Political Economy and Irrigation Technology Adoption Implications of Water Pricing under Asymmetric Information

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Political Economy of Water Pricing

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ABSTRACT: We analyze the design of water pricing rules emerging from farmers’ lobbying and their implications for the size of the lobby, water use, profits and social welfare. The lobbying groups are the adopters of modern irrigation technology and the non-adopters. The pricing rules are designed to meet budget balance of water provision; we considered (i) a two-part tariff composed of a mandatory per-acre fee plus a volumetric charge and (ii) a nonlinear pricing schedule. Our results show that under either pricing schemes, farmers can organize and affect the outcome of the water schedule design. When only a volumetric fee is levied, the budget balance constraint prevents lobbies from influencing the design of the pricing scheme. In terms of expected welfare, the two-part tariff is preferable to the nonlinear pricing scheme or an inflated marginal cost fee.

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

1. Introduction

The provision of water for irrigation is often done by a water district or water users association. 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 be inefficient and would not result in the recovery of the costs of water provision. Scholars have proposed alternative pricing rules such as lump-sum transfers (Hotelling, 1938, 1939), inflated marginal cost (Adam Smith), and inverse proportional to demand elasticity deviation from the marginal cost (Ramsey-Boiteux)\(^1\). Lump-sum transfers and Ramsey-Boiteux pricing have been criticized because: (i) Lump-sum transfers leading to Ramsey-Boiteux pricing are costly to both developed and developing economies, are not Pareto optimal, and are usually paid for from taxes and therefore may face opposition by interest groups who favor smaller government and less taxes (Combes, Julien and Salanié, 1997; Laffont, 2000). (ii) Ramsey-Boiteux pricing requires

\(^1\) Ramsey (1927) and Boiteux (1956)
information about demand elasticity and therefore opens opportunity for political manipulation of the demand elasticity and fixed costs (Averch and Johnson, 1962), which may lead to inefficiency (Laffont, 2000).

In the case of water pricing the use of the volumetric pricing alone is not always possible when metering is costly, not possible, or when charging for water by the volume conflicts with religious beliefs or ethics. In various developing countries, water authorities charge a two-part tariff for irrigation water, for examples see Dinar and Subramanian (1997). Alternatively, for maximal rent extraction monopolists may be willing to practice second-degree price discrimination, but need to know user types, this is not often possible due to asymmetric information. For each of these policies there is considerable flexibility in their designing, indeed the regulator can secure the same revenue from water by using various combinations of fixed and variable fee structure, however the implications of those water fee structures for water demand are not the same. The design of a water pricing policy has important implications for the profits of users, such as farmers. These implications vary across farmers depending on their level of water use, which in turn depends on soil quality and technology choice. Water users therefore have incentives to form lobby groups to influence the design of a pricing policy.

Central water pricing authorities (water users associations or water districts) are usually nonprofit entities operating under budget balance constraints whose decisions are voted on by members either through popular vote (one-person-one-vote system) or through weighted votes reflecting land holdings or assessed value per acre (McCann and Zilberman, 2000). These members are often open to lobbying from different interest groups comprising of water users. With lobbies voters do not only voice their choice but they also attempt to influence the decision making process and since political candidates are mainly interested in being elected, they are
pressed to bias their policies in a direction preferred by strong and organized lobbies (Persson and Tabellini, 2002). Groups of farmers often constitute lobbies to influence policies, which in part may explain different water pricing levels and practices across districts, pricing practices vary from a fixed fee to a two-part tariff, a volumetric water fee, or multipart tariffs. As in many situations, water prices lead to a distribution of benefits among users and create political opposition and interest groups that attempt to influence the decision making process towards an outcome that is most favorable to the influential groups. Since pricing schemes can be met with resistance and are subject to lobbies, therefore omitting political economy aspects of water pricing may lead to ineffective policy recommendations.

In this paper, we consider water-pricing rules that would be preferred by either the adopters or nonadopters of modern irrigation technology and examine how these rules influence technology adoption, profits and social welfare of each group. We look into the political economy implications, for the adoption of modern irrigation technology and welfare, of a two-part tariff schedule composed of a mandatory per-acre fee plus a volumetric charge versus a nonlinear pricing schedule with asymmetric information.

We adopt a positive theory of water pricing and consider the emergence of two alternative groups of power who attempt to influence the regulator in setting a water fee schedule that benefits them. These groups consist either of those who adopt the modern irrigation technology or those that do not or otherwise stated between farmers with poor land quality and others with better lands. Each group consists of heterogeneous farmers. We focus on how water-pricing schedules are designed if these alternative interest groups influence the decision-making process and look into the feasibility of such design. The feasibility of any water fee
schedule depends on the size of the group of farmers that are better off with such schedule, because that will determine whether a majority will support them.

We consider a water authority operating under budget balance constraint that chooses the pricing policy preferred by the majority of farmers. Each, farmer has a single vote, and his type is private information. In a deviation from the benevolent maximizer of welfare, we consider that water authorities’ bylaws constitute an incomplete contract, which makes them residual decision makers, therefore 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. Water authority delivers water as a natural monopolist with constant marginal costs and high fixed costs.

Given its market power, a natural monopolist may choose to use price discrimination to extract surplus from consumer and cover fixed costs. More particularly the monopolist may choose to apply second-degree price discrimination by selling various volumes of water at different unit price, using two-part tariff, increasing/decreasing block tariffs, three-part tariff, which are all particular cases of nonlinear pricing (Wilson, 1993, p.4;136). In the next section, we consider two pricing principles: (i) The two-part tariff and its particular case of inflated marginal cost pricing recommended by Adam Smith to cover fixed costs without recourse to public money to finance the deficit, and (ii) Edgeworth (1913) price discrimination subject to budget balance constraint to help cover costs with less distortion. Under either pricing principle each group of farmers, those who adopt the modern irrigation technology and those who do not adopt it, seek to influence the water authority to design a water-pricing rule that serves best its
interest and eventually put more of the burden to pay for the fixed cost on members of the other group.

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, e.g. McCann and Zilberman (2000), and analyze its political economic implications for water use (Johansson et al., 2002). McCann and Zilberman, derive water-pricing rules that maximize the number of votes and analyze under full information their implications on technology choice and land use in California, and test their validity econometrically. McCann and Zilberman’s median voter model belongs to the Chicago school (Stigler, Posner, Peltzman, Becker) and suffers from two shortcomings. First, the absence of asymmetric information in their model leads to a lack of incentives for the farmers to exert any political influence to extract rents, and limits the regulator's discretion to favor an interest group over the common good. Second, by focusing on water authority decisions to maximize the number of votes, the authors overlook the influence that lobbies exert on decision makers (Laffont and Tirole, 1993; Laffont, 2000). In the median voter model first proposed by Black (1948) and Downs (1957), the decision maker commits to a policy and announces it to maximize favorable votes. The median voter model is different from models with lobbies.

In McCann and Zilberman (p. 82), the decision maker’s objective is to maximize the positive votes to the announced policy but does not discriminate between farmers, with

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2 A collection of articles on the political economy views of the Chicago school is available in Stigler (1988).
3 In the framework of Hotelling’s (1929) spatial competition model, the median voter model comes down to a choice of location.
asymmetric information the decision maker has an opportunity to take into consideration the well
being of a group of farmers above the others. Additionally, even if the regulator decides on
using a particular pricing scheme because it is the most popular, there is discretion on its design
and that is where the importance of lobbies manifests. McCann and Zilberman (2000) take the
context of water users associations in California, water districts are nonprofit organizations
controlled by members elected by farmers according to either a popular vote or weighted voting
system. The political structure of a district is such that farmers decide on inputs and technology
to grow crops; depending on water availability and investment costs, the district makes water
available through water rights acquisitions and storage, the district aims at delivering water in a
timely and reliable fashion. The district signals water scarcity through prices and farmers signal
their wishes to the district managers through votes. Due to transaction costs, structure of water
fees, legal constraints, voting concerns, and a variety of other reasons both parties do not receive
the signals perfectly and react to them imperfectly, this creates room for interested parties to
lobby in order to have their interests considered. Although McCann and Zilberman do not take
them into consideration, informational symmetries are prevalent in the functioning of water
districts.

A general model addressing the political economy of pricing with discrete types agents
each trying to affect the pricing schedule is developed in Laffont (2000). In Laffont’s model, the
size of each group is exogenous whereas in our model it is endogenous because farmers self-
select the group to which they belong by deciding to adopt the modern irrigation or otherwise.
Laffont assumes homogeneity within each group; however, farmers are not necessarily
homogenous. In our model, we are dealing with a continuum of types and the size of each lobby
group is the result of self-selection, including intra-group heterogeneity is important in determining the political power of each group.

The main results of this paper are that under 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. In terms of expected welfare, the two-part tariff is preferable to the nonlinear pricing scheme or the inflated marginal cost fee. Compared to the inflated marginal cost fee where lobbies are not important, the effect of lobbies is welfare improving with a two-part tariff but not with nonlinear pricing. A priori, compared to the two-part tariff, the nonlinear pricing seems to lead to less water use both in expected value and with either group of farmers in majority. With respect to the adoption of modern irrigation technology, we find that the nonlinear water fee is designed to lead all farmers to adopt the same irrigation technology and pay for water following a schedule that closely matches the cost of water function, because farmers are granted a reservation profit this does not lead to land retirement. The inflated marginal cost tariff leads to more adoption of modern irrigation technology than the two-part tariff when in the later case farmers who adopt the modern irrigation technology influence the decision-making process.

This paper is organized as follows; in the next section, we present the model's general setup. In section three, we discuss the two-part tariff model and its particular case of inflated marginal cost. Section four, covers the second-degree price discrimination model. Section five, presents a numerical simulation of the previous models using a calibrated model of cotton production in the San Joaquin Valley in California. Section six 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, $\theta$ 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:

$$\pi^t(w';\theta) = P y^t(w';\theta) - T^t(w') - \psi^t.$$

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 $\psi^t$ 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 $w^t$ already defined above and $h^t(\theta)$ are respectively the quantity of applied water per-acre and the irrigation effectiveness of technology $t$. The irrigation effectiveness of technology $t$ is defined by:

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

where $\varepsilon$ is a very small positive value and $\alpha = 1$ 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 $\theta$ 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. The modern irrigation technology benefits farmers with low types more than those who have high types, for realistic values of $\alpha$, we have $h''(\theta) > h'(\theta)$ and the difference decreases as $\theta$ increases.

*Production function*

If we express the general production function using the effective water use $e'$, then one can show that the level of water use with the modern technology decreases if the elasticity of marginal productivity of applied water is greater than one. Consider the elasticity of marginal productivity of effective water: $emp' = -e' \frac{\partial^2 y' / \partial e'^2}{\partial y' / \partial e'}$, its magnitude depends on the specification of the production function and the level of effective water use, the optimal quantity of applied water decreases with respect to farmer’s type when $emp' > 1$ (Caswell and Zilberman, 1986). A class of production functions that meets this requirement is the family of quadratic production functions. We therefore assume the following constant returns to scale production function $y'(w'; \theta) = -d + bw'h - a\left(w'h\right)^2$ where $a > 0, b > 0$, and $d \geq 0$ are constants.

*Farmers’ decision-making*

We consider a nonprofit water authority operating as a natural monopoly under a budget constraint. Its costs of providing a volume of water, $w$, is $C = \phi w + K$ where $\phi$ is the marginal cost and $K$ is the fixed cost. We assume that capital costs are indivisible and that the regulator is

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4 This implies that $w_t > \frac{b}{4ah}$
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. 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. 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 \( \theta \in [0, \theta_2] \), where \( \theta_2 \) solves \( \pi''(\theta_2) = \pi''(\theta_1) \) such that \( \pi' > 0, \forall t \in \{L, H\} \), farmers adopt the modern technology (\( t=H \)) since \( \pi'' \geq \pi_0 \) and \( \pi'' \geq 0 \). For \( \theta \in [\theta_1, 1] \) 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 \( \theta \) increases. Given the assumptions that \( h''(\theta_i) \) is concave and \( emp_i^t > 1 \), they also show that there is a single crossing point between \( \pi_i^L \) and \( \pi_i^H \).

We assume that a group of farmers if large enough (more than 50%) it can influence the design of the water fee schedule. If \( \theta_2 > 0.5 \) then farmers adopting the modern irrigation technology have a majority (we refer to that as majority-1) while if \( \theta_2 < 0.5 \) 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. Under either majority, \( \theta \) is the land quality that solves for \( \pi''\left(w_i^H(\theta_i); \theta_i\right) = \pi''\left(w_i^L(\theta_i); \theta_i\right) \), farmers with land quality below \( \theta_2 \) adopt the modern irrigation technology while farmers with land quality higher than \( \theta_2 \) maintain the traditional irrigation technology.
3. Two-part tariff and inflated marginal cost

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 \( T''_i (w'_i(\theta)) = \delta_i \phi w'_i(\theta) + g_i \). The budget balance condition is:

\[
g_i + \phi (\delta_i - 1) \left( \int_0^{\theta_i} w''_i(\theta) dF(\theta) + \int_{\theta_i}^{1} w'_i(\theta) dF(\theta) \right) = K.
\]

Since \( \theta^+ \) takes either a value \( \theta^+_1 \) or \( \theta^+_2 \) depending on the group that is in the majority the solutions for \( w''_i, \ w'_i, \ \delta_i, \ \) and \( g_i \) in (3) will differ by subscript \( i \). Profit maximization by all farmers implies a water demand:

\[
w'_i(\theta) = \frac{1}{2ah'} \left( b - \frac{\delta_i \phi}{Ph'} \right) ; \forall (i,t) \in \{1,2\} \times \{L,H\},
\]

which transforms (3) into:

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

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 \( \delta_1 \) and \( g_1 \) by solving the following maximization problem: \( \max_{\delta_1, g_1} \int w''_1(\theta) d\theta \) subject to (5) with \( \theta^+ = \theta^+_1 \), and \( w'_1 = \arg \max \pi'_1 \left( \frac{w'_1(\theta)}{\theta} \right) ; \forall t \in \{L,H\} \) as determined from (4).
The solution to this problem can be represented as follows by denoting

\[ A(\theta_1) = \frac{b}{2a} \left( \frac{\theta_1^{1-\alpha}}{1-\alpha} - \ln(\theta_1) \right) > 0 \quad \text{and} \quad B(\theta_1) = \frac{1}{2aP} \left( 1 - \frac{1}{\theta_1} - \theta_1^{1-2\alpha} \right) < 0. \]

\[ \delta_i(\theta_i^*) = \frac{b}{2a} \frac{\theta_i^{1-\alpha}}{1-\alpha} - \theta_i^* \left( A(\theta_i^*) - \phi B(\theta_i^*) \right) \]

\[ \frac{\phi}{2aP} \frac{\theta_i^{1-2\alpha}}{1-2\alpha} + 2\theta_i^* \phi B(\theta_i^*) \]

The volumetric fee is therefore \( \phi \delta_i(\theta_i^*) \) and the fixed fee is:

\[ g_i(\theta_i^*) = K - \phi (\delta_i - 1) \left[ A(\theta_i^*) + \delta_i \phi B(\theta_i^*) \right]. \]

Under majority-2, the group influencing the decision making solves

\[ \max_{\delta_1, \delta_2, \theta_2^*} \int_{\delta_2, \theta_2^*}^1 \pi_2^L(w_2^L(\theta_1; \theta_2))d\theta_1 \text{ subject to (5) with } \theta^* = \theta_2^*, \text{ and } w_2^L = \arg \max_w \pi_2^L(w^L_2(\theta_1; \theta_2)); \forall t \in \{L, H\}. \]

This gives the following volumetric and fixed fees:

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

\[ \frac{1}{2aP} \left( \frac{1}{\theta_2^*} - 1 \right) + 2 \left( 1 - \theta_2^* \right) B(\theta_2^*) \]

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

In Section 2.5 we use numerical simulation to find values for \( \theta_1^* \) and \( \theta_2^* \) and analyze the shape of \( \delta_i(\theta_i^*) \) and \( g_i(\theta_i^*) \) in (6)-(9) with respect to \( \theta_i^* \).

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 price; a higher fixed cost entails higher per acre fee. The marginal cost of water provision affects both the variable and the per acre portions of

\[ ^5 \text{Notice that since } \theta \in [0,1], \text{ therefore } \ln(\theta) \leq 0 \text{ and } \frac{1}{\theta} \geq 1. \]
the water fee schedule, however the sign of the derivatives of $\delta_i$ and $g_i$ with respect to $\phi$, $P$, or $\theta_i^*$ cannot be established since $\delta_i$ is not monotonic with respect to these coefficients. However, it is expected that if $\delta_i$ is high, $g_i$ must be low to meet the budget balance constrain, this implies that $\theta_i^*$ tends to be high, but when $\delta_i$ is low and $g_i$ is high, $\theta_i^*$ tends to be low. Essentially, farmers have incentives to adopt the modern irrigation technology when the unit fee of water is high and the per-acre fee is low, this is because a high per-acre fee and lower unit fee for water reduce farmers' profits without affecting their water use.

Since the water authority operates under a budget balance condition it implies that if $K = 0$ and $\delta_i > 1$, then it must be that $g_i < 0$. 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.

In case there is no per-acre fee then $\delta_1 = \delta_2 > 1$ has to solve the quadratic equation (7) or (9). Both equations give the same solution for $\theta_i^*$, 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:

$$
\delta_i = \delta_2 = \frac{-A + \phi B + \sqrt{4KB + (A + \phi B)^2}}{2\phi B}.
$$
In Laffont (2000), because the size of each group is exogenous and only discrete values for $\theta$ are considered, two different values for the water fee are obtained depending on the group in majority. However, if the size of the group in majority is endogenous and only the volumetric price is used, farmers self-select into either group regardless of the group influencing the decision-making. In this case, the budget balance constraint is a strong enough institutional constraint to neutralize the effect of lobbies.

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.

The welfare under the inflated marginal cost and under the two-part tariff are respectively,

\[
W(\alpha) = \int_{\theta^*}^{\theta^*} \pi^H(\theta) dF(\theta) + \int_{\theta^*}^{\theta^*} \pi^L(\theta) dF(\theta), \text{ when } g_i = 0.
\]

\[
W^I(\alpha) = 0.5 \left( \int_{\theta^*}^{\theta^*} \pi^H_i(\theta) dF(\theta) + \int_{\theta^*}^{\theta^*} \pi^L_i(\theta) dF(\theta) \right) + 0.5 \left( \int_{\theta^*}^{\theta^*} \pi^H_{2i}(\theta) dF(\theta) + \int_{\theta^*}^{\theta^*} \pi^L_{2i}(\theta) dF(\theta) \right)
\]

where $\pi^H_i$ is the profit under majority-$i$ using technology $t$. In the numerical simulation section, we represent the above findings and conduct robustness analysis by varying the price of output.

### 4. Second-degree price discrimination

We now examine a second-degree price discrimination policy where the unit price changes with the volume (initially suggested by Edgeworth, 1913). With second-degree price discrimination
the water agency needs to devise individualized pricing schemes. In the absence of perfect information about land quality (i.e. farmers types) the problem becomes a principal-agent problem and hence there is a need to develop a revelation mechanism. According to the majority in power a farmer of type $\theta$ is given a take-it-or-live-it contract consisting of the pair

$$\{w_i' (\theta), T_i^r (w_i' (\theta))\} : \forall (i, r) \in \{1, 2\} \times \{L, H\}.$$  

Budget balance requires

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

Welfare under majority-$i$ is given by:

$$W_i^H = \int_0^{\theta'} \pi_i^H (\theta) dF (\theta) + \int_0^1 \pi_i^L (\theta) dF (\theta),$$

the expected welfare with second-degree price discrimination is:

$$(15) \quad W^H = 0.5W_1^H + 0.5W_2^H.$$  

Under majority-$i$ the optimal water fee schedule is the solution of,

$$\max_{\{w_i', T_i^r\} \theta'} \int \pi_i^r (\theta) dF (\theta),$$

subject to budget balance constraint (13), $\pi_i^r (\theta) \geq 0; \forall \theta \in [0, 1]$, 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 the appendix.

$$\pi_i^L (\theta) \leq 0; \forall \theta \in [0, \theta_s],$$  

$$(18) \quad \pi_i^L (\theta) = PH \left[ w_i^H \left( b - 2ah^H w_i^H \right) \right] ; \forall \theta \in [0, \theta_s],$$

$$\phi \leq 0; \forall \theta \in [\theta_s, 1],$$  

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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 $\theta$. 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

$$\int_0^{\theta_1^*} \left( P_y^{H}(w^H;u) - T_i^{H}(w^H - \psi^{H}) \right) du$$

subject to (19), (20), and $\pi_i'(\theta) \geq 0; \forall \theta \in [0,1]$, we assume that farmers’ payoffs from outside opportunities is zero. Under majority-1, members of that group are allowed informational rents therefore the incentive compatibility constraints (17) and (18) do not apply.\(^6\) With $\theta_s = \theta_1^*$, integrating (20) between $\theta_1^*$ and $\theta$ gives:

$$P_y^{L}(\cdot) - T_i^{L}(\cdot;\theta_s^*) = \int_{\theta_1^*}^{\theta} P\hat{\Phi} w_i^L \left( b - 2ah^L w_i^L \right) du.$$  

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

$$\begin{cases} P_h^{H}(b - 2ah^H w_i^H) = \phi \\
\int_{\theta_1^*}^{\theta} P\hat{\Phi} \left( b - 4ah^L w_i^L \right) du = \phi \\
\end{cases} \quad ; \forall \theta \in \left[0,\frac{1}{2}\right]$$

\(^6\) Similarly, under majority-2 farmers who adopt the modern irrigation technology are allowed informational rents therefore constraints (19) and (20) do not apply.
In (22), farmers who adopt the modern irrigation technology and influence the decision making process value water at its marginal cost, but farmers using the traditional irrigation technology value water at below its marginal cost since as stated in footnote 3 we have
\[ w_{i}^{L} > \frac{b}{4ahL}. \]

In order to derive the fee schedule for farmers who use the traditional irrigation technology we use (21) and add to it \[ \pi_{i}^{H} (\cdot;\theta_{i}^{*}) - \pi_{i}^{H} (\cdot;0) = \int_{0}^{\theta_{i}^{*}} P_{H_{i}} \delta_{W_{i}^{H}} \left( b - 2ah^{H} w_{i}^{H} \right) du \] on both sides of the equation.\(^7\) With a reservation profit equal to zero for the lowest land quality, \[ \pi_{i}^{H} (\cdot;0) = 0, \] and profits equality at \( \theta_{i}^{*}, \) \[ \pi_{i}^{H} (w_{i}^{H}(\theta_{i}^{*});\theta_{i}^{*}) = \pi_{i}^{L} (w_{i}^{L}(\theta_{i}^{*});\theta_{i}^{*}), \] we get the following water fee schedule for farmers who adopt the traditional irrigation technology,

\[ T_{i}^{L} (w_{i}^{L}) = P_{y_{i}^{L}} (w_{i}^{L};\theta) - \int_{0}^{\theta_{i}^{*}} P_{H_{i}} \delta_{W_{i}^{L}} (b - 2ah^{L} w_{i}^{L}) du - \int_{0}^{\theta_{i}^{*}} P_{H_{i}} \delta_{W_{i}^{H}} (b - 2ah^{H} w_{i}^{H}) du. \]

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,

\[ T_{i}^{H} = \phi w_{i}^{H} + F' \frac{F'}{\theta_{i}^{*}}; \text{where } F' = \int_{\theta_{i}^{*}}^{\theta_{i}^{*}} \left( \phi w_{i}^{L}(u) - T_{i}^{L}(w_{i}^{L}(u)) \right) du + K. \]

In (23), 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 \( w_{i}^{L} \) and a non-zero intercept.\(^8\) The water fee schedule for the group in majority is a two-part tariff, where the

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\(^7\) We use the envelope theorem on the profit of farmers who adopt the modern irrigation technology to derive \( \pi_{i}^{H} (\cdot;\theta_{i}^{*}) \).

\(^8\) Notice that the first integral depends on \( \theta \) therefore it gives an expression that is function of \( w_{i}^{L}(\theta) \) and a constant at \( \theta_{i}^{*} \), additionally the second integral in (23) is a definite integral and is therefore a constant.
variable part is the marginal cost of water provision, the fixed part depends on the size of the group in majority, since it depends on $\theta_1^*$. From (24) one can see that if all farmers adopt the modern irrigation technology, farmers pay for water according to a schedule that matches the cost of water provision.

The second equation in (22) is a Volterra integral equation of the second kind, whose solution is usually possible only in a numerical form. However, in this case the cutoff point $\theta_1^*$ can be inferred as follows from the profit expressions without having to solve for $w_i^L$ in (22).

Water fee schedules have to be designed such that $\pi^L_i \left( w_i^L; \theta_1^* \right) = \pi^H_i \left( w_i^H; \theta_1^* \right)$. When $\theta = \theta_1^*$ then using (23), $\pi^L_i \left( w_i^L; \theta_1^* \right) = \pi^H_i \left( w_i^H; \theta_1^* \right)$ reduces to:

$\int_0^{\theta_1^*} P_h^K w_i^H \left( b - 2ah^H w_i^H \right) du = P_y^H \left( w_i^H; \theta_1^* \right) - T_i^H \left( w_i^H \right) - \psi^H$.

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 $\theta_1^*$. Since the profit is an increasing function of $\theta$, and the aggregate profit of farmers who adopt the modern irrigation technology increases with the size of the group, therefore

$\int_0^{\theta_1^*} \left( P_y^H \left( w^H; u \right) - T_i^H \left( w_i^H \right) - \psi^H \right) du$ is maximized when $\theta_1^* = 1$, this result will be confirmed numerically in the next section.\(^9\) First, this implies that under asymmetric information using second-degree price discrimination, farmers who adopt the modern irrigation technology can

---

\(^9\) We do not find similar results under the inflated marginal cost pricing policy because under the latter there is only one two-part fee structure that all farmers have to face, however in the nonlinear pricing policy farmers in majority face a two-part tariff, the rest faces a nonlinear tariff. A nonlinear tariff allows extracting all the informational rent; therefore, all farmers have an incentive to belong to the group in majority.
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 in paying for the fixed costs of water provision. Farmers are assumed to receive at least zero profit, since farmers with the poorest lands are in the majority group, therefore charging each farmer in the group his valuation for water and an equal fraction of the fixed cost gives always a higher profit than any deviation from it. Indeed, if farmers who adopts the traditional irrigation technology pay for water less then its marginal cost, then the fixed part of the tariff of all farmers has to compensate for that deficit. From (23) and (24), an increase in $\theta_i^*$ leads to an increase in the fixed part of the water fee schedule for farmer who adopt the traditional irrigation technology but decreases the fixed fee for farmers who adopt the modern irrigation technology. Therefore, every farmer at the margin has an interest in adopting the modern irrigation technology and $\theta_i^*$ extends to 1 because any deviation from that behavior is not optimal. Indeed, let $Z^t(\theta) = \int P\tilde{\beta}_{i\theta} w_i^t(b-2ah'w_i^t) d\theta$, then (23) is rewritten as:

$$T_i^L(w_i^L) = P_y(L(w_i^L;\theta) - Z^L(\theta) + Z^L(\theta_i^*) - Z^H(\theta_i^*) + Z^H(0),$$

(26)

Notice that $\pi^L = P\tilde{\beta}_{i\theta} w_i^L(b-2ah'w_i^t)$ is the slope of optimal profit, by construction we always have $\pi^L(\theta_i^*) > \pi^L(\theta_i^*)$, since profit is monotonic we also have $Z^L(\theta_i^*) > Z^H(\theta_i^*)$. This implies that the fixed part, $Z^L(\theta_i^*) - Z^H(\theta_i^*) + Z^H(0)$, of the tariff in (26) is positive and that it increases as $\theta_i^*$ increases. Now if $T_i^L$ increases as $\theta_i^*$ increases, this implies that $F'$ and $\frac{F'}{\theta_i}$ in (24) decrease as $\theta_i^*$ increases as suggested above.
Using a similar approach, under majority-2 the optimal water uses and corresponding water fee schedules are given by:

\[
\begin{align*}
\Phi^h L \left( b - 2ah^L w^L_2 \right) &= \phi + \int_0^{\theta^h_2} P_{h}^{h} \left( b - 4ah^H w^H_2 \right) \, du \quad ; \forall \theta \in \left[ 0, \theta^h_2 \right], \\
\Phi^L L \left( b - 2ah^L w^L_2 \right) &= \phi \quad ; \forall \theta \in \left[ \theta^L_2, 1 \right]
\end{align*}
\]

(27)

\[
T^H_2 \left( w^H_2 \right) = P_{y}^H \left( w^H_2 ; \theta \right) - \psi^H - \int_0^{\theta^h_2} P_{h}^{h} \left( b - 2ah^H w^H_2 \right) \, du,
\]

(28)

\[
T^L_2 = \frac{\phi w^L_2 + F^*}{1 - \theta^L_2} ; \text{where } F^* = \int_0^{\theta^L_2} \left( \phi w^H_2 (u) - T^H_2 \left( w^H_2 (u) \right) \right) \, du + K.
\]

(29)

Under majority-2, farmers who adopt the modern irrigation technology pay for water following a nonlinear water fee schedule and value water at below its marginal cost while those in majority are charged a two-part tariff and value water at its marginal cost.

Compared to majority-1, 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 no farmer adopts the modern irrigation technology, then the profit of farmers who adopt the traditional irrigation technology has a negative intercept that depends on the value of $K$, see curve $\pi^L$ in figure 1 and equation (29). However, this situation is not possible, since only farmers who use water pay a fee and farmers adopting the traditional irrigation technology pay for water at its marginal cost therefore, the variable costs of water provision are covered but not the fixed cost because $\int_{\theta^L_2 \geq 0} K du < K$. Therefore, water fee schedule has to be designed to allow for $\pi^H_2$ to be higher than $\pi^L_2$ for enough land types to cover for the portion of the fixed cost that cannot be covered by farmers using the traditional irrigation technology. If one increases enough the profit of farmers who adopt the modern irrigation technology from zero to $\pi^H_2$, this induces a
shift of $\pi^L$ to $\pi^L_2$, since a positive water fee from farmers who adopt the modern irrigation technology decreases the intercept in (29). This leads to a shift of $\theta^0$ to $\theta^0_2$, an increase in $\theta^*_2$ from zero, and reduces the burden of farmers in majority-2 in paying for the fixed cost of water provision therefore maximizes their profit. By construction $\theta^*_2$ should be between $\theta^0_2$ and $\theta^0$, if $\theta^0$ is small enough as it will be shown in the numerical part then the interval $[\theta^0_2, \theta^0]$ is small enough therefore $\theta^0$ is a good approximation of $\theta^*_2$. If $\theta^*_2 > \theta^0$, this implies that $\pi^L_2 < \pi^L$, 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 $\theta^*_2 \in [\theta^0_2, \theta^0]$. In extreme cases where $\pi^H_2$ is higher than $\pi^L_2$ 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. Modern irrigation technology adoption with majority-2](image-url)
The results of this section suggest that under majority-1 all farmers adopt the modern irrigation technology because that way farmers 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 extracting all the informational rent; therefore, all farmers have an incentive to belong to the group in majority.

5. Numerical simulation

To numerically simulate 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 US$500/acre while that of drip technology is assumed to be US$633/acre. Therefore, $\psi^H = $US$133$. 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. 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

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10 The USDA’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.
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 US$15.63 per acre-foot. The cost of groundwater was about US$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 US$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 US$25 million. The district has about 100,000 acres of farmed cropland, which implies that the corresponding capital cost per acre is US$250.\textsuperscript{11}

![Figure 2. Profits by land type in the two-part tariff scheme](image)

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 (figure 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,

\textsuperscript{11} The acreage data is from Tsur (1997).
the water fee schedule is designed in such a way as to make the group in minority (farmers who adopt the modern irrigation 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.

Under either majority, the size of the group influencing the decision-making varies with the model's parameters; figure 3 shows the shape of $\delta_i$ as function of the size of the group in majority. Under majority-1, $\delta_1$ is not monotonic when $\theta_1^* > 0.5$, but it is decreasing over almost the entire admissible interval (except when land type is close to 1, in which case $\delta_1$ is always greater than one). This is intuitively clear since the more there are farmers who adopt the modern irrigation technology, the lower is the aggregate water use therefore there is less need to charge above the marginal cost of water provision. Under majority-2, admissible values of $\delta_2$ are at very low values of land type and is less than one. In figure 4, under either majority the fixed portion of the water fee schedule is positive and almost always increasing with the size of the group, but not monotonic over admissible values of majority sizes $\theta_i^*$. 

![Figure 3. Value of $\delta_i$ as function of $\theta_i^*$](image)

(a) Majority-1  
(b) Majority-2
In figure 5, it is clear that aggregate water use under majority-1 is much lower than water use under majority-2; in fact, for any given land type water use under majority-1 is always lower than that under majority-2. The volume of water consumed is 2.961 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 this is offset by lower water use and therefore 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; US$399.61 versus US$384.80, expected welfare is US$392.21.
In case farmers are charged for water only using volumetric price, then the per-unit cost of water is the same regardless of the group influencing the decision-making. The departure from the marginal cost is $\delta_1 = \delta_2 = 6.5$, 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 is increasing and is monotonic, with lower water use higher fees are required to pay for the fixed cost of water provision (figure 7.a).

Figure 6. Water fee schedule by land type in the two-part tariff scheme

Figure 7. Irrigation technology adoption under the volumetric water pricing
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 per-acre fee encourages more adoption of modern irrigation technologies (figure 7.b). Under the volumetric pricing, water use and fees are closer to those under majority-1 with the two-part tariff (figure 8). Aggregate water use under the volumetric 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 the volumetric water fee, welfare is US$378.47, which is lower than the expected welfare under the two-part tariff, US$392.21. Using the volumetric water fee alone improves water conservation since it encourages the adoption of modern irrigation technologies, but leads to a lower excepted welfare compared to the two-part tariff. The two-part tariff leads to lower water use and higher welfare 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 $\theta_1^*$ that solves for (25) falls outside the range of land types, and is largely higher than one. This
leads us to believe that even with the true value of \( w_{1}^{L} \) it must be that \( \theta_{1}^{L} = 1 \) 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, and we discussed that if land retirement occurs at very low values of \( \theta \) one can approximate the size of the group of farmers who adopt the modern irrigation technology to be \( \theta_{2}^{*} \equiv 0.073 \). Over a large portion of land type qualities, profit with majority-2 is higher than that with majority-1 (figure 9), welfare with majority-1 is US$350.91 while that with majority-2 is at least equal to US$384.38, leading to an expected welfare that is no less than US$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 where water use is higher at all land types (figure 10). 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 (figure 11).
In table 1, we summarize the welfare and water uses under the various pricing schemes with alternative majorities. It shows that the expected welfare under the two-part tariff is higher than that under the nonlinear pricing, some of the welfare losses are due to information asymmetry.\footnote{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.} 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 efficient that 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 pricing are only an approximation 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. Summary of welfare and water uses

<table>
<thead>
<tr>
<th>Welfare/Water</th>
<th>majority-1</th>
<th>majority-2</th>
<th>Expected value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-part tariff</td>
<td>$399.61</td>
<td>$384.80</td>
<td>$392.21</td>
</tr>
<tr>
<td></td>
<td>2.961af</td>
<td>7af</td>
<td>4.98af</td>
</tr>
<tr>
<td>Inflated marginal cost</td>
<td>$378.47</td>
<td>$378.47</td>
<td>$378.47</td>
</tr>
<tr>
<td></td>
<td>2.637af</td>
<td>2.637af</td>
<td>2.637af</td>
</tr>
<tr>
<td>Nonlinear pricing</td>
<td>$350.91</td>
<td>$384.38+</td>
<td>$367.64+</td>
</tr>
<tr>
<td></td>
<td>2.741af</td>
<td>6.156af+</td>
<td>4.448af</td>
</tr>
</tbody>
</table>

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 such variation are provided in table 2. In the two-part tariff case, both majorities are sustainable at all output prices we considered. However, in the two-part tariff majority-1 cannot be enforced when $P = $0.4$, the same applies to majority-2 at very high output prices for example $P = $1.91$. Table 2 shows that as output price increases the adoption of modern irrigation technology is non-decreasing with the volumetric pricing and with majority-1 under the two-part tariff and the second-degree price discrimination. However, under majority-2, regardless of the pricing scheme, an increase in output price seems to reduce 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, an increase in the per-acre fee reduces the adoption of the modern irrigation technology.

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

### 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 found that when the budget has to be balanced lobbies matter. A volumetric fee leads to higher modern irrigation technology than a two-part tariff, when in the later case farmers who adopt the modern irrigation technology influence the decision-making process, and is independent of lobbies. However, the volumetric water fee leads to a lower expected welfare but also to a lower water use than the two-part tariff.

When the decision maker designs a nonlinear water fee, we found 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.

It appears that two-part fee structures in general are preferable to other alternatives, indeed from above 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. 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. Taking into consideration the above interaction between farmers and the regulator, developing countries, in order to avoid using a volumetric fee alone and for its ease of implementation, the use of a combination of per-acre fee and a volumetric fee may be used to achieve a high welfare level and yet some adoption of modern irrigation technologies. In more developed economies, where water metering is more acceptable and feasible the volumetric fee is used, and gives moderate welfare and high adoption of modern irrigation technologies. Other countries combine the volumetric fee with a fixed component
based on considerations other than acreage; this gives the lowest welfare but leads to a much higher adoption of modern irrigation technologies.

The model in this paper could be improved by modeling more explicitly lobbyists’ behavior. In this paper, we assume ad-hoc that a group of farmers influences the decision-making process without looking into how such groups becomes in majority or why the regulator pays a 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, the endogeneity of the size of the lobbies in our model and the fact that the success of a lobby appears ex-post makes the use of probabilities of success of a lobby in influencing policies reasonable.
References


Political Economy of Water Pricing


Appendix

Truth-telling mechanism design

In this section, we design a truth-telling mechanism, the individual land quality parameter $\theta$ is not known to other farmers. The only information available about $\theta$ is its probability distribution $f(\theta)$, its cumulative distribution function $F(\theta)$, and its support $[0,1]$, independence between the $\theta$s 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 $\theta$. 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 $\{w_i'(\hat{\theta}), T_i'(w_i'(\hat{\theta}))\}$; $\forall (i,t) \in \{1,2\} \times \{L,H\}$ 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 $\Pi^i_t(\hat{\theta},\theta) = P_y^i \left(w_i'(\hat{\theta});\theta\right) - T_i^i \left(w_i'(\hat{\theta})\right) - \psi^i$, 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 $\theta$ and announces $\hat{\theta}$. For $\{w_i'(\hat{\theta}), T_i'(w_i'(\hat{\theta}))\}$ to be a truth-telling mechanism it implies that for every $\theta$ and $\hat{\theta}$ in $[0,1]$, the farmers profit when his type is $\theta$ (respectively $\hat{\theta}$) and reveals $\theta$ (respectively $\hat{\theta}$) is greater than his profit when his type is $\theta$ (respectively $\hat{\theta}$) and reveals $\hat{\theta}$ (respectively $\theta$), which expressed mathematically gives:

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

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

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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 $w = w_i'(\theta)$ and $\hat{w} = w_i'(\hat{\theta})$ and dropping the indices $i$ and $t$ and using $u$ as integration variable, then (A.1) and (A.2) imply:

\begin{equation}
(A.3) \quad -\int_{\hat{w}}^{w} \left( P \frac{\partial y'(u; \theta)}{\partial u} - \frac{\partial T(u)}{\partial u} \right) \, du \leq 0, \text{ and}
\end{equation}

\begin{equation}
(A.4) \quad \int_{\hat{w}}^{w} \left( P \frac{\partial y'(u; \hat{\theta})}{\partial u} - \frac{\partial T(u)}{\partial u} \right) \, du \leq 0.
\end{equation}

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

\begin{equation}
(A.5) \quad \int_{\hat{w}}^{w} \int_{\hat{v}}^{v} P \frac{\partial^2 y'(u; v)}{\partial u \partial v} \, du \, dv \leq 0.
\end{equation}

Recall that $\frac{\partial^2 y'(w_i'(\theta); \theta)}{\partial w_i'(\theta) \partial \theta} = \frac{\partial h'(\theta)}{\partial \theta} \left(b - 4ah'(\theta)w_i'(\theta)\right)$ and that $w_i'(\theta) > \frac{b}{4ah'}$, which implies from (A.5) that $\frac{\partial^2 y'(w_i'(\theta); \theta)}{\partial w_i'(\theta) \partial \theta} < 0$, therefore $w_i'(\theta)$ is a decreasing function of $\theta$.\textsuperscript{13}

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

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

\textsuperscript{13} Since we are assuming that the elasticity of marginal productivity of effective water is greater than 1 which gives $w_i' > \frac{b}{4ah'}$. 

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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 $\theta$ is taken. Expression (A.6) implies:

$$\left[P \left(b h' (\theta_i) - 2a w_i' (\theta) \left(h' (\theta) \right)^2 \right) - \frac{\partial T_i' \left(w_i' (\theta) \right)}{\partial w_i' (\theta)} \right] w_i' (\theta) = 0 .$$

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

$$\pi_i = P h_w w_i \left(b - 2a h' w_i \right)$$

With $\theta_0$ being the lowest land quality starting from which irrigation technology $t$ is used, then integrating expressions (A.8) between $\theta$ and $\theta_0$, and using the profit expression in (1), ex-post the optimal water tariff is obtained by a rearrangement of (1):

$$T_i' \left(w_i' \right) = P y' \left(w_i'; \theta \right) - \pi_i' \left(\cdot; \theta \right) - \psi' - \int_0^{\theta_0} \pi_i' \left(w_i'(u); u \right) du .$$

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 $\{w_i' (\theta), T_i' \left(w_i' (\theta) \right)\}$ constitutes an incentive compatible mechanism if for all $\theta \in [0, 1]$ we have:

$$\frac{\partial w_i' (\theta) \right)}{\partial \theta} \leq 0 , \text{ and}$$

$$T_i' \left(w_i' \right) = P y' \left(w_i'; \theta \right) - \pi_i' \left(\cdot; \theta \right) - \psi' - \int_0^{\theta_0} P h_w (u) w_i'(u) \left(b - 2a h' (u) w_i'(u) \right) du .$$
The above proposition establishes the relation between $w'_t(\theta)$ and $\theta$ and the relation between the water quota $w'_t(\theta)$ and the appropriate water fee $T'_i(w'_t(\theta))$. Under majority-$i$ expressions (A.8) and (A.10) will be the incentive compatible constraints in the regulator problem for all irrigation technology $t$. 