

## The Relative Efficiency and Implementation Costs of Alternative Methods for Pricing Irrigation Water

Yacov Tsur and Ariel Dinar

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*A useful means for achieving efficient allocation of irrigation water is to put the right price tag on it. This article discusses some of the more pervasive pricing methods and compares their efficiency performance, paying special attention to the impact of the cost of implementing each method on its efficiency. The article uses an empirical example to demonstrate numerically the relative efficiency of the different pricing methods and the important role of implementation costs. The volumetric, output, input, tiered, and two-part tariff methods all can achieve efficiency, although the type of efficiency varies from one method to another. These methods also differ in the amount and type of information, and the administrative cost, needed in their implementation. The example indicates that water pricing methods are most pronounced through their effect on the cropping pattern—more so than through their effect on water demand for a given crop. Implementation costs have a large effect on water tariffs and on welfare and hence should have an important role in determining the desirable method to use in any given water situation.*

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Water is an essential input in various economic sectors. Growing populations, improved lifestyle, and dwindling water supplies (both in terms of quantity and quality) exacerbate the competition for scarce water resources. It is thus of great importance that the existing water resources be allocated efficiently. In an economically efficient allocation, the marginal benefit of water use should be equal across all users; otherwise, society benefits by reallocating water to the sector with the highest marginal benefit. A useful means for achieving efficient water allocation is to put the right price tag on it. Consequently, a variety of methods for pricing water have been developed. They differ in their implementation, the institutions they require, and the information on which they are based. In this article we discuss some of the more pervasive pricing methods and compare their efficiency performance, paying special attention to the cost associated with implementing each method.

For reasons such as economies of scale in supply, presence of externalities, small number of participants, uncertainty, and strong temporal interdependen-

Yacov Tsur is with the Department of Agricultural Economics and Management at The Hebrew University of Jerusalem and the Department of Agricultural and Applied Economics at The University of Minnesota. Ariel Dinar is with the Agriculture and Natural Resources Department at the World Bank. The authors gratefully acknowledge comments from K. William Easter, Eithan Hochman, Herve Plusquellec, James Roumasset, David Steeds, and three anonymous referees as well as data collection on pricing methods in some countries by R. M. Chellappan.

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cies, the management of irrigation water systems is often regulated by some sort of public intervention. Consequently, a plethora of management methods has evolved in the thousands of years since people first practiced irrigation (Young and Haveman 1985).

A large volume of literature deals with irrigation water management in general and water pricing in particular (see, for example, Rhodes and Sampath 1988; O'Mara 1988; Cummings and Nercissiantz 1992; Le Moigne and others 1992; Sampath 1992; Small and Carruthers 1991; Shah 1993; Plusquellec, Burt, and Wolter 1994; and Tsur and Dinar 1995). Yet, to the best of our knowledge, the efficiency performance of the different management practices has not yet been compared comprehensively. We attempt to fill some of this gap by evaluating how several of the commonly used methods for pricing irrigation water fare on the efficiency scale. We consider a sustainable (or steady-state) water situation and thus avoid intertemporal considerations such as those that emerge when water is mined from a nonreplenishable aquifer (see Tsur, Park, and Issar 1989).

Section I describes the methods for pricing water and looks at information and institutional aspects regarding their implementation, an issue that has received very little attention (see Roumasset 1987 and Easter and Tsur 1995). Section II provides details of pricing methods that are applied in several countries. Section III defines efficiency concepts in the context of water pricing and evaluates the performance of the different pricing methods in this regard. Section IV presents an empirical example to demonstrate numerically the relative efficiency of the different pricing methods and the important role of implementation (transaction) costs. Section V concludes.

## I. PRICING METHODS FOR IRRIGATION WATER AND THEIR IMPLEMENTATION COSTS

The costs of supplying irrigation water consist of the variable costs of processing and delivering water to end users and the fixed costs of capital operation and maintenance (O&M). Variable costs depend on the amount of water delivered, while fixed costs do not. In most countries, fixed costs are heavily subsidized (United Nations 1980). The method by which irrigation water is delivered affects the variable cost as well as the irrigation technology applied and the feasible pricing methods. Water may flow continuously or in certain time periods (in which case it may or may not be delivered on demand); the conveyance system may consist of open channels or closed pipes. Often the irrigation water in a region is delivered by more than one method, depending on tradition, physical conditions, and water facilities and institutions (United Nations 1980).

Bos and Wolters (1990) investigated farmers representing 12.2 million hectares (1 hectare = 10 dunams  $\cong$  2.5 acres) of irrigated farms worldwide and found that in more than 60 percent of the cases water authorities charge on a per unit area basis. Less than 15 percent of the irrigation projects charge for water using

a combination of area and volumetric methods. About 25 percent of the projects charge using the volumetric method.

The descriptions of methods for pricing irrigation water in this section draw on Rhodes and Sampath (1988) and Sampath (1992). Implementation of these pricing methods requires appropriate institutions, such as a central (national, regional, district, village) water agency, and entails the costs of administration, monitoring and collection of information, and enforcement. We briefly discuss the costs of collecting information and the type of institutions needed to implement each pricing method.

### *Volumetric Pricing*

Volumetric pricing methods charge for water using a direct measurement of the volume of water consumed. Variations of the volumetric approach include (a) indirect calculations based on measurement of minutes of known flow (as from a reservoir) or minutes of uncertain flow (proportion of the flow of a river) and (b) charges for a given minimal volume even if it is not consumed.

Volumetric pricing requires information on the volume of water used by each user, that is, it requires facilities to meter water. Once water meters are installed, implementation is fairly straightforward, involving routine maintenance and periodic meter readings. In the absence of a water market, a central water authority or water user organization is required to set the price, monitor use, and collect fees. The implementation cost associated with volumetric pricing is relatively high.

### *Output Pricing and Input Pricing*

Output pricing methods charge irrigators a water fee for each unit of output they produce. Thus, output pricing requires information on the output level of each water user. Its advantage is that it does away with the need to measure individual water consumption, which in many regions (particularly in developing countries) is an expensive, or even impossible, task. If the crop is used for export (for example, cotton), output must be measured, and the cost associated with imposing water fees is small. Otherwise, the measurement of output can be as formidable as that of water, implying that output pricing is rather a poor means for pricing water (indeed, examples of output pricing are rare).

Input pricing methods charge for water use by taxing inputs. Irrigators pay a water fee for each unit of a certain input—for example, fertilizer—used.

### *Area Pricing*

Area pricing charges for water used per irrigated area, depending on the kind and extent of crop irrigated, the irrigation method, the season of the year, and other factors. In many countries, the water rates are higher when the water is delivered from storage (investment) than when it is diverted directly from streams. The rates for pumped water are usually higher than those for water delivered by gravity. In some cases, farmers also must pay the per acre charges for nonirrigated acres.

Area pricing is easy to implement and administer and does not require water conveyance facilities to be metered. This method needs only land-by-crop data (if the per hectare water fees vary across crops) or only farm size data (if a unified fee is used). Simplicity and low agency costs explain the popularity of this method.

#### *Tiered Pricing and Two-Part Tariff Pricing*

With tiered pricing—a multirate volumetric method—water rates vary as the amount of water consumed exceeds certain threshold values. Two-part tariff pricing methods involve charging irrigators a constant marginal price per unit of water purchased (volumetric marginal cost pricing) and a fixed annual (or admission) charge for the right to purchase water. All farmers pay the same admission charge. This pricing method has been advocated, and practiced, in situations where a public utility produces with marginal cost below average cost and must cover total costs (variable and fixed).

Both tiered pricing and two-part tariff pricing elaborate on the volumetric method. Once water meters are installed, the extensions to multiple rates (tiered pricing) are straightforward; the two-part tariff requires, in addition to the volumetric rate, a fixed admission fee per farmer.

#### *Betterment Levy Pricing*

Betterment levy pricing methods charge water fees per unit area, based on the increase in land value accruing from the provision of irrigation.

#### *Water Markets*

Water markets exist in different forms throughout the world, in industrial and developing countries alike. Water markets may be formal or informal, organized or spontaneous. Their participants may trade water rights (for example, the right to purchase some quantities of water at a particular price during specific periods of time), or they may trade water at the spot or for future delivery. In some countries, markets for water or for water rights have been formed and determine water prices, usually measured on the basis of volume or flow of water. They range from sanctioned markets for water rights, such as in Chile (Hearne and Easter 1995), to spontaneous spot markets, such as in Brazil (Kemper 1996). Compared with an administratively imposed price, well-defined tradable rights should formalize and secure the existing water rights held by users, economize the transaction costs, and increase the efficiency of water use by inducing users to internalize the full opportunity cost of water, as determined by the market.

In a stylized water market, in any year, each irrigator is given a water endowment (or entitlement) and is free to sell or buy shares of entitlements from other farmers at the going rate. Water entitlements may be based on historical or legal rights, or they may be set by an elected or assigned committee (or water agency). Endowments may vary from year to year according to the availability of water. This method requires no water meters for individual users below the diversion

point and is sure to internalize any private information farmers have. Water markets are likely to provide incentives for water to flow from less productive to more productive users.

To operate properly, water markets require a well-defined structure of water rights, a clear and comprehensive set of rules for trading these rights, and a judicial body for overseeing the trading activities and resolving disputes. In addition, water markets require a well-developed conveyance system for transporting water to all participants.

## II. EXAMPLES OF PRICING METHODS IN SEVERAL COUNTRIES

This section provides examples of the various pricing methods as they are applied in several countries.

### *California (United States)*

Multirate volumetric pricing of publicly supplied water is common in the state of California in the United States. Depending on the irrigation district, prices range between \$2 per acre-foot to more than \$200 per acre-foot (1 acre-foot = 1,256 cubic meters). On average, farmers paid about \$5 per acre-foot for water from the federal Central Valley Project in 1988, compared with \$48 per acre-foot average capital depreciation cost and \$325 per acre-foot average marginal cost of delivery (Rao 1988). Cummings and Nercissiantz (1992) estimate the average water price at \$19.32 per acre-foot, which they claim covers a mere 39 percent of the estimated scarcity value (the in situ value of groundwater). The recent prolonged drought in California from 1986 to 1992 has led to the development of innovative water banks and water markets through which water prices are determined (see Easter and Tsur 1995).

### *India*

Irrigation pricing methods vary throughout India, depending on geographic location, the command area of the project (region, state, country), the system of irrigation (storage, diversion, pumped), crops grown, seasons, the nature of agreement (long lease, short lease), and the procedure used to extract penalties for unauthorized use (Gole, Amble, and Chopra 1977). Some examples of pricing methods are (United Nations 1980):

- Area charges that vary by crop or across seasons
- Area charges that vary according to the method of irrigation (flood, ridges, or furrows)
- Area charges that are agreed on for one or more years (to be paid whether or not water is used)
- Volumetric rate per estimated volume of water consumed, applied generally in areas with pumped irrigation and tube wells (estimates are based on crop water requirements)

- Penalty rates per acre charged for using water in an unauthorized manner or for wasting water
- Percolation rates charged for each cultivated acre within 200 yards of a canal that receives percolation or leakage water from the canal
- A flat area charge covering all areas serviced by the project, whether or not they are actually irrigated during a given season or year
- A betterment levy, applied per unit area served by the project. For example, water charges for farmers in Tamil Nadu in 1993 were Rs200–Rs210 per hectare (in 1993, 31.5 rupees = 1 U.S. dollar). This rate is considered to be among the highest water charges in India (World Bank 1995).

### *Jordan*

Most of the agricultural activity in Jordan is concentrated in the Jordan Valley, while the majority of the population lives in the urban centers in upland areas. So, in addition to competition over scarce water resources, a conveyance cost is associated with transferring water to urban uses. Crop water requirements vary substantially between regions because of soil and climatic conditions. Upland irrigation is based mainly on the extraction of groundwater. Private wells are not monitored. The cost of pumped water in 1993 was estimated at JD0.05 per cubic meter (in 1993 1 Jordanian dinar = 1.5 U.S. dollars, and in 1986 JD1 = \$2.85). In the Jordan Valley, water is provided through pipes to more than three-quarters of the irrigated land. Water authorities use volumetric pricing, but water is greatly underpriced. For example, in the East Ghor canal (the Jordan Valley Irrigation Project), the water authority charged farmers JD0.003 per cubic meter for the first 1.5 meters of irrigation depth and JD0.006 per cubic meter for any additional amount. O&M costs alone were estimated at JD0.02 to JD0.03 per cubic meter (Arar 1987). In 1993 the water authority priced all irrigation water in the Jordan Valley at JD0.006 per cubic meter irrespective of the volume used (Hayward and Kumar 1994).

Although most of the water supply to agriculture is piped and easy to monitor, the existing pricing method does not take advantage of it. The water authority does not monitor or price irrigation water in the upland area. In the Jordan Valley, the volume supplied to individual users is measured, but the price does not influence efficient use of water. The water authority makes allocations based on the crop grown and availability of water. The policy of favoring equity over efficiency may encourage farmers to grow low-profit crops, most of which cannot cover the real cost of water. Profitable crops such as citrus (irrigated with 10,000 cubic meters of water per hectare), bananas (20,000 cubic meters per hectare), and grapes (8,000–11,000 cubic meters per hectare) are water-intensive. Because water is scarce in Jordan, price signals may not be sufficient to allocate the water; irrigators need additional guidance from the government in the form of preferred cropping patterns. This may create an additional policy dilemma for food security.

In contrast to water for irrigation, water for municipal and industrial uses, which is also metered, is priced on the basis of block tariffs (tiered pricing) imposed every three months. The water component in the pricing method (in addition to a sewerage charge) varies by location, which reflects the marginal cost of water supply. Water charges in the municipal and industrial sectors vary between JD0.06 and JD0.6 per cubic meter (in 1993), depending on the quantity of water used and the location (Hayward and Kumar 1994).

### *Morocco*

In Morocco, costs vary by location, based on specific conditions in each region. For example, in the Haouz irrigation district, water is supplied both for irrigated agriculture (65,000 hectares) and for urban use in Marrakech (650,000 inhabitants). In 1993–94 the Haouz Office, which is the district's management arm, supplied about 300 million cubic meters of water, of which Marrakech received 35 million (50–60 percent of its annual consumption, with the rest from groundwater sources). The Haouz Office provides water to Marrakech free of service charge. The town treats and distributes the water to households through a metered system that allows a tiered volumetric pricing method (aimed at covering treatment and distribution costs only) and to industries for a flat fee.

For households in Marrakech, the bimonthly charge per cubic meter was DH0.73 for the first 24 cubic meters, DH2.17 for 24–60 cubic meters, and DH3.25 for any quantity beyond 60 cubic meters (8.4 Moroccan dirhams = 1 U.S. dollar in 1993). The industrial rate was DH2.01 per cubic meter (Morocco, Direction de la Statistique, 1993). Irrigators in the Haouz irrigation district pay an average price of DH0.16 per cubic meter of water. There are discounts related to geographical areas and to certain infrastructure setups. For example, farmers can pay a discounted price by participating in maintenance of the irrigation system. Water volumes are measured by several means. In perimeters with surface irrigation, gates are used to measure flow, which is converted to volume. In sprinkler-irrigated perimeters, volume is measured directly using meters installed at the farm-level outlet.

The operational cost of monitoring water use and enforcing payments in the Haouz irrigation district provides a good example of the costs of pricing systems. These costs, not including investment in measuring equipment, can be calculated from data available in Morocco; Ministry of Agriculture and Agricultural Development (1994); and from the Haouz Office (El Hadj El Hallani, personal communication, 1995). In 1994 the collection rate for fees to cover these costs was 76 percent.

The Haouz Office employs 175 irrigation water monitors for regulating water distribution in the canals, 56 staff for invoicing, and 12 staff for collecting payments. The average annual salary at the irrigation sector of the Haouz Office in 1994 was DH7,700 (Agro-Concept 1995). The total annual cost of monitoring, regulation, and enforcement is therefore DH1,871,100, or DH0.004 per cubic meter delivered. This very conservative estimate does not take into ac-

count additional variable costs. For example, temporary staff are also hired in the peak season to monitor water use. A rough estimate suggests that the Haouz Office hires 5–10 temporary personnel per 400 hectares of irrigated land, which adds about 875–1,750 additional temporary staff to the payroll.

### *Spain*

There are important differences in water tariffs paid by farmers in Spain (Maestu 1995). Two types of tariffs were designed to compensate the government for its investment in, and operation and maintenance of, publicly financed water projects.

First, the water basin authorities charge the beneficiaries of the waterworks an annual regulation tariff and a water use tariff. The regulation tariff is calculated as 4 percent of the initial investment costs adjusted annually for inflation. The amount of investment to which the 4 percent is applied is a political decision that can vary over time and by basin. The water basin authority sets the water use tariff to cover average O&M costs, based on estimated future budget costs. The authority charges farmers for O&M costs either on the basis of irrigated area (using information on crops grown and standard per-area water coefficients) or on the basis of volume in new irrigation projects that are equipped with metering devices. The final charge to the farmer also may include charges to the local user associations (irrigation cooperatives).

Second, the water basin authorities charge a tariff for occupation of the public domain for water. This charge is equivalent to 4 percent of the value of the land used for the waterworks (dams, reservoirs, canals, roads). In addition, the authorities charge a pollution tax that is calculated individually. Farmers are exempt from this tax at present.

In Almeria, the charge for water, including all relevant tariffs mentioned earlier, is Ptas16 per cubic meter (125 pesetas = 1 U.S. dollar in 1995), including the cost of energy, which users pay to the irrigation cooperative. In Tajo-Segura, the tariff for irrigation water is Pta1 per cubic meter.

### *Turkey*

Pricing and cost recovery policies vary among water use sectors in Turkey. Water authorities charge domestic and industrial users by volume. They charge farmers an annual area-based fee that varies by crop and region. In projects operated by the State Hydraulic Works (DSI), that fee has two components, an O&M component and a capital cost recovery surcharge component. The O&M charge is supposed to recover costs born by DSI in the previous year, with no adjustment for inflation. Because the government has the right to adjust the fee, it is usually set at a level lower than that proposed by DSI. In 1993 the O&M component for wheat in the Southern Anatolia Project was LT163,000 per hectare, compared with LT448,300 per hectare for gravity and pump irrigation. The O&M fee for cotton was LT462,000, compared with LT1,086,800 per hectare for gravity and pump irrigation (13,585 Turkish liras = 1 U.S. dollar in 1993).



The capital cost recovery surcharge is based on land area. DSI can charge users for this component only 10 years after completion of the project, and for a period not to exceed 50 years, with no inflation considerations. The capital cost recovery surcharge varies by region, ranging between LT4,100 and LT8,500 per hectare. The reported collection rate for the O&M fees and the capital cost recovery surcharge in 1992 was 33 percent (Kasnakoglu and Cakmak 1995).

### *Chile*

Chile is one of the few countries where tradable water rights have been officially established. Water rights are allocated to users in the form of shares of the river flow (for example, there are 25,000 shares in the Río Alqui, each supposed to deliver 1 liter per second in a good year; see Hearne and Easter 1995). Economic analysis of water markets in four of Chile's river valleys—the Maipo, Elqui, Limarí, and Azapa valleys (Hearne and Easter 1995)—demonstrates that the market transfer of water use rights produces substantial economic gains from trade in both the Elqui and Limarí valleys. These economic gains produce rents for both buyers and sellers. In the Elqui valley, net gains from trade per share were within the range of transaction values observed in the 1990s in Chile of Ch\$400,000. In the Limarí valley, gains from trade per share were three times the recent price of Ch\$1,200,000 for a share of water from the Cogotí reservoir (403 Chilean pesos = 1 U.S. dollar in June 1993). When trading was active, especially in the Limarí valley, transaction costs did not present an appreciable barrier to trading. Nonetheless, in the large canal systems with fixed flow dividers in the Elqui and Maipo valleys, there have been few transactions.

### III. EFFICIENCY OF WATER ALLOCATION

An efficient allocation of water—or any other scarce resource—is one that maximizes the total net benefit that can be generated by the available quantity of the resource given the available state of technology. If the net benefit to be maximized involves variable (short-run) costs and abstracts from capital and other costs that are fixed in the short run, the allocation is quasi (or short-run) efficient. When the fixed inputs are chosen optimally, the short- and long-run outcomes are the same. In the absence of distortions (taxes) or costs associated with implementing an allocation scheme (for example, collecting water fees, monitoring, enforcing quotas), an efficient allocation is first-best or Pareto efficient. In the presence of distortionary actions or implementation costs, an allocation that maximizes the total benefit net of all costs, including implementation and distortionary costs, is second-best efficient (Baumol and Bradford 1970). Such is the situation, for example, when taxes distort decisions regarding input and output and collecting these taxes is costly. In this section we discuss the performance of the various pricing methods vis-à-vis efficiency criteria.

### *Volumetric Pricing*

The optimal volumetric pricing rule requires that the water price be set equal to the marginal cost of water supply. In the absence of implementation costs, the (variable) cost of supply consists solely of the cost of delivery. In this case, the marginal cost pricing rule, in which the water price is set at the level of marginal delivery cost, is optimal. Water pricing, however, entails costly activities, such as maintaining and reading water meters, administering the collection of water fees, and resolving disputes with farmers. The costs incurred by these activities, referred to as implementation costs, are augmented to the cost of delivery and become an integral part of the cost of supply. The marginal cost of water supply consists of the marginal delivery cost and the marginal implementation cost.

In the presence of implementation costs, the optimal volumetric pricing rule is of the form:

$$\text{water price} = \text{marginal delivery cost} + \text{marginal implementation cost}$$

where all values are measured in dollars per cubic meter (detailed derivation can be found in Tsur and Dinar 1996). Because the marginal cost pricing rule ignores implementation, the presence of implementation costs requires departure from marginal cost pricing. It also implies that volumetric pricing cannot achieve a first-best (efficient) outcome. Volumetric pricing thus may not be superior to other pricing methods, such as those based on output or area fees. The pricing method that achieves the highest social benefit then becomes a practical matter that depends crucially on the implementation costs associated with each method. This point is illustrated in section IV.

### *Output Pricing*

The output pricing method prices water by imposing a tax on output. The optimal tax depends on the nature of the production technology and the implementation costs (see Tsur and Dinar 1996 for details). The allocation obtained under output pricing is second best when implementation costs are nil. This is because the output fee and the zero price of water will distort decisions regarding input and output away from the first-best outcome achieved under the marginal pricing rule. The presence of implementation costs constitutes another source of deviation from a first-best allocation.

Without implementation costs, output pricing is inferior to volumetric pricing (that is, it achieves a lower social benefit): it achieves only a second-best allocation, while volumetric pricing achieves a first-best allocation. With implementation costs, however, both methods are second best, and the method that generates a higher benefit depends on the costs associated with implementing each method.

### *Area Pricing*

With area pricing, farmers pay a fixed fee per hectare or acre for the right to receive irrigation water. The per hectare fee is a fixed cost that, once paid, can

no longer affect decisions regarding input and output. It can, however, affect the choice of crop (if per hectare water fees vary across crops) or induce some farmers to switch to unirrigated farming, thereby affecting the aggregate demand for water. For farmers who pay the water fee, the demand for irrigation water is larger than it would be under marginal cost pricing, and the resulting water allocation is inefficient. However, the implementation costs associated with per area pricing are smaller than those associated with volumetric or output pricing. Therefore, area pricing may well generate a higher social benefit.

#### *Tiered Pricing and Two-Part Tariff Pricing*

Tiered pricing is common when water demand or supply have periodic (seasonal, daily) variations. During periods of excess supply, setting the water price equal to the marginal cost of supply achieves (short-run) efficiency. During periods of excess demand, the water price accounts also for water scarcity and is increased by the scarcity rent. An alternative tiered pricing method increases the water price each time demand exceeds one of a few prespecified levels.

The two-part tariff method consists of volumetric pricing plus a fixed admission charge per farmer. The admission charge can serve to balance the budget of the water supply agency, thus extending short-run volumetric pricing to account for long-run fixed costs. The implementation of the annual admission charge as a Pigouvian poll tax avoids the distortionary effects of other tax schemes. Some analysts therefore consider the two-part tariff method as capable of achieving long-run efficiency (see Feldstein 1972a, 1972b; and Laffont and Tirole 1994, pp. 19–34).

#### *Water Markets*

The basic premise of modern economics is that markets, under certain conditions, achieve first-best efficiency when no implementation costs are present. These “certain conditions” include a competitive environment (no single agent can affect outcomes), fully informed agents operating under certainty, no externalities, and no increasing returns to scale in production. In the case of water, these conditions are frequently violated. Water is expensive to transport; hence, water markets tend to be localized, consisting of a limited number of participants, some of whom may be able to influence outcomes. Water supply is often uncertain. Water resources (for example, rivers, aquifers) may be shared by many users who inflict externalities on one another (for example, groundwater pumping by one farmer reduces the water level and increases pumping costs to other farmers). Finally, water supply systems, like other public utilities, may exhibit increasing returns to scale. For these reasons, water markets are unlikely to attain a first-best allocation in actual practice.

Yet, even when distorted, the suboptimal outcomes of water markets may outperform the other pricing methods when implementation costs are taken into consideration. Introducing water markets amounts to privatizing the water sector, an immediate result of which is that the cost associated with the collection

of information is internalized. This eliminates a major source of implementation costs. In addition, water markets induce the transfer of water from less productive to more productive farmers and eliminate corruption incentives to which centralized allocation mechanisms are more sensitive.

#### *Which Method to Implement?*

The preferred pricing method is the one that yields the highest social benefit. In the absence of implementation costs, the volumetric method (or one of its related methods—tiered or two-part tariff pricing) is optimal. With implementation costs, other methods may perform better. Implementation costs vary widely from region to region because of variations in climate, demography, social structure, water rights, water facilities, history, and general economic conditions. Therefore, the net benefit associated with each method also varies from region to region. In the following section we perform some calculations to illustrate the effects of implementation costs and inefficiencies on water prices and welfare.

#### IV. AN EMPIRICAL ILLUSTRATION

We present here a numerical example to evaluate the performance of some of the pricing methods discussed above regarding efficiency of water allocation. We consider the production of two crops, cotton and wheat, by means of two inputs, water ( $q$ ) and nitrogen ( $x$ ). Nitrogen is purchased in the marketplace; water is provided by a water agency. Other inputs are assumed to be fixed. We use a quadratic approximation for the per hectare water-nitrogen production functions,  $g_j(q, x) = \alpha_j + \beta_j q + \gamma_j x + \delta_j q^2 + \phi_j x^2 + \eta_j q x$ , where  $j$  denotes cotton or wheat. Table 1 lists the parameters estimated by Hexem and Heady (1978). Output and nitrogen prices, using the state of Haryana in India as an example, were taken from India, Directorate of Economics and Statistics (1993) and are presented in table 2. Additional production costs that are not related to water or nitrogen are \$78.50 per acre (\$196.30 per hectare) for cotton and \$45.10 per

Table 1. *Parameter Estimates of the Quadratic Production Functions for Cotton and Wheat*

Coefficient	Cotton	Wheat
Intercept, $\alpha$	233.71	-10,414
Water (acre-inch), $\beta$	23.65	852.01
Nitrogen (pounds per acre), $\gamma$	0.438	11.6
Water*water, $\delta$	-0.182	-12.9
Nitrogen*nitrogen, $\phi$	-0.0033	-0.032
Water*nitrogen, $\eta$	0.0209	0.0925
Range of water input (acre-inches)	8-40	0-40
Experimental range of nitrogen input (pounds per acre)	0-120	0-200

Note: Yield is measured in pounds per acre. Metric conversion: 1 acre-inch = 102.8 cubic meters; 1 pound = 2.24 kilograms; 1 pound per acre = 1.102 kilograms per hectare.

Source: Hexem and Heady (1978).

Table 2. *Output and Input Prices for Cotton and Wheat Production*  
(U.S. dollars)

Indicator	Cotton		Wheat	
	Per pound	Per ton	Per pound	Per ton
Output	0.8	1,750	0.15	300
Nitrogen	0.089	0.199	0.089	0.199

Note: Prices are from the state of Haryana in India and are in constant 1993 U.S. dollars (Rs31.5 = \$1).

Source: India, Directorate of Economics and Statistics (1993).

acre (\$112.70 per hectare) for wheat (India, Directorate of Economics and Statistics 1993).

Modifying Howitt and Vaux (1995), the marginal cost ( $MC$ ) of water delivery (not including implementation costs) is represented by  $C'(q) \equiv MC(q) = 11.5 + 0.000671q$ , where  $C'$  is dollars per acre-inch and  $q$  is measured in acre-inches. The cost of supplying  $q$  acre-inches of water is thus  $11.5q + 0.000671q^2 / 2$ .

The farmer chooses the cropping pattern and allocates inputs, taking all prices—including the price of water—parametrically. The water agency chooses the pricing method and the water rates. We consider the efficiency effects of volumetric, output, input, and area pricing, allowing prices to vary between crops. The results are presented in table 3.

We assume that implementation costs are incurred as a fraction of water proceeds and that these costs vary among the pricing methods. The last column of table 3 provides the implementation costs. For example, case 1 is free of implementation costs, while the 0.05 entry of case 2 implies that from each \$1.00 raised as water proceeds, \$0.05 are used up by water pricing activities. (Tsur and Dinar 1996 provide a detailed analysis of such implementation costs.)

A few interesting observations emerge from the results in table 3. First, welfare is affected most dramatically by the effect of water pricing on choice of crop. Without water pricing (case 0), the farmer chooses to grow cotton, because it gives the highest profit. Cotton, however, consumes a lot of water (82.89 acre-inches per acre) and costs the society dearly to deliver the water. Thus, despite the farmer's high profit of \$1,011.84 per acre, the social benefit net of the cost of water is only \$56.35 per acre. Introducing a simple per acre pricing scheme under which the water fee is \$231 or more for each acre of cotton and nothing for an acre of wheat (case 9) induces the farmer to switch to wheat production. The result is that water consumption decreases to 33.82 acre-inches per acre, the farmer's profit decreases to \$781.05 per acre, and the social benefit increases to \$391.79 per acre. In neither case are water fees actually collected (in the first case water is supplied free of charge, and in the second case farmers avoid paying for water by choosing to grow wheat), but the mere effect on choice of crop increases the social benefit almost sevenfold.

The second observation concerns the sensitivity of water prices to implementation costs. In cases 1–4 volumetric pricing is employed with escalating imple-

Table 3. *Efficiency Effects of Alternative Methods for Pricing Irrigation Water*

Case and pricing method	Minimum water fee <sup>a</sup>		Crop	Water input	Water proceeds	Nitrogen input	Output	Farmer's profit	Cost of water	Social benefit	Implementation costs
	Cotton	Wheat		(acre-inches per acre)	(U.S. dollars per acre)	(pounds per acre)	(pounds per acre)	(U.S. dollars per acre)	(U.S. dollars per acre-inch)	(U.S. dollars per acre)	(percentage of water proceeds)
0. None	0.00	0.0000	Cotton	82.886	0.00	311.97	1,299.510	1,011.84	955.49	56.35	0.0
1. Volumetric	9.70	11.5210	Wheat	30.823	355.10	216.52	5,220.540	408.71	354.78	409.03	0.0
2. Volumetric	5.90	5.5690	Wheat	32.369	180.27	218.76	5,309.928	596.75	372.59	395.41	5.0
3. Volumetric	4.10	2.0690	Wheat	33.278	68.83	220.07	5,333.858	711.65	383.07	392.26	7.5
4. Volumetric	3.10	0.0000	Wheat	33.815	0.00	220.85	5,338.023	781.05	389.26	391.79	10.0
5. Volumetric with balanced budget	9.70	11.5103	Wheat	30.825	354.81	216.53	5,220.750	409.03	354.81	391.29	5.0
6. Output	0.18	0.0000	Wheat	33.815	0.00	220.85	5,338.023	781.05	389.26	391.79	0.0
7. Input	2.50	0.0017	Wheat	33.814	9.14	220.67	5,337.916	780.67	389.25	391.79	0.0
8. Input	2.50	0.0000	Wheat	33.815	0.00	220.85	5,338.023	781.05	389.26	391.79	10.0
9. Area	231.00	0.0000	Wheat	33.815	0.00	220.85	5,338.023	781.05	389.26	391.79	0.0
10. Area with balanced budget	621.00	389.2610	Wheat	33.815	389.26	220.85	5,338.023	391.79	389.26	391.79	0.0

a. For cases 1–5, the water fee is measured in dollars per acre-inch of water used, in cases 6–8, in dollars per pound of output or input, and in cases 9–10, in dollars per acre of land.

Source: Authors' calculations.

mentation costs: case 1 entails no implementation costs, case 2 entails a cost of 5 percent (that is, \$0.05 of each \$1.00 of water proceeds are used to cover expenses associated with implementation activities), case 3 entails a cost of 7.5 percent, and case 4 entails a cost of 10 percent. In all cases the water price for cotton production is kept high enough to induce farmers to grow wheat. The price of water for wheat production drops from \$11.52 per acre-inch in case 1 to \$5.57 per acre-inch in case 2. With 7.5 percent implementation costs, the price of water is further reduced to \$2.07 per acre-inch in case 3. When implementation costs are 10 percent or more (case 4), the pricing activities are costly enough to render water pricing undesirable, except for the nominal charge on water going to cotton production, whose only role is to switch production away from this water-intensive crop.

The third observation that emerges from table 3 is that an inefficient but simple method such as per acre pricing may outperform an efficient but complicated method, taking implementation costs into account. Cases 4 and 9 yield the same outcome using different methods: in case 4, volumetric pricing is employed, and in case 9 area pricing is used. In both cases, only water in cotton production is priced to discourage production of this crop. If, however, volumetric pricing entails some fixed costs, for instance, because of the need to install water meters, which have not yet been incurred, then it is better to use area pricing and avoid the fixed costs and the ensuing implementation costs associated with volumetric pricing.

From cases 1–4, higher implementation costs lead to lower water prices and thus lower water proceeds that are insufficient to cover the costs of delivery. Often the water agency is required to have a balanced budget. We look at the effect on welfare of a balanced budget constraint imposed on volumetric pricing in case 5, which imposes the constraint on case 2 (with 5 percent implementation costs). The result is that the farmer's profit is reduced quite significantly from \$596.75 to \$409.03 per acre, while social benefit decreases slightly from \$395.41 to \$391.29 per acre. Thus, mandating a balanced budget on the water agency inflicts a heavy toll on farmers. Without this constraint, the water agency's deficits would have to be financed by taxpayers' money. Given its small effect on total welfare, the choice of whether to impose the balanced budget constraint is mostly political, involving considerations of income distribution and pressure groups.

Case 6 considers output pricing. It appears that because of the distortionary effects of this method, water is priced to affect only the choice of crop, not the choice of water input, given that the right crop (wheat) was chosen.

Cases 7 and 8 look at input pricing with 0 and 10 percent implementation costs, respectively. As in the other cases, the main role of water pricing is to affect the choice of crop by imposing a tax of \$2.5 per pound or more on nitrogen applied in cotton production. Given this tax, wheat is the chosen crop, and the impact on water input of taxing nitrogen is rather limited when implementation costs are nil and vanishes completely when implementing the input tax takes up \$0.10 or more from each \$1.00 of taxes raised.

Cases 9 and 10 consider area pricing without and with a balanced-budget constraint, respectively. Imposing a fee of \$231 or more for each acre of cotton and \$0 for each acre of wheat is sufficient to induce the profit-seeking farmer to grow wheat (case 9). When the farmer is also required to cover the cost of water delivery, this cost is imposed as a per acre fee on wheat, and a higher per acre fee on cotton is needed to ensure that cotton will not be chosen (case 10). From society's point of view, the balanced budget constraint makes no difference (the social benefit is the same in both cases): with it the burden of paying for water delivery falls on the user (the farmer), and without it the burden falls on the taxpayers.

## V. CONCLUSIONS

In this article we investigated the efficiency performance of several methods of pricing irrigation water, paying special attention to the costs associated with implementing them. Efficient use of irrigation water requires that the pricing method affect demand. The volumetric, output, input, tiered, and two-part tariff methods all satisfy this condition and can achieve efficiency, although the type of efficiency (short or long run, first or second best) varies from one method to the other. These methods also differ in the amount and type of information and in the administrative cost needed to implement them. Pricing methods that do not influence water input directly, such as area pricing, lead to inefficient allocation. Such methods, however, are in general easier to implement and administer, and they require a modest amount of information.

We found that water pricing methods are most pronounced through their effects on the cropping pattern—more so than through their effect on water demand for a given crop. Implementation costs are found to have a large effect on water prices and on welfare and hence should have an important role in determining the desirable method to use in any given water situation. In the conditions of the numerical example, for instance, moderate implementation costs of 10 percent (that is, \$0.10 of each \$1.00 raised as water proceeds are used to finance pricing-related activities) render the (second-best) efficient volumetric method equal in performance to an inefficient but simple per area pricing method that entails no implementation costs. If the volumetric method also involves fixed costs, such as the cost of installing water meters, then area pricing is superior to volumetric pricing. With implementation costs of less than 10 percent and a previously installed metered water conveyance facility, the volumetric method is superior.

A volumetric method that uses the marginal cost pricing rule achieves first-best (the maximum attainable total benefit) efficiency in the absence of implementation costs. But this method requires information on the water application of each user (that is, metered water) and in general entails implementation costs. In such cases the optimal departure from marginal cost pricing achieves second-best efficiency.



The output (or input) pricing method cannot achieve first-best efficiency, because it distorts input-output decisions. Without implementation costs, the outcome of an optimal output pricing can be considered as second best. The presence of implementation costs introduces another source of deviation from first-best efficiency (in addition to the distortionary effect mentioned above), hence the outcome may be considered as third best. However, whether output pricing is inferior to volumetric pricing depends on the magnitude of implementation costs, because implementing these methods entails different activities and requires different information and data. In the numerical example, input pricing is better than output pricing, and both input and output pricing are inferior to volumetric pricing in the absence of implementation costs. The introduction of 10 percent implementation costs makes all three methods equivalent, because water prices are used to affect only the choice of crop, not the demand for water once the right crop has been chosen.

Area pricing can affect water input through its effect on choice of crop but cannot otherwise affect demand for water. Area pricing is, however, easy to implement and administer and requires minimal information. Our numerical example shows that with moderate 10 percent implementation costs on volumetric pricing, area pricing is as good as volumetric pricing. And when volumetric pricing involves fixed costs (for example, the cost of installing water meters), area pricing outperforms volumetric pricing.

Despite numerous imperfections (caused mainly by spatial and intertemporal externalities, small number of participants, uncertainty, and economies of scale in supply), the market mechanism is still an excellent means for securing the transfer of water from low-value to higher-value activities. It puts the burden of information collection on water users and avoids problems of asymmetric information that are commonly found in principal-agent situations. The cost of information collection—a major component of implementation costs—is thus drastically reduced. Water markets require well-developed water conveyance facilities, a system of water rights and water endowment (or entitlement) for each user contingent on the availability of water, a complete set of rules for trading in water endowments and in water rights, and the appropriate institution to oversee trading activities and resolve conflicts when they arise. Once the water institutions and conveyance facilities are in place, the implementation costs associated with water markets are small (or negligible), which is why this mechanism is an attractive means for achieving efficiency.

Efficiency, an important objective, may not always warrant the social cost associated with implementing pricing methods that are considered efficient. Implementation costs should always be considered, and the pricing method to be used depends crucially on these costs. Other forces that work against efficient pricing are either political or considerations of equity and fairness. If farmers are well organized, they can effectively collude to exert political pressure on their own behalf. In addition, politicians may find that it is in their interest to support farmers, because it increases their chances for reelection (see de Gorter and Tsur

1991), and one manifestation of this support may be subsidized water. Equity considerations in pricing irrigation water, which are discussed in Tsur and Dinar (1995), imply that the pricing of water should not make farmers worse off. Raising water prices, for instance, entails lowering farm income as well as land values (Rosegrant and Binswanger 1994). This brings in the issue of whether water is an appropriate means for achieving social ends such as income distribution. Results of the preliminary analysis of Tsur and Dinar (1995) suggest a rather limited scope for water policies in achieving income distribution goals, but further work is needed before definite conclusions can be reached.

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