Inequality, Information and Groundwater Management - a case study in rural Tunisia

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Abstract

This paper examines the empirical link between inequality and common property resource extraction. Using a unique data collected from Merguellil river basin in Tunisia, we find groundwater table falls less in villages with more unequal land distribution, while only weak evidence of inverted U-shape relationship between groundwater conservation and land inequality as predicted by several theoretical models. We also design a choice experiment to elicit farmers' willingness to pay for a community-based management regime for groundwater use, and their demand for information sharing and accountability. We find that farmers are inclined to a cooperative management of groundwater and stabilizing the watertable level, and majority demand a transparent system with independent monitoring, which is absent from the current management scheme under decentralization movement. We further examine the effect of land distribution inequality and heterogeneity on farmers' willingness to pay.

1 Introduction

Around the globe, depletion of aquifers caused by over-extraction of groundwater has become a major threat to freshwater ecosystems especially in arid and semi-arid regions. The agricultural sector is a major culprit as farmers

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often rely on groundwater as a major source of abundant renewable resource extracted at a fairly low cost. Oftentimes, groundwater constitutes *de facto* an unregulated common property resource (CPR for abbreviation). Once a farmer has invested in wells or boreholes, excluding him from extracting water out of the aquifer is either impossible or highly costly. However, each farmer's withdrawal has an impact on all the farmers who share the same aquifer by affecting future levels of the water table as well as water quality. Thus, groundwater is often exploited beyond its optimal level due to the presence of externalities. The existence of these externalities that are hard to internalize accelerates the depletion of water resource and drives the demand for collective action at community level during last two decades. However, the widespread failure to provide collective action in reality leads us to ask a question: what factors are more conducive to successful collective actions and what other factors impede cooperation. To find the answer for this question is the main objective of this paper. In the paper, we exploit the groundwater management experience in Merguellil river basin in Tunisia and identify inequality and asymmetric information as the two main factors that prevent cooperation.

A large literature has developed attempting to identify conditions that are conducive to collective action and sustainable management of common property resources. An important issue relates to the manner in which the inefficiencies due to the very nature of common property resources ought to be addressed. A number of studies have highlighted the design of rules by local communities to manage common resources. Ostrom [2000] provides a body of evidence based on a number of case studies where such regulations were instrumental in the successful management of common resources. Typically local management of commons may succeed when 1) access is limited to a well defined group of users who abide by specific rules set by the community; and 2) users are responsible for monitoring and enforcement, and punish non-compliance according to the severity of the offense. However, Baland and Platteau [2003] draw the attention to the fact that rules devised by communities to manage local common property resources do not necessarily aim to improve the efficiency of the use of resources unlike what a number of analyses have argued. Rather those rules often have a distributive motive as they serve the purpose of regulating the access to the resources.

Two features of community-based management of common property resources may matter for efficiency. The first is group size and the second is group heterogeneity. While there seems to be some consensus that small group sizes tend to help efficiency (Sandler [1992], Baland and Platteau [1996]), the effect of group heterogeneity on the efficiency of the management of common property resources remains an open question. In an influential contribution, Olson [1965] argues that if a public good is productivity-enhancing and wealthier agents derive a larger benefit from the public good than their less wealthy counterparts, then the richer agents may have incentive to provide it and bear all the costs involved even if the poorer agents may free-ride in their contributions. Thus, according to Olson, inequality may foster the provision of a public good.

In the context of common property resource extraction, Baland and Platteau [1997] argue that increased inequality in terms of the appropriation constraints or a disequalizing transfer from a poor and constrained user of a common resource to a rich and unconstrained user can be efficiency enhancing. In their model, the reduction in effort (e.g. resource extraction) resulting from the poor agent dominates the increase in effort induced by the rich user so that the aggregate effort level decreases with higher inequality. However, they also recognize that the existence of exit option may also give incentive to the rich users to accelerate the extraction of the resource. Therefore, the effect of inequality on resource extraction becomes less clear under these two counteracting forces. In a similar setting with inequality in the appropriation constraints, but a two-agent two-stage fishing model, Dayton-Johnson and Bardhan [2002] show that the relationship between inequality and economic efficiency is U–shaped. Their intuition is that at perfect equality conservation is Nash Equilibrium, while mean-preserving spreads of wealth distribution will reduce one's wealth to a point where his claim on the final-period resource stock provides insufficient incentive to conserve. And as inequality becomes even more unequal, conservation becomes the dominant strategy of the wealthier resource user so that efficiency increases with inequality when it is beyond a threshold. In a more specific setting of groundwater exploitation, Aggarwal and Narayan [2004] also demonstrate that efficiency and inequality are likely to be related in a non-linear fashion. Similar to Dayton-Johnson and Bardhan [2002], Aggarwal and Narayan [2004] also consider a two-stage model of groundwater extraction. But instead of extracting at both stages, farmers invest in capacity (well depth) at the first stage and decide the level of water extraction at the second stage. The inequality considered in their paper is in the ability to make investment. By endogenizing investment in wells, farmers end up competing by over-investing in capacity under open access. This fierce competition is the main factor responsible for groundwater over-exploitation. In addition they show that there is a U-shaped relationship between inequality and efficiency in the use of groundwater. When inequality (in terms of access to credit to dig wells) is low, the usual Nash equilibrium under open access obtains. However when inequality becomes moderate the stock of groundwater drops substantially before increasing again with higher levels of inequality. Although different in many settings, these three papers share the same feature, that is inequality in study is in the constraints of appropriation effort (or investment) and profit is only function of the resource in concern. However, there is another kind of inequality that is not considered in these papers: that is, inequality in an input that is complementary to the common property resource in production function. This type of inequality is common if the resource in study is water while land as another important input in production is usually distributed unequally. How is land inequality affects the efficiency in use of water is the question that we are going to examine in this paper. Bardhan et al. [2007] has studied this problem in a general theoretical framework, from contribution to public goods to extraction of common-property resources. While as they focus on finding out the joint profit maximizing inequality level, we are interested in studying how the existing heterogeneity affects the use of groundwater and users' willingness to take collective action, and more importantly how to induce resource users to cooperate in resource use at the presence of land inequality.

In addition, all the above analysis remain at a theoretical level, and there have been very few works studying this problem empirically. The main constraint we believe lies in the difficulty in obtaining appropriate data. Yet, some studies have addressed this problem using experimental data collected in the laboratory (Cardenas [2003]), while others study the relationship between inequality and group participation in contributions to public or common goods rather than exploitation of common property resources with real data collected from the field (Molinas [1998], Bardhan [2000], Alesina and Ferrara [2000], La Ferrara [2002], Alix-Garcia and Harris [2011]). A few exceptions include the papers by Libecap and his coauthors (Johnson and Libecap [1982], Libecap and Wiggins [1985]) who emphasize the role of asymmetric information and heterogeneity in common property resources exploitation.

Our paper contributes to the literature by providing new evidence on CPR exploitation using the real data collected from the field. In particular, we examine the empirical relationship between inequality in land distribution within villages and the fall in groundwater level using a unique data set collected from Tunisia. In addition, we investigate the willingness of Tunisian farmers to engage in collective action and stabilizing the watertable level in the face of the current over-exploitation of groundwater resources in the Merguellil Valley, where farmers rely on groundwater as an abundant source of low cost water and keep digging wells and boreholes without any regard to the law restricting such investment. As a result, the water table level keeps falling: it has decreased over the past 20 years from -42 meters in 1986 to -52 meters in 2006 and is expected to reach nearly -60 meters in the next 10 years.

This is a typical illustration of the tragedy of the commons where individual rationality conflicts with collective rationality: each farmer seeking his own self-interest makes eventually the community worse off. As a result, farmers have to dig deeper every year to get enough water for their crops and therefore incur increasing pumping costs. Water policy makers are concerned about the current unsustainable path. The question they have to address is: given the over-exploitation of the resources and the low enforcement of the legislation on unlicensed sources of water, how can farmers be led to internalize the externalities that they impose upon one another and society at large (costly pumping, water quality, etc.).

The application of Folk Theorem in CPR management implies that long-term repetition of the same game may foster cooperation. While if resource use is private information and asymmetric among heterogeneous resource users, cooperation is susceptible to deceit or deviation from cooperative rule and hard to form (Libecap and Wiggins [1984, 1985]). Since most groundwater extraction in the study area is from private wells and water stealing is common, how to foster cooperation becomes particularly challenging. To address this issue we design a choice experiment to ask for the farmers' willingness to pay to shift to a collective action equilibrium in which water extraction will be restricted and paid for. We pay special attention to the role of information and monitoring in farmers' decision making, and correspondingly include ***transparency*** and *accountability* as two important policy attributes. If it is heterogeneity and asymmetric information that deters cooperation, enhanced information sharing and accountability would be preferred by most farmers and strengthen their preferences for collective action. Any policy intervention that tries to induce cooperation but ignores this point wouldn't be able to solve the overextraction problem. Therefore, our purpose in conducting the choice experiment is to elicit farmers' preferences for information sharing and accountability and identify the factors that restrain resource users from using water more sustainably.

Our formal analysis begins with a theoretical model of heterogeneous farmers exploiting groundwater resources in Section 2. We analyse the effect of enhanced inequality on water extraction under both baseline model and an extended model where differentiated market price is considered. We also model farmers' decision making in choosing management regime and examine the impact of inequality and heterogeneity. Section 3 introduces the survey area and its water management institutional design. It later introduces the design and implementation of the choice experiment. Section 4 displays the results of empirical analysis, which includes two parts: empirical test of the relationship between inequality and water extraction at village level and the analysis of choice experiment at individual level. The paper concludes in Section 5.

2 Theoretical Model

In this section, we develop a simple model with the view of highlighting some of the key features we set out to investigate empirically. We build our model based on the generalized framework provided by Bardhan et al. [2007], which studies the effect of inequality on a range of collective actions, from the provision of pure public goods to the extraction of common property resources, in a situation where the unequally distributed private input and the collective good input are complements in the production function.

2.1 Baseline model

Although extraction of common property resources is a dynamic process, our model abstracts from the dynamic externality [1] and simplifies the problem into a static one. Following Bardhan et al. [2007], we assume a concave production function with one private input (land l_i) and a common property resource (groundwater w_i). We assume both inputs are complements, and groundwater is shared by n resource users[2]. In the unregulated situation, each farmer chooses extraction effort e_i to maximize individual profit:

$$\pi_i = f(l_i, w_i) - e_i$$

where e_i is the extraction effort of groundwater, and is assumed to be linear with extraction cost.

Both static and dynamic externality are captured in the production function through the common property input, $w_i = be_i + cE$, where $b > 0$ is constant production efficiency coefficient, and E is the total extraction effort by all the resource users who share the same aquifer, i.e., $E = \sum_{i=1}^{n} e_i$. The constant $c < 0$ captures the negative externality of other farmers' extraction on the available groundwater.

Following Bardhan et al. [2007] we make the following 4 assumptions:

Assumption 1. The production function $f(l_i, w_i)$ is strictly increasing and concave function and twice differentiable on $\mathbb{R}_+^2$ with respect to both inputs, $f_{12} > 0$, $\lim_{l \to 0} f_2 = 0$, and f satisfies the Inada endpoint conditions.

Assumption 2. $b \geq 0$ and $b + cn > 0$ to ensure positive total extraction.

Assumption 3. The marginal return of the collective input $h(l_i, w_i) \equiv f_2(l_i, w_i)$ is quasi-concave.

Assumption 4. The function h has property: $h_{22} > 0$ and $h_{12} < 0$.

Note that Assumptions 1, 3 and 4 are all satisfied by the Cobb-Douglas production function.

[1] In literature, there are three types of externality in groundwater use: *(i)* stock externality: exploitation of a stock of groundwater; *(ii)* pumping cost externality: increase in extraction and pumping cost due to the water table declines; and *(iii)* risk externality: inherent value of groundwater as a substitute source of water in times of surface water shortage (Provencher and Oscar [1993], Karousakis and Koundouri [2006]). We mainly focus on the first two types in this paper.

[2] Theoretically groundwater is shared by the whole watershed, we assume in the empirical analysis that each village shares certain amount of groundwater independently.

Farmer's problem is to choose the level of extraction effort e_i that maximizes his profit taking the other farmers' extraction efforts as given. i.e., the solution is noncooperative Nash Equilibrium. By standard Kuhn-Tucker conditions, we obtain:

$$f_2(l_i, be_i + cE) = \frac{1}{b+c} \tag{1}$$

Define function $g(l_i) > 0$ as the solution to $f_2(l_i, g(l_i)) = \frac{1}{b+c}$, we can draw its property into Lemma 1:

Lemma 1: $g(l_i) > 0$, $g'(l_i) = -\frac{h_1}{h_2} > 0$ and $g''(l_i) \leq 0$ for any $l_i > 0$

Proof: See Appendix 2.

By Lemma 1, we establish that the response curve of common property input (water) to private input (land) is concave if and only if the marginal return of common property input is quasi-concave. That is, water extraction increases with land endowment at a decreasing rate. Intuitively, the monotonicity result indicates that, with mean-spreading land distribution, big farmers would increase their water extraction while the small farmers would decrease theirs. However, the relative size of these two opposing effects depends on the curvature of the above response curve. Concavity of the response curve guarantees the decreased water input by small farmers is bigger than the increased level by big farmers.

Therefore, we can examine how land distribution affects water stock change $\Delta X = R - W$, where R is regeneration of groundwater (assumed exogenous), and total water extraction $W = \sum_{i=1}^{n} w_i$.

Following Persson and Tabellini [1994], we measure each farmer's land area as a distance deviated from the mean in the whole distribution, i.e. $l_i = a + \sigma\varepsilon_i$, where a is average of land endowment, and $\sigma\varepsilon_i$ is individual-specific land endowment with zero mean. In particular, an increase in the mean-preserving spread σ captures the idea of increase in inequality.

Proposition 1: *Suppose Assumption 1-4 are satisfied, the fall in stock of groundwater decreases with enhanced land inequality, i.e.* $\frac{d \mid \Delta X \mid}{d\sigma} < 0$.

Proof: Take derivative of W with respect to σ gives,

$$\frac{d \mid \Delta X \mid}{d\sigma} = \frac{dW}{d\sigma} = \sum_{i=1}^{n} g'(l_i)\varepsilon_i$$

The sign of the derivative depends on the sign of the weighted sum of the slope of response curve $g(l_i)$. If we sort farmers according to their land endowment from the minimum to the maximum such that $\varepsilon_1 < \cdots < \varepsilon_{k-1} < 0 < \varepsilon_k < \cdots < \varepsilon_n$, we then have

$$\begin{aligned}\sum_{i=1}^{n} g'(l_i)\varepsilon_i &= \sum_{i=1}^{k-1} g'(l_i)\varepsilon_i + \sum_{i=k}^{n} g'(l_i)\varepsilon_i \\ &< \sum_{i=1}^{k-1} g'(l_k)\varepsilon_i + \sum_{i=k}^{n} g'(l_k)\varepsilon_i \\ &= g'(l_k)\sum_{i=1}^{n} \varepsilon_i = 0\end{aligned}$$

The inequality condition follows directly from Lemma 1 that $g'(l_i)$ is a decreasing function. ■

This theoretical result is consistent with Olson [1965]'s argument about the positive monotonic relationship between inequality and public goods provision. The basic idea of this baseline model is that the assumption of increasing return of water with land guarantees more efficient use of water with bigger land holder, and therefore higher inequality leads to less extraction and better conservation of CPR. However, this result has been challenged by both Dayton-Johnson and Bardhan [2002] and Aggarwal and Narayan [2004] who show theoretically that the relationship could be an inverted U-shape in the case of CPR extraction. While both papers consider a scenario in which inequality is in the capacity of extraction in a dynamic model, in next section we show it is also possible to derive a non-monotonic relationship between inequality and conservation of CPR in our static model with inequality defined in the other production input which is complement to CPR.

2.2 Differentiated market prices

In the baseline model, it is implicitly assumed that all farmers face the same price for their produce and this price is normalized at $\delta = 1$. In reality, there is evidence of market imperfection in the marketing of agricultural products in Tunisia in general and in the Merguellil in particular[3]. Due to market imperfection, farmers no longer face the same unique price, but a differentiated price according to their land endowment $\delta(l_i)$. This heterogeneity in price leads to difference in payoffs of the *inside options* for water users. We assume that bigger farmers (those with larger land endowment l_i) have better opportunities to sell their products at higher prices, i.e. $\delta'(l_i) > 0$. Accordingly, the profit function now takes the form:

$$\pi_i = \delta(l_i) f(l_i, w_i) - e_i$$

Assumption 5. $\delta'(l_i) > 0$, $\lim_{l_i \to 0} \delta(l_i) = 1$ and $\lim_{l_i \to \infty} \delta(l_i) < \infty$.

The first order condition of the above optimization problem shows marginal product of water input is now amplified by a factor $\delta(l_i)$. As big farmers have bigger amplifier, they can use water till a level where marginal product of water is well below the marginal cost, according to

$$\delta(l_i) f_2(l_i, be_i^n + cE^n) = \frac{1}{b+c} \tag{2}$$

Lemma 2:

Define $\phi(l_i)$ so that $\delta(l_i) f_2(l_i, \phi(l_i)) = \frac{1}{b+c}$. In the presence of differentiated prices, the response curve of the collective input (water) to the private input (land) is positive and increasing:

a) $\phi(l_i) > 0$ for any $l_i > 0$

b) $\phi(l_i) > g(l_i)$ for any $l_i > 0$

c) $\phi'(l_i) = -\frac{h_1}{h_2} - \frac{h}{h_2} \frac{\delta_i'}{\delta_i} > 0$

d) The sign of $\phi''(l_i)$ is ambiguous, depending on the shape of $\delta(l_i)$.

In the following, we consider two types of exit option functions:

i) *Concave Inside Option*: If we impose the restriction that $\delta(l_i)$ is a concave function, i.e., δ increases

[3] Albouchi [2006] in his PhD thesis mentions that due to credit constraints, small farmers (who either cannot afford to have their own means of transport or rent vehicles) are forced to sell their products to intermediaries who collect harvests directly from the farms. By doing so, they give up an important part of the margin to these intermediaries who, in turn, will sell the products in wholesale markets in Kairouan and Tunis. On the other hand, big farmers often have their own vehicles (ISUZU) or are able to rent trucks to transport their large quantities of products to the major wholesale markets. In addition, big farmers tend to have better information about prices in the various wholesale market and are therefore able to choose the right time to sell their products.

with land area at a decreasing speed, or $\delta''(l_i) < 0$, we have$\phi''(l_i) < 0$.

ii) *Convex Inside Option:* In this case δ increases with land area at an increasing speed, or $\delta''(l_i) > 0$. If the curvature is big enough, we may have $\phi''(l_i) > 0$. Otherwise, we have $\phi''(l_i) < 0$. The sign may also change with l_i. $\phi''(l_i)$ could be positive at low values of l_i and turns negative at high values of l_i.

Proof: See Appendix 2.

We recall from the baseline model that the effect of inequality on resource extraction depends on the weighted sum of response curve slope. With exit options, we have $\frac{dW}{d\sigma} = \sum_{i=1}^{n} \phi'(l_i)\varepsilon_i$, which sign is further determined by the curvature of $\phi(l_i)$. When we have a mean-preserving spread of land distribution, big farms would increase water use but small farms would decrease since water response curve to land is upsloping. Then the marginal effect depends on the relative size of the rise from the big farms versus the cut from small farmers. If the response curve $\phi(l_i)$ is concave, the rise from the big farmers is smaller than the cut from small farmers, so that the total marginal effect is negative. However, the sign would be opposite if $\phi''(l_i)$ is positive. This happens if the increasing speed of $\delta'(l_i)$ is bigger than the decreasing speed of $g'(l_i)$ in the case without exit options. In other words, when big farmers increase water use in the presence of the exit option faster than small farmers decrease their water use with a mean-preserving spread of land distribution, the total water extraction increases with inequality. By Lemma 2, $\phi''(l_i)$ can be always negative or positive or be positive for small l_i but negative with big l_i, depending on the curvature of the exit option. If $\phi(l_i)$ is concave throughout, the sign of the weighted sum is negative, i.e., higher inequality in land distribution leads to lower total water extraction. This is same as in the baseline model. However, if $\phi'(l_i)$ is convex at low l_i and concave at high l_i, total water extraction may increase with inequality first and decrease later, i.e., a U-shaped relationship between water conservation and inequality in land. In the end, a mean-preserving spread in land distribution may affect water extraction in a non-monotonic way. We make the following proposition:

Proposition 2: *Given the Assumption 1-5, in the case with dif-*

ferentiated market where profit function is amplified by a factor $\delta(l_i)$, the fall in the stock of groundwater may increase or decrease with enhanced land inequality, where the former can only happen if there is a convex inside option.

More intuitively, the effect of inequality on water extraction with convex inside options depends on two opposite effects: the negative effect of concave water response (without differentiated market) versus the positive effect of convex inside option. For example, when we move from pure equality to medium inequality at which the latter effect is so big that may dominate the former effect, the total extraction increases with inequality. While when we further move to higher inequality where fewer farms enjoy the high price wedge, the negative effect of concave water response may take the dominance and total extraction falls below the one under medium inequality. In this case, the relationship between inequality and resource extraction is an inverted-U shape. However, if inside option is concave, or if the effect of convex inside option is not big enough to offset the concave water response at any land level, resource extraction changes with inequality monotonically. In the end, this is an empirical question that we are going to examine in the next section of the paper.

2.3 Participation in cooperative regime

Since the purpose of this paper is to identify the factors that deter or foster cooperation, this section examines how land inequality affects farmers' willingness to participate in a voluntary cooperation regime in a theoretical framework. Although noncooperation is the Nash Equilibrium in unregulated situation, cooperation can benefit resource users as a whole by internalizing all the externalities that resource users impose on each other. From the social planner's point of view, cooperation is no doubt the first best if there is no other social cost such as monitoring cost to ensure the enforcement of cooperation. However, the benefit from cooperation is not distributed evenly across resource users and the objection from certain types of users may damage the cooperation. In this section we examine how inequality and heterogeneity affect the users' willingness to join in cooperation.

Under cooperation, farmers choose their extraction efforts $\{e_i\}$ to maximize their joint profits:

$$\max_{\{e_i\}\geq 0} \sum_{i=1}^{n} [\delta(l_i) f(l_i, be_i + cE) - e_i]$$

FOC for this optimization problem:

$$\delta(l_i) f_2(l_i, be_i^* + cE^*) = \frac{1}{b+nc} \tag{3}$$

With cooperation, farmers consider the social marginal product of their extraction effort $\frac{1}{b+nc}$, rather than the private marginal product $\frac{1}{b+c}$. As $c < 0$, the former is bigger than the latter. Define $w_i^* \equiv be_i^* + cE^* = (b+c)e_i^* + cE_{-i}^*$ and $\psi(l_i)$ as the response curve of water to land input under cooperation, we have

Lemma 3: Water input under cooperation is lower than the non-cooperative equilibrium level for any farm with positive land area. The difference is bigger for larger land endowment:

a) $w_i^n > w_i^* > 0$, $e_i^n > e_i^* > 0$ for any i with $l_i > 0$;

b) $\frac{d(w_i^n - w_i^*)}{dl_i} > 0$ and $\frac{d(e_i^n - e_i^*)}{dl_i} > 0$ for any $l_i > 0$.

Proof: see Appendix 2.

When deciding whether to join the cooperation in water management, a farmer has to consider whether the net benefit from cooperation is positive:

$$\Delta\pi_i = \delta(l_i) [f(l_i, \psi(l_i)) - f(l_i, \phi(l_i))] - e_i^* + e_i^n \tag{4}$$

and it varies across farms according to:

$$\begin{aligned} \frac{d\Delta\pi_i}{dl_i} &= \delta'(l_i) [f(l_i, \psi(l_i)) - f(l_i, \phi(l_i))] + \delta(l_i) [f_1(l_i, \psi(l_i)) - f_1(l_i, \phi(l_i))] \\ &+ \delta(l_i) \left[\psi'(l_i) f_2(l_i, \psi(l_i)) - \phi'(l_i) f_2(l_i, \phi(l_i))\right] + \frac{de_i^n}{dl_i} - \frac{de_i^*}{dl_i} \end{aligned}$$

The first two terms are negative, while the third and fourth terms are positive[4]. Therefore, the sign of the derivative depends on the relative sizes of these two opposite terms.

[4] The third term is positive because $f_2^* - f_2^n = f_2^n \frac{(1-n)c}{b+nc} > 0$ increases with f_2^n which further increases with l_i (see the proof for Lemma 3 in Appendix 2).

More intuitively, we can decompose the relative benefit from cooperation into two countervailing effects: a private loss due to reduced production effort against a public gain from reduced externality. On one hand, all farms have to suffer a private loss since all farms use less water for production under cooperation, regardless of farm size. And by Lemma 3, the bigger the farm sizes, the bigger the cut in water input, and therefore the bigger private profit loss under cooperation. While on the other hand, all farmers share the same reduced externality (as externality enters production function as the total extraction efforts of all farms). Therefore, the net benefit from cooperation is bigger for small farmers, i.e., $\frac{d\Delta\pi}{dl_i} < 0$.

The effect of change in inequality on resource extraction can be written as:

$$\begin{aligned} \frac{d\triangle\pi_i}{d\sigma} &= \frac{d\triangle\pi_i}{dl_i} * \frac{dl_i}{d\sigma} + \sum_{j\neq i} \frac{d\triangle\pi_i}{dl_j} * \frac{dl_j}{d\sigma} \\ &= \frac{d\triangle\pi_i}{dl_i}\varepsilon_i + \sum_{j\neq i} \frac{d\triangle\pi_i}{dl_j}\varepsilon_j \end{aligned} \tag{5}$$

where,

$$\begin{aligned} \frac{d\Delta\pi_i}{dl_j} &= \delta(l_i)\left[\frac{d\psi(l_i)}{dl_j} f_2(l_i,\psi(l_i)) - \frac{d\phi(l_i)}{dl_j} f_2(l_i,\phi(l_i))\right] - \left(\frac{de_i^*}{dl_j} - \frac{de_i^n}{dl_j}\right) \\ &= \frac{de_i^n}{dl_j} - \frac{de_i^*}{dl_j} \\ &= -\frac{c}{b(b+cn)}\left[\phi'(l_j) - \psi'(l_j)\right] > 0 \end{aligned}$$

A mean-preserving spread of land distribution affects $i's$ net profit from cooperation through two channels: 1) through change of one's own land area ("decreasing returns to scale effect"); 2) through change of externality by the change of others' land area ("reduced negative externality effect"). An empirically interesting question that we are examining is: for a fixed land endowment l_i (for example, mean value of farm size), how does farmer's preference for collective action vary with inequality. In this case, inequality affects net profit only by changing the negative externality (i.e., the second term in Eq. (5)):

$$\frac{d\triangle\pi_i}{d\sigma}\,|_{l_i} = -\frac{c}{b(b+cn)} \sum_{j\neq i} \left[\phi'(l_j) - \psi'(l_j)\right] \varepsilon_j \,|_{l_i}$$

Therefore, the effect of inequality on one's net profit for a fixed farm size depends on the weighted sum of the change of response curves' slopes of all the other farms. As $c < 0$, $\phi'(l_i) > \psi'(l_i)$ for any $l_i > 0$, the sign of the weighted sum depends on the curvature of the response curve, i.e., $\kappa \equiv \phi''(l_i) - \psi''(l_i)$. If $\kappa < 0$, the weighted sum is negative for a fixed farm with mean land size, while it is more likely to be positive if $\kappa > 0$. Moreover, the sign of κ may vary with l_i since $\phi''(l_i)$ and $\psi''(l_i)$ have also been proved to be nonconstant by Lemma 2. As a result, the sign for the sum of the weighted slope difference is ambiguous, depending on the curvature of the difference of the two response curves.

Proposition 3: *Assume Assumption 1-5 are all satisfied,*

a) In a voting experiment for a collective action on water management, bigger farm holders are less likely to vote for the collective action as their net benefits from cooperation are smaller.

b) The effect of land distribution inequality on the net benefit of cooperation varies among farmers. For a fixed farm size at mean value, the sign of the effect of land inequality depends on the curvature of the difference of two response curves between NE and cooperative equilibrium. Higher inequality leads to bigger net profit for the mean land value if the difference of two response curves is a convex function.

So far, we have developed several theoretical predictions from the model that we can investigate in the next empirical part, which consists of two parts: First, we will examine the empirical relationship between inequality and groundwater stock change at village level; Second, we will conduct analysis on the data from choice experiment to elicit farmers' preferences for cooperation in water management and examine how inequality and heterogeneity influences farmers' preferences. Before the formal analysis, we first provide some background information about the survey area and describe the choice experiment that we have designed.

3 Empirical Analysis

Our main goal is to investigate empirically how inequality and heterogeneity affects the *outcome* of common property resource extraction and the possibility of collective action in resource management. For the first purpose, we collect the groundwater table data and land distribution data in Merguellil Valley of

Tunisia over time periods. While for the second, we design a choice experiment to ask for farmers' preferences and their willingness to pay to shift to a cooperative outcome. In the following two sections, we will first make full use of village level data on inequality to investigate its effects on the fall in the water table. Second, we will exploit the information from the choice experiment to shed light on the farmers' preferences for policy change.

3.1 Survey area

Geographical condition

Situated in North Africa, Tunisia has a typical Mediterranean climate in the North and a Saharan climate in the South. Water availability varies widely across the country and over the seasons. Since the 1970s, successive Tunisian governments have engaged in large scale investment programmes to equip the country with an extensive water infrastructure with the aim of mitigating the effects of the vagaries of the weather. Thus, no less than 29 large dams, 200 tanks, and 766 lake reservoirs, more than 3000 boreholes and 151,000 wells have been built since the 1970s (Le Goulven et al. [2009]). Nearly 80% of the country's water is consumed by the agricultural sector, which is the largest water user and has contributed vastly to rural development.

Our study area, the Merguellil river basin, is located in the central area of Tunisia. Its population was 102,600 in 1994 population census and 85% residing in the *gouvernorat* of Kairouan. Approximately 85% of the total population live in the remote rural area but this proportion is decreasing steadily given the trend of rural-to-urban migration. Located in central Tunisia, this region has not been directly impacted by the growth of tourism but it has undergone changes through its relationship with the coastal areas: labour migration, water transfers and emergence of new markets for agricultural produce, especially water consuming products such as fresh fruits and vegetables.

The large El Haouareb dam divides the river basin into two parts: a hilly region upstream and the Kairouan plain downstream. The mean annual rainfall is approximately 300 mm in the plain and increases up to 510 mm in the upper part. Rainfall varies widely in time and space, and nearly 80% of annual rainfall is produced within a period of 12 days. This occasionally causes violent floods. The sporadic and unpredictably violent surface runoff led to the construction of the El Haouareb dam in 1989. However, the dam hardly serves the main function of storage because nearly two-thirds of the outflow of the El Haouareb reservoir infiltrates into the karst aquifer while another quarter disappears through evaporation (Le Goulven et al. [2009]). Therefore groundwater becomes the major water source in the Kairouan plain. Due to the limited recharge of water released from the dam, changes in the water table levels are largely driven by pumping for irrigation purpose. Economic development, intensification of agriculture combined with a population growth have led to excessive water withdrawals from aquifers. Furthermore, the export of water from the hinterland to the coastal cities for tourism purpose, has exacerbated the problem of over-exploitation of water resources. Like in many parts of the country, the subsidization of private wells has resulted in their dramatic increase from 100 in 1960s to about 5000 in 2008 (Le Goulven et al. [2009]). As a result, the water table level has been falling relentlessly over from -42 meters in 1986 to -52 meters in 2006. It is expected to reach nearly -60 meters in the next 10 years by 2015.

Institutional evolution

Collective management of irrigation water at the tribe level was common in the region during 18th and 19th century, and dates back from the 13th century in oases (Al Atiri [2006]). Water was considered as a right by farmers and was shared equitably between the irrigation perimeters according to rules enforced initially by communities and later on from the early 20th century, enforced more formally by associations of stakeholders.[5] However, changes in social structure together with technology change introduced by French colonization imposed pressure on resource use and weakened the traditional collective management system. After independence in 1956, the Tunisian government took over the management right from the tribes and implemented policies that encouraged rural development by centralizing water management. These include building large hydraulic infrastructure and transferring water spatially from the hinterland to coastal areas, subsidizing intensive irrigation technologies and setting up water management institution from top to down. These policies have played a very important role in economic growth in Tunisia, but

[5]For instance, the *associations of oasis owners* created between 1912 and 1920, and the *associations of special interest in hydraulics* instituted in 1933 whose functions are similar to the modern Association of Collective Interest (AIC) and Group of Collective Interests (GIC) (Al Atiri [2006]).

meanwhile intensified the pressure on water demand. This has resulted in the fall of the groundwater table as well as other ecosystem degradation such as soil erosion have become major environmental problems in the region.

Since the 1970s, the development and management of public irrigation schemes was ensured by a centralized agency (*Office de Mise Valeur* or OMV) represented in each *gouvernorat*. In 1989, the OMVs were replaced by regional offices of the Department of Agriculture in charge of agricultural development in each (*Commissariats Régionaux de Développement Agricole,* CRDA). Towards the end of the 1980s, the willingness of the State to disengage from the management of the schemes was reaffirmed by the decentralization of the management of the irrigation schemes. Thus water users' associations—Association of Collective Interest (AIC) which were later in 1999 turned into Group of Collective Interests (GIC)—were created to be part of local collective management schemes. Their number increased rapidly from 100 AIC in 1987 to over 2700 GIC at the end of 2002. Among these 1100 were involved in the management of irrigation water. Thus, by late 2001 nearly 60% of irrigated public land was transferred from the CRDA to GICs (Albouchi [2006]). Over time the ambit of the GICs has extended from the maintenance and management of irrigation schemes to rural development. The evolution of these institutional arrangements reflects the state's commitment to decentralization and empowerment of water user associations. However, these associations do not seem to have the financial, technical and organizational capabilities to adequately fulfill their mission. Thus, farmers have little confidence in these institutions which are confronted with internal conflicts and tensions. Many farmers complain about the unreliable supply of the water in irrigation schemes under the management of GICs and resort to private wells whenever there is water shortage. The wells are deepened using a local manual technique (*forage à bras*) as the water table drops, without intervention of the CRDA water police because the authorties prefer to turn a blind eye to these practices and to encourage regional agricultural development. As Le Goulven et al. [2009] put it, "*The Merguellil basin provides an ideal case study to analyse the effect of the progressive establishment of water infrastructure, ..., [it] also provides the opportunity to examine the modes of governance, as well as the economic and regulatory tools which might assist in the control of access to water resources*".

3.2 Choice experiment: Design and Implementation

Design of the experiment

We design a choice experiment to elicit farmers' preferences for collective action towards achieving the stabilization of the water table level and management of the common resource in a sustainable manner. Our aim is to determine the farmers' willingness to pay to switch to a cooperative outcome that would upset the status quo. To do so, the choice experiment will focus on some of the main constraints faced by the farmers that explain their current non-cooperative behaviour. Relaxing those constraints may induce a shift in the farmers' behaviour. The extent to which current actions remain private information is clearly a major contributing factor to the current lack of coordination among farmers even within the GICs. For instance, the constant use of unlicensed wells and boreholes, and sabotage of the monitoring system through the destruction of meters are commonplace and prevent water user associations from functioning efficiently. Thus, transparency and information revelation regarding farmers' water use and defrauding behaviour, by reducing information imperfection, may be an effective pathway to foster cooperation. Measures to improve the transparency and enforcement of the system are therefore critical in any policy change. Finally, since water consumption is proportional to the total irrigated areas, imposing a constraint of irrigated lands might be useful in conserving water. After consulting Tunisian local researchers (Institut National Agronomique de Tunisie, INAT and Institut de recherche pour le développement, IRD) and local stakeholders (Ministry of the Agriculture, and the Regional Commission for Agricultural Development, CRDA of Kairouan), we selected policy attributes of interest to the farmers in Merguellil as shown in Table 1.

Table 1: Choice Experiment Attributes

Attributes	Description
Restriction on irrigated land area	Extent of land restriction in irrigation: 0%, 10%, 20%, 30%
Meter reading	Institution responsible for reading the meters: 1. Water management unit organized by Department of Agriculture 2. Local Authority
Transparency	Publicize water use, damage to meters: 1=Yes, 0=No
Installation fee	How much fee would you pay (in Tunisian Dinars per year): 0, 10, 20, 30

The first attribute pertains to the *restriction on irrigated land area.* It constitutes a straightforward and transparent method for reducing water usage. It has the advantage of being easily monitored by the neighboring farmers, and therefore a desirable attribute to control water extraction. In the empirical analysis, we will treat this variable as an ordinal categorical variable, with four dummies to denote each of the four levels: 0, 10, 20 or 30% land restriction (in real empirical framework, only three dummies will appear to achieve full-rank of variable matrix). The second attribute, *meter reading* indicates the institution the farmers would trust to be responsible for monitoring the meters and is a proxy variable for accountability. Because corruption may occur, it is important that the water users believe in the fairness of the monitoring system. This attribute is captured by a binary variable that denotes two different regimes: a new water management unit organized by department of Agriculture, and local authority. The third attribute relates to *transparency.* This attribute aims at making information regarding individual water use, fraud and sabotage public so that the system can be trusted and be less prone to free riding. It is captured by a simple binary variable, indicating whether water use information for every water user is published on a blackboard in the village every month. The fourth attribute included in the choice experiment, the *installation fee*, asks farmers how much they would be willing pay to install a water meter on the wells. This attribute allows us to estimate welfare changes in monetary term.

In combining the levels of the attributes into choice sets, orthogonality design has been used to avoid strict dominance of one alternative over the others. Careful arrangement ensures balanced distribution of attribute levels and balanced utility across alternatives. These combinations generate 64 possible choice sets. In this choice experiment, 16 out of the 64 possible choice sets were selected and separated into two groups with each consisting of eight choice sets. Table 2 shows the example of a choice set [6].

Implementation of the survey

A trial survey was carried out in a small sample of farmers in the Kairouan plain to assess the relevance of the questions and the reaction of the farmers. In May and June 2007, the actual survey of 250 farmers was conducted. The survey was carried out mainly in the downstream catchment where much of the over-exploitation of the groundwater takes place, with a few surveyed villages located upstream. Each farmer has to fill 8 choice sets. During the implementation of the survey, the enumerator carefully explained the policy attributes and how to make choices: this was done to avoid any misunderstanding given the low literacy levels among farmers.

In addition, the enumerators provided the respondents with information on the current state of the water table and its likely future negative evolution should the current rate of water extraction continue. The government's intentions were explained in the following paragraph:*'In order to stabilize the groundwater table at the current level, the government is designing a policy to encourage people to reduce water use. In order to do this, the government plans to charge groundwater use by metering. The Department of Agriculture will institute a water management unit throughout the Merguellil Valley. It will install water meters for all the wells in the the gouvernorat of Kairouan (Merguellil Valley) and will charge groundwater use based on the volume used. The volumetric price will be the same as in the public irrigation scheme.'* To prevent strategic voting, respondents are informed that "*the majority rule would be applied on the final voting outcome. i.e., if more than half of the people in the village vote for policy change, the new water management association will*

[6]The full version of the questionnaires are attached in appendix.

Table 2: Choice Set Example

	Restriction on land area to be irrigated	Who reads the Meter	Transparency	Installation Fee (TD/year)	Tick the Policy you Prefer
Policy A	20% of land is not to be irrigated	Water Management Unit	Not Public	20	☐
Policy B	No restriction	Water Management Unit	Water use and damage of meter made public to all farmers every month	30	☐
Policy C	I would like to keep the status quo and don't vote for the new policy AND WATER TABLE WILL KEEP FALLING				☐

be formed and collective action will be taken."

In addition to the choice experiment, the survey also includes sections on 1) socio-economic and demographic characteristics; 2) cultivation and irrigation information; and 3) information about the farmers' attitudes towards the environment and the use of water in the region, to gain an understanding of how personal beliefs shape users' attitudes towards policy. The information collected in these sections is required to control for heterogeneity among farmers and investigate the effect of such heterogeneity on preferences.

A supplementary village survey was conducted in all the sample villages in December 2010 and January 2011 in order to better capture the heterogeneous circumstances faced by farmers in the Merguellil. Village level data pertaining to the water table change since 1990 was collected. We also collected information on the distribution of farm land and the distribution of well depths for the year 2007. This information allows us to examine the effect of inequality within each village on the farmers' behaviour. A map of the sampled villages is attached in Figure (A1) in appendix. The villages in the West and North West of El Haouareb Dam are located in the upstream part of the aquifer. These include villages in the town of Hafouz and some villages in the town of Chebika. The distance of each village to the dam is also collected.

3.3 Choice experiment: Model specification

We specify three different choice models: multinomial logit, conditional logit and mixed logit. While multinomial logit model is a standard limited dependent variable model, conditional logit model is used to control for individual's fixed effects as each respondent completes 8 choice sets. However, both multinomial logit and conditional logit are subject to the assumption of independence from irrelevant alternatives (IIA) which may be violated either due to nested choices or unobserved variables. The IIA assumption postulates that the odds between two alternatives is independent of the change in an third alternative. Put differently, this assumption predicts "that a change in the attributes of one alternative changes the probabilities of the other alternatives proportionately" (Train [1998]). Moreover, it is reasonable to believe that different individuals may have different preferences on those attributes. Mixed logit is a highly flexible model that obviates these limitations of standard logit models by allowing for unrestricted substitution patterns, correlation in unobserved factors and random taste variation (Train [2003]). Instead of constant coefficients in utility function, it assumes coefficients vary randomly over individuals representing each individual's tastes.

$$U_{nj} = \alpha Z_n + \beta_n' X_{nj} + \varepsilon_{nj} \tag{6}$$

where, Z_n are observed individual n's characteristics, X_{nj} are choice j's attributes, β_n is a vector of unobserved coefficients assumed to vary across individuals according to some distribution; ε_{nj} is an unobserved random term that is identically and independently distributed extreme value, independent of α, β, X, and Z.

In this model, the probability of individual n chooses choice j is:

$$P_{nj} = \int \left(\frac{e^{\beta_n' x_{nj}}}{\sum_k e^{\beta_n' x_{nk}}} \right) f(\beta) d\beta$$

In words, the mixed logit probability is a weighted average of the logit formula evaluated at different values of β, with the weights given by the density $f(\beta)$ (Train [2003]). We will estimate the mixed logit model assuming the variables coefficients have normal distribution.

We will first analyse how policy attributes alone affect farmers' choice. Then, we will control for farmers' individual characteristics, i.e. variables Z_n in equation (6). As the logit model identifies only through within-group (choice set) variation, it is necessary to interact Z_n with alternative specific constant (ASC) in the model to account for preference heterogeneity that can be explained by observed factors.

4 Empirical results

4.1 Data description and inequality measurement

Our final data consists of a sample of 246 households living in 28 villages in the Merguellil Valley. We focus mostly on farmers outside the public irrigation perimeters located in Chebika, Kairouan and El Batan since they rely almost exclusively on private wells as their source of water supply. The mean age of the farmers in our sample is 40 years. All respondents except one are men.

Most respondents (nearly 75%) did not study beyond primary school.

Regarding farm characteristics, the average farmer cultivates seven hectares equipped with one private well or borehole. It is interesting to note that the average well is 45 meters deep (with a standard deviation of 9m) which is still below the authorized depth of wells.[7] If this figure is reliable then it may imply that the regulation limiting the depth of wells is too liberal and is not suitable to address the current over-exploitation even if it was enforced. The water table level decreased by 18m on average between 1990 and 2007. However, the fall in the water table between 2007 and 2011 is captured by a categorical variable. Indeed, although our question asked specifically the levels of the water in 2007 and the current level, the respondents' (here the village leaders) answers were very vague such that the fall in the water table appears in only three levels: 5m, 10m, 15m.[8] We therefore recode the continuous water table fall data into three categories and treat it as a three-level ordered categorical variable: 1 denotes *expected reasonable decrease in the water table* (5m); 2 denotes *fast decrease* in the water table (10m); and 3 represents *very fast decrease* in the water table (15m). Irrigation technologies are also fairly widely spread in the regions: for instance 75% of farmers use drip irrigation and 40% use sprinklers. The summary statistics of the survey data is listed in Table (A1) in appendix.

The information collected on land distribution within each village allows us to measure inequality within village. We also measure a similar inequality indicator based on well depth. As the data on land distribution are grouped observations[9], we measure land distribution inequality based on the method proposed by Kakwani and Podder [1976]. In particular, we estimate parametrically the Lorenz curve using the grouped observations by assuming the following specification $\eta = a\pi^{\alpha}(\sqrt{2}-\pi)^{\beta}$, and calculate the Gini concentration

[7]Tunisian law regulates groundwater extraction by restricting the depth of private wells. Wells with less than 50 meters can be dug without authorization, while wells with depth beyond 50 meters require authorization from the Minister of Agriculture who sets a limit on the the depth and speed of the flow. Sometimes payment is required if the use of such well is not considered as being in the public interest.

[8]Note that the mean water table fall is 6.5m between 2007 and 2011.

[9]More specifically, the data show the number of farms in a village with farm land in each of following categories: 0-2 hectares; 2-4 hectares; 4-6 hectares; 6-10 hectares; 10-20 hectares; 20-50 hectares and over 50 hectares.

ratio as:

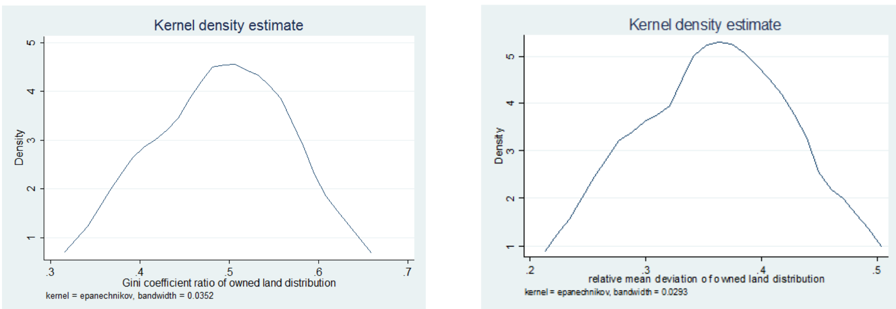
$$
\begin{aligned}
CR &= 2\int_0^{\sqrt{2}} f(\pi)d\pi \\
&= 2a(\sqrt{2})^{1+\alpha+\beta}B(1+\alpha,1+\beta) \qquad (7)
\end{aligned}
$$

where, $B(1+\alpha,1+\beta)$ is the Beta function. For the purpose of comparison, we also estimate the relative mean deviation which is defined as:

$$
\begin{aligned}
T &= \frac{1}{2\mu}\frac{1}{N}\sum_{i=1}^{N}|x_i-\mu| \\
&= (\sqrt{2})^{1+\alpha+\beta}\frac{a\alpha^{\alpha}\beta^{\beta}}{(\alpha+\beta)^{\alpha+\beta}} \qquad (8)
\end{aligned}
$$

where, the second equation represents the empirical estimated Lorenz curve above[10].

The inequality measurements are shown in Figure 1. The left panel shows the distribution of the Gini concentration ratio while the right panel shows the distribution of the relative mean deviation. Both measurements show a large variation of land inequality level across villages.



(a) Geni coefficients

(b) Relative Mean Deviation

Figure 1: Inequality of land distribution within village

We also measure the inequality of well depths for each village based on individual well's depth (Figure 2). Except for an outlier, the distribution of relative mean deviation of well depths across villages is more homogenous than land distribution and is mostly centered around 0.1-0.2.

[10] A brief introduction of this method is included in Appendix. Please refer to Kakwani and Podder (1976) for details of this method.

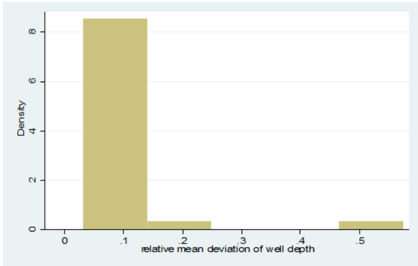
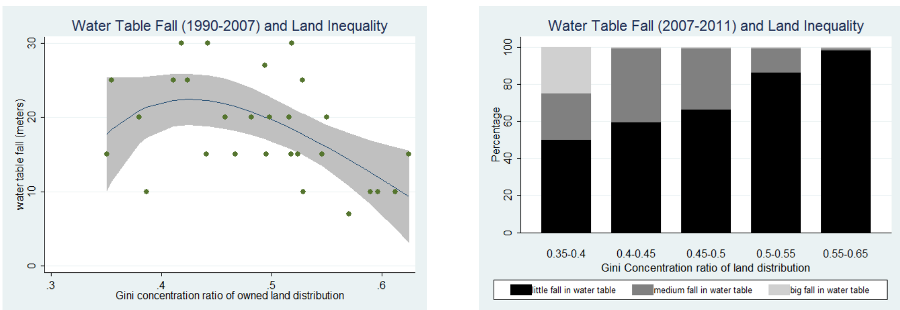


Figure 2: Inequality of well depths distribution within village

4.2 The effect of inequality in land distribution on water resource exploitation

As discussed earlier, there are disagreements in the theoretical literature regarding the effect of inequality on common property resource conservation. The paper does not attempt to settle the disagreement, but rather attempts to contribute to the discussion by providing an empirical analysis using evidence from Tunisia. We are interested in investigating the extent to which inequality in land distribution and in well depth determines the variation in the water table across villages. Given a very small sample size for village level inequality data (28 villages), this section is more of the nature of a ”stylised fact” than an econometric analysis. For this purpose, we first show a nonparametric analysis of the relationship between water table fall and land inequality in Figure 3.



(a) (b)

Figure 3: Water Table Fall and Land Inequality

Panel (a) depicts the scatterplot of water table fall during 1990-2007 against Gini coefficient of land inequality, with a fractional polynomial curve, which shows water table fall during 1990-2007 has a U-shaped relationship with Gini coefficient. This pattern echoes the theoretical inverted U-shaped relationship between groundwater exploitation and inequality (Dayton-Johnson and

Bardhan [2002], Aggarwal and Narayan [2004]), i.e. extreme equality or extreme inequality is good for groundwater conservation, while median inequality accelerates groundwater extraction. Similarly, Panel (b) shows the stacked histogram of water table fall categories during 2007-2011 by Gini coefficient groups: as Gini coefficient increases, it's more likely that water table falls less.

To complement with the nonparametric analysis, we also run a parametric regression of water use against land inequality according to the following specification:

$$\ln(\Delta Water\ Table)_i = \beta_1 CR_i + \beta_2 CR_i^2 + \beta_3 T_i^{well} + \alpha X_i + \varepsilon_i \quad (9)$$

where, the dependent variable measures the fall in the water table level (log). The right hand side variables include the inequality measurements of land and well depths, as well as other relevant village characteristics.

The first four columns in Table 3 show the OLS estimation of the effect of the determinants on the fall in water table levels from 1990 to 2007. The coefficient of Gini concentration ratio is consistently positive and statistically significant (at the 5% or 10% level depending on the specification) while its square term is negative and significant. The turning point of land inequality is around 0.44-0.47, just below the median point at 0.50. This result echoes the theoretical inverted U-shaped relationship between groundwater exploitation and inequality (Aggarwal and Narayan [2004]), i.e. extreme equality or extreme inequality is good for groundwater conservation, while median inequality accelerates groundwater extraction. The result remains qualitatively identical when inequality is measured by relative mean deviation (column 2). Moreover, there is no evidence that inequality in well depths contributes to water table fall in a similar manner as land inequality (column 3 - 4) unless we control for inequality in land distribution as well (column 5-6). The effect is more significant especially after we remove the outlier in the distribution of relative mean deviation of well depths. However, as mean deviation of well depth is mostly distributed around 0.1-0.2, the turning point for the U-shape of well depth inequality (around 2.8) is too far on the right of the distribution to be plausible. Therefore we remove the quadratic term in regression and find land inequality remains significant inverted U-shape relationship with watertable fall from 1990 to 2007 (column 7). To our surprise, neither the number of farms nor the area of farmland has effect on the fall of groundwater table, after controlling for the land inequality measures.

Notwithstanding these appealing results, the above regressions may suffer from *endogeneity* because our inequality measures (land and well depth) are based on 2007 data while the data on the change in the water table level pertains to the period 1990-2007. It is natural to think that farmers would respond to the fall in the water table by digging deeper wells. As a result, inequality in well depth may be affected by the fall in the water table. On the other hand, the critical situation of the water resources in general and the water table level in particular may also have impact upon the land inequality. For instance, although land is usually transferred through inheritance, there are also a number of cases where farms are sold to relatively wealthy outsiders (especially civil servants and executives) who are able and willing to invest in agriculture[11]. This recent dynamic is made more salient by the critical water situation. However, we can hardly find any instruments for the endogenous variables. To circumvent the endogeneity problem, we estimate equation (9) using the change in the water table level between 2007 and 2011 as the dependent variable. We estimate this model using an ordered logit model because as we explained earlier, the responses provided by the farmers have only three which we recoded into a categorical variable. To avoid multicollinearity, we do not include the quadratic term. The results are shown in column (8)-(14). We find that higher inequality in land distribution is associated with a diminished decrease in the water table after attempting to circumvent endogeneity. These results suggest that inequality seems to facilitate water conservation. More specifically, we calculate the odds-ratio using the coefficients in the table, and find that if a village's Gini concentration ratio of land distribution decreases by 0.01, the odds of a *fast decrease* in the water table versus an *expected reasonable decrease* are 1.25, holding everything constant. Likewise, the odds of a *very fast decrease* in the water table versus a *fast decrease* are 1.25, ceteris paribus. The coefficient of well depth remains insignificant in most specifications. As *downstream* is highly correlated with limited dependent variable, we remove it from the regressions. The *distance downstream* shows significantly positive impact on groundwater table fall, i.e., villages located further downstream experienced more serious fall in groundwater table, indicating the externality across villages.

[11]Personal correspondence with Tunisia environmental department officer

Table 3: The Effect of Inequality on Groundwater Table Fall

	water table fall from 1990 to 2007 (log)							water table fall from 2007 to 2011						
	OLS							ordered logit						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Land Gini Concentration	29.783 **				25.400 *	17.151	24.648 *	-22.175 *	-22.246 **				-23.567 *	-22.57 *
ratio	(12.340)				(13.262)	(12.025)	(13.118)	(12.642)	(10.119)				(12.569)	(12.134)
Land Gini Concentration	-31.922 **				-27.825 **	-20.452	-27.084 **							
ratio (sq)	(12.312)				(13.130)	(11.827)	(12.988)							
Relative Mean Deviation		26.032 **								-24.914 **				
of land distribution		(11.733)								(11.454)				
Relative Mean Deviation		-38.487 **												
of land distribution (sq)		(15.811)												
Relative Mean Deviation			-5.119	14.037	-3.663	18.705 **	-3.545				31.316	63.389 *	21.919	59.696
of well dpeth distribution			(4.755)	(11.254)	(4.176)	(9.453)	(2.717)				(20.216)	(36.884)	(20.283)	(37.299)
Relative Mean Deviation			7.013	-83.776	4.262	-103.886 ***								
of well depth distribution (sq)			(8.683)	(49.592)	(7.583)	(42.680)								
downstream	-0.496	-0.438	-0.319	-0.427	-0.420	-0.405	-0.382							
	(0.322)	(0.316)	(0.350)	(0.335)	(0.348)	(0.304)	(0.343)							
downstream*distance	0.002	0.001	-0.002	-0.002	0.002	0.004	0.002	0.1229 *	0.101 *	0.0986 *	0.0706	0.0627	0.140 **	0.131 *
	(0.007)	(0.007)	(0.009)	(0.008)	(0.008)	(0.007)	(0.007)	(0.065)	(0.052)	(0.052)	(0.051)	(0.054)	(0.067)	(0.068)
number of farms in	-0.00040	-0.00040	-0.00008	-0.00020	-0.00037	-0.00066	-0.00028	0.00567			0.01203 **	0.00833	0.00544 *	0.00194
village	(0.00036)	(0.00036)	(0.00054)	(0.00051)	(0.00051)	(0.00046)	(0.00049)	(0.00443)			(0.00537)	(0.00582)	(0.003)	(0.003)
total farm land area	0.00002	0.00002	0.00002	0.00002	0.00002	0.00004	0.00002	-0.00042			-0.00094	-0.00071		
	(0.00004)	(0.00004)	(0.00005)	(0.00004)	(0.00004)	(0.00004)	(0.00004)	(0.00061)			(0.00057)	(0.00059)		
percent of farms within	0.728 *	0.654	0.792	1.776 *	1.052	2.265	0.996	2.720	2.558	2.674	-10.283	-9.220	-6.503	-3.003
public irrigation scheme	(0.402)	(0.393)	(0.923)	(1.020)	(0.806)	(0.848)	(0.755)	(2.227)	(2.160)	(2.148)	(9.223)	(10.603)	(9.268)	(10.919)
constant	-3.506	-1.001	3.376 ***	2.672 ***	-2.235	-0.941	-2.080							
	(2.928)	(2.019)	(0.328)	(0.489)	(3.220)	(2.859)	(3.183)							
N	28	28	28	27	28	27	27	28	28	28	28	27	28	27
Prob > F	0.044	0.052	0.408	0.209	0.088	0.017	0.067	-11.572	-13.278	-13.328	-11.462	-9.969	-10.950	-8.655
adjusted R-sq	0.477	0.293	0.022	0.130	0.266	0.441	0.288	0.015	0.014	0.014	0.014	0.015	0.009	0.005

The evidence in this section shows that village level inequality in land distribution has a positive effect on groundwater resource conservation in our sample villages, although we are not quite sure about the U-shaped relationship due to small sample size (hence poor inference). Inequality in well depth, however, may accelerate water extraction, probably due to fierce competition among water users. The particular geological condition in Merguellil plain facilitates this possibility. Villages further downstream from the dam also face higher water table fall, as the dam and upper stream users reduce the overflow of water from upstream.

4.3 Choice experiment: Estimation results

We have analyzed the effect of land inequality on common property resource conservation in the previous section. While from a policy perspective, land redistribution is an unlikely policy tool for water conservation. Instead, to avoid the tragedy of the commons, the removal of hurdles that impede cooperation among water users appears to be a more practical and appealing alternative. For this purpose, we design a choice experiment to find out whether farmers prefer collective water conservation and if yes, what other institutional design has impeded them from engaging in collective action. This section shows the results of choice experiment.

Table 4 presents the results of the various choice models controlling only for the choice sets attributes: That is, we estimate the probability of choosing a particular management policy as a function of the attributes of the policy and the alternative specific constant (ASC) alone, ignoring the heterogeneity of respondents. The ASC takes value 1 for either of the policy options A and B, and equals 0 for the 'status quo' option. The first two columns are the results from multinomial logit and conditional logit regressions separately, while column (3)-(5) present the mixed logit results where some policy attributes coefficients are treated as random coefficients. Furthermore correlation between random coefficients are allowed in Column (6). We summarize the main results from Table 4 as follows: *(i)* The positive ASC coefficients in all columns indicate that on average farmers have positive willingness to pay for the watermeter, henceforth are willing to engage in collective action to achieve groundwater conservation. *(ii)* Farmers are indifferent to restrictions on irrigated land that do not exceed 10%. They are weakly against a 20% land restriction but strongly oppose restrictions of 30% and above. As a matter of fact, fallowing is a common practice in the Merguellil valley, and irrigated land restriction of less than 20% does not affect the agriculture production much. Beyond this level, however, such restriction becomes a binding constraint. Although, from the perspective of water management, land restriction is a straightforward policy instrument with low monitoring cost, it may face strong opposition from farmers. *(iii)* Throughout all specifications, farmers express a preference for a transparent regime which makes private information on individual water use public to all users. As mentioned in the last section, "water stealing" by digging well deeper or damaging water meter is common under current water management scheme. Demand for information and transparency reveals that hidden action leads to exploitation competition among farmers and damages the potential of cooperative use of groundwater. *(iv)* Moreover, the positive and significant coefficient of the *meterreading* variable shows that farmers prefer the new arrangement to be monitored (reading water meter and collecting fees) by local government to the elected GIC leader. This result is consistent with the story that farmers mistrust the current existing structures of the GICs which are often seen as accomplices with some vested interests, by indulging themselves in private dealing with some farmers to the detriment of the general interests. Although during the survey we emphasized the fact that our experiment intends to design a a new regime organized by the central department of agriculture, the similarity of the denomination of institution used in the survey (Water user association and GIC) seem no different to farmers who draw inference from past experience. Thus, outsiders tend to be considered as more neutral and therefore preferred by many farmers[12].

Considering the possibility that different farmers may have different degree of preferences over transparency and accountability, we estimate the model in mixed logit specifications and results are presented in Column (3)-(6), where the coefficients for these two variables are assumed random and normally distributed. Farmers' preferences for land restriction are assumed to be homogeneous across farmers as fallowing is a common practice in the whole region. In other words land restriction is not characterized by random coefficients in our analysis. In Column (3) and (4), we allow only one random parameter for either *transparency* or *meterreading* separately in each specification. The average coefficient for each variable remains the same sign as in the multinomial or conditional logit model. In Column (3), the average coefficient for variable

[12]This point is also confirmed by the Tunisian environment officials.

Table 4: Choice Experiment Results without individual characteristics

	(1) multinomial logit	(2) conditional logit	(3) mixed logit	(4) mixed logit	(5) mixed logit	(6) mixed logit
ASC	-0.350 ***	1.207 ***	1.328 ***	1.330 ***	1.545 ***	1.620 ***
	(0.123)	(0.112)	(0.124)	(0.119)	(0.133)	(0.134)
irrigated land restriction 10%	0.032	-0.067	-0.002	-0.138	-0.071	-0.027
	(0.121)	(0.079)	(0.089)	(0.088)	(0.098)	(0.096)
Irrigated land restriction 20%	0.040	-0.063	-0.152	-0.113	-0.227 **	-0.225 **
	(0.135)	(0.094)	(0.106)	(0.098)	(0.110)	(0.110)
irrigated land restriction 30%	-0.422 ***	-0.396 ***	-0.704 ***	-0.465 ***	-0.812 ***	-0.837 ***
	(0.173)	(0.086)	(0.107)	(0.092)	(0.116)	(0.115)
meter reading by local authority	0.167 ***	0.149 **	0.265 ***	0.093	0.172	0.193 *
	(0.084)	(0.064)	(0.074)	(0.109)	(0.116)	(0.115)
transparency	0.298 ***	0.246 ***	0.307 **	0.305 ***	0.316 **	0.354 **
	(0.100)	(0.062)	(0.149)	(0.067)	(0.154)	(0.160)
fee	-0.005 **	-0.008 **	-0.006	-0.010 **	-0.009 *	-0.009 **
	(0.002)	(0.004)	(0.005)	(0.004)	(0.005)	(0.005)
Standard Deviation of Random Coefficient						
meter reading by local authority				1.275 ***	1.274 ***	1.287 ***
				(0.118)	(0.125)	(0.128)
transparency			1.930 ***		2.063 ***	1.486 ***
			(0.157)		(0.174)	(0.196)
Correlation between coefficients						
corr(meterreading,transparency)						1.464 ***
						(0.215)
N	5736	5736	5736	5736	5736	5736
Prob > LR χ^2	0.000	0.000	0.000	0.000	0.000	0.000
log likelihood	-3910.119	-1881.360	-1732.209	-1819.071	-1686.891	-1667.561

transparency is 0.307, slightly higher than the one if assumed constant. The standard deviation of this coefficient is statistically significant, implying a large variation of this coefficient across the population. By normal distribution, we can calculate that 56.3% of farmers have positive coefficients for this variable. That is to say, a weak majority of farmers prefer transparent management. Likewise, Column (4) presents result of mixed logit model assuming the coefficient for *meterreading* is a random parameter. The average coefficient of this variable becomes statistically insignificant when heterogeneity is allowed. The standard deviation is large and significant indicating wide variation in water users' preference for this policy attribute. This result is preserved when both *meterreading* and *transparency* are treated as random but uncorrelated coefficients in Column (5). Nevertheless, if we allow both coefficients be correlated (Column (6)), the average coefficient on *meterreading* turns bigger and significant at 10%, with 56% of respondents indicating preference for local authority. Moreover, the positive correlation between two coefficients suggests that those who prefer transparency also prefer outsiders (in this case local authority instead of GIC leader) to monitor the new system. This result again reconciles our former discussion about the current GIC management.

Based on results in column (6) in Table 4, we can calculate farmers' willingness to pay for the new transparent although more restrictive system in terms of water consumption. On average, farmers are willing to pay 172 Tunisian Dinar (TD) to shift to the new regime, which aims to enforce cooperative use of water and stabilize groundwater table. They are also going to reduce their contribution by TD 89 if more than 30% of land is prohibited from irrigation relative to the non-restrictive scenario. Farmers are on average willing to pay additional TD 38 for a transparent regime, although there are about 40% of respondents who prefer not publishing water user's information and not knowing other users' use. Moreover, on average farmers are willing to pay TD 20.5 for local authority to take accountability, ceteris paribus.

So far we have known farmers' preferences for policy change. Nevertheless, the above discussion doesn't take account of the heterogeneity across villages and farmers. This concern takes us to Table 5, in which we include all the other observed and unobserved heterogeneity at village and individual level in the choice models. The specifications are similar to Table 4, including a multinomial logit model (Column (1)) and various mixed logit model specifications (Column (2)-(5)) . Column (2)-(4) have similar specifications except the variables that are assumed to have random coefficients. As both standard deviations and correlation between random coefficients are significant, we consider the specification presented in Column (4) as a better fit than the former two and henceforth only discuss its result here. Besides the finding that the policy attributes have qualitatively the same effects on farmers' choice as in Table 4, we also observe the following interesting results :

First, although the number of farms within village has little effect, land inequality does have impact on farmers' preferences. We assume a nonlinear effect which also interacts with land value. We find farmers from villages with higher land inequality are more willing to engage in collective action and pay for a water conservation regime. According to the results in Column (4), the marginal effect of land Gini coefficient at mean (log) land value and mean Gini-coefficient on willingness to pay for the policy change is 4.61[13] , meaning as land Gini coefficient increases by 0.1 unit (mean preserving) from the mean value, i.e., from 0.49 to 0.59, the probability of mean land value holder to opt for the new policy increases by 46.1%.

Second, rich farmers (with greater proportion of irrigated land and higher land value)[14] tend to be more reluctant to a policy change. This can be seen from the negative marginal coefficient on *log(landvalue)*, which is -0.628 at mean value of land Gini coefficient (since the marginal effect has the same sign as the marginal coefficient). In addition, the negative coefficient of the interaction term between *transparency* and *log(landvalue)* reveals that richer farmers dislike transparency, although on average farmers prefer transparency. This finding confirms the usual assumption that rich farmers are the beneficiaries of the current water management scheme.

Third, education has a positive effect on farmers' willingness to pay for water conservation action. Compared to the illiterate counterparts, farmers with primary school education qualification are more willing to vote for the policy change, although even higher education doesn't show higher effect. Interest-

[13]The marginal effect in logit model is calculated as $f(\beta X)\beta = \frac{exp(\beta X)}{1+exp(\beta X)}\beta = \frac{exp((-156.894+2*122.444*0.4900227+4.114*10.18511)*0.4900227)}{1+exp((-156.894+2*122.444*0.4900227+4.114*10.18511)*0.4900227)} * (-156.894 + 2 * 122.444 * 0.4900227 + 4.114 * 10.18511) = 4.61$.

[14]Usually those growing olive trees and other water demanding crops such as water melon, tomatoes, etc.

ingly, farmers' environmental awareness and concern show positive impact [15]. However, only the concern of water scarcity in the aquifer (indicated by Factor 1) is not enough for one to make change, but the awareness of externality makes difference. We find those who are more aware of the externality of own's action on other people are more likely to opt for the new policy which may improve water management.

Fourth, as expected, farmers living in villages downstream are more keen to stabilize groundwater table as they tend to be particularly harmed by the water use of farmers living upstream, although further downstream does not necessarily mean higher demand for a groundwater conservation policy[16].

Finally, we also find farmers who have experienced a greater fall in the water table fall since 1990 are more likely to vote for a cooperative management of the resource.

By now, we should point out that the specifications through Column (2)-(4) may suffer from endogeneity bias caused by the fact that water table fall from 1990-2007 is also an outcome variable that may be determined by unobserved village level characteristics. These village characteristics may for example reflect the coordination tradition in the village, or other social connection among villagers, which could also affect villagers' preferences for policy change. To account for these possible unobserved characteristics, we include two new variables "*villagers' coordination in village ceremony*" and "*villagers' coordination in maintenance of mosque*" in the last column. These two variables reflect the coordination degree in traditional or religious activities and are evaluated by the village leader. They are included as an effort to proxy for omitted variable

[15] We asked five questions in the villager survey about farmers' general attitude towards water conservation in the region in the form of score of importance. These scores are then integrated into two factors using factor analysis.Factor 1 shows one's awareness of water scarcity in the local aquifer, factor 2 indicates one's awareness of externality of self's water use on the others. Lower scores indicate a higher degree of environmental awareness.

[16] This result seems puzzling. While it may not be if we realize that the degree of land inequality is positively correlated with the distance to the dam downstream. In a regression of land inequality level (not included in the current paper) on binary variable *downstream* and interaction term $downstream * distancetothedam$, we find both coefficients are significantly positive. This fact may be resulted from the local landscape and its unique geological environment. As land inequality has positive effect on villagers' preference on water conservation, downstream distance may work through the same mechanism. Here, we treat land inequality as an exogenous variable which is formed by geology and in history, we don't assume it be correlated with other unobservables which also affect people's preference on collective action.

Table 5: Choice Experiment Results with individual characteristics

	(1) multinomial logit	(2) mixed logit	(3) mixed logit	(4) mixed logit	(5) mixed logit
Attributes and interactions					
ASC	1.547 ***	40.560 ***	48.366 ***	50.585 ***	11.441 **
	(0.279)	(10.708)	(11.553)	(11.815)	(9.490)
Irrigated land restriction 10%	-0.001	-0.069	-0.132	-0.096	-0.097
	(0.125)	(0.093)	(0.102)	(0.100)	(0.101)
Irrigated land restriction 20%	-0.036	-0.205 *	-0.267 **	-0.260 **	-0.260 **
	(0.140)	(0.110)	(0.115)	(0.114)	(0.115)
Irrigated land restriction 30%	-0.469 ***	-0.698 ***	-0.794 ***	-0.825 ***	-0.824 ***
	(0.181)	(0.112)	(0.121)	(0.121)	(0.121)
meter reading by local authority	0.193 **	0.240 ***	0.140	0.110	0.120
	(0.088)	(0.077)	(0.119)	(0.118)	(0.119)
transparency	0.308 ***	0.326 **	2.946 **	2.765 **	2.800 **
	(0.105)	(0.149)	(1.322)	(1.201)	(1.195)
transparency*log(landvalue)			-0.250 **	-0.241 **	-0.243 **
			(0.128)	(0.117)	(0.117)
fee	-0.003	-0.007	-0.009 *	-0.009 *	-0.008 *
	(0.002)	(0.005)	(0.005)	(0.005)	(0.005)
Inividual Characteristics					
Number of farms in the village	-3.86E-005	-0.001	-0.001	-0.001	-0.003 ***
	(0.00004)	(0.00039)	(0.00044)	(0.00046)	(0.00074)
Land Gini Concentration ratio	-4.776 ***	-123.158 ***	-151.030 ***	-156.894 ***	-35.590 **
	(1.565)	(37.266)	(40.358)	(41.268)	(17.625)
Land Gini Concentration ratio (sq)	1.729	96.164 ***	119.690 ***	122.444 ***	
	(2.634)	(36.507)	(39.391)	(40.306)	
Relative Mean Deviation of well depth dist'n	-0.157	-1.148	-1.547	-1.697	0.041
	(0.107)	(1.594)	(1.705)	(1.736)	(1.562)
% irrigated land	0.036	-0.754	-0.898 *	-0.910	-0.770
	(0.048)	(0.512)	(0.558)	(0.590)	(0.603)
land value (log)	-0.137 ***	-2.232 ***	-2.475 ***	-2.645 ***	-2.388 ***
	(0.044)	(0.729)	(0.774)	(0.798)	(0.790)
Land Gini concentration ratio.*(log)landvalue	0.283 ***	3.229 **	3.769 **	4.114 **	3.590 **
	(0.097)	(1.486)	(1.570)	(1.618)	(1.608)
factor 1 of environment concern score	-0.033	-0.147	-0.218	-0.248	-0.290 *
	(0.092)	(0.159)	(0.168)	(0.177)	(0.180)
factor 2 of environment concern score	-0.181 **	-0.477 **	-0.433 ***	-0.423 ***	-0.503 ***
	(0.078)	(0.116)	(0.123)	(0.131)	(0.134)
Education-primary school	-0.036	1.033 ***	1.161 ***	1.154 ***	1.144 ***
	(0.035)	(0.230)	(0.245)	(0.254)	(0.251)
Education-secondary school and above	-0.024	0.274	0.428	0.394	0.371
	(0.037)	(0.246)	(0.270)	(0.279)	(0.288)
downstream	0.030	2.612 ***	2.660 ***	2.732 ***	2.190 ***
	(0.053)	(0.493)	(0.534)	(0.547)	(0.544)
downstream*distance to the dam	0.001	-0.019 *	-0.014	-0.015	0.006
	(0.001)	(0.010)	(0.011)	(0.012)	(0.012)
(log) watertable fall 1990-2007 (m)	0.005	1.228 ***	1.262 ***	1.292 ***	2.475 ***
	(0.035)	(0.369)	(0.400)	(0.416)	(0.575)
coordination degree in village ceremony					3.078 ***
					(0.631)
coordination degree in mosque maintanance					0.095 **
					(0.352)
Standard Deviation of Random Coefficient					
meter reading by local authority			1.257 ***	1.233 ***	1.246 ***
			(0.139)	(0.135)	(0.136)
transparency		1.872 ***	1.967 ***	1.608 ***	1.601 ***
		(0.159)	(0.171)	(0.241)	(0.240)
Correlation between coefficients					
cov(meterreading-local,transparency)				1.185 ***	1.173 ***
				(0.252)	(0.260)
N	5,424	5,424	5,424	5,424	5,424
LR χ^2		247.54	315.33	342.9	343.28
Log likelihood (pseudo in mlogit)	-3143.814	-1520.28	-1485.33	-1471.54	-1454.92

in the previous regressions. The coefficients on both variables are surprisingly highly significant and positive, implying that these two variables have at least partly captured the omitted villages' fixed effect that have influenced villagers' policy preference. Under this new specification, the impact of land Gini coefficient turns less significant. To avoid multi-collinearity, we remove its quadratic term in the regression. As a result, the marginal effect of Gini coefficient on the probability of a farmer who has mean level of land value and is in a village with mean Gini coefficient to vote for policy change reduces to 0.60 [17], i.e. for 0.1 unit increase in land Gini coefficient from the mean value (0.49), the probability of voting for policy change for a farmer with mean land value increases by merely 6%. Moreover, the demand for transparency keeps consistently high. The average willingness to pay for a regime especially with transparency varies from TD -40 for the highest land value holder to TD 112.5 for the lowest land value holder, with the medium land value holder's willingness to pay at TD 33.6.

In summary, the result from choice experiment shows majority of farmers are willing to pay a significant amount of money for a transparent collective water management system with neutral agent accountable for the management. This result on the other hand reveals the main obstacles that impede the formation of cooperation under current institution are asymmetric information and lack of monitoring. Although such information problems arise from high transaction costs of collecting and conveying data regarding the status of the resource being exploited (Libecap [2008]), our experiment shows, on average farmers are willing to pay for the transaction cost in order to implement a cooperative water management regime. Moreover, installing water meter and a "name and shame" policy by publishing water use information once a month offers a practical policy alternative at a reasonable low cost.

5 Discussion and Conclusion

A major priority for Tunisian water managers in the Merguellil Valley is to find ways to stop the continuous decline of the water table. This issue is important because of the economic and environmental consequences of such decline. The main cause of this depletion of the groundwater, the over-exploitation of

[17] The marginal effect is calculated as: $f(\beta X)\beta = \frac{exp(\beta X)}{1+exp(\beta X)}\beta = \frac{exp((-35.590+3.590*10.18511)*.4900227)}{1+exp((-35.590+3.590*10.18511)*.4900227)} * (-35.590 + 3.590 * 10.18511) = .60145887$

the aquifer due to the multiplication of unlicensed wells and boreholes, is well known. Despite the existence of a legislation regulating drilling of boreholes and wells, the authorities are reluctant to enforce the law for both economic and social reasons. Nonetheless, managing the groundwater has become imperative if irreversible damages are to be prevented. To provide a better understanding of the farmers' likely attitudes towards policy changes designed to stabilize the water table level, a policy choice experiment has been used. The present experiment seeks to elicit farmers' willingness to pay to shift from the current status quo regime where the groundwater is being over-exploited to a regime that ensures a sustainable management of the groundwater.

Undoubtedly, this new regime will be costly to the farmers because that under the new policy 1) groundwater will be no longer free; 2) meters will be installed in each farm and institutions monitoring closely water use as well as potential defrauding behavior will be implemented; 3) restriction to irrigated areas might be imposed in cases of serious water scarcity. The main benefit to the farmers is that a stabilization of the water table, in addition to ensuring a good quality of water, guarantees the reliability of the water supply and a relatively low extraction cost.

Our analysis suggests that, assuming that the respondents are representative of the farming community of the Merguellil Valley, farmers seem ready for a policy change to manage the groundwater, even if this means they have to pay substantial short term costs (pricing of groundwater, metering and quantity restriction) to reap long term benefits. The condition for such acceptance however, is that farmers require transparency and independent monitoring. These requirements, they believe, should guarantee them equal and fair treatment. Heterogeneity among farmers is key in explaining the willingness to shift to an alternative regime or to remain with the status quo. As land distribution becomes more unequal, farmers seem to be more willing to engage in collective action to achieve a more sustainable management of the aquifer. On the other hand, we also find evidence to support that heterogeneity is good for local property resource preservation, in particular, greater land inequality also results in the milder fall of the water table. However this fact is not perceived by villagers, who usually have higher demand for equality in water use under more unequal land distribution. This seemingly contradictory finding reconciles the prediction by Baland and Platteau [1999] : In voluntary provision problems, inequality may contribute to the efficient outcome while “in regulated settings, inequality tends to reduce the acceptability of available regulatory schemes”. Finally, the opposition of policy change may very likely come from wealthier farmers, as they are the beneficiaries from the current region and they may oppose to any new policy that could threaten their current position.

Our findings have very strong policy implications. As more government involvements try to be put in place to tackle the “common property tragedy”, it is important to notice any intervention needs to remove the obstacles which impedes cooperation at local level in the first place, as it might be ”partly determined by the same factors that make collective actions unsuccessful” (Bandiera et al. [2005]). Besides changing wealth distribution, building a transparent system and sharing information with all users may be a more practical policy option.

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Appendix 1

Table A1: Summary Statistics

	mean	s.d.
Individual level (sample size=246)		
Gender (1=male)	1.004	
Age	40.615	14.77
Education		
Illiterate	0.18	0.39
Primary school	0.54	0.5
Secondary school	0.22	0.41
college	0.02	0.14
university	0.04	0.19
Cultivated land area(ha)	7.39	6.71
% of land irrigated	0.92	0.202
currently in GIC	0.03	
number of private wells	1.05	0.24
Use dripping technology	0.75	0.44
Use sprinkling technology	0.39	0.49
Village level (sample size=28)		
number of households	472.36	523.1
number of farms	355.75	319.76
0-2 ha	50.04	44.07
2-4 ha	64.36	52.92
4-6 ha	70.14	90.42
6-10 ha	84.5	88.99
10-20 ha	49.43	50.03
20-50 ha	29.36	39.69
>50 ha	7.93	8.88
Downstream to the dam	0.86	0.36
Fall of watertable from 1990 to 2007(meter)	18.36	6.78
Mean of welldepth	45.55	9.36

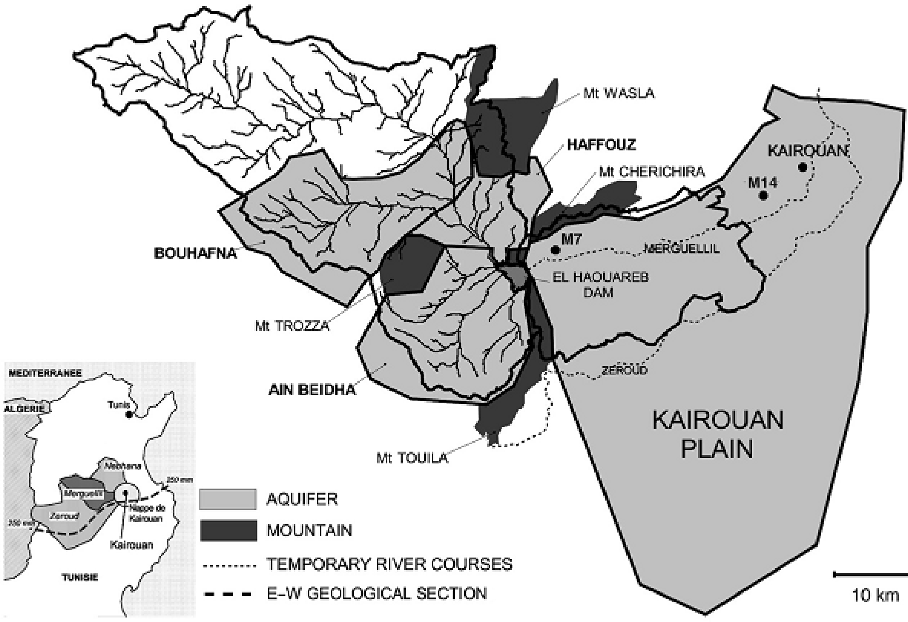

Figure A1: Location of Survey Area. Cited from Al Atiri[2006]

Appendix 2

Proof for Lemma 1.

The proof follows entirely from Bardhan et al. [2007]. By the definition of $g(l_i)$, $f_2(l_i, g(l_i)) = h(l_i, g(l_i)) = \frac{1}{b+c}$. By the implicit functions theorem, we determine:

$$g'(l_i) = -\frac{h_1}{h_2} \tag{10}$$

It is obvious from Assumption 1 with $h_1 = f_{12} > 0$ (i.e. the two inputs are complementary) and $h_2 = f_{22} < 0$ that $g'(l_i) > 0$. It implies the response curve of collective input to the private input ($w_i = g(l_i)$) is upward sloping and always above zero for any positive private (land) input. This result is derived directly from the setting of constant marginal extraction cost which is the same for everyone and the assumption of complementarity relationship of both inputs.

By differentiating expression (10) with respect to land, we get:

$$g''(l_i) = -\frac{h_{11}h_2^2 - 2h_1h_2h_{12} + h_{22}h_1^2}{h_2^3} \tag{11}$$

The condition $g''(l_i) \leq 0$ is equivalent to the determinant of the bordered hessian matrix $\begin{vmatrix} 0 & h_1 & h_2 \\ h_1 & h_{11} & h_{12} \\ h_2 & h_{12} & h_{22} \end{vmatrix} = 2h_1h_2h_{12} - h_{11}h_2^2 - h_{22}h_1^2$ being ≥ 0 which in turn is equivalent to $h(l_i, w_i)$ being quasi-concave (Theorem 21.20 in Simon and Blume [1994]).

Proof for Lemma 2.

Under differentiated price, most farmers produce under an amplified marginal product of water and thus would extract more water than in the baseline model. In another word, $\phi(l_i) > g(l_i)$. This effect of product price on resource use is also discussed in the Clark model of fisheries under open access: resource users may accelerate their extraction in the presence of higher resource prices all things being equal (Clark [1973]). By the implicit functions theorem, we determine the slope of the response curve of water to land as

$$\phi'(l_i) = -\frac{h_1}{h_2} - \frac{h}{h_2}\frac{\delta_i'}{\delta_i} \tag{12}$$

where δ_i and δ_i' are abbreviations for $\delta(l_i)$ and $\delta'(l_i)$ separately. By Assumption 3-5 and Lemma 1, $\phi'(l_i) > g'(l_i) > 0$, i.e. the response curve of water under differentiated market is upward sloping and has a steeper slope, not only because water is complement to land, but also because the price wedge gives farmers the incentive to accelerate extraction. Same as in the baseline model, the effect of mean-preserving spread in land distribution depends on the curvature of the response curve, which is

$$\phi''(l_i) = g''(l_i) - \frac{h^2 h_{22}}{h_2^3}\left(\frac{\delta_i'}{\delta_i}\right)^2 + \frac{2h\left(h_2 h_{12} - h_1 h_{22}\right)}{h_2^3}\frac{\delta_i'}{\delta_i} + \frac{h}{h_2}\frac{2\delta_i'^2 - \delta_i''\delta_i}{\delta_i^2} \tag{13}$$

$$\phi''(l_i) = g''(l_i) - \frac{h^2 h_{22}}{h_2^3}\left(\frac{\delta_i'}{\delta_i}\right)^2 + \frac{2h}{h_2^2}\left(h_{12} + g'(l_i)h_{22}\right)\frac{\delta_i'}{\delta_i} + \frac{h}{h_2}\frac{2\delta_i'^2 - \delta_i''\delta_i}{\delta_i^2} \tag{14}$$

However, the sign of expression (13) is ambiguous. We establish earlier that $g''(l_i) \leq 0$. By Assumption 3-4, we are certain that the second term is positive and the third term is negative if $0 \leq g'(l_i) \leq -\frac{h_{12}}{h_{22}}$ and positive if $g'(l_i) \geq -\frac{h_{12}}{h_{22}}$. Finally, the sign of the last term depends on the sign of $2\delta_i'^2 - \delta_i''\delta_i$.

As the function itself displays, the curvature of $\phi(l_i)$ depends on the shape of $\delta(l_i)$. We can demonstrate this with a simple exercise. Assume $\delta(l_i)$ is convex at lower part of the land distribution and concave at higher end. Define $\tilde{l}$ as the inflection point of the price function $\delta(.)$, i.e. the point at which the second derivative $\delta''(l_i)$ changes from being positive (for any $l_i < \tilde{l}$) to negative (for any $l_i > \tilde{l}$). For intermediate values of land endowment l_k, i.e. around the inflection point $\tilde{l}$, δ_k' is relatively larger than the slopes for small or large endowments. The sign of $2\delta_i'^2 - \delta_i''\delta_i$ in equation (13) is unambiguously positive for $l_i \to \tilde{l}^+$ since then $\delta_i'' < 0$, implying that the fourth term in Eq. (13) is negative together with the first and the third term. Then the sign of $\phi''(l_i)$ depends on the magnitude of the positive effect (second term) relative to the negative effects (the other three terms). For $l_i \to \tilde{l}^-$, the sign of $2\delta_i'^2 - \delta_i''\delta_i$ is ambiguous without further structure imposed on the shape of the price function $\delta(.)$. In any event, whatever its sign, the overall sign of $\phi''(l_i)$ remains undetermined.

As land endowment moves away from $\tilde{l}$, δ_i' decreases and becomes negligible when l_i is small enough or big enough. Neglecting all terms with δ_i' we then have $\phi''(l_i) \approx g''(l_i) - \frac{h}{h_2}\frac{\delta_i''}{\delta_i}$. For large land endowment where $\delta_i'' < 0$, we are certain that $\phi''(l_i) < 0$. While for small land endowment where $\delta_i'' > 0$, then $\phi''(l_i) \lesseqgtr 0$ again depending on the relative magnitude of the two terms. ■

Proof for Lemma 3.

By Eq. (2) and (3) we have: $f_2^* \cdot (b + nc) = f_2^n \cdot (b + c)$, so that $f_2^* > f_2^n$, where f_2^* and f_2^n represent marginal product of water input under cooperative and noncooperative equilibrium separately. Since f_2 is a decreasing function of water input w_i, we then easily get $w_i^n > w_i^* > 0$ for any i. And because $e_i = \frac{w_i - \frac{c}{b+cn}\sum_{j\neq i} w_j}{b}$, a fall in all w_i (and any other w_j) also leads to a fall in e_i, i.e., $e_i^n > e_i^* > 0$.

Moreover, $f_2^* - f_2^n = f_2^n \frac{(1-n)c}{b+nc} > 0$, that is $f_2^* - f_2^n$ increases with f_2^n, which by assumption further increases with land endowment, then the difference between marginal product of water under two optimum is bigger for larger land holder. Since marginal product of water decreases with water input, for a bigger drop in marginal product of water, larger farmer has to suffer a bigger cut in water input under cooperation. In other words, the difference $w_i^n - w_i^*$ becomes larger for big farmers, or equivalently $\phi'(l_i) > \psi'(l_i)$, i.e. water response curve to land has a bigger slope under the Nash Equilibrium. Given that both functions $\phi(l_i)$ and $\psi(l_i)$ are increasing and greater than 0 for $l_i > 0$, it has to be the case that farmers' water extraction is consistently lower should they agree to engage in cooperation: i.e. $\phi(l_i) > \psi(l_i)$ for any $l_i > 0$. The difference in water input is also reflected in difference in water extraction effort, and $\frac{d(e_i^n - e_i^*)}{dl_i} > 0$. In other words, bigger farmers have to bear more of the brunt of the conservation effort should they join cooperation.■

Method to measure inequality from grouped observation

This appendix introduces briefly the method of using grouped observation to calculate inequality measurement first developed by Kakwani and Podder [1976].

Suppose a positive variable X of a family is a random variable with probability distribution function $F(x)$, and density function $g(x)$, and mean μ. The first moment distribution function of X is given by

$$F_1(x) = \frac{1}{\mu}\int_0^x Xg(X)dX$$

The Lorenz curve is the relationship between $F(x)$ and $F_1(x)$. The curve is shown in Figure A2. The equation of the line $F_1 = F$ is called egalitarian line.

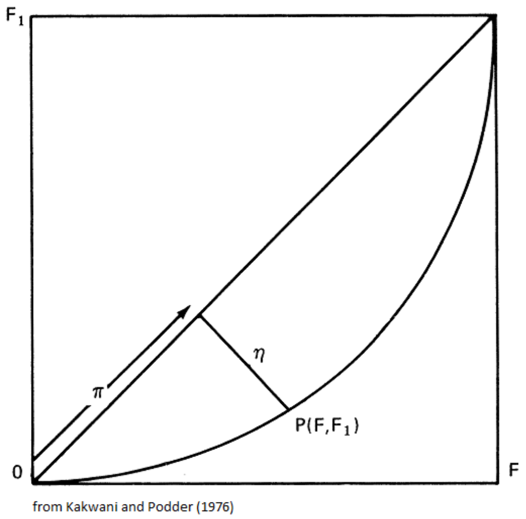

Figure A2: Lorenz curve

Let P be any point on the curve with co-ordinates (F, F_1), and
$\pi = \frac{1}{\sqrt{2}}(F+F_1)$ and $\eta = \frac{1}{\sqrt{2}}(F-F_1)$;

then η will be the length of the ordinate from P on the egalitarian line and πwill be the distance of the ordinate from the origin along the egalitarian line. Since the Lorenz curves lie below the egalitarian line, $F_1 \leq F$ which implies $\eta \geq 0$. Further, if X is always positive, the above equation implies η to be less than or equal to π.

The equation of the Lorenz curve in terms of π and η can now be written as:

$$\eta = f(\pi)$$

where πvaries from zero to $\sqrt{2}$.

We can write the Lorenz curve functional form as:

$$\eta = a\pi^{\alpha}(\sqrt{2}-\pi)^{\beta}, \qquad a>0, \alpha>0, \beta>0 \tag{15}$$

when $\alpha = \beta$ the Lorenz curve has a symmetric shape, with the value of η at $\pi$and $(\sqrt{2} - \pi)$ be equal for all values of π.

In the empirical application, we estimate F and F_1 using the grouped observations of land distribution, calculate $\hat{\pi}$and $\hat{\eta}$, and regress $log(\hat{\eta})$ on $log(\hat{\pi})$ and $log(\sqrt{2} - \hat{\pi})$ according to eq. (15) to obtain the estimates $\hat{a}$, $\hat{\alpha}$ and $\hat{\beta}$, which can be substituted into eq. (7) and (8) for Gini Concentration Ratio and Relative Mean Deviation of land distribution.