

Aflaj Research Unit

Working Paper 0213



On the Equity of Revenue Creation in a Community Based Water Management System

Dennis Powers*, Head of Projects, Aflaj Research Unit, University of Nizwa
Abdullah Al Ghafri, Director, Aflaj Research Unit, University of Nizwa

Abstract

This paper considers the revenue creation of a traditional water management system that has been used in Oman for centuries, called a falaj (pl Aflaj). In a falaj community revenue for maintenance of the system may be generated by the auctioning of water owned by the falaj institution. This paper considers the equity property of weekly auctions to raise revenue for the falaj. A theoretical model is presented that identifies the factors that determine the equity in revenue creation. The paper then analyzes data from four falaj systems and finds that the majority of revenue created is derived from a relatively small minority of the community population. However, it should be noted that such inequity does not derive from exploitive power inside the community, but because a minority places the highest value on the auctioned water.

*Corresponding author. E-mail address: dennis@unizwa.edu.om

1. Introduction

This paper considers the revenue creation of a traditional water management system that has been used in Oman for centuries, called a falaj (pl Aflaj). In a falaj community revenue for maintenance of the system can be generated in one of two ways. The falaj community may own land and water and produce a crop which is sold for revenue. Alternatively the falaj may own water rights and rent the water rights in weekly auctions to farmers in the community for revenue. This paper considers only the second and analyzes the equity property of weekly auctions to raise revenue for the falaj.¹

There are two dimensions of equity considered. The first is related to the distribution of water in the community, and therefore is also related to efficiency. The question here is whether auctions result in a distribution of water that is equitable and efficient. The second dimension of equity focuses on auctions as a method to raise funds for the maintenance of the falaj system and which members of the community are paying for maintenance of the system. To address these questions a theoretical model of the water auction market in the community and the resulting water demand, and revenue created by the auction market is constructed. This model is then tested and the degree of equity in revenue creation is measured. The final section concludes with a discussion of the results.

The remainder of the paper is organized as follows: Section 2 provides basic background information on the falaj and falaj auction markets. Section 3 presents a review of the literature on the falaj and falaj auctions. Section 4 constructs an economic model of the falaj and derives its implications for the questions at hand. Section 5 presents empirical tests of the model, while section 6 discusses the results. Section 7 offers conclusions.

2. Background

A falaj is an irrigation system in which water is tapped at a higher elevation and its conveyance is powered only by gravity.² Once the water reaches the agricultural area, the community has devised rules for its distribution and management, including the funding of the falaj maintenance. Periodic water auctions are used to enhance distribution, as well as to fund maintenance. In particular, the water is distribution to individual farms on a time basis. That is, each share receives a specific amount of time of irrigation, where the quantity then depends only on the flow rate. The period over which the rotation occurs and all farmers receive their share is called the *dawran* (for example, the dawran may be ten days). For falaj communities using auctions, one day of the dawran is set aside to be auctioned to those in the community. The primary purpose of the auctions is to raise revenue for the falaj maintenance, but they also serve to distribute water in the community.

¹ Powers et al (2013) has examined the efficiency and revenue creation properties of these auctions, but did not address the equity properties.

² See Al-Ghafri (2004), Sutton (1986) and Wilkinson (1977).

Since the falaj funds maintenance with the auctioning of water, both the equity in funding and the distribution of water are linked. That is, if the auctioned water is distributed widely in the community, then the funding of the falaj is more equitable than if the auctioned water is distributed to only a few. Hence the distribution of water via auctions is critical. This distribution derives from the demand for water, which in turn derives from the ex ante distribution of water and land. While the falaj likely originally distributed water and land proportionally, given many systems are centuries old, over time water and land holdings have become separated, and thus water holdings are not necessarily proportional to land holdings. This is the critical feature that determines the demand for auctioned water, and thus the distribution of that water, and the identification of who is funding the falaj.

3. Literature Review

Given the longevity of the aflaj and the fact that over three thousand are still in use, the aflaj have garnered much attention (see Wilkinson (1977) for seminal work in the aflaj). Despite this economists have been relatively slow to study these systems. This section will discuss the few exceptions.

Abdel Rahman and Omezzine (1996) does not study falaj auction markets in particular, but is a survey of the various economic institutions used in the falaj systems and is concerned with the overall performance of falaj communities. A simple supply and demand framework is assumed to understand prices. Abdel Rahman and Omezzine note potential inefficiencies and calls for further research into the economics of the aflaj.

Al-Marshudi (2007) studies several falaj systems with the purpose of describing the falaj auction markets and comparing these markets to traditional markets in other countries. He finds that the falaj auction markets results are consistent with a simple supply and demand framework, and the markets are therefore expected to produce efficient outcomes.

While the above research is more descriptive in nature, Zekri, Katagama, and Boughanmi (2006) study auction markets with the purpose of estimating the elasticity of water demand. It is often argued that the elasticity of water demand is near zero, implying water markets are unable to conserve water. Using data on auction prices from four falaj systems, Zekri et. al. find the elasticity to be significantly greater than zero, and conclude the water management institutions of the aflaj are efficacious in conserving water.

Finally, Powers et al (2013) has modeled the falaj auction markets to determine their efficacy in generating revenue. It is found that the repeated nature of the auction markets lead to the winners becoming revealed prior to the auction, thereby reducing participation in the auctions, and reducing prices and auction revenue.

The present paper follows Powers et al (2013) by building an explicit model of the falaj auction markets. However, while that model focused on the auctions themselves to determine both how they function and their implications for auction participation and revenue generation, this paper focuses on the source of demand for auctioned water, and the implications for the distribution of water in the community, and how that distribution determines the burden of funding the falaj maintenance.

4. The Model

While the auctions take place weekly, this model will simplify by assuming there is only one auction per growing season. As will be seen, those with the highest marginal product of water will win the auction. This is consistent with Powers (2013) model, in which the weekly characteristic of the falaj auctions is explicitly modeled. There it is demonstrated the auctions result in efficiency in which those with the highest marginal product of water win the auctions.

4.1 The Individual's Problem

Assume all farmers only grow a single variety of date palm. The production per tree can be described as follows:

$$(1) \quad y_i = f(w_i),$$

where y_i is production per tree of agent i , w_i is water applied per tree of agent i , and f is the production function that exhibits

$$(1A) \quad f'(w_i) > 0 \text{ for } 0 < w < \bar{w}$$

$$(1B) \quad f'(w_i) < 0 \text{ for } w > \bar{w}$$

$$(1C) \quad f''(w_i) < 0 \text{ for all } w$$

Let n_i be the total number of trees owned by agent i , a_i be the athars owned by agent i , and q_i be the athars rented by agent i . Finally, let p be the price of an athar and let r be the flow rate. In this case the water applied per tree for agent i is given by

$$(2) \quad w_i = (a_i r + q_i r) / n_i.$$

Hence total production for agent i is given by

$$(3) \quad n_i y_i = n_i f\left(\frac{a_i r}{n_i} + \frac{q_i r}{n_i}\right)$$

and profits of agent i , π_i , are given by

$$(4) \quad \pi_i = n_i f\left(\frac{a_i r}{n_i} + \frac{q_i r}{n_i}\right) - p q_i$$

Agent i 's problem is to maximize (4) by choosing q_i . The first-order condition is given by

$$(5) \quad d\pi/dq_i = n_i f'(w_i) \frac{r}{n_i} - p \leq 0$$

Or

$$(5A) \quad d\pi/dq_i = f'(w_i)r \leq p$$

4.1.1 Corner Solution

A corner solution arises if $\frac{d\pi}{dq_i} \leq 0$ at $q_i = 0$. That is, $q_i^* = 0$ if the marginal profit of the first athar rented is negative. Substituting $q_i = 0$ in (5A), a corner solution arises when

$$(6) \quad f'\left(\frac{a_i r}{n_i}\right) r \leq p.$$

4.1.2 Interior Solution

An interior solution arises when $\frac{d\pi}{dq_i} = 0$ at $q_i^* > 0$. That is, the agent rents water until the marginal profit is driven to zero. This is given by

$$(7) \quad f'(a_i r/n_i + q_i r/n_i) r = p$$

One can then show the demand for rented athars is given by

$$(8) \quad q_i^d = g(p/r)(n_i/r) - a_i,$$

where $g(\cdot) = f'^{-1}(\cdot)$

This demand can be expressed as a volumetric demand as follows

$$(8a) \quad (q_i^d/n_i)r = g(p/r) - (a_i/n_i)r,$$

where P/r is the volumetric price of water.

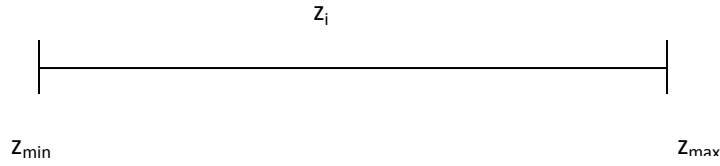
4.2 Equilibrium

Equilibrium requires the demand of all agents sum to the total number of athars rented. However, if there is an unequal ex-ante distribution of athars in the community, some agents may be in a corner solution, having zero demand, it is important to distinguish between agents with zero demand and those with positive demand.

4.2.1 Ordering Agents

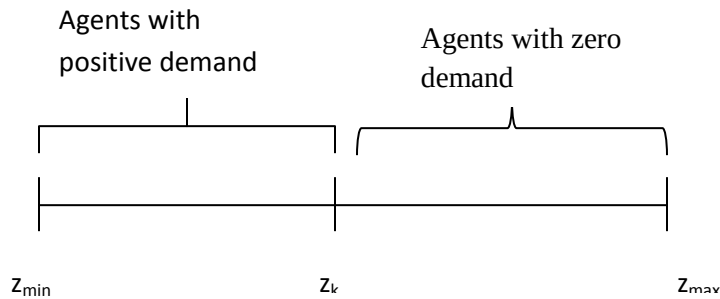
From the first-order condition one can see the marginal profit of the first unit of rented water is inversely related to the owned athars/trees ratio; that is, a_i/n_i ratio. Hence the agents will be ordered by the a_i/n_i ratio. Defining $z_i = a_i/n_i$, the agents are ordered from the lowest z to the highest, implying the agents are then ordered from the highest marginal profit of rented water to the lowest. In this case agent 0 has a z equal to z_{min} and agent z_I has a z equal to z_{max} . This is pictured in Figure 1.

Figure 1



Now define agent k as the agent for whom $f' \left(\frac{a_i r}{n_i} \right) r = p$ at the equilibrium price. Hence agent k is the agent for whom his first-order condition is met at $q_i = 0$. For agents $i < k$, they will have $z_i < z_k$, and thus have $f' \left(\frac{a_i r}{n_i} \right) r > p$, implying positive demands. For agents $i > k$, they will have $z_i > z_k$, and thus have $f' \left(\frac{a_i r}{n_i} \right) r < p$, implying zero demands. Hence agent k is the threshold agent. Those with a value of z less than z_k having positive demand, and those with a value of z more than z_k having zero demand. This is pictured in Figure 2.

Figure 2



It should be noted that an unequal ex-ante distribution of athars has been assumed. If athars were equally distributed prior to the rental market opening, then agents would have identical demands

for rented athars. However, only the more general case of an unequal ex-ante distribution will be considered.

4.2.2 Equilibrium Conditions

There are two equilibrium conditions. These are

$$(9) \quad p^* = f'(z_k r)r$$

$$(10) \quad \int_{i=0}^k q_i^d = Q,$$

The first condition defines the equilibrium price in terms of agent k , determining the agents that have positive demands. The second conditions sums all the positive demands for agents 0 to k and states total demand must equal total athars rented, Q .

To proceed substitute (8) into (10) to yield

$$\int_{i=0}^k (g(p/r)(n_i/r) - a_i) di = Q$$

Now substitute for the price the equilibrium price given by equation 9, into (10A) to yield

$$\int_{i=0}^k ((f'(z_k))(n_i/r) - a_i) di = Q$$

But since $g(\cdot) = f'^{-1}(\cdot)$, one has

$$\int_{i=0}^k (z_k r(n_i/r) - a_i) di = Q$$

Or

$$(11) \quad \int_{i=0}^k (z_k n_i - a_i) di = Q.$$

Equation (11) defines the equilibrium k . This determines the equilibrium price by equation (9) and identifies the agents that rent athars.

4.3 Characteristics of the Equilibrium

4.3.1 Effect of a Change in the Flow Rate

To determine the effect of a change in the flow rate, r , consider equation 11. Equation 11 determines the equilibrium value of k , which identifies the agents that rent athars. As one can see r does not appear in the equation. Hence, changes in the flow rate will not impact which agents rent athars. Stated alternatively, the model predicts the same agents rent athars, even as the flow rate changes. The logic behind the result is straightforward. While changes in the flow rate affect the marginal product of rented water, such changes affect all agents in the same way, implying the ordering of agents by the value of z_i does not change.

While a change in the flow rate does not change *who* buys the rented water, it will change the price of the rented water, and thus the revenue collected. Recall the price is given by equation (9), in which case it is clear the equilibrium price depends on r . The comparative static result is given by

$$(12) \quad \partial p^*/\partial r = f''(z_k r) z_k r + f'(z_k r).$$

While this has an ambiguous sign, one can express the volumetric price as $p^*/r = f'(z_k r)$, in which case the comparative static result is

$$(12A) \quad \partial(p^*/r)/\partial r = f''(z_k r) z_k < 0,$$

which is unambiguously negative. That is, as the flow rate falls (rises), the equilibrium (volumetric) price rises (falls).

4.3.2 Identifying Reduced Form Demands

As shown in the deriving of equation (11), the reduced form demand for rented athars by agent i is given by

$$(13) \quad q_i^d = z_k n_i - a_i = n_i(z_k - z_i)$$

This states the demand for rented athars depends positively on the number of trees owned, and negatively on the number of athars owned. While it depends on the equilibrium k , it does not depend on the flow rate of athars. Of course it is important to realize this is a reduced form demand equation, derived after substituting for the equilibrium price. This implies any agent's actual purchase of athars, in equilibrium, is independent of the flow rate.

While equation (13) identifies an agent's reduced form demand for athars, one can divide by n_i to find the reduced form demand for athars/tree. This given by

$$(13A) \quad q_i^d/n_i = z_k - z_i$$

And this can be restated as

$$(13B) \quad q_i^d/n_i + z_i = z_k.$$

Total athars per tree is equal to a constant, z_k , for all agents that rent athars. For those agents that do not rent athars, recall their owned athars per tree exceed the constant z_k .

4.4 Equity Implications

Using the results above one can now consider the equity implications of the equilibrium. To do so the identification of those renting the athars is identified, as well as the revenue collected from

them is found. Moreover, equity in water distribution is also considered as the total athars per tree is calculated for different agents. This information is given in Table 1.

Table 1				
	<i>Athars Rented</i>	<i>Revenue Collected</i>	<i>Total Athars per tree (rented plus owned)</i>	
<i>Agents renting water, i.e. agents $i = 0, \dots, k^*$</i>	$q_i^d = n_i(z_k - z_i)$	$p^* n_i(z_k - z_i)$	z_k	
<i>Agents not renting water, i.e. agents $i = k^*, \dots, I$</i>	0	0	$z_i > z_k$	

The fact that k^* is independent of the flow rate implies that it is the same agents, year after year, that fund the falaj maintenance. Hence the raising of revenue via water auctions will result in an inequitable burden of falaj maintenance. In particular, agents with a relatively low (owned athars/owned trees) ratio will fund the maintenance of the falaj system, and agents with a relatively high (owned athars/owned trees) ratio will benefit from the maintenance, but will not fund the maintenance.³ However, since price changes with the flow rate, the revenue collected from these k^* agents will change as the flow rate changes.

Finally, the last column of Table 1 shows that there is an inequitable distribution of total athars per tree available to the community. This inequity does not exist due to any characteristic of the weekly auction markets, or to differences in productive investments by agents, but it exists due to a lack of agent-to-agent market for athars. Were such markets available agents with more athars/tree, and thus relatively low marginal product of water, would trade to agents with less athars/tree, and thus relatively high marginal product of water, thereby resulting in an equalization of athars/tree in the community.

5. Evidence of Inequity and Tests of the Model

This section will confront the theoretical model with data from auction results from four falaj systems. The four systems are from the village of Samail in Oman. Each system operates independently of the others. For each system the authors were able to obtain data on the winning price of each athar auctioned in each weekly auction, the identity of the winner of each athar in each weekly auction, and the flow rate of the falaj for each year. The name of the falaj systems, along with the years for which data is available, is given below in Table 2.

³ Of course agents can, in the long-run, choose the owned athars/trees ratio. While changing owned athars may not be possible, it is possible to change the number of trees cultivated. This paper abstracts from these long-run equilibrium considerations, but future research should reconsider the issue of equity in the context of the long-run choices.

TABLE 2: Falaj Systems			
Falaj	Years for which Data is Available		
Al Farfara	2005 - 2012		
Belfae	1997 - 2003		
Mhaideth	2004 - 2011		
Samdi	2009 - 2011		

5.1 Measuring Inequity in the Funding of Falaj Maintenance

Table 1 highlighted the inequity in the collection of falaj revenue from auction markets implied by the theoretical model of section 4. The current section will provide descriptive statistics measuring inequity in the funding of falaj maintenance. To accomplish this three measurements are used to describe the degree of inequity in all four auction markets.

First, the percentage of total revenue from the top 10 buyers in the auction markets in the four falaj systems is calculated. While an admittedly arbitrary number, it does provide a first look at inequity. Second, revenue contribution of the top 10% of the buyers is calculated. Finally, the Gini coefficient for each falaj system, measuring revenue contribution inequality instead of income inequality, is calculated. This data appears in Table 3.

Table 3: Inequality in Revenue Creation			
Falaj	Percent of Revenue from Top 10 Buyers	Percent of Revenue from Top 10% of buyers	Gini Coefficient
Al Farfara	48%	23%	0.36
Belfae	63%	53%	0.79
Mhaideth	62%	52%	0.77
Samdi	70%	56%	0.83

Except for Al Farfara, all measures of inequality, including the Gini coefficients, are high, suggesting significant inequities in the collection of revenue for falaj maintenance. While the numbers from Al Farfara are lower than the others, it still shows significant inequity. The first column indicates that only ten buyers in the community are providing 48% of the funds for the falaj maintenance. What is different in Al Farfara is that most of the buyers participating are participating at a high rate. That is, they have fewer infrequent buyers compared to the other falaj systems. But there is still substantial inequality present, as can be seen in the Gini coefficient for Al Farfara.

As a final measurement of inequity a “core” group of buyers in each falaj is defined. The core group is the buyers that purchased at least one athar in each year for which data exists. First the core as a percentage of all people who purchased at least one athar is calculated, and then the core as a percentage of the falaj community population is calculated. Finally, the percentage of athars purchased by the core is calculated. This is presented in Table 4. As Table 4 demonstrates, again with the exception of Al Farfara, a relatively small portion comprises the core group of buyers, yet this core group is purchasing the majority of athars in the falaj communities. For example, in Mhaideth, only 17 people are buying every year. These 17 represents 22% of all buyers, but only x% of the population. However, this core group is providing 84% of the funding for falaj maintenance.

Table 4: Inequity in the Core			
Falaj	Number in the Core	Percentage of Buyers in Core	Percentage of Athars Purchased by the Core
Al Farfara	20	53%	83%
Belfae	12	17%	68%
Mhaideth	17	22%	84%
Samdi	16	25%	81%

5.2 Testing the Model

The theoretical model of section 5 showed that in equilibrium there is inequity in the funding of falaj maintenance, and section 6 provided measurements of that inequity. This section will test the model of section 5. To test the model two implications of it are identified. These are

1. The quantity purchased by an individual is a function of their athar/tree ratio.
2. The quantity purchased by an individual buyer will not change over time, or for different flow rates.

The data collected is from the auction records of four falaj systems in Oman, but does not contain the data required to test the first implication. Hence only the second implication is tested. While this implication has a very simple test (no variance in amounts purchased over time and no impact of the flow rate changes), it is important to realize that the theoretical model is based on the simplifying assumptions that the athar/tree ratio does not change for *any* agent, and that there are no other sources of water for *any* agent. These simplifying assumptions were made because it is believed that these variables are slow to change, and thus not relevant from a theoretical modeling perspective. However, these variables, and perhaps others, could change over time, implying some change in the amount purchased by any given buyer. However, given the belief that these other variables are slow to change, this first implication can be operationalized by stating that the amount purchased by any buyers will be relatively constant. Moreover, the

implication that the amounts purchased do not depend on the flow rate will still be true, regardless of whether there are any changes in the amount purchased due to changes in athar/tree ratio or alternative sources of water. Hence, testing the effect of flow rate on amounts purchased provides a meaningful, direct test of the model.

Because it is not obvious how to test whether amounts purchased are “relatively constant” this is measured and tested in two ways. First, the variation in the amount purchased per year will be measured, and then test of the significance of the variation will be conducted. Second, as explained above, while changes in some variable can cause changes in the amounts purchased, there is no change expected due to the changes in the flow rate. Hence, the amount purchased will be regressed against the flow rate as the second test of the model. However, before proceeding, the correlation coefficient of amounts purchased by each buyer over time periods is examined. Though not a hypothesis test it is offered as a descriptive statistic.

5.2.1 Correlation across Time

For each falaj the correlation coefficient between the amounts purchased by buyers in one year to all other years is computed. As there are many correlation coefficients, only the maximum, minimum, and average for each falaj is reported. These results are reported in Table 5.

Table 5: Correlation Coefficients of Amounts Purchased Between Time Periods			
Falaj	Maximum	Minimum	Average
Al Farfara	0.99	0.60	0.85
Belfae	0.89	0.42	0.68
Mhaideth	0.94	0.73	0.84
Samdi	0.91	0.80	0.84

Table 5 illustrates that there is substantial correlation in buyer behavior over all time periods, provide evidence consistent with the model of section 5.

5.2.2 Test of Variation in Buyer Behavior

Across the years for which data exist, and for each falaj, first standard deviation for each buyer over all the years for which data exists is calculated. However, as the standard deviation is sensitive to the units measured, it does not provide the best measure of variation. That is, those that buy large amounts will have a larger variation. Hence the coefficient of variation (standard deviation divided by the mean) will be used.

The model prediction is that the coefficient of variation (CV) is “small”. However, since small is a relative term, the question is to what can one compare the CV to determine if it is small enough to be consistent with the model. To make such a comparison, the CV of core group of buyers is measured, and compared to the CV of the non-core. As the core group is purchasing the majority of athars, and participating regularly in auction, the assumption is that the core group of buyers represents those for whom the result of the model applies. The non-core group is those infrequent

buyers whose behavior may be best explained by changes in the variables not captured by the theoretical model. Hence the hypothesis is that the CV of the core should be significantly less than the CV of the non-core. This is tested by performing estimating the following equation

$$(14) \quad CV_{j,i} = \alpha + \beta D_{j,i}$$

where D is a dummy variable taking on a value of 1 if agent j is in the core, and a value of 0 if not in the core. The hypothesis is again that β is negative; that is, those in the core will have a lower CV than those not in the core. The estimates of β are presented in Table 6, along with the mean CV of the core and non-core. In both estimated equations, β is negative and significant, consistent with buyer behavior being constant over time.

Table 6: Test of the Coefficient of Variation			
Falaj	Mean CV of Core	Mean CV of Non-Core	β Estimate from (14)
Al Farfara	0.07	2.05	-1.98*
Belfae	0.50	1.89	-1.39*
Mhaideth	0.31	2.13	-1.82*
Samdi	0.42	1.58	-1.16*

*Significant at 99% level

5.2.3 Effect of Flow Rate on Buyer Behavior

This subsection will test whether the flow rate has a significant effect on the percentage of athars purchased by an individual. That is, the following equation is estimated:

$$(15) \quad \%Athars \text{ Purchased by Agent}_t^i = \alpha + \beta flow_t^i$$

The hypothesis is β is zero. This equation is estimated for all four falaj separately, with both a pooled model and a fixed effects model. The results are provided in Table 7 below, as estimates of β are reported, with standard errors in parentheses. All estimates are near zero, and none of the estimates are statistically significant, as predicted by the theoretical model.

Table 7: Effects of Flow Rate on Athars Purchased		
Falaj	Estimate of β: Pooled Regressions	Estimate of β: Fixed Effects Model
Al Farfara	-1.14E-18 (1.47E-03)	7.21E-20 (6.60E-04)
Belfae	-1.10E-17 (2.03E-03)	4.60E-18 (2.55E-03)
Mhaideth	-6.71E-18 (2.05E-03)	3.34E-05 (7.73E-04)
Samdi	7.56E-18 (2.11E-03)	2.97E-19 (8.52E-04)

6. Discussion of Results

The paper has presented a theoretical model that predicts auction markets used to fund falaj maintenance result in an inequitable funding mechanism if there is an unequal ex-ante distribution of athars. In particular, agents that own *more* athars will contribute less to funding, and in many cases will contribute nothing to the funding of maintenance. Instead, the burden of funding will fall on those that own the fewest athars. Moreover, the paper has presented empirical evidence that strongly support these results.

While the evidence of inequity is significant, it should not be interpreted as evidence of exploitation of the “poor” by the elite. Rather, it must be understood in the context of the history of the aflaj of Oman. Historical records (reference?) reveal that the communities began with a system in which land and athars were assigned in proportion to the amount an individual invested in the falaj. Hence, those that have the greatest number of athars are those that would have born the greatest cost in development of the falaj. Thus, one can view the athar owners as a part owner of a business that rents its service to others. In this sense, the rental fees help to fund the falaj. Thus rental fees are simply the reward for having originally invested in the falaj. And while athar and land ownership has changed over time, presumably any sale price of athars or land would have taken into consideration the resulting effects of athar rentals.

Not only is any inequity not evidence of exploitation, it is not even necessary that inequity exists. The degree of inequity depends on the ex-ante distribution of athars. Were athars distributed proportional to tree holdings (or land holdings), then the demand for rented athars would be equal for all agents, and the contribution to maintenance would thus be equal. And given the historical evidence that athar holdings were proportional to land holdings, the present state is owing to changes in water and land holdings over time. Thus the inequity in contribution to falaj maintenance is not by design, but by historical accident.

Moreover, whether by design or not, the manner of raising revenue appears to be the opposite of exploitive. Powers (2013) showed that the repeated auctions result in prices below the marginal value. Hence falaj management has chosen a method that thought preserving efficiency, actually results in the individuals paying below their marginal value of water. Thus it is as if the falaj management has realized those “poor in water” will fund their maintenance, but rather than charge a price reflecting marginal value (which with the low elasticity of water demand is likely to be high), they choose a method that results in low prices for those poor in water. Hence this paper demonstrates that those who own relatively little water will fund the falaj maintenance, but when combined with Powers (2013), a method is chosen that does not charge them excessively high prices.

Though it is true the inequity in falaj maintenance funding should not be viewed as exploitive, it is nevertheless the case that the falaj funding falls on relatively few people in the community, and this may impact the ability of the falaj, as an institution, to adapt its funding mechanism. In recent years many falaj communities have suffered from the lack of funds, and falaj communities have turned to the government for assistance (reference?). Powers et al (2013) demonstrates the falaj auctions do not maximize revenue, implying some other mechanism to fund the falaj may be needed. However, given the fact that representation in falaj management is proportion to athars owned, it is clear that those who own the most athars, and thus have the most control over falaj management, would have less incentive to adopt an alternative funding mechanism.

Moreover, while the paper has focused on inequity in falaj funding, the theoretical model also establishes there may exist an unequal ex-post distribution of athars, which results from a prohibition on farmer-to-farmer renting of athars. One potential reason for such a prohibition is that it may undermine the ability of the falaj to raise revenue through auctions. That is, if private trading results in an equal ex-ante distribution of athars, then there will be less demand for auctioned athars, and revenue will be reduced. This reduction in revenue would have to either be met by payments by athar owners, or by a reduction in the flow rate of the falaj. In either case, those that own the most athars would be negatively affected by allowing a private market. And since those that own the most athars are in control of falaj management there is a disincentive to adopt a market mechanism allowing farmer-to-farmer trading of athars in the community.

Finally, the paper has assumed the athar/tree ratio is constant, implying a short-run analysis. In the long-run the athar/tree ratio is a variable chosen by agents. If the price of rented water results in lower profitability of farming, a farmer may want to increase the athar/tree ratio. However, if the prohibition of private trading of athars does not allow for an increase in athars, then the athar/tree ratio can only be increased by reducing the number of trees cultivated. Hence the long-run trend would be to reduce trees under cultivation until equalization of the athar/tree ratio. In this case, the auction mechanism coupled with the lack of a private market for renting athars has the potential to result in a reduction of cultivation in the community, and thus an inefficient use of land and water.

For the above reasons, the inequity in the falaj funding mechanism may result in inertia in the falaj institutions, which leave the falaj at a less efficient outcome. Such possibilities call for further research into the long-run characteristics of the falaj system related to the economic outcomes of existing institutions, and the adaptability of falaj social institutions. While the present model abstracts from these important long-run issues, it does offer a theoretical model, supported by empirical evidence, as the basis for further study of the long-run characteristics of the falaj.

7. Conclusions

This paper has studied the weekly auctions funding mechanism used by a traditional water management system, the falaj, which has been used in Oman for over a millennium. This paper has demonstrated, both theoretically and empirically, that if there is an unequal ex-ante distribution of athars, the auction markets used results in an inequitable burden of falaj maintenance, where those owning the fewest athars pay the most for falaj maintenance. Additionally, inertia in falaj institutions may exist due to the fact that those managing the falaj are likely to be negatively affected by any change in the system. Moreover, the theoretical model constructed of the falaj has been shown to be consistent with the evidence, suggesting the model can be extended to cover other important issues, such as the long-run analysis of falaj systems, which is left for future research.

References

- Abdel Rahman, Hayder and A. Omezzine. 1996. Aflaj Water Resources Management: Tradable Water Rights to Improve Irrigation Productivity in Oman. *Water International*. 21:70-75.
- Al-Ghafri, A.S. 2004 *Study on water distribution management of Aflaj irrigation systems of Oman*. PhD thesis, Hokkaido University, Japan.
- Al Marshudi, A. 2007 The falaj irrigation system and water allocation markets in Northern Oman. *Agricultural Water Management*, **91**, 71-77.
- Powers, D., Al Ghafri, A, and Timothy Schettino. 2013. An economic analysis of falaj auction markets, *Aflaj Research Unit Working Paper*, WP0113, University of Nizwa.
- Sutton, S. 1984 The falaj – a traditional co-operative system of water management. *Waterlines*, 2, 8-12.
- Wilkinson, J. 1977. Water and Tribal Settlement in South-East Arabia: A Study of the Aflaj of Oman. Clarendon Press. Oxford, UK.
- Zekri, S, Kotagama, H., and Boughanmi, H. 2006 Temporary Water Markets in Oman. *Agricultural and Marine Sciences*, 11, 77-84.