POLITICAL ECONOMY AND IRRIGATION TECHNOLOGY ADOPTION IMPLICATIONS OF WATER PRICING UNDER ASYMMETRIC INFORMATION

by

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Political Economy and Irrigation Technology Adoption

Implications of Water Pricing under Asymmetric Information*

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Abstract: We analyze the design of two water pricing rules emerging from two alternative farmer lobby groups, formed by the adopters and the non-adopters of modern irrigation technology. We examine the implications of these rules for the endogenously determined lobby size, for irrigation technology adoption, water use and social welfare. Two pricing rules are considered here: (i) two-part tariff, with a volumetric part and a fixed part and (ii) nonlinear pricing, with the price of water varying with volume, each designed to meet the budgetary costs of water provision. Under each of these rules, we find that the group in majority prefers a fee designed to shift the burden of the cost of water provision on the other group. The characteristics of the resulting fee structure and its welfare implications are further explored through a numerical illustration.

Key words: Asymmetric information, Nonlinear pricing, Political economy, Technology adoption, Water pricing.

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The provision of water for irrigation is often done by a water district or water users association that operate as a natural monopoly since the fixed costs of water provision (dam construction or banking) are very high while marginal costs are low. Water pricing using the marginal cost rule would therefore be inefficient and would not result in the recovery of the costs of water provision. Scholars have therefore, proposed alternative pricing rules such as lump-sum taxes on water users (Hotelling, 1938, 1939) or Ramsey-Boiteux prices that deviate from marginal cost in inverse proportion to demand elasticity (Ramsey, 1927; Boiteux, 1956). Lump-sum taxes have been criticized because they are not Pareto optimal, they are inequitable and they do not create incentives for efficient water use (Combes, Julien and Salanié, 1997; Laffont, 2000). Ramsey-Boiteux pricing requires information about demand elasticity (Laffont, 2000).

In practice, water providers have typically relied on multipart tariffs, with a fixed part based on acreage and a variable part based on the volume of water, to cover the costs of provision[1]. Each of these parts could be designed to vary across farmers based on their characteristics. However, such a scheme requires private information about farmer characteristics. A simple pricing scheme that can be implemented without requiring the revelation of private information is a two-part tariff with each of the parts invariant across

[1] Examples of countries, such as Algeria, Australia, and Spain, using two-part tariffs can be found in Dinar and Subramanian (1997). In some countries, volumetric pricing alone is not possible either because metering is costly or because charging for water by the volume conflicts with religious beliefs or ethics. In such cases, only per acre fee is charged for water.

farmers. More complex schemes may involve second-degree price discrimination where various volumes of water are sold at different unit prices using increasing/decreasing block tariffs that could be in the form of two- (or more) part tariffs. These are all particular cases of nonlinear pricing that seek to extract the entire surplus from the farmers (Wilson, 1993, p.4; 136)[2]. Since second-degree price discrimination is based on farmer characteristics, it requires designing a revelation mechanism.

Water districts typically have considerable flexibility in the design of the pricing scheme they choose and with either of the two schemes considered here, there are various combinations of fixed and volumetric fees that can achieve the same budget targets.[3] The design of the pricing scheme can affect the choice of modern irrigation technology adoption, water use and profits of farmers and therefore create incentives for farmers to organize into lobbies to influence that design. Water district decisions are typically voted on by their elected members that are often open to lobbying from different interest groups comprising of water users among their constituency and choose policies preferred by strong and organized lobbies in order to garner votes for future elections (McCann and Zilberman, 2000; Persson and Tabellini, 2002). In some countries such as Brazil, Azevedo and Asad (2000) found that the political power structure, information asymmetry, and rigid institutions are important in determining the outcome of water pricing reforms. Political considerations preventing the collection of water fees from

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[2] Edgeworth (1913) recommended price discrimination subject to budget balance constraints to help cover costs with less distortion.

[3] Water district bylaws typically constitute an incomplete contract, which makes them residual decision makers that are subject to capture by interests groups (Laffont, 1999). Indeed, the best design of rules and laws fails to predict all possible present and future contingencies, therefore leaving room for the regulator to exert discretion as some situations arise.

some water users are obstacles to cost recovery, and induce efficiency and equity distortions as found in the case of Dakar, Senegal (Cueva and Lauria, 2000). In the case of Pakistan, Wambia (2000) explains how imperfect information, competing interests, group loyalty, and the support of political candidates shaped reforms in the water sector. Reforms that consisted in decentralizing water management in the country and increasing cost recovery through more efficient pricing of irrigation and drainage services.

In this paper, we adopt a positive theory of water pricing and consider two alternative lobbies that attempt to influence the water district to set a water fee schedule to benefit them. These groups consist of those who adopt the modern irrigation technology and those that use the traditional irrigation technology. Each group consists of heterogeneous farmers. The pricing schemes analyzed here are a two-part tariff schedule composed of a mandatory per-acre fee plus a volumetric charge versus a nonlinear pricing schedule under asymmetric information. We also analyze a special case of the two-part tariff, an inflated marginal cost pricing rule, (recommended by Adam Smith) with no per acre fee. We examine the characteristics of the water-pricing schedule that would emerge if water districts choose the schedule preferred by the group in majority and the feasibility of that design. The latter depends on size of the group of farmers that is better off with that schedule which determines if it is in a majority. We examine the implications of alternative pricing schemes influence technology adoption, profits and social welfare of each group of water users.

Much of the literature examining water conservation and modern irrigation technology adoption under either full information, e.g. Caswell and Zilberman (1986) or asymmetric information, e.g. Dridi and Khanna (2005), has assumed that water price is given. In such setting, farmers respond to the regulator's pricing decision to maximize profits and choose irrigation technology in a Stackelberg-like fashion. Only a few studies address the political economy dimension of water pricing policies (Johansson et al., 2002). Among these, McCann and Zilberman (2000) derive water-pricing rules that would appeal to the maximum number of voters and analyze their implications for technology choice and land use in California. They rely on a median voter model under full information, following the Chicago School (Stigler, Posner, Peltzman, Becker). In their model, the water district has full information about the farmers' profits from different pricing schemes and chooses the scheme that would receive the maximum number of favorable votes. In reality, water districts operate under conditions of informational asymmetries due to the high transactions costs and legal constraints on accessing private information. The presence of asymmetric information allows water districts to exercise discretion in choosing pricing schemes that favor a particular group of farmers. Additionally, it provides incentives for farmers to exert political influence by forming lobby groups to extract rents (Laffont and Tirole, 1993; Laffont, 2000). Laffont (2000) develops a general political economy model with two types of agents each trying to affect the pricing schedule. He treats the size of each group of agents as exogenous. In contrast, we consider a continuum of heterogeneous farmer types who self-select into two groups, the size of which is determined endogenously.

The main results of this paper are that under either the two-part tariff or the nonlinear pricing, farmers of either group have an incentive to and can organize to affect the outcome of the water schedule design in their favor; the exception being the inflated marginal cost water fee, which is lobby-independent. The pricing schedule preferable to each group is driven by two motivations, first to maximize the size of their group (to increase their ability to influence the water district) and second to extract as much surplus from the other group as possible and therefore shift the burden of water provision to the other group. Under a two-part tariff, the pricing scheme preferred by the modern technology adopters (if in majority) involves a high volumetric price of water but a low fixed cost per acre. This provides greater incentives for modern technology adoption; increases the number of adopters and shifts the burden of water costs to those consuming a large volume of water using the traditional technology. The pricing scheme preferred by the traditional technology adopters has the opposite features, it reduces the incentive to switch to the modern technology by pricing water cheap while increasing the fixed costs of technology adoption. In fact, the water fee schedule is designed in such a way as to make the group in minority bear not only their share of the fixed cost of the project but also to pay for the variable cost of other water users.

Under non-linear pricing, we find that the group in the majority prefers a two-part tariff with a linear volumetric price plus a fixed fee for itself, but a nonlinear price for the other group that extracts all the surplus from water use. This severely reduces incentives to be a part of the non-majority group and the nonlinear water fee therefore leads all (or nearly all) farmers to adopt the same irrigation technology and pay for water following a schedule that closely matches the cost function of water provision. The two-part tariff leads to a higher expected social welfare and larger expected water use as compared to the nonlinear pricing scheme.

In the next section, we present the general setup of the model. In section 3, we discuss the two-part tariff model and its particular case of inflated marginal cost. Section 4, covers the second-degree price discrimination model. Section 5, presents a numerical illustration of the previous models using a calibrated model of cotton production in the San Joaquin Valley in California. Section 6 concludes the paper.

2. General setup

We consider farmers differentiated by parameter $\theta \in [0,1]$ that reflects each farmer's soil type and skills, θ is distributed with density $f(\theta)$ and a cumulative distribution $F(\theta)$ over the support $[0,1]$, we assume that *f* is a uniform distribution. Farmers have a choice of two irrigation technologies, $t \in \{L, H\}$ where *L* is the traditional technology (e.g. furrow irrigation) and *H* is the modern technology (e.g. sprinkler or drip irrigations). A representative farmer’s per-acre profit when technology *t* is adopted is:

(1) $$\pi^t(w^t;\theta) = Py^t(w^t;\theta) - T^t(w^t) - \psi^t .$$

where P is the market price of the agricultural output, y^t is the output per acre, w^t is water intake in acre-feet, T^t is the per acre water fee, and ψ^t is the per acre cost of irrigation technology *t*. It is assumed that $\psi^L = 0$ while $\psi^H > 0$.

Irrigation technology

Let $e^t = w^t h^t(\theta)$ be the quantity of effective water used by the farmer when technology *t* is adopted where $h^t(\theta)$ is the irrigation effectiveness of technology *t* defined as follows:

$$h^t(\theta) = \begin{cases} \theta^\alpha & ;\forall 0 < \theta \le 1 \\ \varepsilon & ;\forall \theta = 0 \end{cases}; \tag{2}$$

and ε is a very small positive value. We assume that $\alpha = 1$ if the traditional technology is adopted ($t = L$) and $\alpha \in]0,1[$ if the modern technology is adopted ($t = H$). The function $h^t(\theta)$ is increasing with respect to θ and can be thought of as the percentage of water absorbed or used effectively by the plant, hence it is bounded by 1 at $\theta = 1$ (as in Caswell and Zilberman, 1986). Regardless of the technology adopted, the percentage of water absorbed by the plant is very small at $\theta = 0$ which is the case for poor quality land. For realistic values of α, we have $h^H(\theta) > h^L(\theta)$ and the difference decreases as θ increases; thus the modern irrigation technology benefits farmers with low types more than those who have high types.

Production function

We assume that the production function y^t is such that the elasticity of marginal productivity of effective water use, $emp^t = -e^t \dfrac{\partial^2 y^t / \partial e^{t2}}{\partial y^t / \partial e^t}$, is greater than 1. Under this condition, water use declines with respect to land quality or type (Caswell and Zilberman, 1986). A class of production functions that meets this requirement is the family of quadratic production functions. We assume the following constant returns to scale production function $y^t\left(w^t;\theta\right) = -d + bw^t h^t - a\left(w^t h^t\right)^2$ where $a > 0, b > 0,$ and $d \geq 0$ are constants. Water use declines with land quality if $w_i^t > \frac{b}{4ah^t}$.

Farmers' decision-making

We consider a nonprofit water district operating as a natural monopoly under a budget constraint. Its costs of providing a volume of water, *w*, is $C = \phi w + K$ where ϕ is the marginal cost and *K* is the fixed cost. We assume that capital costs are indivisible and that the water district is operating at or below the full capacity. We also assume that all farmers have equal and unrestricted access to water and no preexisting water rights exist.[4] A farmer's decision regarding water use and technology is made in two steps. First, he determines the optimal level of water use that maximizes profits given technology *t*, and then he chooses the technology that gives the highest profit. It can be shown that for $\theta \in \left[0, \theta_s\right]$, where θ_s solves $\pi^H(\theta_s) = \pi^L(\theta_s)$ such that $\pi^t > 0, \forall t \in \left\{L, H\right\}$, farmers adopt the modern technology (*t*=*H*) since $\pi^H \geq \pi^L$ and $\pi^H \geq 0$. We assume there is no idle land. For $\theta \in \left[\theta_s, 1\right]$ the traditional technology is selected (*t*=*L*). Caswell, Zilberman, and Casterline (1993) show that the profit differential (net of the fixed costs of adoption) declines as θ increases. Given the assumptions that $h^H\left(\theta\right)$ is concave and $emp^t > 1$, they also show that there is a single crossing point between π^L and π^H.

[4] This would be a reasonable assumption in situations where water is stored in a dam or water bank and is available to an irrigation district either as a sole source of water or to complement other scarce water sources.

We assume that a group of farmers if large enough (more than 50%) can influence the design of the water fee schedule. If $\theta_s = \theta_1^* > 0.5$ then farmers adopting the modern irrigation technology have a majority (we refer to that as majority-1) while if $\theta_s = \theta_2^* < 0.5$ then farmers adopting the traditional technology are in a majority (we refer to that as majority-2). There is a 50% chance that one of the two groups will be in the majority.

3. Two-part tariff

Under majority-*i*, the marginal cost is inflated/deflated by $\delta_i > 0$; therefore farmers pay $\delta_i \phi$ per unit of water used and a mandatory per-acre fee g_i that is levied on all farmers regardless of their water use. The per acre cost of water use is therefore $T_i^t\left(w_i^t(\theta)\right) = \delta_i \phi w_i^t(\theta) + g_i$. The budget balance condition is:

(3) $$g_i + \phi\left(\delta_i - 1\right)\left(\int_0^{\theta_s} w_i^H(\theta)dF(\theta) + \int_{\theta_s}^1 w_i^L(\theta)dF(\theta)\right) = K .$$

Since θ_s takes either a value θ_1^* or θ_2^* depending on the group that is in the majority, the solutions for w_i^H, w_i^L, δ_i, and g_i in (3) will differ by subscript *i*. Profit maximization by all farmers implies a water demand:

(4) $$w_i^t(\theta) = \frac{1}{2ah^t}\left(b - \frac{\delta_i \phi}{Ph^t}\right) \qquad ;\forall\left(i,t\right) \in \left\{1,2\right\} \times \left\{L,H\right\},$$

After simplification (3) becomes:

(5) $$g_i + \phi\left(\delta_i - 1\right)\left[\frac{b}{2a}\left(\frac{\theta_s^{1-\alpha}}{1-\alpha} - \ln(\theta_s)\right) + \frac{\delta_i \phi}{2aP}\left(1 - \frac{1}{\theta_s} - \frac{\theta_s^{1-2\alpha}}{1-2\alpha}\right)\right] = K .$$

In this setting, information about farmer's type is not needed to implement the pricing policy since all farmers face the same water fee schedule based on their water use regardless of their type. Under majority-1, the regulator chooses δ_1 and g_1 by solving the following maximization problem: $\max_{\delta_1, g_1} \int_0^{\theta_1^*} \pi_1^H \left(w_1^H(\theta);\theta\right) dF(\theta)$ subject to (5) with $\theta_s = \theta_1^*$, and $w_1^t \equiv \arg\max_w \pi_1^t \left(w_1^t(\theta);\theta\right); \forall t \in \{L, H\}$ as determined from (4).

The solution to this problem can be represented as follows by denoting $A(\theta_s) = \frac{b}{2a}\left(\frac{\theta_s^{1-\alpha}}{1-\alpha} - \ln(\theta_s)\right) > 0$ and $B(\theta_s) = \frac{1}{2aP}\left(1 - \frac{1}{\theta_s} - \frac{\theta_s^{1-2\alpha}}{1-2\alpha}\right) < 0$.[5]

(6) $$\phi\delta_1\left(\theta_1^*\right) = \frac{\frac{b}{2a}\frac{\theta_1^{*1-\alpha}}{1-\alpha} - \theta_1^*\left(A(\theta_1^*) - \phi B(\theta_1^*)\right)}{\frac{1}{2aP}\frac{\theta_1^{*1-2\alpha}}{1-2\alpha} + 2\theta_1^* B(\theta_1^*)} .$$

With the volumetric fee being $\phi\delta_1\left(\theta_1^*\right)$ the fixed fee is therefore:

(7) $$g_1\left(\theta_1^*\right) = K - \phi\left(\delta_1 - 1\right)\left[A(\theta_1^*) + \delta_1 \phi B(\theta_1^*)\right].$$

Under majority-2, the group influencing the decision solves $\max_{\delta_2, g_2} \int_{\theta_2^*}^{1} \pi_2^L \left(w_2^L(\theta);\theta\right) dF(\theta)$ subject to (5) with $\theta_s = \theta_2^*$, and

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[5] Notice that since $\theta \in [0,1]$, therefore $\ln(\theta) \le 0$ and $\frac{1}{\theta} \ge 1$.

$w_2^t \equiv \arg\max_w \pi_2^t\left(w_2^t(\theta);\theta\right); \forall t \in \{L, H\}$. This gives the following volumetric and fixed fees:

(8) $$\phi\delta_2\left(\theta_2^*\right) = -\frac{\frac{b}{2a}\ln(\theta_2^*) + \left(1-\theta_2^*\right)\left(A(\theta_2^*) - \phi B(\theta_2^*)\right)}{\frac{1}{2aP}\left(\frac{1}{\theta_2^*} - 1\right) + 2\left(1-\theta_2^*\right)B(\theta_2^*)},$$

(9) $$g_2\left(\theta_2^*\right) = K - \phi\left(\delta_2 - 1\right)\left[A(\theta_2^*) + \delta_2\phi B(\theta_2^*)\right].$$

From (6)-(9) we observe that the fixed cost of water provision affects only the per acre fee charged to farmers and not the volumetric fee, $\frac{d\delta_i}{dK} = 0$; a higher fixed cost of water provision entails higher per acre fee, $\frac{dg_i}{dK} = 1$. Using total differentiation on $\pi^L\left(w^L(\theta_i^*);\theta_i^*\right) = \pi^H\left(w^H(\theta_i^*);\theta_i^*\right)$ one can show the intuitive result that $\frac{d\theta_i^*}{dK} = 0$, $\frac{d\theta_i^*}{d\phi} > 0$, $\frac{d\theta_i^*}{dP} > 0$, and $\frac{d\theta_i^*}{d\psi^H} < 0$. The marginal cost of water provision affects both the variable and the per acre portions of the water fee schedule, however the sign of the derivatives of δ_i and g_i with respect to ϕ or P are not tractable, because it is not possible to determine the sign of $\frac{d\delta_i}{d\theta_i^*}$. However, we expect that if δ_i is high, g_i would need to be low to meet the budget balance constraint. A high δ_i would create greater incentives to increase the efficiency of water use by adopting the modern irrigation technology and increase θ_i^*. A low g_i would lower the fixed costs of production and reduce the level of land quality below which land would be retired. Together, this would imply that farmers have greater incentives to adopt the modern irrigation technology when the unit fee of water is high and the per-acre fee is low and vice versa if δ_i is low and g_i is high.

We consider two special cases of the two part tariff. First, if $K = 0$ and $\delta_i > 1$ then it must be that $g_i < 0$, since the water authority operates under a budget balance condition. In this case, a per-acre subsidy payment is needed to pay back farmers since they are charged a volumetric price for water that exceeds the cost of water. Since g_i is constant across farmers, the reimbursement serves as a transfer payment from farmers who use water the most (i.e. farmers with low land quality and those who use the traditional irrigation technology) to those who use it the least (i.e. farmers with high land quality and those who use the modern irrigation technology). If $K = 0$ and $\delta_i < 1$ then it must be that $g_i > 0$. Now farmers are charged a price below the marginal cost of water and farmers who use water the least subsidize those who use it the most.

Second, if there is no per-acre fee, $g_i = 0$, then from (7) and (9) we can see that $\delta_1 = \delta_2 > 1$. In that case, the two-part tariff reduces to an inflated marginal cost pricing rule (as suggested by Adam Smith). Both equations would now give the same solution for θ^*, which implies that regardless of the majority influencing the decision, the design of the water fee is the same; thus the design is majority-neutral. The departure from the marginal cost is:

$$(10) \qquad \delta_0 = \frac{-A + \phi B + \sqrt{4KB + \left(A + \phi B\right)^2}}{2\phi B}.$$

In this case, the budget balance constraint is a strong enough institutional constraint to neutralize the effect of lobbies. This result differs from that obtained by Laffont (2000) who finds that the departure from the marginal cost under the inflated marginal cost rule differs depending on the group in majority. This difference arises because, unlike Laffont (2000) we are assuming a continuum of land types and because we allow farmers to self-select into either group, based on their individual profits, regardless of the group in majority.

In summary, with only a volume-based water fee schedule, the design of the fee is neutral to political manipulation if water authority operates subject to budget balance constraints. On the other hand, whether in the presence or absence of a fixed cost of water provision, the design of a two-part tariff is always dependent on the group of farmers in majority and its size.

Welfare, defined as the aggregate profit, under inflated marginal cost and under the two-part tariff are respectively,

(11) $$W = \int_0^{\theta^*} \pi^H(\theta) dF(\theta) + \int_{\theta^*}^1 \pi^L(\theta) dF(\theta) \text{, when } g_0 = 0.$$

(12) $$\begin{aligned} W^I &= 0.5\left(\int_0^{\theta_1^*} \pi_1^H(\theta) dF(\theta) + \int_{\theta_1^*}^1 \pi_1^L(\theta) dF(\theta) \right) \\ &+ 0.5\left(\int_0^{\theta_2^*} \pi_2^H(\theta) dF(\theta) + \int_{\theta_2^*}^1 \pi_2^L(\theta) dF(\theta) \right), \end{aligned}$$

where π_i^t is the profit under majority-*i* using technology *t*. In section 5, we use a numerical illustration to explore conditions under which each of these two majorities can be sustained and their implications for the pricing schedule, technology adoption and social welfare.

4. Second-degree price discrimination

We now examine a second-degree price discrimination policy where the unit price changes with the volume and the water district needs to devise individualized pricing schemes. We develop a revelation mechanism to induce truth telling by farmers, in the absence of perfect information about land quality (i.e. farmers types). According to the majority in power a farmer of type θ is given a take-it-or-live-it contract consisting of the pair $\left\{ w_i^t(\theta), T_i^t\left(w_i^t(\theta) \right) \right\}; \forall \left(i,t \right) \in \left\{ 1,2 \right\} \times \left\{ L,H \right\}$, where $T_i^t\left(. \right)$ is an individualized water fee that is paid only when land is irrigated ($w_i^t > 0$). Budget balance requires

(13) $$\int_0^{\theta^s} T_i^H\left(w_i^H(\theta) \right) dF(\theta) + \int_{\theta^s}^1 T_i^L\left(w_i^L(\theta) \right) dF(\theta) = \phi\left(\int_0^{\theta^s} w_i^H(\theta) dF(\theta) + \int_{\theta^s}^1 w_i^L(\theta) dF(\theta) \right) + K .$$

Welfare under majority-*i* is given by:

(14) $$W_i^{II} = \int_0^{\theta^s} \pi_i^H(\theta) dF(\theta) + \int_{\theta^s}^1 \pi_i^L(\theta) dF(\theta) ,$$

Expected welfare with second-degree price discrimination is:

(15) $$W^{II} = 0.5 W_1^{II} + 0.5 W_2^{II} .$$

Under majority-*i* the optimal water fee schedule is the solution to the following problem:

(16) $$\max_{\{w_i^t, T_i^t\}} \int_{\theta^s} \pi_i^t(\theta) dF(\theta) ,$$

subject to budget balance constraint (13), $\pi_i^t(\theta) \geq 0; \forall \theta \in [0,1]$, and some of the following incentive compatibility constraints depending on the group in majority. Detailed derivation of the truth-telling mechanism can be found in Dridi and Khanna (2005) and is provided in appendix 1.

(17) $$\dot{w}_i^H(\theta) \leq 0; \forall \theta \in [0, \theta_s],$$

(18) $$\dot{\pi}_i^H(\theta) = P\dot{h}^H w_i^H \left(b - 2ah^H w_i^H\right); \forall \theta \in [0, \theta_s],$$

(19) $$\dot{w}_i^L(\theta) \leq 0; \forall \theta \in [\theta_s, 1],$$

(20) $$\dot{\pi}_i^L(\theta) = P\dot{h}^L w_i^L \left(b - 2ah^L w_i^L\right); \forall \theta \in [\theta_s, 1].$$

Expressions (17) and (18) are derived from the incentive compatibility constraints for farmers who adopt the modern irrigation technology and expressions (19) and (20) are derived for farmers who use the traditional irrigation technology. A dot on top of the variables is used when the derivative is taken with respect to land type θ. Conditions (17) and (19) imply that water use needs to be non-increasing with respect to farmer's type, and equations (18) and (20) ensue from the assumption that the farmer reveals the land quality that maximizes his profit.

Under majority-1, the group influencing the water authority maximizes

$\int_0^{\theta_1^*} \left(Py^H\left(w^H; u\right) - T_1^H\left(w^t\right) - \psi^H\right) dF(u)$ subject to (19), (20), and $\pi_1^t(\theta) \geq 0; \forall \theta \in [0,1]$.

We assume that the farmers' reservation level of profits is zero. Under either majority, members of the majority group are allowed informational rents therefore the incentive compatibility constraints would not apply to them. This would imply that under majority-1, (17) and (18) do not apply.[6] With $\theta_s = \theta_1^*$, integrating (20) between θ_1^* and θ gives:

(21) $$Py^L(.) - T_1^L - \pi_1^L\left(.;\theta_1^*\right) = \int_{\theta_1^*}^{\theta} P\dot{h}^L w_1^L \left(b - 2ah^L w_1^L\right) du .$$

In order to maximize (16), we use (21) and replace $\int_0^{\theta_1^*} T_1^H(u)du$ by its value from the budget constraint in (13). After differentiating with respect to w_1^H and w_1^L, we obtain the following first-order conditions,

(22) $$\begin{cases} Ph^H\left(b - 2ah^H w_1^H\right) = \phi & ;\forall\,\theta \in \left[0,\theta_1^*\right] \\ Ph^L\left(b - 2ah^L w_1^L\right) = \phi + \int_{\theta_1^*}^{\theta} P\dot{h}^L\left(b - 4ah^L w_1^L\right)du & ;\forall\,\theta \in \left[\theta_1^*,1\right] \end{cases}.$$

The first condition in (22) shows that under majority-1 the adopters value water at its marginal cost. The second condition in (22) shows that farmers using the traditional irrigation technology value water below its marginal cost since the right hand side of that condition is less than ϕ (because $w_1^L > \dfrac{b}{4ah^L}$).

In order to derive the fee schedule for farmers who use the traditional irrigation technology we use (21) and add to it $\pi_1^H\left(.;\theta_1^*\right) - \pi_1^H\left(.;0\right) = \int_0^{\theta_1^*} P\dot{h}^H w_1^H\left(b - 2ah^H w_1^H\right)du$ on

[6] Similarly, under majority-2 farmers who adopt the modern irrigation technology are allowed informational rents therefore constraints (19) and (20) do not apply.

both sides of the equation.[7] Since reservation profits are equal to zero for the lowest land quality, $\pi_1^H\left(.;0\right)=0$, and $\pi_1^H\left(w_1^H(\theta_1^*);\theta_1^*\right)=\pi_1^L\left(w_1^L(\theta_1^*);\theta_1^*\right)$ at θ_1^*, we get the following water fee schedule for farmers who adopt the traditional irrigation technology,

$$T_1^L\left(w_1^L\right)=Py^L(w_1^L;\theta)-\int_{\theta_1^*}^{\theta}P\dot{h}^L w_1^L\left(b-2ah^L w_1^L\right)du-\int_0^{\theta_1^*}P\dot{h}^H w_1^H\left(b-2ah^H w_1^H\right)du\,. \tag{23}$$

Using budget balance constraint in (13) and fee schedule in (23), we get the water fee schedule of farmers who adopt the modern irrigation technology as follows:,

$$T_1^H=\phi w_1^H+\frac{F'}{\theta_1^*} \qquad ;\text{where } F'=\int_{\theta_1^*}^{1}\left(\phi w_1^L(u)-T_1^L(w_1^L(u))\right)du+K\,. \tag{24}$$

The result obtained in (23) shows that under majority-1, the water fee schedule for farmers adopting the traditional irrigation technology is a two-part tariff with a variable part that is nonlinear with respect to w_1^L (and less than the marginal cost of provision) and a non-zero intercept.[8] On the other hand, from (24) we see that the water fee schedule for the group in majority is also a two-part tariff, but the variable part is now a linear function of the marginal cost of water provision and the fixed part depends on the size of the group in majority (that is, it depends on θ_1^*).

To infer the value of θ_1^* we need to solve the second equation in (22). However, this is a Volterra integral equation of the second kind, whose solution is usually possible

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[7] We use the envelope theorem on the profit of farmers who adopt the modern irrigation technology to derive $\pi_1^H\left(.;\theta_1^*\right)$.

[8] Notice that the first integral depends on θ therefore it gives an expression that is function of $w_1^L\left(\theta\right)$ and a constant at θ_1^*, additionally the second integral in (23) is a definite integral and is therefore a constant.

only in a numerical form. Nevertheless, we can infer its value from the profit expressions without having to solve for w_1^L in (22). Since θ_1^* is defined such that $\pi_1^L\left(w_1^L;\theta_1^*\right)=\pi_1^H\left(w_1^H;\theta_1^*\right)$ equation (23), reduces to:

(25) $$\int_0^{\theta_1^*} P\dot{h}^H w_1^H\left(b-2ah^H w_1^H\right)du = Py^H\left(w_1^H;\theta_1^*\right)-T_1^H\left(w_1^H\right)-\psi^H .$$

For $\theta\in\left[0,\theta_1^*\right]$, the left-hand side of (25) is the optimal profit of farmers who adopt the modern irrigation technology function obtained using the envelope theorem. Therefore there is a one-to-one identity between the left-hand side and the right-hand side of (25) for every value of θ_1^*. Since profit is an increasing function of θ and the aggregate profit of farmers who adopt the modern technology increases with the size of the group, therefore $\int_0^{\theta_1^*}\left(Py^H\left(w^H;u\right)-T_1^H\left(w^t\right)-\psi^H\right)du$ is maximized when $\theta_1^*=1$.

These results have two main implications. First, farmers who adopt the modern irrigation technology can constitute a majority (majority-1) and therefore can influence the design of the pricing scheme. Second, the water fee schedule is designed in a way that leads all farmers to adopt the modern irrigation technology and therefore minimizes each farmer's burden of paying for the fixed costs of water provision. As shown by (24), charging each adopter in the group their valuation for water and an equal fraction of the fixed cost gives always a higher profit than any deviation from it. On the other hand, farmers who adopt the traditional irrigation technology pay less then the marginal cost of water provision but have to pay a higher fixed tariff to compensate for the budget deficit.

The fixed tariff for the non-adopters increases while that for the adopters decreases as θ_1^* increases (as shown in (23) and (24)). Therefore, every farmer at the margin has an interest in adopting the modern irrigation technology and θ_1^* tends to 1; any deviation from that behavior is not optimal (see Appendix 2).

Using a similar approach, under majority-2 the optimal water uses and corresponding water fee schedules are given by:

(26) $$\begin{cases} Ph^H\left(b-2ah^H w_2^H\right)=\phi+\int_0^{\theta} P\dot{h}^H\left(b-4ah^H w_2^H\right)du & ;\forall\theta\in\left[0,\theta_2^*\right] \\ Ph^L\left(b-2ah^L w_2^L\right)=\phi & ;\forall\theta\in\left[\theta_2^*,1\right] \end{cases},$$

(27) $$T_2^H\left(w_2^H\right)=Py^H(w_2^H;\theta)-\psi^H-\int_0^{\theta} P\dot{h}^H w_2^H\left(b-2ah^H w_2^H\right)du \,,$$

(28) $$T_2^L=\phi w_2^L+\frac{F''}{1-\theta_2^*} \qquad \text{;where } F''=\int_0^{\theta_2^*}\left(\phi w_2^H(u)-T_2^H(w_2^H(u))\right)du+K \,.$$

Under majority-2, farmers who adopt the modern irrigation technology pay for water following a nonlinear water fee schedule and value water below its marginal cost while those in majority are charged a two-part tariff and value water at its marginal cost. Unlike, the results obtained for majority-1 above, we now find that nonlinear pricing with majority-2 is expected to lead to a non-unanimous decision to adopt the traditional irrigation technology. Indeed, if we assume that all farmers adopt the traditional irrigation technology, so that $\theta_2^*=0$, then $F''=K$ (in (28)), then their profits have a negative intercept of *K*. The profits of the non-adopters in this case are shown by the curve π^L in figure 1 and the profits of the adopters would either be zero or lie below π^L

for all θ. Such a situation is however not sustainable because while it will cover the variable costs of water provision, it will not cover the fixed costs, because only farmers who use water ($w_i^t > 0$ and have non-zero profits) pay a water fee (that is equal to its marginal cost) and $\int_{\theta_2^0>0}^{1} Kdu < K$. Therefore, the water fee schedule has to be designed to allow for π_2^H to be higher than π_2^L for enough land types such that they can cover the portion of the fixed cost not covered by farmers using the traditional irrigation technology. The non-adopters are better off if there are at least some adopters of the modern irrigation technology. This is because, as one increases the profit of farmers who adopt the modern irrigation technology from zero to π_2^H, it induces a shift in π^L to π_2^L. A positive water fee from farmers who adopt the modern irrigation technology decreases the intercept in (28) and reduces the burden on farmers in majority-2 of paying for the fixed cost of water provision and therefore increases their profit. By construction θ_2^* should be between θ_2^0 and θ^0 (figure 1). If θ^0 is small enough as shown in the numerical section then the interval $\left[\theta_2^0, \theta^0\right]$ is also small and θ^0 is a good approximation of θ_2^*. If $\theta_2^* > \theta^0$, this implies that $\pi_2^L < \pi^L$, farmers in majority-2 can have higher profits by reducing the size of the group of farmers who adopt the modern irrigation technology, this can be done by finding $\theta_2^* \in \left[\theta_2^0, \theta^0\right]$. In extreme cases where π_2^H is higher than π_2^L over a range of land types greater than 0.5, majority-2 cannot be sustained and either the decision process is easily captured by majority-1 or the regulator maximizes a welfare function that is independent of lobbies' preferences.

<< Figure 1 about here >>

The results of this section suggest that under majority-1 all farmers adopt the modern irrigation technology because that way they face a two-part water fee that is closer to the cost structure of water provision. For the same reasons, under majority-2 not all but almost all farmers keep using the traditional irrigation technology. Under the two-part tariff there is only one two-part fee structure that all farmers have to face, however in the nonlinear pricing policy farmers in the majority face a two-part tariff, the rest faces a nonlinear tariff. A nonlinear tariff allows extraction of all the informational rent; therefore, all farmers have an incentive to belong to the group in majority.

5. Numerical illustration

To numerically illustrate the models presented above we use parameters from previous studies (Khanna, Isik, and Zilberman, 2002; Shah and Zilberman, 1991) based on data for cotton production in the San Joaquin Valley in California. We assume the following values of the production function parameters: $d = 1589$, $b = 2311$, and $a = 462$. The technology choices considered here are furrow and drip irrigation technologies (as in Shah and Zilberman). The fixed cost of furrow irrigation equipment is assumed to be \$500/acre while that of drip technology is assumed to be \$633/acre. Therefore, $\psi^H = \text{US\$133}$. Land type θ is assumed uniformly distributed over the support $[0,1]$. The irrigation effectiveness of furrow is assumed to be 0.6 by Shah and Zilberman which implies that $\theta = 0.6$ in our framework and the corresponding efficiency of modern irrigation technology (drip) is $h^H(0.6) = 0.95$; therefore $\alpha = 0.1$. We assume the price of cotton is US $0.6 per pound as in Khanna, Isik and Zilberman[9] To obtain the marginal cost of water we use data about the Arvin-Edison water storage district (Kern County, California) located southeast of the San Joaquin Valley where water is extracted from both ground and surface sources (Tsur, 1997). In 1987, 125,964 acre-feet of surface water were used for irrigation at a cost of $15.63 per acre-foot. The cost of groundwater was about $28.67 per acre-foot; the demand for groundwater was 13,883 acre-feet, this gives a weighted average cost of water mobilization in the region of $16.92/acre-foot. In Thomas (2001; p.83), the fixed cost of construction of a water bank in the Arvin-Edison was projected to be $25 million. The district has about 100,000 acres of farmed cropland, which implies that the corresponding capital cost per acre is $250.[10]

With a two-part tariff, the level of modern irrigation technology adoption is $\theta_1^* = 0.535$ with majority-1, but it falls to $\theta_2^* = 0.080$ with majority-2. The size of the group influencing the decision-making is much larger under majority-2 than with majority-1. This is because under majority 1 the volumetric fee is much higher ($4.24 instead of $0.29) while the fixed fee is lower ($89.14 instead of $328.65). Thus under majority-1 the structure of the water fee gives more incentive to adopt water saving technologies than under majority-2. Under majority-2, farmers are charged less than the marginal cost per unit of water consumed. In fact, the water fee schedule is designed in such a way as to make the group in minority (farmers who adopt the modern irrigation

[9] The USDA (2004)'s Cotton Price Statistics 2003-2004 reports an average price of 59.71 cents per pound in the San Joaquin Valley and 60.15 cents per pound nationwide.
[10] The acreage data is from Tsur (1997).

technology and consume less water) bear not only their share of the fixed cost of the project but also to pay for the variable cost of other water users.

Aggregate water use under majority-1 is much lower than water use under majority-2; in fact, our numerical illustration shows that for any given land type, water use under majority-1 is always lower than that under majority-2. This is because the price per unit of water is much higher under majority-1 as compared to under majority-2. The volume of water consumed is 2.96 acre-feet under majority-1 and that under majority-2 is 7 acre-feet. Under majority-1, most farmers who adopt the modern irrigation technology pay lower total water fee than under majority-2 but they also have lower water use and profits. The lower water use under majority-1 is because farmers adopt the modern irrigation technology. Welfare under majority-1 is higher than that under majority-2; \$399.61 versus \$384.80, expected welfare is \$392.21.

In case farmers are only charged a volumetric price for water, the per-unit cost of water is the same regardless of the group influencing the decision-making. The departure from the marginal cost is $\delta_0 = 6.5$, this is higher than either values found under the two-part tariff where part of the costs is paid for through the per-acre fee. Except at very low modern irrigation technology adoption levels, the departure from the marginal cost monotonically increases as the size of the group of farmers who adopt the modern irrigation technology increases; indeed it is expected that with lower water use, higher fees are required to pay for the fixed cost of water provision (figure 2).

<< Figure 2 about here >>

Under the volumetric water fee alone, the size of the group adopting the modern irrigation technology is $\theta_0^* = 0.628$ obviously the absence of a per-acre fee encourages more adoption of the modern irrigation technology. Under a volumetric price only, water use and fees are closer to those under majority-1 with the two-part tariff. Aggregate water use is 2.637 acre-feet; this is to be compared with an expected water use under the two-part tariff of roughly 5 acre-feet. With only a volumetric water fee, welfare is \$378.47, which is lower than the expected welfare under a two-part tariff, \$392.21. Using a volumetric water fee only, improves water conservation since it encourages greater adoption of modern irrigation technology but leads to lower excepted welfare compared to the two-part tariff. The two-part tariff leads to lower water use and higher welfare relative to a volumetric price only when we have a majority-1 influencing the decision making process.

With second-degree price discrimination, we find that with majority-1 all farmers opt for the modern irrigation technology as shown in the previous section. Since water demand with the traditional irrigation technology in (22) could not be found in a closed form, for illustration we assume that all farmers value water at its marginal cost and find that numerically the cutoff point θ_1^* that solves for (25) falls outside the range of land types, and is considerably higher than one. This leads us to believe that even with the true value of w_1^L it must be that $\theta_1^* = 1$ as discussed in the previous section. With majority-2, assuming that all farmers adopt the traditional irrigation technology, farmers whose land type is less than 0.073 retire their lands and realize a zero profit. As discussed earlier this is not a sustainable situation because the fixed costs of water provision cannot be recovered. However, to the extent that it occurs, one can approximate the size of the group of farmers that adopt the modern irrigation technology to be $\theta_2^* \cong 0.073$. Welfare with majority-1 is $350.91 while that with majority-2 is at least equal to $384.38, leading to an expected welfare that is no less than $367.64. Aggregate water use is lower as expected with majority-1, 2.741 acre-feet versus at least 6.156 acre-feet with majority-2 and our numerical illustration shows that water use is higher for all land types. Water fee under either majority reflects the variability in water use across farmers, and are generally much higher with majority-2 than with majority-1 (figures 3 and 4).

<< **Figure 3 about here** >>

<< **Figure 4 about here** >>

In table 1, we summarize the results under the various pricing schemes with alternative majorities. It shows that the expected welfare under a two-part tariff is higher than that with nonlinear pricing; some of the welfare losses in the latter case are due to information asymmetry.[11] Expected welfare with the two-part tariff is also higher than that with the inflated marginal cost scheme where lobbies have no effect on the pricing schedule; this shows that although a volumetric water fee is more water-efficient than a two-part tariff, the existence of lobbies is not always associated with lower ex-ante welfare. Welfare with majority-2 under the two-part tariff and the nonlinear pricing are to a certain extent comparable, however the results of majority-2 under the nonlinear

[11] Land retirement under the nonlinear pricing scheme does not occur because all farmers are granted zero reservation profit. Under the two-part tariff, land retirement does not occur, but it is due to the model parameters, for instance a higher value for ψ^H would change that.

pricing are only an approximation and therefore should be interpreted cautiously. With the inflated marginal cost water use is always the lowest, however as stated in the introduction the use of the volumetric pricing alone is not always possible.

<< Table 1 about here >>

Most of the model's parameters are technological in nature, i.e. the production function parameters depend on the product under consideration and the climate where it is grown and the cost of water provision depends on water availability and the capacity of water provision. In order to check for the persistence of the results we vary output price below and above the observed price for cotton. Results of these variations are provided in table 2. In the two-part tariff case, both majorities are sustainable at all output prices considered here. However, in the two-part tariff majority-1 cannot be enforced when $P = \$0.4$. Similarly, majority-2 cannot exist at very high output prices such as $P = \$1.91$.

<< Table 2 about here >>

Table 2 shows that as output price increases the adoption of modern irrigation technology increases with the volumetric price. This is also the case with majority-1 under the two-part tariff and with the second-degree price discrimination policy. However, under majority-2, regardless of the pricing scheme, an increase in output price reduces the adoption of the modern irrigation technology. An increase in output price increases water use, since $w_i^L > w_i^H, \forall i$, therefore majority-2 is better off when higher per-acre fee and lower volumetric fee are levied. The higher the per-acre fee and the lower the volumetric fee the smaller the incentives for the adoption of the modern irrigation technology.

6. Conclusion

It is often argued that water-pricing practices do not reflect the value of water or its opportunity cost and do not promote water conservation or its efficient use; they are not always determined with economic efficiency in mind (Spulber and Sabbaghi, 1998). Water pricing reforms often involve political dimensions that can be detrimental to their success; in addition to informational problems, there are power structures between individuals and between individuals and institutions that undermine the reform efforts (Dinar, 2000), hence the need to look into the political economy aspects of water pricing.

In this paper, using a political economy model where two groups of farmers attempt to influence the design of water fee schedule, we find that when the budget has to be balanced lobbies matter. A volumetric fee leads to greater modern irrigation technology adoption than a two-part tariff, determined by the adopters of the modern irrigation technology, and is independent of lobbies. However, the volumetric water fee leads to a lower expected welfare and to lower water use than the two-part tariff.

When the decision maker designs a nonlinear water fee, we find that most farmers align themselves with the group influencing the decision-making and are charged a water fee that is closer to the first best. Indeed farmers pay the marginal cost for each unit of water used and their fair share in the fixed cost of water provision, water use is lower under the nonlinear pricing scheme.

Our analysis shows that two-part fee structures in general are preferable to other alternatives. Indeed from the numerical analysis, the two-part tariff leads to higher welfare and even though the use of nonlinear water fee leads to lower welfare, in the end for most farmers the fee structure has a fixed and variable components as shown in section 4. In terms of policy, the regulator when choosing a water fee structure has to consider its ease of implementation, acceptability by water users, and strike a balance between welfare and efficient water use. In some developing countries, for its ease of implementation a combination of per-acre fee and a volumetric fee may be preferred to using only a volumetric fee. Our results show that this achieves a high welfare level and yet some adoption of the modern irrigation technology. In more developed economies, or where water metering is more acceptable and feasible the volumetric fee is used, and gives moderate welfare and greater adoption of the modern irrigation technology, hence more water conservation. Other countries combine the volumetric fee with a fixed component based on considerations other than acreage; this gives the lower welfare but leads to much greater adoption of the modern irrigation technology.

The model in this paper could be extended by more explicitly modeling the lobbyists' behavior and the likelihood of a particular lobby group being in the majority. In this paper, we simply assume that a group of farmers influences the decision-making process without looking into why the regulator pays particular attention to some lobbies and not the others. The success in lobbying is usually the result of financial and non-financial efforts that we did not consider here (Persson and Tabellini, 2002). Nevertheless, by allowing for endogenously determined sizes of the lobbies, in our model we are able to examine if particular lobby groups are sustainable and assess their effects on expected social welfare.

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Appendix 1: *Truth-telling mechanism design*

In this appendix, we design a truth-telling mechanism, the individual land quality parameter θ is not known to other farmers. The only information available about θ is its probability distribution $f(\theta)$, its cumulative distribution function $F(\theta)$, and its support $[0,1]$, independence between the θs is assumed. In this setting, water users when subscribing to a water use contract reveal a parameter $\hat{\theta}$ about their characteristic, the revealed parameter is not necessarily their true parameter θ. The decision maker or the group of farmers in control of the decision-making process, majority-*i*, have the task of designing a schedule consisting of a water quantity and a water fee $\left\{w_i^t(\hat{\theta}), T_i^t\left(w_i^t(\hat{\theta})\right)\right\}; \forall (i,t) \in \{1,2\} \times \{L,H\}$ for every announced parameter $\hat{\theta}$. They are take-it-or-leave-it contracts, nonnegotiable, and ex-post enforceable. The above contract needs a truth-telling or an incentive compatible revelation mechanism.

Let $\Pi_i^t\left(\hat{\theta},\theta\right) = Py^t\left(w_i^t(\hat{\theta});\theta\right) - T_i^t\left(w_i^t(\hat{\theta})\right) - \psi^t$, the profit realized by the farmer when using the irrigation technology *t* and when the decision-making process is under the control of majority-*i*, the farmer's true type is θ and announces $\hat{\theta}$. For $\left\{w_i^t(\hat{\theta}), T_i^t\left(w_i^t(\hat{\theta})\right)\right\}$ to be a truth-telling mechanism it implies that for every θ and $\hat{\theta}$ in $[0,1]$, the farmers profit when his type is θ (respectively $\hat{\theta}$) and reveals θ (respectively $\hat{\theta}$) is greater than his profit when his type is θ (respectively $\hat{\theta}$) and reveals $\hat{\theta}$ (respectively θ), which expressed mathematically gives:

(A.1) $$Py^t\left(w_i^t(\theta);\theta\right) - T_i^t\left(w_i^t(\theta)\right) \geq Py^t\left(w_i^t(\hat{\theta});\theta\right) - T_i^t\left(w_i^t(\hat{\theta})\right) \text{, and}$$

(A.2) $$Py^t\left(w_i^t(\hat{\theta});\hat{\theta}\right)-T_i^t\left(w_i^t(\hat{\theta})\right)\geq Py^t\left(w_i^t(\theta);\hat{\theta}\right)-T_i^t\left(w_i^t(\theta)\right).$$

Expressions (A.1) and (A.2) are useful to determine the relation between the farmer's type and his incentive compatible water use, i.e. to determine if the farmer's for example overstates his true land type, should he receive more or less water than what his true type requires and will be charged for water accordingly. Setting $w=w_i^t(\theta)$ and $\hat{w}=w_i^t(\hat{\theta})$ and dropping the indices *i* and *t* and using *u* as integration variable, then (A.1) and (A.2) imply:

(A.3) $$-\int_{\hat{w}}^{w}\left(P\frac{\partial y^t\left(u;\theta\right)}{\partial u}-\frac{\partial T(u)}{\partial u}\right)du\leq 0\text{, and}$$

(A.4) $$\int_{\hat{w}}^{w}\left(P\frac{\partial y^t\left(u;\hat{\theta}\right)}{\partial u}-\frac{\partial T(u)}{\partial u}\right)du\leq 0.$$

Using *v* as integration variable and adding (A.3) to (A.4) we get:

(A.5) $$\int_{\theta}^{\hat{\theta}}\int_{\hat{w}}^{w}P\frac{\partial^2 y^t\left(u;v\right)}{\partial u\partial v}dudv\leq 0.$$

Recall that $\dfrac{\partial^2 y^t(w_i^t(\theta);\theta)}{\partial w_i^t(\theta)\partial\theta}=\dfrac{\partial h^t(\theta)}{\partial\theta}\left(b-4ah^t(\theta)w_i^t(\theta)\right)$ and that $w_i^t>\dfrac{b}{4ah^t}$, which implies from (A.5) that $\dfrac{\partial^2 y(w_i^t(\theta);\theta)}{\partial w_i^t(\theta)\partial\theta}<0$, therefore $w_i^t(\theta)$ is a decreasing function of θ.[12]

[12] Since we are assuming that the elasticity of marginal productivity of effective water is greater than 1 which gives $w_i^t>\dfrac{b}{4ah^t}$.

Once the relation between $w_i^t(\theta)$ and θ is established, we now determine the appropriate level of water fee that makes the pair $\left\{w_i^t(\hat{\theta}), T_i^t\left(w_i^t(\hat{\theta})\right)\right\}$ an incentive compatible contract. The first-order condition for truth telling (the value of $\hat{\theta}$ that maximizes $\Pi\left(\hat{\theta},\theta\right)$) is:

(A.6) $$\left.\frac{\partial \Pi\left(\hat{\theta},\theta\right)}{\partial \hat{\theta}}\right|_{\hat{\theta}=\theta} = 0 .$$

Henceforth, in order to make less burdensome the notation we will use a dot on top of the variable when its derivative with respect to θ is taken. Expression (A.6) implies:

(A.7) $$\left[P\left(bh^t(\theta_i) - 2aw_i^t(\theta)\left(h^t(\theta)\right)^2\right) - \frac{\partial T_i^t\left(w_i^t(\theta)\right)}{\partial w_i^t(\theta)}\right]\dot{w}_i^t(\theta) = 0 .$$

If we set $\pi_i^t\left(w_i^t(\theta), h^t(\theta)\right) = \Pi\left(\theta_i, \theta_i\right)$, then using (A.7) or the envelope theorem, the total derivative of π_i^t with respect to θ is:

(A.8) $$\dot{\pi}_i^t = P\dot{h}^t w_i^t\left(b - 2ah^t w_i^t\right)$$

With $\underline{\theta}$ being the lowest land quality starting from which irrigation technology *t* is used, then integrating expressions (A.8) between θ and $\underline{\theta}$, and using the profit expression in (1), *ex-post* the optimal water tariff is obtained by a rearrangement of (1):

(A.9) $$T_i^t\left(w_i^t\right) = Py^t\left(w_i^t;\theta\right) - \pi_i^t\left(.;\underline{\theta}\right) - \psi^t - \int_{\underline{\theta}}^{\theta} \dot{\pi}_i^t\left(w_i^t(u);u\right)du .$$

Obviously, the water fee schedule in (A.9) imposes second-degree price discrimination, since users are offered different water quantities at different prices, but all users of the same type pay the same price for a given water quantity. We summarize the previous steps in the following proposition.

Proposition A pair $\left\{ w_i^t(\theta), T_i^t\left(w_i^t(\theta) \right) \right\}$ constitutes an incentive compatible mechanism if for all $\theta \in \left[0 \le \underline{\theta}, 1 \right]$ we have:

(A.10) $$\frac{\partial w_i^t(\theta)}{\partial \theta} \le 0, \quad \text{and}$$

(A.11)

$$T_i^t\left(w_i^t \right) = P\ y^t\left(w_i^t;\theta \right) - \pi_i^t\left(.;\underline{\theta} \right) - \psi^t - \int_{\underline{\theta}}^{\theta} P\ \dot{h}^t(u)\ w_i^t(u)\left(b - 2a\ h^t(u)\ w_i^t(u) \right) du\ .$$

The above proposition establishes the relation between $w_i^t(\theta)$ and θ and the relation between the water quota $w_i^t(\theta)$ and the appropriate water fee $T_i^t\left(w_i^t(\theta) \right)$. Under majority-*i* expressions (A.8) and (A.10) will be the incentive compatible constraints in the regulator problem for all irrigation technology *t*.

Appendix 2:

In this appendix, we show that under majority-1 the water fee for the modern irrigation technology adopters decreases as the size of the group increases. Let $Z^t\left(\theta \right) = \int P\dot{h}^t w_1^t\left(b - 2ah^t w_1^t \right) d\theta$, then (23) is rewritten as:

(A.12) $$T_1^L\left(w_1^L \right) = Py^L(w_1^L;\theta) - Z^L\left(\theta \right) + Z^L\left(\theta_1^* \right) - Z^H\left(\theta_1^* \right) + Z^H\left(0 \right),$$

Notice that $\dot{\pi}^t = P\dot{h}^t w_1^t \left(b - 2ah^t w_1^t\right)$ is the slope of optimal profit, by construction we always have $\dot{\pi}^L\left(\theta_1^*\right) > \dot{\pi}^H\left(\theta_1^*\right)$, since profit is monotonic we also have $Z^L\left(\theta_1^*\right) > Z^H\left(\theta_1^*\right)$. This implies that the fixed part, $Z^L\left(\theta_1^*\right) - Z^H\left(\theta_1^*\right) + Z^H\left(0\right)$, of the tariff in (A.12) is positive and that it increases as θ_1^* increases. Now if T_1^L increases as θ_1^* increases, this implies that F' and $\frac{F'}{\theta_1^*}$ in (24) decrease as θ_1^* increases as suggested above.

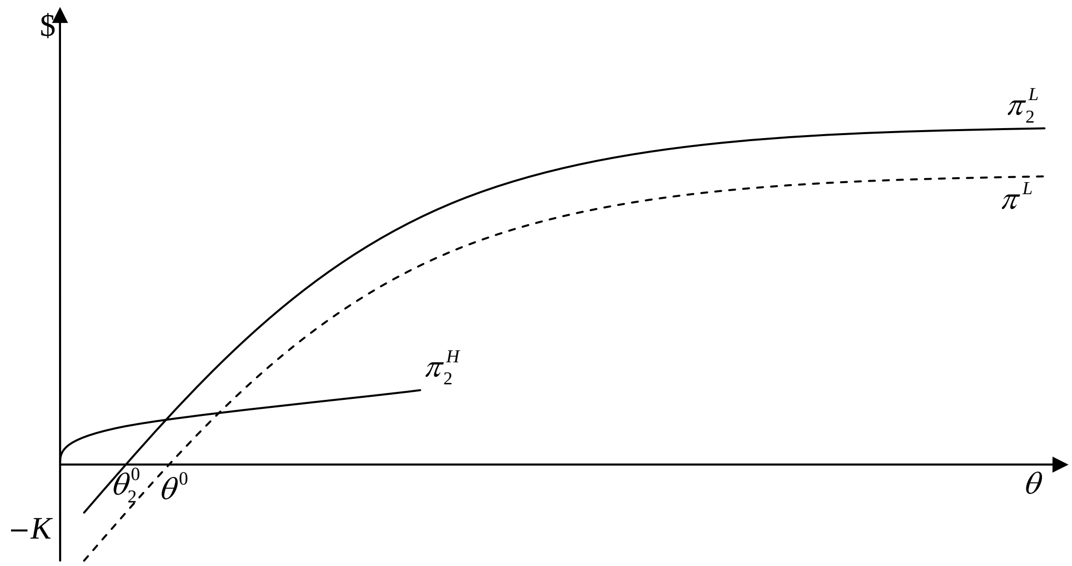

Figure 1. Modern irrigation technology adoption with majority-2

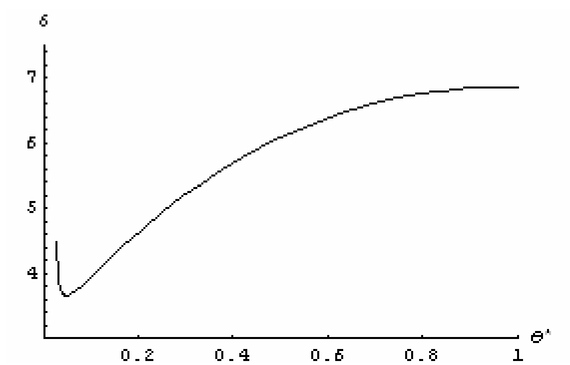

Figure 2. Departure from marginal cost by land type cutoff of irrigation technology adoption under the volumetric water pricing

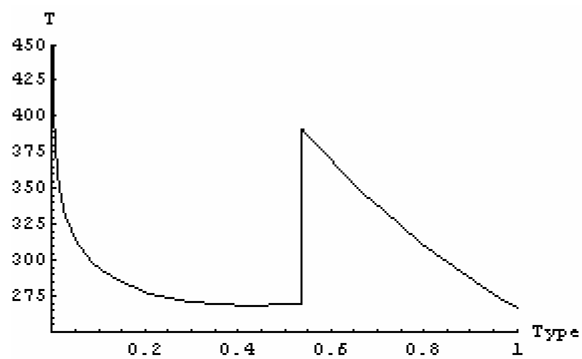

Figure 3. Water fee schedule by land type in the two-part tariff scheme (Majority-1)

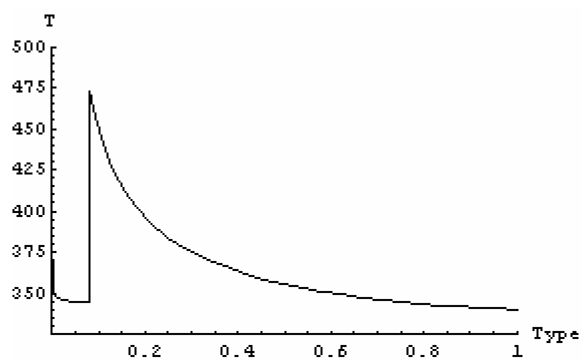

Figure 4. Water fee schedule by land type in the two-part tariff scheme (Majority-2)

Table 1. Effect of Pricing Policies and Lobby Groups on Water Prices, Technology Adoption, Profits and Social Welfare

		Majority-1	majority-2	Expected value
Two-part tariff	$\sum \pi$	\$399.61	\$384.80	\$392.21
	$\sum w$	2.961af	7af	4.98af
	θ^*	0.54	0.08	-
	(δ_i, g_i)	(4.24 , \$89.14)	(0.29 , \$328.65)	-
Inflated marginal cost	$\sum \pi$	\$378.47		\$378.47
	$\sum w$	2.64af		2.64af
	θ^*	0.628		-
	(δ_0, g_0)	(6.464,\$0.00)		-
Nonlinear pricing	$\sum \pi$	\$350.91	>\$384.38	>\$367.64
	$\sum w$	2.74af	>6.16af	4.45af
	θ^*	1	0.073	-

Table 2. Sensitivity of results to changes in output price

Pricing scheme		**Output price (\$/pound)**		
		0.5	**0.6**	**0.7**
Two-part tariff	**majority-1**	$\theta_1^* = 0.516$	$\theta_1^* = 0.535$	$\theta_1^* = 0.551$
		$\delta_1 = 3.963$	$\delta_1 = 4.238$	$\delta_1 = 4.476$
		$g_1 = \$102.43$	$g_1 = \$89.14$	$g_1 = \$77.68$
	majority-2	$\theta_2^* = 0.087$	$\theta_2^* = 0.080$	$\theta_2^* = 0.073$
		$\delta_2 = 0.319$	$\delta_2 = 0.286$	$\delta_2 = 0.260$
		$g_2 = \$322.34$	$g_2 = \$328.65$	$g_2 = \$333.93$
Inflated marginal cost $\delta_i > 1$		$\theta^* = 0.627$	$\theta^* = 0.628$	$\theta^* = 0.629$
		$\delta = 6.593$	$\delta = 6.464$	$\delta = 6.378$
Nonlinear tariff	**majority-1**	$\theta_1^* = 1$	$\theta_1^* = 1$	$\theta_1^* = 1$
	majority-2	$\theta_2^* \cong 0.098$	$\theta_2^* \cong 0.073$	$\theta_2^* \cong 0.058$