Pi_t^i}{\partial w_t^i} - \lambda = 0, \quad \forall t = 1, \cdots, N-1; i = 1, \cdots, M$.
6. 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.
7. The inter-agent Euler equation for the Nth period is: $\beta^n \frac{\partial U_n^j}{\partial \Pi_n^j}\frac{\partial \Pi_n^j}{\partial w_n^j} = \beta^n \frac{\partial U_n^k}{\partial \Pi_n^k}\frac{\partial \Pi_n^k}{\partial w_n^k}$.
8. These may be considered as necessary conditions for our derived implications from the inter-temporal Euler conditions. $\sum_{i=1}^{M} \frac{\partial U_t^i}{\partial h_t^i} > 0$, is the necessary condition for the same implications.
9. As $\frac{\partial U_t^j}{\partial h_t^j} \geq \frac{\partial U_t^k}{\partial h_t^k}$.
10. This assumption will not affect the general nature of the results unless we assume differential levels of pumping cost.
11. This cannot be a condition for utility maximization as this condition is assumed to be not imposed and even if it is informally imposed it cannot be completely monitored.
12. Because $h_t^j = \overline{w}_t{}^j + n_j^i - w_t^j = \overline{w}_t{}^j - n_i^j - w_t^j$; we get $\frac{\partial h_t^j}{\partial n_i^j} = -1$.
13. The norm term is $h_t^i = \overline{w} - w_t^i$ for all non-terminal periods and $h_t^i = 0$ for the terminal period.
14. For convenience, the simulation can be scaled up to a larger population given sufficient computational resources.
15. Price of output $P_f = 1$ per unit of output, price of water $P_w = 1$ per unit of water, share of water in the value of production $\delta = 0.4$, $N = 10$.
16. In setting the length of our analysis period we were guided by the 200 years used in Ranjan (2010).
17. The simulation process revealed 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) 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 maximising their utility in perpetuity. To resolve this issue we introduced a 'stock lower limit' on the resource stock. When the stock was reduced to this lower limit, beyond that period there was no more utility received from norm adherence. This forced the agents to terminate their optimisation 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.
18. Tested for stock lower limit values of 1, 0.5 and 0.3. See Figure 2 and Table 2 and relevant description.
19. With slower declines for the cases with higher marginal utility for norms. As seen in Figure 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.
20. Kappa = 5, 1.
21. For kappa = 5. For kappa =1 and 10, see results in Table 3.
22. Assuming positive value for marginal utility from norm adherence.
23. We were unable to produce results due to non-convergence of these simulations, as our computational capacity was insufficient. However, the empirical model with adjustments for inter- and intra-trade is presented in this Appendix.
24. where $\left(n_i^i = 0\right)$.
25. where $\left(n_i^i = 0\right)$.
26. where $\left(n_i^i = 0\right)$.
27. where $\left(n_i^i = 0\right)$.
28. Whose profit function is $\Pi_t^1 = P_f f^1\left(w_t^1\right) - \frac{(1-\alpha)}{M2} T(m) + p_w' m - P_w \sum_{j\neq 1}^{50} n_1^j$.

Acknowledgments

Co-funding for the research leading to this paper was provided by the Water Science and Policy Center, University of California, Riverside. We thank Daniel Bromley for very constructive comments on an earlier version of the paper. 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 financial support and hospitality during the stage of finalising of this paper.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Acheson, James M. 1993. “Capturing the Commons: Legal and Illegal Strategies.” In *The Political Economy of Customs and Culture: Informal Solutions to the Commons Problem*, edited by Terry L. Anderson, and Randy T. Simmons. Lanham, MD: Rowman and Littlefield.

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

Bardhan, Pranab. 1999. “Water Community: An Empirical Analysis of Cooperation on Irrigation in South India.” *Working Paper*. Berkeley: Department of Economics, University of California.

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

Botelho, Anabela, Ariel Dinar, Ligia Pinto, and Amnon Rapoport. 2015. “Promoting Cooperation in Resource Dilemmas: Predictions and Experimental Evidence.” *Journal of Behavioral and Experimental Economics* 54: 40–49.

Botelho, Anabela, Ariel Dinar, Ligia Pinto, and Amnon Rapoport. 2014. “Time and Uncertainty in Resource Dilemmas: Equilibrium Solutions and Experimental Results.” *Experimental Economics* 17 (4): 649–672.

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*. New York: Russell Sage.

Bowles, Samuel, Sandra Polania-Reyes. 2012. “Economic Incentives and Social Preferences: Substitutes or Complements?” *Journal of Economic Literature* 50 (2): 368–425.

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

Bromley, Daniel W., and David Feeny. 1992. *Making the Commons Work: Theory, Practice, and Policy*. San Francisco, CA: ICS Press.

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*. Washington, DC: World Bank.

Cordell, John, and Margaret A. McKean. 1982. “Sea Tenure in Bahia, Brazil.” In *Proceedings of the Conference on Common Property Resource Management*, edited by David Feeny A. J. Thomson, W. Bromley, Margaret McKean, Pauline Peters, Jere Gilles, Ronald Oakerson, and C. Ford Runge, 183–206. San Francisco, CA: ICS Press.

Crawford, Sue E. and Elinor Ostrom. 2005. “A Grammar of Institutions.” In *Understanding Institutional Diversity*, edited by Elinor Ostrom, 137–174. Princeton, NJ: Princeton University Press.

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.

Easter, K. William, and Qiuqiong Huang, eds. 2014. *Water Markets for the 21st Century, What Have We Learned?* Berlin: Springer.

Easter, K. William, Mark Rosegrant, and Ariel Dinar, eds. 1998. *Markets for Water – Potential and Performance*. Dordecht: Kluwer Academic Publishers.

Fehr, Ernst, and Urs Fischbacher. 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 K. M. Schmidt. 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, Toulouse, August 25–29. http://www.eea-esem.com/EEA-ESEM/2014/m/viewpaper.asp?pid=571.

Frohlich, Norman, and Joe A. Oppenheimer. 1996. “Experiencing Impartiality to Invoke Fairness in the NPD: Some Experimental Results.” *Public choice* 86: 117–135.

Glaeser, Edward L., David I. Laibson, José A. Scheinkman and Christine L. Soutter. 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.

Hazewinkel, Michiel, ed. 2001. *Lagrange Equations, Encyclopedia of Mathematics*. Berlin: Springer.

Hotimsky, Samy, Richard Cobb, and Alan Bond. 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 Economy* 114 (1): 1–37.
Mundlak, Yair. 2001. “Production and Supply.” In *Handbook of Agricultural Economics*, edited by B. Gardner, Bruce, and Gordon Rausser, 4–77. New York: 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 Paper 2005.78*. Venice: Fondazione Eni Enrico Mattei.
North, Douglass C. 1990. *Institutions, Institutional Change, and Economic Performance*. Cambridge: Cambridge University Press.
Osés-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.
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.
Osés-Eraso, Nuria, and Montserrat Viladrich-Grau. 2011. “The Sustainability of the Commons: Giving and Receiving.” *Experimental Economics* 14 (4): 458–481.
Ostrom, Elinor. 2000. “Collective Action and the Evolution of Social Norms.” *The Journal of Economic Perspectives* 14 (3): 137–158.
Ostrom, Elinor. 2002. *Improving Irrigation Governance and Management in Nepal*, edited by Ganesh Shivakoti, and Elinor Ostrom. Oakland, CA: ICS Press.
Ostrom, Elinor. 2008. “Developing a Method for Analyzing Institutional Change.” In *Assessing the Evolution and Impact of Alternative Institutional Structures*, edited by Sandra Batie, and Nicholas Mercur, 48–76. London: Routledge Press.
Oswald, Odile. 1992. “An Expert System for the Diagnosis of Tank Irrigated Systems: A Feasibility Study.” *Working Paper No. 22*. Colombo: International Irrigation Management Institute.
Ostrom, Vincent, and Elinor Ostrom. 1972. “Legal and Political Conditions of Water Resource Development.” *Land Economics* 48 (1): 114.
Palanisami, Kuppannan. 2009. “Water Markets as a Demand Management Option: Potentials, Problems and Prospects.” In *Strategic Analyses of the National River Linking Project (NRLP) of India, Series 3: Promoting Irrigation Demand Management in India: Potentials, Problems and Prospects*, edited by Saleth, Rathinasamy Maria, 47–70. Colombo: International Water Management Institute (IWMI).
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): 229–244.
Ranjan, Ram. 2010. “Social Norms, Social Capital and the Sustainability of Small Scale Economies.” *Journal of Natural Resources Policy Research* 2 (3): 213–228.
Rinaudo, Jean-Daniel. 2002. “Corruption and Allocation of Water: The Case of Public Irrigation in Pakistan.” *Water Policy* 4 (5): 405–422.
Rustagi, Devesh, Stefanie Engel, and Michael Kosfeld. 2010. “Conditional Cooperation and Costly Monitoring Explain Success in Forest Commons Management.” *Science (New York, N.Y.)* 330: 961–965.
Saleth, Maria R. 2014. “Water Markets in India: Extent and Impact.” In *Water Markets for the 21st Century*, edited by K. W. Easter, and Q. Huang, 239–261. Berlin: Springer.
Saleth, Maria, R., and Ariel Dinar. 2004. *The Institutional Economics of Water: A Cross-Country Analysis of Institutions and Performance*. Cheltenham: 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*. New Delhi: Indian Statistical Institute, Delhi Planning Unit. http://www.isid.ac.in/~pu/dispapers/dp04-21.pdf.
Shivakoti, Shivakoti, and Elinor Ostrom. 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.
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 (1–3): 189–196.
Toope, Stephen J., Ken Rainwater, and Tony Allan. 2003. “Managing and Allocating Water Resources: Adopting the Integrated Water Resource Management Approach.” Developments in Water Science 50: 1–8.
UNWWAP. 2006. *United Nations World Water Development Report*. Technical report. New York: UNESCO.
van Steenbergen, F., and Tushar Shah. 2002. “Rules Rather Than Rights: Self-regulation in Intensively Used Groundwater Systems.” In *Intensive Use of Groundwater: Challenges and Opportunities*, edited by Ramon Llamas, and E. Custodio, 241–256. Brookfield, VT: A. A. Balkema.

Wade, Robert. 1994. *Village Republics: Economic Conditions for Collective Action in South India*. San Francisco, CA: ICS Press.
Ward, Christopher. 2000. "The Political Economy of Irrigation Pricing in Yemen." In *The Political Economy of Water Pricing Reforms*, edited by Ariel Dinar, 381–394. New York: Oxford University Press.

Auxiliary Appendix: Simulation of water trade[23]

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 utilisation 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 Lagrangian problems:

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

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

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: $\Pi_t^1 = P_f\left(A\left(w_t^1\right)^{\delta 1}\right) - \frac{\alpha}{M1} T(m) - p_w' m - P_w\left(n_1^2 + n_1^3 + \cdots + n_1^5\right)$
For all other agents i in group P: $\Pi_t^i = P_f\left(A\left(w_t^1\right)^{\delta 1}\right) - \frac{\alpha}{M1} T(m) - P_w\left(n_i^1 + n_i^2 + \cdots + n_i^5\right)$[24]
The utility function of each agent i in group P is $U\left[\Pi_t^i,\ \mathrm{h}_t^i\right] = \mathrm{Z}\left(\Pi_t^i\right)^{\gamma}$

Group Q:

For agent 1: $\Pi_t^1 = P_f\left(A\left(w_t^1\right)^{\delta 2}\right) - \frac{(1-\alpha)}{M1} T(m) - p_w' m - P_w\left(n_1^2 + n_1^3 + \cdots + n_1^5\right)$
For all other agents i in group Q: $\Pi_t^i = P_f\left(A\left(w_t^1\right)^{\delta 2}\right) - \frac{(1-\alpha)}{M1} T(m) - P_w\left(n_i^1 + n_i^2 + \cdots + n_i^5\right)$[25]
The utility function of each agent i in group Q is $U\left[\Pi_t^i,\ \mathrm{h}_t^i\right] = \mathrm{Z}\left(\Pi_t^i\right)^{\gamma}$

Inter-group trade:

All other parameters held 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 $\delta 2 = 0.6$. Assigning the higher productivity to group Q, we assume they are the first movers and group P are the followers.

The Maximisation Problem for group P is: given the water usage of group Q how to maximise sum of discounted utility over time. As maximising 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:

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

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:

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

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-groups and intra-group trade, social norms and transaction costs

The modelling 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 Lagrangian problems:

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

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

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

Group P:

For agent 1: $\Pi^1_t=P_f\left(A\left(w^1_t\right)^{\delta 1}\right)-\frac{\alpha}{M1}T(m)-p'_w m-P_w\left(n^2_1+n^3_1+\cdots+n^5_1\right)$
For all other agents i in group P: $\Pi^i_t=P_f\left(A\left(w^1_t\right)^{\delta 1}\right)-\frac{\alpha}{M1}T(m)-P_w\left(n^1_i+n^2_i+\cdots+n^5_i\right)$.[26]
The utility function of each agent i in group P will be $U\left[\Pi^i_t,\ \mathrm{h}^i_t\right]=\mathrm{Z}\left(\Pi^i_t\right)^{\gamma}+\mathrm{K}\left(\overline{w}^i_t+n^j_i-w^i_t\right)$

Group Q:

For agent 1: $\Pi^1_t=P_f\left(A\left(w^1_t\right)^{\delta 2}\right)-\frac{(1-\alpha)}{M1}T(m)-p'_w m-P_w\left(n^2_1+n^3_1+\cdots+n^5_1\right)$
For all other agents i in group P: $\Pi^i_t=P_f\left(A\left(w^1_t\right)^{\delta 2}\right)-\frac{(1-\alpha)}{M1}T(m)-P_w\left(n^1_i+n^2_i+\cdots+n^5_i\right)$[27]
The utility function of each agent i in group P will be $U\left[\Pi^i_t,\ \mathrm{h}^i_t\right]=\mathrm{Z}\left(\Pi^i_t\right)^{\gamma}+\mathrm{K}\left(\overline{w}^i_t+n^j_i-w^i_t\right)$

Inter-group trade:

All other parameters held 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 Maximisation Problem for group P is; given the water usage of group Q how to maximise sum of discounted utility over time.

If maximising 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:

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

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

But with the agent gaining positive utility from the social norm, i.e. if $\frac{\partial U^1}{\partial h} = K > 0$, the marginal condition for maximising 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. $P_f f_m^1\left(w_t^1\right) - \frac{\alpha}{M1} T'(m) - P'_w < 0$, i.e. the marginal gains in productivity from the inter-group trade is overshadowed by its marginal cost. The only reason inter-groups 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: $P_f f_m^1\left(w_t^1\right) - \frac{1-\alpha}{M2} T'(m) + P'_w > 0$,[28] i.e. $P_f f_m^1\left(w_t^1\right) + P'_w > \frac{1-\alpha}{M2} T'(m)$, 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 1A). 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.

Table 1A. 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 tw0 groups, no social norms and trading	1	1	$\delta 1 = 04$ $\delta 1 = 06$	$K = 0$	$A = 5$	$Z = 5$	$\gamma = 0.4$	$\beta = 0.91$	$N1 = 5$ $N2 = 5$
Model with two groups, social norms and trading	1	1	$\delta 1 = 04$ $\delta 1 = 06$	$K = 5$	$A = 5$	$Z = 5$	$\gamma = 0.4$	$\beta = 0.91$	$N1 = 5$ $N2 = 5$