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Irrigation District Adoption of Water Conserving Rate Structures

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Abstract

A binary choice model was used to identify the attributes that influence irrigation district adoption of conservation rate structures. Using principles of rate design and irrigation district administration as a framework, measures of irrigation district rate structure objectives and physical and economic conditions were developed. The factors investigated characterize the constraints under which districts operate, value and cost of water, quantity of water delivered and revenue risk for districts. Rate structure adoption was predicted with over 75% accuracy. Both significant and non-significant factors are key to understanding rate choice. District's were more likely to adopt conservation rate pricing when the cost of water to farmers was greater, higher value crops were grown and in areas with warmer and longer growing seasons. These conditions may be interpreted as reflecting the presence of greater opportunity costs in allocating water between low and higher valued uses. Conservation rate pricing was less likely to be adopted by district's where the proportion of alfalfa to total acreage was higher and with higher per acre deliveries of water. Somewhat surprisingly, annual variation in water deliveries (which should increase the risk of revenue shortfalls) and size of the district (larger districts being more sophisticated) have little bearing on the type of rate structure adopted.

Irrigation District Adoption of Water Conserving Rate Structures

In response to legislation and litigation to encourage efficient water use, conservation policies for irrigation districts that receive water from U.S. Bureau of Reclamation (BOR) projects have recently been implemented. A central element of these policies is the recommendation or requirement that rate structures with "conservation pricing" be adopted by irrigation districts. Conservation pricing is defined as a billing strategy that "is based, at least in part, on the quantity of water delivered" and where the unit price of water is uniform or increasing as the volume of water used increases (BOR 1996 p.7). Responsibility for designing and implementing conservation pricing is assigned to irrigation districts. However, irrigation districts have a variety of objectives and constraints so that conservation based rate structures will not be of interest to or appropriate for all districts. Over half of the rate structures used by irrigation districts supplied by Bureau of Reclamation water lack incentive to conserve and only 20% percent of districts had a rate structure where the price per unit increases with the quantity of water delivered (Michelsen et al. 1997). To help implement their conservation pricing policy the Bureau of Reclamation has produced two guidebooks (BOR 1996 and BOR 1997) and is developing a program to assist districts in designing conservation oriented rate structures (BOR 1996, BOR 1997). For this conservation pricing policy and implementation program to be effective it is essential have an understanding of irrigation district objectives and conditions which determine the adoption of their rate structures. We have found no other published research on the attributes influencing selection of and actual adoption of irrigation district rate structures.

In this paper, a theoretical model of rate structure selection is formulated and empirically tested. Measures of irrigation district objectives and economic and physical conditions were constructed using economic principles of rate design and irrigation district administration as a framework. An empirical data set of these measures was developed from an unpublished survey of district rate structures and from a variety of other sources of information on water use, crop production and revenue characteristics and climate conditions. The rate structure selection model was tested successfully and the factors that influence irrigation district adoption of rate structures analyzed. The results of this research will benefit and be used by district managers and Bureau of Reclamation staff to strategically and efficiently target efforts in conservation rate structure design and adoption.

Irrigation District Rate Structure Objectives

In terms of production technology, cost structure and demand, irrigation districts share many of the characteristics of public utilities. Irrigation districts typically have decreasing production costs with increasing levels of output (natural monopolies), are capital intensive with high, lumpy fixed costs (dams, pump and distribution systems), are the exclusive supplier with territorial integrity, provide a good that is nonstoreable and nontransferable by the user (physical, legal and institutional restrictions), and provide an essential service with inelastic demand (adapted from Bonbright, et al. 1988; Phillips 1985). Bonbright et al. (1988) lists eight criteria for a sound or desirable rate structure. They are:

1. Simplicity, understandability, public acceptability and feasibility of application.
2. Freedom from controversies as to proper interpretation.
3. Effectiveness in yielding total revenue requirements.
4. Revenue stability from year to year.
5. Stability of rates (minimum of unexpected changes).
6. Fairness (equity) of the rates in apportionment of total costs among customers.
7. Avoidance of undue discrimination in rate relationships.
8. Efficiency of the rates in discouraging wasteful use while promoting all justified types and amounts of use.

In a study of efficient water pricing, Brill, Hochmam and Zilberman (1998, p.953) condense Bonbright's eight criteria and assert that three management criteria are necessary for an optimal pricing policy, efficient water allocation, balanced budget and equity distribution in proportion to historical water use.

Whereas irrigation district's share many cost, production and demand characteristics with public utilities, district internal management and external regulatory environment departs from public utilities. Public utilities are publicly or shareholder owned and government regulated. Irrigation districts are farmer owned, non-profit organizations whose cost-sharing arrangements are characterized as equity-constrained welfare maximization (Aadland and Koplin). Irrigation districts are organized and operate as agricultural cooperatives (Rosen and Sexton). Agricultural cooperatives are formed to take advantage of economies of scale in marketing agricultural products or supplying agricultural inputs (chemicals, seed etc.) and irrigation water. Four principles define the operation of a cooperative (Vitaliano):

- service at cost,
- benefits in proportion to use,
- member farmer control, and

- limited returns to equity capital.

Non-profit farmer administered cooperatives have some additional and different rate design criteria than public utilities. The service at cost principle is a reflection of non-profit cooperative organizational principles and legal and contractual water allocation and repayment obligations. Irrigation district costs include Bureau of Reclamation water supply service and repayment contracts and construction, operation and management of district water delivery facilities. The water supply costs assessed by the Bureau of Reclamation are based on federal project construction, operation and maintenance costs, net of subsidies. These costs are largely fixed, with the exception of water lift energy costs. Distribution facilities are a large part of district costs, and these are also fixed or invariant to the quantity of water delivered to a single location. District pricing of water reflects this arrangement where a fixed assessment is charged per acre of irrigated land or share in the district to cover service costs. Fixed assessments satisfy the service at cost principle and also many of the desirable criteria for a rate structure.

Legal, institutional and physical restrictions limit the ability or incentive for the Bureau of Reclamation, irrigation districts or water users to consider other costs. Water allocations are based on legal water rights and established water duties (amount of water per acre of land determined as necessary for that use). The nonprofit constraint on equity capital return directly contrasts to public utilities. Whereas public utility rates are set to provide a return to the large capital costs and that return is highly regulated, irrigation district assessments are set by the water users to exactly cover service costs.

Farmers within a district receive benefits not as stockholders nor even board members of the district but as water users. Thus benefits accrue to the district member in proportion to use. Member-user control is also vested in members as users, not as owners. Irrigation districts are not one-person one vote democracies, rather political power is wielded in proportion to water use. However, "proportional voting does not imply less control over a cooperative by member-users than under [one-person one-vote systems] but rather a redistribution of voting power with emphasis on use of the organization instead of mere membership..." (Vitaliano p147). We thus witness in irrigation districts at the urban fringe an annual hookup charge targeted at "gentleman farmers" to spread annual fixed costs to smaller water users.

Difficulties in efficient pricing of decreasing production cost goods have long been recognized. A utility's characteristic production technology of lower costs with increasing levels of output will result in a budget deficit for the district when strict efficiency pricing (the price of water to farmers is priced at the marginal cost of providing that water. Revenues with marginal cost pricing will not cover costs of an increasing returns to scale utility. Hotelling argued that efficient pricing should be marginal cost pricing and that the deficit in decreasing cost industries should be financed by a lump sum tax. Ruggles introduced welfare or allocative implications into marginal cost pricing arguments with key objections introduced by Vickery and Wiseman in the selection of investment alternatives, income distribution distortion effects and the equity judgements in marginal cost pricing. Bonbright was critical of public utility pricing to achieve social objectives and was concerned with workable principles so that "public utility services are designed to be sold at cost, or at cost plus a fair profit" (Bonbright 1988, p.23). Sexton advocates the efficient price for cooperatives be a user charge based upon marginal cost and a fixed fee (such as an assessment on land in the district under irrigation) set to cover the break-even cost. A multipart pricing structure (fixed charge plus marginal price per unit) satisfies cost recovery requirements and achieves the efficiency of marginal cost pricing, but provides limited incentive to conserve. Average cost pricing per unit of water could satisfy a districts' cost recovery requirements and provide some incentive to conserve, but because of variability in supply while costs remain largely fixed, average cost pricing increases revenue stability risk and does not meet rate structure efficiency criteria. Problems in designing district rate structures that satisfy cost of service and efficiency criteria are compounded by legal or institutional conditions that specify water allocation quantities independent of costs. Declining marginal supply costs, legally established water allocations, high fixed costs, desire for revenue stability, simplicity, cost of service principles and cost recovery requirements has lead many irrigation districts to adopt rate structures classified as non conservation oriented.

Conservation rate structures assume that water supply or opportunity costs are uniform or increasing. As discussed above, this is not the case with many irrigation districts. Opportunities for economic gain from reallocation efficiency of water are often limited because of legal, institutional, equity or physical constraints. When opportunity costs can be realized, irrigation districts (their member users) will have incentive to adopt increasing cost or conservation oriented rate structures in terms of economic efficiency. Although efficiency is typically the focus of economic studies, it is one of a several different rate structure objectives. A model and measures of rate structure adoption are developed in the next section.

Model of Rate Structure Adoption -- model structure and specification

Rate structures are a discrete choice of a management technology adopted by districts in the management of water. A model of rate structure choice by an irrigation district would maximize the net benefits of farmers in the district. Such a model would however be quite complex because it involves two divergent concepts of benefits: (1) farmers benefitting individually from district water allocations and costs and (2) farmers benefitting collectively from economically efficient and stable long term water allocations and costs. How districts represent their farm constituents and work out this balance is quite varied. It is beyond the scope here to fully develop a model of endogenous rate selection, but using simple production theory concepts and indicators of opportunity costs, we can construct a series of hypotheses about factors which would influence rate structure choice.

A major distinction between a district that charges a unit price versus a flat rate would be the amount of water each farmer would choose to have delivered. In a pure fixed flat fee allocation, the cost to each farmer is the same and each farmer is allocated the same amount of water per acre ($\underline{w}$), regardless of the marginal production cost or value of that water. The marginal price of water to the farmer is zero and has no connection to production cost or value. In this case there is no individual economic incentive to conserve and if there are no alternative more highly valued uses (e.g. farmers have homogeneous production costs and no other water allocation gains are possible) a district would be able to satisfy most rate structure criteria by using a fixed flat fee rate structure. District and production characteristics that may indicate these conditions include (with many caveats), large water deliveries per acre (sufficient supply), smaller crop revenue per acre (low water value), and/or small diversity in crop production (limited number of crops produced, low value associated with efficiency improvements).

When there are uses of water valued greater than zero, the economically efficient distribution of water would be:

$$VMP_1(w_i) = P_w;$$

where VMP_I is the value of the marginal product for farmer I, w_i is the optimal water application by farmer I given his demand and P_w; is the price of water (presumably reflecting the marginal cost of supply). It is also evident that the costs in terms of reduced farm profits of a fixed supply without the possibility of trade increase with a greater disparity between a farmer's demand for water and the fixed allocation i.e.

$$C_i(\underline{w}) = c(VMP(w_I), VMP_i(\underline{w}), P_w).$$

Also

$$\partial C/\partial vmp > 0;$$

$$\partial C/\partial \underline{w} < 0;$$

$$\partial C/\partial P_w > 0.$$

In general, the probability that a district would not choose to allocate water on a fixed average basis would be in part due to the costs that the fixed allocation imposes on its members. In a district that is water short, marginal cost pricing may not limit demand to available supplies (we will deal with this case separately). Defining Prob as the probability that a district has a variable (per unit or increasing rate structure elements) as opposed to a fixed price structure, we have the following simplified hypotheses:

$$\partial Prob_k/\partial vmp > 0;$$

$$\partial\ Prob_k\ /\partial \underline{w} < 0;$$

$$\partial\ Prob_k\ /\partial P_w > 0.$$

Climatic variables obviously effect VMP of water (e.g. temperature and length of growing season), thus we would also have

$$\partial Prob/\partial vmp\ \partial vmp/\partial GDD > 0,$$

where GDD is growing degree days for a district in a season, a factor is crop yield and diversity of crops that can be grown.

The likelihood that farmers would want to internally trade water among themselves would be a function of the diversity of water demand within the district. Given a diversity of crops and farm practices, it seems evident that the following condition would result:

$$VMP_1(\underline{w}) \neq VMP_2(\underline{w});$$

This creates the classic condition for trade but, for a variety of reasons, it may not be possible to set up a secondary internal market for trading (reallocating) water. A water allocation allowing choice of water delivered (based on pricing) would increase total net benefits of farmer, i.e.,

$$VMP_1(w_1) = VMP_2(w_2) = P_w;$$

If we define the diversity of demand as the variance in value per acre within a district (S), then this hypothesis follows:

$$\partial Prob/\partial S > 0.$$

Internal water marketing would serve as an alternative to pricing. State laws are a major factor allowing internal trading, thus

$$\partial Prob/\partial ST_r > 0$$

where ST_r is a state that does allow internal trading.

In addition to individual farmer incentives, the district has collective objectives such as repayment of fixed obligations, efficient delivery of water and sufficient total supply. Per unit pricing of water with variability in supply (deliveries) make these objectives more difficult to achieve. A model of collective decisions is difficult, but obviously some observations from utility literature would suggest the following:

$$\partial Prob/\partial FC > 0$$

$$\partial Prob/\partial \sigma_{supplies} < 0,$$

where increased variability in water supplies (deliveries) would be associated a fixed rate structure to maintain revenue stability.

We can assess these tendencies with a logit or probit formulation of district water pricing. In general a binary choice model has the following form:

$$Prob (Y = 1) = F(B'x)$$

$$Prob (Y = 0) = 1 - F(B'x)$$

where Y = 1 are districts with conservation oriented rate structures (uniform and increasing per unit pricing elements) and where Y = 0 are districts with fixed fee rate structures.

For probit:

$$\text{Prob } (Y = 1) = \Phi\ (B'x)$$

where the Φ is the cumulative normal distribution.

For logit, we have

$$\text{Prob } (Y=1) = \Lambda\ (B'x)$$

where the Λ is the cumulative logistic distribution.

The generalized form of the rate structure adoption probability model is:

Prob (Y) = *f* (Num, Rev_AC, Cost, Water, STD, Acres, EFF, ALF, GDD, ST)

Variable definition and mean values.

Name	Definition	Mean
NUM	Number of crops grown in the district (diversity measure)	3.93
REV-AC	Farm revenue per irrigated acre in the district	719.4
COST	Cost of district water delivery per acre foot	23.88
WATER	10 year average water deliveries per acre	2.98
DIFF	Difference in revenue per acre between highest and lowest crop	1546
ACRES	Irrigated acres in district	36850
EFF	Efficiency, amount of water delivered as a percent of diverted	.6995
STD	Standard deviation of water deliveries	.196
ALF	Forage crops acres per total district acres	.44
GDD	Growing degree days – crop potential	1068
ST	State dummy variable WA OR ID CA NV AZ CO UT WY TX NM SD ND NE	

Irrigation District Data

An empirical data set of these variables was developed from unpublished survey's of district rate structures, water use and cropping patterns and from Census of Agriculture and

National Climate Center data. The data used in this study matches county and agricultural census data with respective district level data. To obtain a comprehensive view of district rate structures, an analysis of an unpublished survey of BOR irrigation districts was conducted (Negre et al.). The survey provided a comprehensive enumeration is water rates; rate design, and assessment charges. Rate survey data were matched with district level data on costs, cropping patterns, water usage. Agricultural census and county data were also matched with the district rate survey to ascertain crop patterns, growing degree days, revenues and cost of crops grown in the districts.

Results

Using the economic principles of rate design as a framework, measures of irrigation district rate structure objectives and physical and economic conditions were developed. The factors investigated or the binary choice independent variables, characterize the constraints under which districts operate, value and cost of water, quantity of water delivered, and revenue risk for districts. In the estimation of binary choice models justification of the use of the normal distribution (probit) or logistic distribution (logit) is unresolved (Greene). We assumed a logit model. The log likelihood function was estimated by an iterative procedure (LIMDEP). Rate structure adoption was predicted with 75% accuracy. Both significant and non-significant factors are key to understanding rate choice. The statistical results and partial derivatives are shown in Table 1 and Table 2. District's were more likely to adopt conservation rate pricing when the cost of water to farmers was greater, higher value crops were grown and in areas with warmer and longer growing seasons. These conditions may be interpreted as reflecting the presence of greater opportunity costs in allocating water between low and higher valued uses. Conservation rate pricing was less likely to be adopted by district's where the proportion of alfalfa to total acreage was higher and with higher per acre deliveries of water. Somewhat surprisingly, annual variation in water deliveries (which should increase the risk of revenue shortfalls) and size of the district (larger districts being more sophisticated) have little bearing on the type of rate structure adopted. By examining the attributes of districts in relation to their multiple objectives and constraints, assistance and recommendations in rate structure design can be targeted to those districts most likely to adopt conservation pricing

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Table 1 -- Rate Structure Adoption, Logit Model Statistical Results

Variable	Partial Derivative[1]	Logit Coefficient	Standard Error	Z^2	P	Mean
NUM	-4.33E-02	-0.2049	0.21112	-0.971	0.33178	3.945
REV_AC	5.01E-05	2.37E-04	3.53E-04	0.672	0.50134	723.2
DIFF	-4.00E-05	-1.89E-04	1.72E-04	-1.099	0.27178	1556
ALF	-0.3663	-1.7342	1.0366	-1.673	0.09433	0.4435
ACRES	1.13E-06	5.33E-06	5.14E-06	1.037	0.29958	3.70E+04
EFF	-0.30071	-1.4237	1.0499	-1.356	0.17509	0.6991
COST	7.18E-03	3.40E-02	2.09E-02	1.624	0.10438	23.99
WATER	-4.66E-02	-0.22078	0.15906	-1.388	0.16512	2.997
STD	0.26679	1.2631	1.6565	0.763	0.44576	0.1964
GDD	3.80E-04	1.80E-03	7.79E-04	2.309	0.02097	1068
WA	0.37097	1.7563	1.1596	1.515	0.12987	9.82E-02
OR	0.1919	0.90856	1.1632	0.781	0.43476	7.36E-02
ID	0.1185	0.56101	1.1801	0.475	0.63452	6.14E-02
CA	0.67638	3.2023	1.5623	2.05	0.04039	0.1288
AZ	4.45E-02	0.21054	1.8446	0.114	0.90913	6.14E-02
CO	0.58788	2.7833	1.3588	2.048	0.04053	6.14E-02
UT	0.38972	1.8451	1.1507	1.603	0.10883	0.1166
WY	-3.57E-02	-0.16883	1.1589	-0.146	0.88418	7.36E-02
TX	-0.18467	-0.87431	1.5145	-0.577	0.56374	3.68E-02
NM	-1.77E-02	-8.37E-02	1.3346	-0.063	0.95001	4.91E-02
SD	-4.67E-03	-2.21E-02	1.5669	-0.014	0.98874	1.84E-02
ND	3.69E-02	0.17465	1.2711	0.137	0.89071	4.91E-02
NE	-6.90E-02	-0.32678	0.87174	-0.375	0.70776	0.1043

1/Partial derivatives of probabilities with respect to the vector of characteristics computed at the means of the Xs. Observations used for means are all observations.

2/Measures of fit

Number of observations	163
Log likelihood function	-80.74738
Restricted log likelihood	-112.2918
Chi-squared	63.08890
Degrees of freedom	22
Significance level	0.7712502E-05

3/Frequencies of actual & predicted outcomes

	Predicted		
Actual	0	1	TOTAL
0	55	19	74
1	19	70	89
TOTAL	74	89	163