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Equity–Efficiency Optimizing Resource Allocation: The Role of Time Preferences in a Repeated Irrigation Game*

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Abstract

We study repeated water allocation decisions among small scale irrigation users in Tanzania. In a treatment replicating water scarcity conditions, convexities in production make that substantial efficiency gains can be obtained by deviating from equal sharing, leading to an equity–efficiency trade-off. In a repeated game setting, it becomes possible to reconcile efficiency with equity by rotating the person who receives the largest share, but such a strategy requires a longer run perspective. Correlating experimental data from an irrigation game with individual time preference data, we find that less patient irrigators are less likely to use a rotation strategy.

I. Introduction

Livelihood systems that rely on a common pool resource are often confronted with an equity–efficiency trade-off. For instance, in a setting characterized by a scarce common resource that serves as an input into a convex production function, the optimal outcome in terms of aggregate production may be to allocate all resources to a single individual. Without any form of *ex-post* redistribution, such an allocation may conflict with local equity norms, which tend to be particularly strong in small-scale societies. The convexities in the production function means that distributing the common resource more equally between all users leads to significant aggregate welfare losses.

However, in a dynamic context, where the common pool resource has to be allocated repeatedly, it may become possible to reconcile efficiency with equity. If agents consider

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utility over more than one period, a rotation strategy where one individual takes all resources in one round and another person takes all in the following period may become a preferred strategy. In fact, for strictly convex production functions, any deviation from equal sharing, followed by an equal deviation in the other direction will improve aggregate utility, without jeopardizing equality.

Repeated interactions introduce an element of timing, such that individuals do not only consider instantaneous utility, but a stream of future utility, appropriately discounted. Individual time preferences will therefore influence what equilibrium prevails. Rotation will only be an optimal strategy if players sufficiently value the utility derived from future payoffs. In other words, the optimal solution in terms of both equity and aggregate efficiency will only come about when agents are patient enough.

In this article, we test if patience is indeed a prerequisite for equity–efficiency optimizing distribution behaviour when agents have social preferences and rely on a convex production technology. We start by presenting a simple two period model where one player decides on the distribution of a single production input between himself and another producer. With convex production technology, our model predicts that taking everything in one round and taking nothing in the following round is optimal if the player that makes the decisions becomes more patient. To test our model, we run a field lab experiment amongst traditional small-scale irrigation users in the Southern Highlands of Tanzania. The data on distribution behaviour is then correlated with a measure of time preference, which we obtained from a standard time preference elicitation experiment. We find a remarkable tendency to share equally (D'Exelle, Lecoutere and Van Campenhout, 2012a). From a dynamic perspective, we find that many players rotate, and that more impatient irrigation users rotate significantly less.

This article is related to several other articles. First of all, it builds on the growing evidence that people not only care about their own income, but also about how it compares with the income of others (see Camerer, 2003 for an overview in a behavioural economics context). New utility models have been elaborated that account for social preferences through inequality aversion (e.g. Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000). While most evidence on inequality aversion comes from experiments with university students (Camerer and Thaler, 1995), this aversion seems to be particularly large in small-scale, close-knit societies (see e.g. Henrich *et al.*, 2001).

The importance of impatience has been noted in the theoretical bargaining literature. In bilateral bargaining, if agents are identical and make alternating offers, equilibrium distributions approach equality as impatience diminishes (Rubinstein, 1982). Experiments that test these models find some support, but also note a countervailing tendency that favours fair outcomes (Binmore, Swierzbinski and Tomlinson, 2007). In our model, only one player can decide on the distribution, but the fact that this player has social preferences makes our model reminiscent of such bargaining games. As such, this article also contributes to the large literature that empirically investigates multi-period non-cooperative interactions, while avoiding the main criticism on this literature that agents do not behave in the rational and selfish way these models assume (Binmore, Shaked and Sutton, 1985; Weg and Zwick, 1999; Camerer, 2003).

This article is also an extension to D'Exelle *et al.* (2012a). In that article, we provide a detailed account of the irrigation experiment and describe how small scale irrigation users deal with equity efficiency trade-offs. We find that equal sharing is most common, even in the scarcity treatment where this strategy comes at a substantial cost. Selfish deviations are frowned upon by downstream users, but we also observe that a significant number of them appear satisfied when they receive nothing in the scarcity treatment. The likelihood that upstream users alternate between altruistic and selfish deviations increases in the scarcity treatment, suggesting the existence of rotation as a welfare-enhancing institution that respects local egalitarian norms. This article focusses on rotation an instrument for efficient and equitable redistribution. It theoretically shows that, under certain conditions, present bias can undermine this type of behaviour. The theory is then tested by combining data from the irrigation experiment with a measure of individual time preference.

The remainder of this article is organized as follows. Section II presents an economic model that describes optimal behaviour of agents that care about inequality and rely on a common resource as input in a convex production process. Section III describes the experimental setup. Sections IV and IV look at the equilibria and give some descriptive statistics. Section VI presents the econometric model and results for the analysis of the repeated game. Section VII concludes and looks at lessons that can be drawn from the results of this study.

II. A simple model of equity–efficiency optimizing distribution

In this section, we will present a stylized model of an asymmetric common pool problem where one agent decides how a resource is divided. A dictator game is assumed to be played repeatedly and to happen in a context where social norms force the dictator to be other-regarding. To aid interpretation, we could think of the model as describing an irrigation system where two agents, denote by superscripts ($i = U$ for upstream user and D for downstream user) are positioned along the irrigation channel. In the model, the upstream user has full control over a fixed flow of water and has to decide on how much of this resource to keep for him/herself. The residual is then assumed to go to the downstream user. While irrigation systems are a classic example of dilemmas involving asymmetric relationships, more subtle asymmetries among appropriators in their ability to access common resources are widespread. Such asymmetries might be the consequence of geography, social hierarchy, skills, knowledge and other attributes of the action arena (Janssen and Rollins, 2012). The theory presented in this study is also applicable to such dilemmas.

The model has three key features. First, we assume the upstream user is inequality averse. Second, both agents have convex production technology. Third, agents have limited foresight (up to a maximum of two periods). Social preferences are modelled with a Fehr–Schmidt utility function (Fehr and Schmidt, 1999). In the two agent case of one upstream and one downstream user, utility of the upstream user is determined as:

$$U(y^U) = y^U - \alpha^U \cdot \max\{y^D - y^U, 0\} - \beta^U \cdot \max\{y^U - y^D, 0\}, \tag{1}$$

with y^U and y^D being the income received by the upstream and downstream irrigator, α^U the envy parameter and β^U the guilt parameter. The envy and guilt parameters determine the utility loss due to disadvantageous and advantageous inequality aversion, respectively. It is commonly assumed people feel more envy than guilt, so that $\beta \leqslant \alpha$ and $0 \leqslant \beta < 1$.

Furthermore, as in our distribution game only the upstream user takes distribution decisions, only his/her utility function is relevant in our problem. This means that the upstream user will distribute water access in such a way that the downstream user has an equal or lower final income than the upstream user, that is, $y^D \leqslant y^U$, such that equation (1) reduces to:

$$U(y^U) = y^U - \beta^U \cdot (y^U - y^D). \tag{2}$$

We assume both agents use a common resource as an input in their production functions $f()$, which produces an income y. Both players have the same production function. We will assume convex production technology $y = f(w)$, with $f' > 0$ and $f'' > 0$.

Finally, we also assume that agents have limited foresight (up to a maximum of two time periods), so that the upstream user maximizes utility over two rounds. Denoting ρ^U as the discount rate of the upstream user, we define inter-temporal utility derived from an income stream for the upstream user over two periods as:

$$U(y^U) = U(y_1^U, y_2^U) = U\left(y_1^U + \frac{y_2^U}{1+\rho^U}\right) = U\left(f(w_1^U) + \frac{f(w_2^U)}{1+\rho^U}\right). \tag{3}$$

If we assume the utility function is additive and homothetic of degree one, we can substitute equation (2) into equation (3) to arrive at the objective function of the upstream user's problem:

$$\begin{aligned} U(w_1^U, w_2^U) = f(w_1^U) + \frac{f(w_2^U)}{(1+\rho^U)} - \beta^U \Bigg(f(w_1^U) + \frac{f(w_2^U)}{(1+\rho^U)} \\ - \left(f(W - w_1^U) + \frac{f(W - w_2^U)}{(1+\rho^U)} \right) \Bigg), \end{aligned} \tag{4}$$

which is to be maximized with respect to w_1^U and w_2^U subject to the following inequality constraints:

$$w_1^U \leqslant W, \tag{5}$$

$$w_2^U \leqslant W, \tag{6}$$

$$f(w_1^U) + \frac{f(w_2^U)}{(1+\rho^U)} - \left(f(W - w_1^U) + \frac{f(W - w_2^U)}{(1+\rho^U)} \right) \geqslant 0, \tag{7}$$

where the last inequality comes from the assumption that $\beta \leqslant \alpha$, which in turn means that $y^U - y^D \geqslant 0$, but applied to our two period model.

The Kuhn–Tucker conditions associated to problem (4) subject to the three inequality constraints are the following:

$$f'(w_1^U) - \beta^U (f'(w_1^U) + f'(W - w_1^U)) - \lambda_1 + \lambda_3 (f'(w_1^U) + f'(W - w_1^U)) = 0, \tag{8}$$

$$\frac{f'(w_2^U)}{(1+\rho^U)} - \beta^U \left(\frac{f'(w_2^U)}{(1+\rho^U)} + \frac{f'(W - w_2^U)}{(1+\rho^U)} \right) - \lambda_2 + \lambda_3 \left(\frac{f'(w_2^U)}{(1+\rho^U)} + \frac{f'(W - w_2^U)}{(1+\rho^U)} \right) = 0, \tag{9}$$

$$w_1^U \leqslant W, \lambda_1 \geqslant 0, (w_1^U - W)\lambda_1 = 0, \tag{10}$$

$$w_2^U \leqslant W, \lambda_2 \geqslant 0, (w_2^U - W)\lambda_2 = 0, \tag{11}$$

$$f(w_1^U)+\frac{f(w_2^U)}{(1+\rho^U)}-\left(f(W-w_1^U)+\frac{f(W-w_2^U)}{(1+\rho^U)}\right)\geqslant 0,\quad \lambda_3\geqslant 0,$$

$$\left(f(w_1^U)+\frac{f(w_2^U)}{(1+\rho^U)}-\left(f(W-w_1^U)+\frac{f(W-w_2^U)}{(1+\rho^U)}\right)\right)\lambda_3=0. \tag{12}$$

However, as equation (4) is convex, the internal solution to this problem is a minimum. Therefore, we confine attention to finding solutions on the constraints. We start by investigating the last constraint [equation (12)] and solve recursively. We distinguish two cases: one where the upstream user keeps the entire resource in the first period and one where he/she keeps the entire resource in the second period.

Case 1. $w_2^U=W$.

If we assume that condition (12) holds with equality and the upstream user keeps the entire resource in the second period [$w_2^U=W$, equation (11)], we get:

$$f(w_1^U)-f(W-w_1^U)=\frac{(f(0)-f(W))}{(1+\rho^U)}. \tag{13}$$

This result tells us that if the upstream user is bound by condition (7), guilt feelings do not play a role in distributing the resource in the first period. This is because if equation (7) holds with equality, this imposes that total resources appropriated by the upstream user over the two rounds should equal total resources left for the receiving player over both rounds. More interestingly, the upstream user's time preference does influence the distribution of W in the first period. In general, the optimal strategy of the upstream user is to appropriate a smaller share of the resource if he/she becomes more patient. As we started out by assuming that the upstream user appropriates the entire resource in the second period, this means rotating becomes the preferred option if patience increases. In the extreme case when $\rho^U=0$, we find that the optimal amount of the resource agent U would appropriate in the first period is zero, meaning full rotation. On the other hand, if the upstream user is impatient, he or she will want his or her share as quickly as possible. In the limit of $\rho^U\rightarrow\infty$, the upstream user will appropriate half of the available resource in the first period. This is so because equation (12) reduces to $f(w_1^U)=f(W-w_1^U)$, which will only be the case if $w_1^U=\frac{W}{2}$.

Case 2. $w_1^U=W$.

If equation (7) holds with equality, but now we assume that the upstream user takes all resources in the first period, $w_1^U=W$, we get that:

$$f(W)-f(0)=\frac{(f(W-w_2^U)-f(w_2^U))}{(1+\rho^U)}. \tag{14}$$

Again, guilt feelings do not enter the equation determining optimal resource appropriation by the upstream user in the second period, but his/her time preference does. The only reasonable solution [$0\leqslant w_2^U\leqslant W$, $0\leqslant w_1^U\leqslant W$, $f(0)<f(W)$] is when $\rho^U=0$. If this is the case, we find that it is optimal for the downstream user to take nothing in the second period ($w_2^U=0$), which means perfect rotation. This is because, we are moving along the constraint that requires the resource to be shared equally [equation (7) holds with equality].

In addition, we assume that the upstream user already appropriated the maximum [by also making equation (10) a binding constraint] in the first round. The only situation in which both these constraints can be binding is when future income is valued equally to current income and everything is left to the downstream user.

The above two equations [equation (13) and (14)] that express the upstream user's appropriation in both periods in terms of impatience are central to our empirical model. There is, however, a second parameter that determines rotation: the guilt parameter. We will not provide a derivation for the equilibrium conditions (our objective function is convex, so first order conditions will lead us to a local minimum anyway). Instead, we look at the change in utility from a change in the guilt parameter when we move along the $w_1^U = W$ and the $w_2^U = W$ boundaries:

If $w_1^U = W$, we get:

$$U(w_2^U) = f(W) + \frac{f(w_2^U)}{(1+\rho^U)} - \beta^U \left(f(W) + \frac{f(w_2^U)}{(1+\rho^U)} - \left(f(0) + \frac{f(W - w_2^U)}{(1+\rho^U)} \right) \right), \quad (15)$$

$$\frac{\partial U}{\partial \beta^U} = -f(W) - \frac{f(w_2^U)}{(1+\rho^U)} + \left(f(0) + \frac{f(W - w_2^U)}{(1+\rho^U)} \right), \quad (16)$$

$$\frac{\partial U}{\partial \beta^U} = f(0) - f(W) + \frac{(f(W - w_2^U) - f(w_2^U))}{(1+\rho^U)}. \quad (17)$$

So, if the upstream user appropriates the entire resource in the first period, the utility he or she derives from appropriating resources in the second period is inversely related to his or her guilt feelings. Obviously, in the extreme case where $\rho^U \to \infty$, the change in utility associated with a change in guilt is independent of the resources appropriated in the second period, and $f(0) - f(W) \leqslant 0$, as $f' > 0$. If ρ^U becomes smaller, there is an additional negative effect if the upstream user also decides to appropriate more water than the equal split in the second period.

If $w_2^U = W$, we get:

$$U(w_1^U) = f(w_1^U) + \frac{f(W)}{(1+\rho^U)} - \beta^U \left(f(w_1^U) + \frac{f(W)}{(1+\rho^U)} - \left(f(W - w_1^U) + \frac{f(0)}{(1+\rho^U)} \right) \right), \quad (18)$$

$$\frac{\partial U}{\partial \beta^U} = -f(w_1^U) - \frac{f(W)}{(1+\rho^U)} + \left(f(W - w_1^U) + \frac{f(0)}{(1+\rho^U)} \right), \quad (19)$$

$$\frac{\partial U}{\partial \beta^U} = f(W - w_1^U) - f(w_1^U) + \frac{(f(0) - f(W))}{(1+\rho^U)}. \quad (20)$$

This result indicates that if the upstream user takes all of the resource in the second period, the utility derived from the resource appropriated in the first period is inversely related to the guilt parameter if the upstream user appropriates more than half of the resource, irrespective of the value of the discount rate. If the discount rate reduces, an additional negative effect, independent of the amount appropriated in the first round, is added.

III. Experimental setup

To assess the importance of time preference for equity–efficiency optimizing behaviour, we combine data from two different field experiments. One is a distribution game that mimics features of an irrigation system. The second is an experiment to elicit time preferences of the players. In this section, we describe both experiments in turn.

The irrigation experiment

The distribution game was framed as a series of interactions between two irrigation users. One player, a (randomly assigned) upstream user, was instructed to decide on the division of a constant stream of irrigation water (12 hours of water per round) between him/her and a downstream user that was randomly paired to the upstream user. The players' roles remained fixed throughout the entire game and the paired upstream and downstream users did not know each other's identity. After the upstream user made the decision on how much of the total available hours of water to keep for own production and how much was left for the downstream user, the latter could react to the former's decision. The downstream user was given four different options to react: express satisfaction, remain silent, express disagreement and punish the downstream user. From these options, only the last one involved real costs for both parties. Because direct punishment would be too intrusive, this option was framed as if a mediator was brought in at the cost of the downstream user (30 Tanzanian Shilling (TSH), one dollar was about 1200 TSH at the time of the experiment.) who fines the upstream user by reducing the payoff of the upstream user by 100 TSH.

For each player, the irrigation water input was directly related to cash income through a production function that was the same for each player. As irrigation-dependent production requires a critical water input, these production functions were characterized by a threshold. The threshold represented a minimum water level below which production was equal to a low level, irrespective of the exact water input. In addition, above this critical water input, production showed decreasing marginal returns. This was the baseline treatment, which could be interpreted as a situation of water abundance. The production function was such that there was no conflict between equity and efficiency. Total water availability was sufficient for both water users to reach the minimum water input, and aggregate income was highest at the equal split.

We also introduced a scarcity treatment. During the course of the game, we changed the production function as to simulate a general drop in water availability. More specifically, after five rounds of using the production functions of the baseline abundance treatment, we introduced a new production function with the property that equal sharing now conflicts with efficiency. In all subsequent rounds, total water availability was insufficient for both users to reach the threshold and aggregate revenue is maximal when the upstream user takes all the water (or leaves all water to the downstream user).[1] This treatment was played for ten rounds. The production functions are represented in Table 1.

[1] While the theoretical model assumes a twice differentiable convex production function, we used a production function that features a threshold in the experiment for practical reasons. This does not affect the main result, as the main property that $f(tx_1 + (1-t)x_2) < tf(x_1) + (1-t)f(x_2)$ for $t \in [0, 1]$ also holds for our production function, at least over a certain domain. In other words, the function is also convex over the domain used in the experiment.

TABLE 1

Production function

Hours upstream user	*Treatment 1* Upstream	Downstream	*Treatment 2* Upstream	Downstream
0	50	500	50	350
1	50	500	50	325
2	50	475	50	300
3	50	450	50	250
4	175	425	50	200
5	250	375	50	125
6	325	325	50	50
7	375	250	125	50
8	425	175	200	50
9	450	50	250	50
10	475	50	300	50
11	500	50	325	50
12	500	50	350	50

Irrigated agricultural production is likely to provide the convexity in the production function that is key to our theoretical model. A production function featuring threshold effects may indeed be most appropriate to describe production within an irrigation scheme when water is scarce. Plant physiology is such that a minimum amount of water is necessary to obtain yields (Aiken and Lamm, 2011). In the irrigation sites under study, we found that the bulk of the sites are planted with maize (42%) and beans (30%). The remainder of the area is planted with tomatoes, Chinese cabbage and other vegetables. All these plants need an absolute minimum amount of water to grow and produce crops or fruits. Both maize and tomatoes need at least 400 mm of water to grow, while beans need only slightly more (Onwueme and Sinha, 1991). If irrigation is below this level, plants will shrivel and can only be used as animal fodder or organic fertilizer.

We organized 13 different sessions of the experiment with 156 users, randomly sampled from five traditional self-governed irrigation systems in the Mufindi district, which is located in the Southern Highlands of Tanzania. Per session, the minimum number of participants was eight and the maximum was 14. All participants played the full 15 rounds and did not know beforehand on how many rounds would be played.[2] They also did not

[2] Participants were paid out at the end of the game. One may argue that this does not sufficiently reflect reality, where each farmer gets the return on water investment immediately after each harvest. In addition, it makes it less obvious that impatience is playing a role in rotating behaviour. There are different reasons why we decided to pay participants at the end of the game. Apart from the practical problems in paying out each participant after each round, we doubt that paying after each round would have enabled us to better capture the effect of time preference on rotation within the game. The time difference between the different rounds of the game would simply be too short to generate a detectable effect. More fundamentally, we believe that what is driving human behaviour is present bias, of which the impatience as we measure it is only one manifestation. In other words, the fact that the individual wants to have something now rather than at some point in the future is not what we are interested in *per se*, we only use it as a proxy for a broader present bias because it is relatively easy to elicit through a standard behavioural experiment. We feel that the failure to consider future actions as part of the strategy space is the main reason why people fail to rotate. The approach we therefore took is the one suggested by Cardenas and Ostrom (2004) to take the experiment to the field and try enriching the analysis with important but difficult issues as social context and personal identity. Each round was framed as a season, and decisions had to be made on the distribution of water, a common input on the

know that a second treatment would be introduced after the fifth round. The experiment was carefully designed and tested to make sure that illiterate people also understood the instructions. Several questions were included in the design stage, and the experiment was taken back to the drawing table until we were confident that all participants fully understood the consequences of all decisions and the actions that were available to them. A detailed description of this experiment, together with a description and analysis of upstream and downstream user behaviour can be found in to D'Exelle *et al.* (2012a).

The experiment was designed after careful study of existing irrigation systems in the area. Local resource governance institutions, including those for governing irrigation water, are a blend of formal and informal rules and practices. They are shaped by pragmatism and by people's practices and have a high degree of local specificity (Leach, Mearns and Scoones, 1999; Lecoutere 2011). Water distribution is often organized in such a way that competition is limited and every community member can get an 'equal' share conditional on contributing to water provision activities like canal cleaning. Some form of rotation is often a solution to ensure everyone gets her share of irrigation water (Ostrom, 1990; Potkansky and Adams, 1998; Bruns and Meinzen-Dick, 2005; Lecoutere, 2011). But rotation is not always strictly regulated or enforced.

The irrigation schemes from which the participants were sampled consist of networks of locally dug river diversions and canals. Rudimentary technology is used to manage the flow of water. The irrigation schemes comprise of a patchwork of plots, most of which are relatively small. From pre-experiment focus group discussions, we learned that water governance is driven by avoidance of competition and distributive conflicts in order to maintain harmony in the community. It is inspired by strong beliefs that everybody has a right to water. A fair distribution of irrigation water is regarded essential. Some irrigators believed this share should be proportional to the size and condition of the plot and to the crops' water needs. Some irrigators referred to water sharing schemes allotting equal time slots for water use; others believed it depends more on the goodwill of your upstream user rather than on strict regulation.

In practice, an irrigator in the schemes takes a share of irrigation water on a regular basis by diverting the flow to his or her field(s) during a certain time after which the flow can continue to the downstream user(s). The downstream user is not a passive receiver. In some cases, people opt to disregard infringements on their water share. In other cases, people complain to the offender. Sometimes people call for punishment, especially for serious or recurrent defiance of sharing rules. This often involves mediators, village leaders or officials and mostly implies a cost for the complainant, like the payment of transport or 'facilitation' fee. The offender may have to pay a fine or compensation. In case of severe or recurrent rule breaking, s/he may be barred from accessing land or irrigation water.

Measuring impatience

Within the experimental economics literature, the most common approach to measure impatience is by presenting an individual with a list of pair-wise options. Each pair of

irrigated plot. Such framed experiments are common in situations where the researcher wants subjects to apply the relevant field heuristic when completing a task (Harrison and List, 2004).

TABLE 2

Options used in the time elicitation exercise

Choice	Sequence of prior options chosen	Option A (after 1 month)	Option B (after 3 months)
1		1,000 TSH	1,500 TSH
2	A	1,000 TSH	1,750 TSH
2	B	1,000 TSH	1,250 TSH
3	AA	1,000 TSH	1,900 TSH
3	AB	1,000 TSH	1,600 TSH
3	BA	1,000 TSH	1,400 TSH
3	BB	1,000 TSH	1,100 TSH

TABLE 3

Intervals of discount rates

Category	Sequence of options chosen	Discount rate (%)
1	BBB	<4.45
2	BBA	4.45%–9.54
3	BAB	9.54%–13.39
4	BAA	13.39%–15.47
5	ABB	15.47%–17.26
6	ABA	17.26%–19.52
7	AAB	19.52%–21.40
8	AAA	>21.40

options would typically consist of the option to receive an amount of X now and an option to receive $X+e$ at some fixed date in the future, with $e \geqslant 0$, and going up as one proceeds down the list. When $e=0$, it is expected that the individual takes the money now, as there is no return to waiting. However, as e increases, one would expect more people to take the future income option. The point at which an individual switches from taking the current option to taking the future option provides a bound on his discount rate (Coller and Williams, 1999; Harrison, Lau and Williams, 2002).

Upon testing this experiment in the field, we found that presenting illiterate farmers with such a list of options was problematic. This issue of visual overload has been encountered in other studies that tried to elicit time preferences in Africa (Holden, Shiferaw and Wik, 1998; Klemick and Yesuf, 2008; Bauer and Chytilová, 2010). They all tried to reduce this problem by shortening the list of options, thereby making the measure less precise. Our approach involved three consecutive choices between two options. Whereas for the first choice the two options were the same for all participants, the options for the second and third choices were dependent on the previous choices made. Table 2 presents the sequence. In the first round, each participant was asked to choose between receiving 1,000 TSH after one month (option A) or 1,500 TSH after three months (option B). If the participant preferred option A, we increased the amount of option B in the second round to 1,750 TSH. If, on the other hand, the participant preferred option B, we reduced option B to 1,250 in the second round. By adding a third conditional choice to the sequence, we cover a range of eight possible intervals of corresponding to intervals of discount rates, as illustrated in Table 3.

In our experiment, both payments were situated in the future. This was done to minimize possible conflation with risk considerations (how can one be sure that the organizer keeps his promise and will pay in the future). By situating both options in the future, such considerations are assumed to be the same for each option. In the field we ended up cooperating with a local micro-finance bank. All payments were made in drawing rights on the bank, cash-able from the particular date onward. More information on the experiment, including a literal transcript of the experiment instructions, can be found in D'Exelle, Van Campenhout and Lecoutere (2012b).

IV. Equity and efficiency in irrigation – stylized outcomes

We can derive outcomes for different scenarios. A first scenario is one where all subjects care for both aggregate efficiency and equality. This would result in the upstream user sharing equally during the first treatment and a rotation strategy for the remainder of the experiment.[3] This would mean that both the upstream and downstream user have equal earnings, amounting to 325 TSH in the first five rounds. In the last ten rounds, each player will receive five times 350 and five times 50. Each player would earn 3,625 TSH in this scenario. In the aggregate, this would mean 565,500 TSH, which is the maximum attainable aggregate income in the game. Also in this case, the Gini coefficient is zero.

A second stylized outcome is one in which the upstream users do not care about inequality in the outcome. In other words, $\beta^U = 0$ in equation (2). In this setting, the upstream user would always appropriate the total available number of hours, which is 12, thereby earning 500 TSH in the base period and 350 TSH in the scarcity treatment. His total earnings would thus be 6,000 TSH, the result of $(5 \times 500 + 10 \times 350)$. The downstream user would always refrain from punishing, as this is costly. His return would thus be 750 TSH, the result of (15×50). The aggregate income of this strategy combination would be 526,500 TSH, representing about 93% of the maximum attainable aggregate production. The Gini index would be 0.39.

A third reference scenario we will use as a benchmark is one where players are not interested in efficiency, but only care about equity. This scenario corresponds to a range of situations where β^U is sufficiently large while at the same time patience is sufficiently low (or ρ^U is sufficiently high). In this scenario, we assume that the upstream user always chooses the equal split, appropriating 6 hours of water and leaving the remaining 6 hours of water for the downstream user. In this scenario, the upstream and downstream users have equal earnings, amounting to 325 TSH in the first five rounds and 50 in the remaining ten rounds. Hence, each player would earn 2,125 TSH in total. In this scenario, aggregate earnings would amount to 331,500 for the entire experiment. This corresponds to about 59% of maximized aggregate production. The Gini coefficient here would also be zero.

[3] One may argue that it does not have to be rotation as such, but any strategy that results in equal cumulative benefits for both players over the entire game. For example, if the upstream user appropriates 12 hours during the first five rounds and then leaves all water flowing to the downstream user, equity and efficiency would also be optimal (assuming no discounting). However, in our experiment, participants did not know beforehand on how many rounds would be played. In such circumstances, rotation would be the only equitable strategy.

V. Descriptive statistics

Over all rounds, aggregate earnings amounted to 408,400 THS or 72% of maximum aggregate production, but about 23% more than if everyone plays equal sharing all the time. In other words, the average user earned about 500 TSH more than if equal split would have prevailed all the time. However, the average player earned 1,000 TSH less than what he or she could have earned if perfect rotation would have been played. The Gini coefficient is about 0.24.

Figure 1 shows the frequency distribution of hours appropriated by the upstream user. In the first panel, which pools data over all 15 rounds, we see that the dominant strategy is the equal split. This is surprising, as the pure strategy Nash equilibrium is to appropriate everything in each round. We attribute this to the prevailing norms of equal access to water. If we only consider data from the scarcity treatment (second panel), the equal split remains the dominant strategy, despite the substantial losses in efficiency this brings about. A substantial amount of decisions now involve appropriating 7 hours of water, which results in 75 TSH more than the baseline revenue of 50 TSH, but is sufficiently close to the equal split.

Figure 2 visualizes the evolution of hours appropriated by the upstream user over the 15 rounds for 16 randomly sampled individuals of the 78 upstream irrigation users we subjected to the experiment. Several features spring to mind. First of all, none of the participants play the optimal efficiency-equity trade-off strategy of appropriating 6 hours during the first five rounds and alternating between 0 and 12 hours over the remaining rounds. Secondly, there are a substantial number of people that seem to prefer equity above efficiency. While only four individuals consistently go for the equal split (e.g. individuals seven and ten in Figure 2), 27% of the upstream users remain very close to it (e.g. individuals 11 and 43). Third, very few people in our sample choose strategies that result in efficient but unequal outcomes. For instance, nobody plays the Nash equilibrium of taking 12 hours all the time. In fact, only three individuals always take more than 6 hours. The most extreme case always takes 11 hours. Fourth, more than 60% of the sample in Figure 2 rotates at least once, in that they cross the line of 6 hours. Finally, a substantial part of the data set shows the typical zigzagging pattern of negative serial correlation. Loosely defined, about 37 individuals show signs of such behaviour. Examples of such behaviour are individuals 9, 22, 66, 68 and 71.

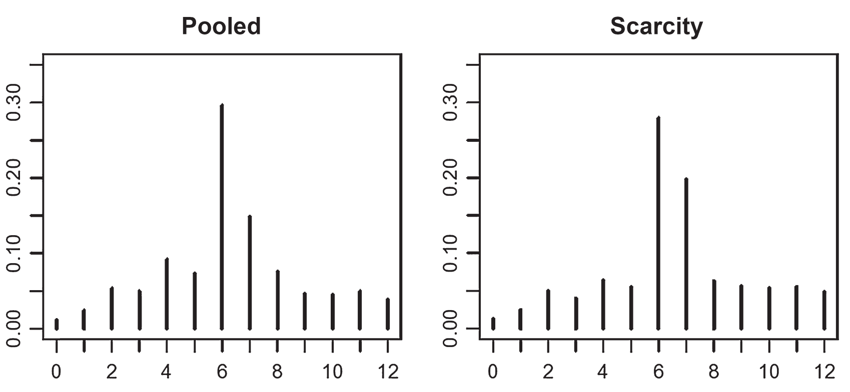

Figure 1. Average distributions

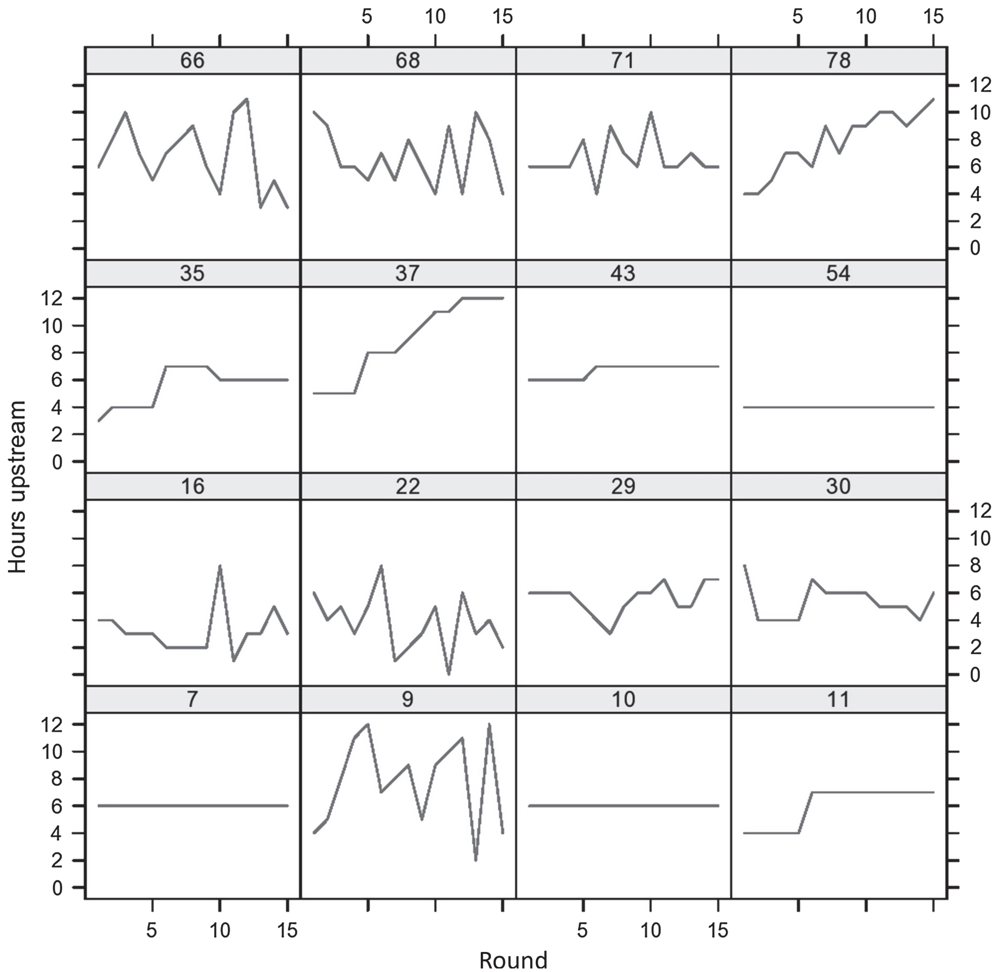

Figure 2. Random subset of upstream users decisions over rounds

VI. Econometric analysis

In this section, we empirically test the following two hypotheses. First, we verify if irrigators adapt their strategy to the incentives provided by the scarcity treatment. Given the context of strong equity norms and the equity–efficiency trade-off in the scarcity treatment, we expect to see significantly more rotation under scarcity. Second, we test if impatient irrigators, as expressed by a higher discount rate, are less inclined to rotate.

To do so, we run a series of regressions that estimate the relationship between the amount of water appropriated in a particular round r and the amount of water appropriated in the previous round $(r-1)$. We will be particularly interested in interactions with the other conditioning variables (an indicator for the treatment, an indicator of the downstream user's reaction and a measure of impatience respectively) that produce negative coefficients, as this suggests rotating behaviour. To see why, let $a_{i,r}$ represent the amount of water taken by the upstream user i, centred around the equal split (in other words, we subtract six from the total hours appropriated by the upstream user) in round r. We then regress this on $a_{i,r-1}$ and allow for individual specific unobserved heterogeneity (η_i):

$$a_{i,r} = \phi_1 a_{i,r-1} + \eta_i + \varepsilon_{i,r.} \tag{21}$$

If we estimate this regression and find a parameter estimate (ϕ_1) that is negative, this means that, on average, a positive deviation from equal split is followed by a negative deviation from equal split and *vice versa.* Such negative serial auto-correlation would suggest an inclination to rotate. At the extreme, with perfect rotation, we would find a parameter estimate equal to -1. Hence, our baseline regression model is given in equation (21), and we will introduce interactions with $a_{i,r-1}$ to answer the three questions raised above.

To answer the first question, we construct an indicator of the scarcity treatment (t_r). This variable takes the value of zero for the first five rounds and becomes one thereafter. We expect the coefficient estimate (ϕ_t) on the interaction of this treatment indicator with the lagged dependent variable to be significantly negative. We add a second indicator that reflects expression of disagreement of the downstream user with the received share in the previous round ($d_{i,r}$). While the reaction of the downstream user does not directly feature in our theoretical model and hence is not central to our theory, we strongly felt that omitting this variable from our empirical specification could lead to biased estimates. In our experimental setup, expressing disagreement was the only way in which the downstream user could try to influence the distribution behaviour of the upstream user. We therefore needed to exclude the possibility that our results are driven by assertive downstream users.

Finally, we also interact an indicator of impatience (ϕ_p) with the centred hours appropriated in the previous period. Impatient individuals are likely to engage less in a rotation strategy ($\phi_p > 0$). We also add all possible interactions between these three variables. The final model will therefore become:

$$\begin{aligned} a_{i,r} = {} & \phi_1 a_{i,r-1} + \phi_t a_{i,r-1} t_r + \phi_d a_{i,r-1} d_{i,r} + \phi_p a_{i,r-1} p_i \\ & + \phi_{td} a_{i,r-1} t_r d_{i,r} + \phi_{tp} a_{i,r-1} t_r p_i + \phi_{tdp} a_{i,r-1} t_r d_{i,r} p_i + \eta_i + \varepsilon_{i,r}. \end{aligned} \tag{22}$$

To estimate this dynamic panel data model, we use the Arellano–Bond estimator (Arellano and Bond, 1991).[4] All regressions also include time dummies as well as irrigation site dummies. Table 4 reports the results.

Our baseline model (1) is a simple auto-regressive panel data model of order one that regresses current hours appropriated by the upstream user minus six on appropriation in the previous period. We do not find any statistically significant relation. When we add an interaction for the treatment [model (2)], we find a positive and statistically significant baseline effect of 0.319. This suggests that a positive (negative) deviation from the equal split is likely to be followed by another positive (negative) deviation from the equal split, but this deviation reduces over time. For example, an upstream user who appropriates all available water in the first round will appropriate only about 8 hours of water in the second

[4] Such models assume a continuous response variable. As our dependent variable is (a transformation of) hours appropriated out of a maximum of 12, one may argue that a generalized linear model such as the (multinomial) probit model would be more appropriate. To check if our results are robust to this criticism, we constructed an indicator function that is one if our dependent variable switched sign between two consecutive rounds and zero otherwise and ran probit regressions with the same explanatory variables as the ones used below. This analysis confirmed the main findings of this article.

TABLE 4

The effect of scarcity and time preference on rotation

	(1)	(2)	(3)	(4)	(5)	(6)
$a(t-1)$	−0.037	0.319	0.381	0.437	0.554	0.621
	(0.40)	(3.26)***	(3.31)***	(3.72)***	(4.41)***	(2.67)***
$a(t-1)$ × disagree			−0.137		−0.215	−0.179
			(0.83)		(1.53)	(1.21)
$a(t-1)$ × impatient				−0.329	−0.293	−0.014
				(1.76)*	(1.57)	(0.97)
$a(t-1)$ × treat		−0.465	−0.654	−0.626	−0.905	−1.284
		(3.93)***	(4.37)***	(4.03)***	(5.20)***	(4.16)***
$a(t-1)$ × treat × disagree			0.350		0.574	1.253
			(1.61)		(2.15)**	(2.69)***
$a(t-1)$ × treat × impatient			0.411	0.575	0.044	
				(1.72)*	(2.30)**	(2.43)**
$a(t-1)$ × treat × disagree× impatient				−0.388	−0.064	
					(1.02)	(2.17)**
N	988	988	982	975	971	971
Individuals	76	76	76	75	75	75
Number of instruments	26	26	39	39	61	61
Sargan test	36.75***	7.20	17.53	31.11*	57.93**	62.25**
F-test rotation in treatment		1.96*		1.61	4.95**	5.58**
F-test rotation if impatient				0.19	1.16	2.42

Notes: t-statistics are in brackets, and based on standard errors that are consistent in the presence of any pattern of heteroskedasticity and autocorrelation within panels. In model (5), patient is a binary indicator while in model (6), patient is a continuous variable. *, ** and *** denotes significance at 10, 5 and 1% respectively.

round (being the result of $0.319 \times 6 = 1.914$). What is more interesting is that we find a significantly negative additional effect under the scarcity treatment that more than offsets the baseline effect. A one sided F-test shows that the overall effect is significantly different from zero and negative. In other words, we can confirm that, under the scarcity treatment, there is a tendency to rotate, increasing efficiency while preserving equity.

Model (3) introduces the reaction of the downstream user into the model. It adds an interaction between having disagreed with the share left by the upstream user in the previous round and the hours that were appropriated by the upstream user in the previous round. It seems that expression of disagreement does not affect distribution behaviour. Model (4) replaces the disagreement effect with the effect of impatience of the upstream user.[5] In the first instance, the effect of impatience on the evolution of hours appropriated is estimated by interacting a dummy variable taking the value of one if a player's discount rate is larger than 17.26%. We find a positive coefficient in the scarcity treatment, indicating that irrigators who are less patient are less inclined to follow a rotation strategy. At the bottom of the table, we ran the F-test on the overall effect of the treatment again, which has lost its significance. We also add a second F-test that looks at the overall effect of being impatient.

[5]The time preference included in the model is for the upstream user. We also ran regressions with additional effects for the downstream user's impatience. However, the results for the downstream user were not significant, while the results for the upstream user remained the same. The interaction between upstream and downstream user's impatience was also insignificant. This suggests that the time preference effect mainly works through the upstream user. This is not surprising as he/she has control over the appropriation decision.

The result suggests that there is no significant effect of being impatient. This is according to expectations, as we expect impatience only to become important when equity efficiency dilemmas arise, which is in the scarcity treatment.

Model (5) captures both the upstream user's time preference and the expression of disagreement by the downstream user. As in the second model, there is a significant rotation effect in the scarcity treatment, strong enough to more than offset the overall positive autocorrelation. However, both coefficients for impatience and punishment are significantly positive, indicating that impatient upstream users, just as upstream users that were confronted with disagreeing downstream users, are less likely to engage in rotation behaviour. The effects are similar in magnitude and large enough to offset the incentive effect created by the scarcity treatment.

Model (6) refines the time preference measure. Instead of using a simple binary variable, we exploit the fact that our experiment produced eight intervals and interpret this as a continuous variable directly measuring the upstream user's discount rate.[6] The results are similar to the previous model, but the effects are even more outspoken. The result suggests that a 1% increase in the discount rate of the upstream user increases current water appropriation by 4% of the amount appropriated in the previous round. The results also suggest that the average upstream user will cease to rotate once his discount rate surpasses 22.1%, *ceteris paribus*. Upstream users need to be sufficiently patient to bring about successful rotation strategies.[7] Disagreement by the downstream user is again reducing rotating behaviour. The joint tests at the bottom of table 4 confirm what we found earlier.

One may argue that the lack of rotation is due to heterogeneity in attitudes toward risk, rather than time preference.Indeed, the fact that participants did not know in advance how many rounds would be played may prompt more risk adverse individuals to refrain from rotating. To test this hypothesis, we elicited attitudes toward risk of the individual players using Binswanger's (1980) behavioural experiment. [8] If we use this variable in the regression instead of time preference, we find that risk has no significant effect on the dynamics of distribution behaviour of the upstream user.This leads us to conclude that it is not attitudes toward risk that drives our results.

Somewhat related to this argument, one may feel that the introduction of a threshold after the fifth round alters expectations with respect to the duration of the experiment,

[6] We did this by taking the midpoints of the discount rate intervals in Table 3. For the first and last interval, we used 2.23% and 22.2% respectively. However, we also ran the regression without the first and last intervals, reducing the sample size by about 300 observations. In addition, we also ran the regression with our impatience measure assumed as continuous and taking simply the class numbers, ranging from 1 to 8. In all cases, regression results were similar in terms of signs and significance.

[7] Even though this is an experiment, one may dispute whether we are identifying a direct causal effect. It is argued that poverty may not be a consequence of impatience but a cause. It may be that a poor individual that is assigned the role of upstream user has an inclination to appropriate less. If poverty causes impatience, this would result in endogeneity bias. We tested for this in the following way. If the above would be the case, the inclusion of a measure of poverty in the regression would most likely render impatience insignificant, as impatience would be little more than a proxy for poverty. We experimented with the inclusion of some variables that indicated food insecurity over the last year, but the effects remained robust.

[8] Binswanger (1980) conducted experiments in India, asking individuals to choose to play one out of six gambles. The outcome of each gamble was determined by tossing a coin and the amount was paid out immediately. The gambles ranged from a safe amount of money (resulting from both heads and tails) to a 50% chance of a large gain and 50% chance of no gain. The six alternatives are constructed in such a way that higher expected returns could only be 'purchased' at the cost of higher variance. Each alternative then corresponds to a risk aversion class.

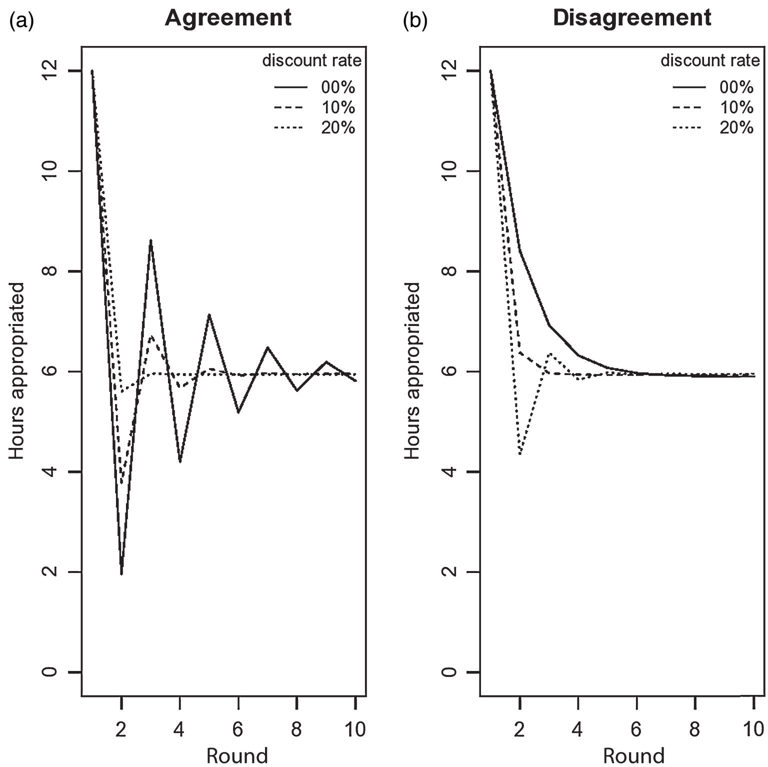

Figure 3. Impulse response functions. (a) Agreement; (b) disagreement

leading to a change in the implicit discount rate applied to future rounds. While it is not clear how the discount rate will change (the introduction of scarcity might have made subjects believe that the fictional resource was soon to run out, or it might have made them believe that the game was only just getting started), we feel that the fact that risk was not correlated to the treatment is reassuring. If expectations of the number of rounds played would be an important variable, we would also expect that people with different attitudes toward risk would react differently to a change in this variable brought about by the treatment. In other words, if everyone all of a sudden thinks the change after the fifth round will mean the game has just begun, risk lovers would start to rotate, making risk correlated to the treatment.

The estimates can be used to look at simple impulse response functions for different scenarios (Figure 3). We only concentrate on the scarcity treatment here and assume that the initial value is total appropriation by the upstream user. The first panel shows how these 12 hours evolve through time for three types of upstream users with varying discount rates (0%, 10% and 20%) and disagreement is not possible. For patient individuals, with low discount rates, the impulse response function shows substantial rotation that persists for a long period. For example, an upstream user with a 0% discount rate that appropriates 12 hours in round one will typically only take 2 hours in round two and let 10 hours flow to the downstream user. The rotation dampens as discount rates increase. However, when we also incorporate the effect of disagreement (second panel), the dynamics change considerably. A same patient user who appropriates 12 hours in the first round will, when faced with disagreement, not rotate but appropriate only a bit less than 12 hours in the subsequent round (8.4 hours). Disagreement seems to completely eliminate the propensity to rotate, especially for the patient users.

In sum, we find that irrigators do respond to the scarcity treatment in our behaviour. That is, in the scarcity treatment, where we simulate an equity-efficiency tradeoff, upstream users respond by appropriating more than the equal share in one round and leaving more than the equal share to the downstream user in the subsequent round. We also find that if the downstream user expresses disagreement over the share received, the upstream user is unlikely to start rotating resource shares.In the scarcity treatment, we find that the upstream user will actually appropriate more if the downstream user disagrees. We also confirm the prediction from our theoretical model that impatient irrigators, as expressed by a higher discount rate, are less inclined to come to a rotation strategy.

VII. Conclusion and policy implications

We study a situation where a common pool resource is shared within a community characterized by strong egalitarian norms. We argue that, in the case where there is a direct conflict between equity and efficiency,these norms may lead to large aggregate welfare losses. We then point out that repeated interaction is able to reconcile equity and efficiency when the players take a sufficiently long run perspective. We develop a simple model that features such an equity-efficiency trade-off and test its predictions using data from an irrigation experiment.

We find that irrigators from the Southern Highlands in Tanzania strongly believe in equity. If we introduce increasing returns to the resource that has to be divided by the upstream user, such that it is most efficient to allocate all resources to one player, we find that irrigators start to rotate, effectively resolving the equity-efficiency conflict. However, the downstream user is able to break this equilibrium by disagreeing on the distribution. In addition, just as disagreeing reduces the tendency to rotate, impatience is also counterproductive.

Indigenous institutions that rely on rotation strategies to overcome equity-efficiency tradeoffs are not all that uncommon in small-scale societies. An example of a successful local institution that relies on such mechanism are ‘rotating savings and credit associations’(ROSCAs), where, in repeated occasions a group of people collect financial resources to lend to one of the group members. An important rationale for the existence of such associations is that with limited access to credit markets, a ROSCA makes it possible to fund lumpy investment expenditures that often function as barriers to entry into an activity (Besley, Coate and Loury, 1993; Handa and Kirton, 1999). Within the group, the savings may be seen as a common pool resource that needs to be distributed equally, but also in a way that potential for increasing returns can be exploited.

Finally, our research shows that equity-efficiency conflicts can only be resolved when agents focus on longer term welfare maximization.Therefore, policymakers should be concerned about issues that are likely to affect time preference (Becker and Mulligan, 1997). For instance, economic shocks, which force people to deal with acute needs, may jeopardize the sustainability of rotation institutions. Policymakers could be helpful in reducing the impact of economic shocks by offering insurance or consumption credit services, among others.

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