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Water Policy 4 (2002) 173–199

Water Policy

www.waterpolicy.net

Pricing irrigation water: a review of theory and practice

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Received 13 July 2001; received in revised form 20 December 2001; accepted 24 February 2002

Abstract

Increasing economic pressures on water resources are causing countries to (re)consider various mechanisms to improve water use efficiency. This is especially true for irrigation agriculture, a major consumer of water. "Getting prices right" is seen as one way to allocate water, but how to accomplish this remains a debatable issue. Methods of allocating water are sensitive to physical, social, institutional and political settings, making it necessary to design allocation mechanisms accordingly. This paper surveys current and past views on allocating irrigation water with a focus on efficiency, equity, water institutions, and the political economy of water allocation.

Keywords: Irrigation water; Water pricing; Water allocations

Contents

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PII: S1366-7017(02)00026-0

1. Introduction

The Earth's renewable fresh water resources are finite. Given world population growth, fresh water availability for 2050 is estimated to be 4380 m^3 per person per year.[1] While this result suggests no foreseeable shortage in per capita availability, fresh water is distributed unevenly in space and time. Indeed, by 2025 as many as 3 billion people may be living in "water-stressed" countries (Seckler, Amarasinghe, Molden, de Silva, & Barker, 1998; Postel, 1999). And by 2050 nearly 1 billion people living in the Middle East and North Africa will have $<650\,m^3$ of water per person, a severe water shortage by any standard.[2]

Irrigated agriculture now occupies 18% of the total arable land in the world and produces more than 33% of its total agricultural production. However, the likelihood of additional irrigation projects sufficient to meet increasing food demands is questionable, given mounting concerns over the adverse effects of large dam projects, and losses of land to salinization (Sampath, 1992; Rosegrant & Meinzen-Dick, 1996; Postel, 1999). More likely is the modernization of existing irrigation systems to enhance efficiency and to cater to the new institutional structures, technology, and food demands (Bandaragoda, 1998). Seckler et al. (1998) estimate that improvements in irrigation efficiency alone may meet one-half of the increase in water demand through 2025.

Because water in general and irrigation water in particular often require initially large capital investments in infrastructure development, governments are often required to allocate water resources. Policymakers use various mechanisms to allocate water, some more efficient and some

[1] Our estimates.
[2] Our estimates.

easier to implement than others (Tsur & Dinar, 1997; Dinar, 1998). They generally involve water pricing of one sort or another, yet the notion of an optimal water-pricing policy does not command consensus among economists, let alone policymakers. Despite the pervasiveness of water pricing as a means to allocate water, there is still disagreement regarding the appropriate means by which to derive the price (Kim & Schaible, 2000). Even if private markets are allowed to allocate irrigation water, governments still have important roles to play in providing stable and appropriate institutions for the successful operation of those markets.

Attempts to chronicle developments in the vast and disperse body of literature surrounding these issues have previously focused on particular aspects of irrigation (Table 1). This survey seeks to concisely review and reference the literature from the last decade on water allocation efficiency and equity in irrigation. We constrain sources to key articles and case studies from the resource economics literature, including external material only when particularly pertinent. The goal of this survey is to provide a useful reference for policymakers concerned with irrigation water and its allocation. We first review the theory and practice of allocation policies in terms of efficiency and equity. A discussion of evolving water institutions and the political economy of water allocation follows. Concluding comments are presented in the last section.

2. Efficiency and equity

There are many ways to define efficiency in water allocations. Sampath (1992) describes four situations under which efficiency can be defined pertaining to the relevant time horizon. We use a similar definition: an efficient allocation of water resources is one that maximizes net benefits to society using existing technologies and water supplies. In the short run, an efficient allocation maximizes net benefits over variable costs and results in the equalization of marginal benefits from the use of the resource across sectors to maximize social welfare (Dinar, Rosegrant, & Meinzen-Dick, 1997). In the long run, maximization of net benefits also includes optimal choices of fixed inputs. In the absence of taxes or other distortionary constraints, an allocation that maximizes net benefits is called *first-best efficient*. When maximization occurs under distortionary constraints (informational, institutional, or political) the resulting allocation is termed *second-best efficient* (Tsur & Dinar, 1997).

Equity of water allocation is concerned with the "fairness" of allocation across economically disparate groups in a society and may not be compatible with efficiency objectives (Seagraves & Easter, 1983; Dinar & Subramanian, 1997). In general, water pricing mechanisms are not very effective in redistributing income (Tsur & Dinar, 1995), but it may be in a government's national interest to increase water available for certain sectors or citizens. To meet this goal it is often necessary to provide subsidized water provision or adopt differing pricing mechanisms to account for disparate income levels (Dinar et al., 1997).

3. Theory

Water resources share similarities with both renewable and non-renewable resources. The problem with surface water (in the absence of storage) is to allocate a renewable supply among

Table 1
Reviews

Reviews—subject	Included studies/countries	Key findings
Dinar (2000)—political economy of water pricing reform	Australia, Brazil, Pakistan, Mexico, Yemen, Honduras, and Morocco	Documents key reform efforts in these countries, noting the effects of political economies on success or failure
Saleth and Dinar (1999)—evaluation of water institutions and water sector performance	Australia, Brazil, Chile, India, Israel, Mexico, South Africa, Spain, Sri Lanka, and USA	With an overall pro-reform climate, it is possible to minimize transaction costs and achieve more than proportionate improvement in water sector performance
Mariño and Kemper (1999)—institutional frameworks	Brazil, Spain, and Colorado	It is essential to review the institutional frameworks that have contributed to successful water markets
IWMI (1999)—non-agricultural uses of irrigation water	Sri Lanka, Mexico, and Pakistan	Due to increasing water scarcity, uses of irrigation water have significant environmental, health, and other domestic consequences
Easter, Dinar, and Rosegrant (1999)—water markets	Review efficiency of allocations resulting from formal and informal water markets. Discuss the mitigating factors, transaction costs, and mitigating strategies involved with water markets	
Easter, Rosegrant, and Dinar (1998)—water markets	Texas, Colorado, US West, California, Chile, Mexico, India, Pakistan, Spain, and Canada	Where water is scarce and large amounts of available water have already been committed to users, the economic benefits from water markets are likely to be the largest
Dinar and Subranian (1997)—pricing policies	Algeria, Australia, Botswana, Brazil, Canada, France, India, Israel, Italy, Madagascar, Namibia, NZ, Pakistan, Spain, Sudan, China, Tanzania, Tunisia, Uganda, UK, and USA	Most countries surveyed are decentralizing water management. Some are developing legal frameworks to decentralize and to encourage private investment through incentives. The development of transferable water rights and water markets is crucial to consider for future water management
Vermillion (1997)—decentralization and management transfer	Philippines, Indonesia, Vietnam, China, Bangladesh, Nepal, Sri Lanka, India, Egypt, Sudan, Turkey, Nigeria, Senegal, Dominican Republic, Colombia, Mexico, USA, and New Zealand	The impacts of management transfer include reduction in the cost of irrigation to farmers and government, enhanced self-reliance of irrigation schemes, expansion of service areas, reduction in the amount of water delivered, and increases in cropping yields. Negative impacts include increased costs of irrigation services, failing financial viability, and deteriorating infrastructure
Merrey (1997)—Summary of IIMI R&D: 1984–1995	Indonesia, Pakistan, Sudan, West Africa, Malaysia, Bihar, India, Gujarat, India, Sri Lanka, Egypt, USA, Colombia, Niger, Nigeria, Philippines, China, and Nepal	Documents the high degree of unreliability and inequity of surface water deliveries and its relationship to salinity. IIMIs research illustrates that WUAs with poor organization and political strength have no clear, enforceable water rights, and therefore suffer from inefficiencies
Parker and Tsur (1997)—Decentralization and Coordination	Israel, Turkey, California, Florida, Australia, Middle East, Jordan–Yarmouk River Basin, and California Bay/Delta	As water becomes scarcer it becomes more expensive via increasing scarcity prices. As a result there has been a global movement away from centralized water management towards decentralized mechanisms to increase distributional efficiency

competing users. For groundwater, withdrawing water now affects the resource available to future generations (depending on the rate of recharge) and therefore allocation over time is important to consider.

Efficiency in allocating irrigation water is accomplished by equating the marginal benefits of a unit of water to the marginal cost of supplying that unit.[3] In practice this proves difficult due to many distortionary constraints associated with irrigation water (Spulber & Sabbaghi, 1998; Easter, Becker, & Tsur, 1997; Thobani, 1997). These constraints and the efficiency and equity of second-best allocations of irrigation water have been given considerable attention. They have been evaluated using both partial equilibrium and general equilibrium (GE) frameworks. Partial equilibrium analyses focus on the irrigation unit (farm, district, sector) assuming the rest of the economy operates in a given way, whereas GE analyses consider other regions or sectors to determine the economy-wide effects of a policy (see examples in Tables 2 and 3). We briefly mention several departures into the literature of second-best theories of water allocation beginning with the public good nature of water provision.

3.1. Public goods

Water from both underground and surface sources often is an open-access good (Easter et al., 1997). As has been mentioned before, there are finite amounts of water that must be shared in common between various sectors, regions, and their users. Over-exploitation of these resources is commonly referred to as the "tragedy of the commons" (Hardin, 1968). This occurs when users ignore the effects of their actions on the resource and other users when pursuing their own self-interests. To address this problem economists often advocate the definition of private water rights and formation of water markets. For example, technology has reduced the economies of scale for tube-well irrigation such that it can be now viewed as a private good category, even for relatively small-scale farmers (Vermillion, 1997). However, privatization can be difficult, especially if the resource is exhaustible, non-renewable (Dasgupta & Heal, 1979) or uncertain (Provencher, 1995).

3.2. Implementation costs

Implementing a pricing method requires appropriate institutions, such as a central water agency (CWA), and entails costs. The physical, institutional, and political environment is manifested in the form of implementation costs. Implementation, or transaction, costs may render some pricing methods impractical and narrow the list of methods from which to choose. Valuing these constraints under various pricing methods is not a trivial task and there appears to be no general rule that one can apply in any given circumstance. Beyond administrative costs, which are relatively easy to value, implementation costs include such things as compliance costs, which can be quite substantial. For example, due to the nature of farming systems in many areas of the world (i.e., variance across seasons, crops, regions, and climates) complex pricing systems that are efficient may be constrained by the informational and administrative costs needed for

[3] Added to the marginal cost of supply would be a scarcity value in the case of groundwater with slow recharge, in the case of stored surface water, or with uncertain supplies (Tsur & Zemel, 1995; Cummings & Nercissiantz, 1992; Tsur & Graham-Tomasi, 1991).

Table 2
Partial equilibrium analyses

First-best		
Hearne and Easter (1998)	Water markets	It has long been recognized that markets provide a means to efficiently allocate water
Thobani (1998)	Marginal cost pricing	Marginal cost pricing has also been called *opportunity cost pricing*, implying that the price of water should be set equal to the opportunity cost of providing it
Easter et al. (1998)	Water markets	Such things as monitoring, return flows, third-party effects, and instream uses have to be considered, when deciding what to include in water transactions
Tsur and Dinar (1997)	Marginal cost pricing	When water supplied is of different quality the marginal value of supply should be reflected in the price
Second-best		
Easter (1999)	Externalities	Summarizes water conditions, irrigation systems, and their potential externalities
Willis, Caldas, Frasier, Wittlesey, and Hamilton (1998)	Externalities	Third-party effects of return-flow from large irrigation dam projects recently have accounted for environmental degradation in Colorado
Smith and Tsur (1997)	Asymmetric information	Use mechanism design theory to propose a water-pricing scheme, which depends only on observable outputs
Easter et al. (1997)	Public goods	It is useful to categorize irrigation service based on their public good nature, depending upon the evolution of technology or institutions
Tsur and Dinar (1997)	Transaction costs	Effects of implementation costs on the performance of different pricing methods are significant in the sense that small changes in costs can change the order of optimality of those methods
Zilberman (1997)	Scarcity	Develops an optimal water pricing, allocation, and conveyance system over space to capture different upstream and downstream incentives
Shah, Zilberman, and Chakravorty (1995)	Scarcity	Find that it may be optimal to increase water prices to encourage more quickly the adoption of water conserving technologies used with groundwater
MacDonnell et al. (1994)	Externalities	Discuss the third-party effects of American West dams and water banking
Easter (1993)	Equity	Illustrates the effect of "fairness" on efficient management of four irrigation systems
Tsur and Dinar (1997)	Equity	Equity effects of pricing are primarily dependent on land endowments
Sampath (1992)	Equity	Argue that consumers benefit from agricultural investments through lower food prices and so should be expected to share in covering the costs
Sampath (1991)	Equity	Notes equity concerns surrounding income redistribution via irrigation distribution have become one of the most important objectives across disciplines
Saliba and Bush (1987)	Equity	Note that higher costs associated with the purchase of water rights may force some users out of the market
Seagraves and Easter (1983)	Equity	Equity concerns include such things as the recovery of costs from users, subsidized food production, and income redistribution

Table 3
General equilibrium (GE) analyses

First-best		
Hurwicz (1998)	Derives the optimality conditions for GE treatments of market failure and second-best policies	
Binswanger, Deininger, and Feder (1993)	Discuss GE assumption in first-best and second-best analysis	
Berk, Robinson, and Goldman (1991)	Compare the advantages and disadvantages GE and partial equilibrium analyses	
Second-best		
Kohn (1998)	Externalities	Illustrates a simple Nash-game scenario that both countries will opt for environmental taxes
Roe and Diao (1997)	Externalities	Describes a situation found where two countries share water resources and thus the water-use decisions of each country will affect the water availability of the other country
Smith and Roumasset (1998)	Trade	Provide a model for water management with multiple sources and transport technologies
Diao and Roe (1995)	Trade	Focus on the environmental and health effects of changing trading patterns
Vaux and Howitt (1984)	Trade	Examine the interregional equilibrium supply and demand relationship for California
Elbasha and Roe (1995)	Endogenous growth	Incorporate pollution and abatement efforts into three types of endogenous growth models
Mohtadi (1996)	Endogenous growth	Show how optimal growth depends upon the type and extent of environmental regulation
Rausser and Zusman (1998)	Scarcity	Explore the affects of water scarcity on the political power balance in a GE format
Schaible (1997)	Scarcity	Examines groundwater demand responses to conservation pricing policies
Equity		
Diao and Roe (2000)	Equity	Water pricing may have a role in policies aimed at affecting income distribution between farming and non-farming sectors
Just, Netanyahu, and Horowitz (1997)	Equity	Examine the equity considerations of water pricing
Carruthers, Rosegrant, and Seckler (1997)	Equity	Generate various scenarios regarding equity concerns as a function of global food supply and demand linked by trade in a GE framework
Rosegrant (1997)	Equity	The effects on food security of changing investment levels can be evaluated for a variety of regions and periods

implementation (Sampath, 1992; Rosegrant & Binswanger, 1994). Tsur and Dinar (1997) find that effects of implementation costs on the performance of different pricing methods are significant in the sense that small changes in costs can change the order of optimality of those methods. While these observations may be straightforward, very little empirical evidence or methodology exists for evaluating the practical limitations of various implementation costs.

3.3. Incomplete information

One such cost arises when the water user has complete information regarding his or her marginal water value, but some of this information is private and unavailable to the CWA. In this case rational individuals may use their private information to advance their own interests and the CWA may have to then spend considerable effort in monitoring and enforcement at society's expense. The literature refers to this as *asymmetric information* and *moral hazard* (Laffont & Tirole, 1993). The pervasive case of unmetered water and the prevalence of per area pricing mechanisms well illustrate this aspect of incomplete information (Bos & Walters, 1990; Smith & Tsur, 1997). Here, a CWA will often resort to the use of per unit area pricing due to the high costs of implementing a meter system. Because the CWA does not have complete information on the value and use of the irrigation water, farmers might have an incentive to underreport actual usage of water if priced volumetrically.

3.4. Scarcity

There are many ways that pricing mechanisms are used to address scarce water supplies. During seasonal shortages, higher marginal cost prices can be used to ration all of the water and to recover fixed costs during peak demand (Seagraves & Easter, 1983). Many informal allocation systems have developed in the absence of prices or formal markets to address scarcity. These traditional, communal arrangements have often operated successfully for many years, but may not be efficient or equitable: *warabandi* system in Pakistan (Easter & Welsch, 1986) and India (Perry & Narayanamurthy, 1998), *subaki* system in Bali (Sutawan, 1989), and the *entornador-entornador* system in Cape Verde (Langworthy & Finan, 1996). When flows are uncertain, shares rather than volumes of water can be allocated to individual farms. When these shares are tradable, efficient allocations can be achieved (Seagraves & Easter, 1983).

Another mechanism to cover scarcity costs is the introduction of a fixed charge to balance the budget of the CWA. In this manner, the short-run efficiency of marginal cost pricing can be extended (using a two-part tariff method) to account for long-run fixed cost considerations (e.g., Egypt—Wichelns, 1998). Similarly an annual *Pigouvian* tax can be used to manage scarcity. This avoids distortionary affects of other taxing forms and is therefore capable of achieving long-run efficiency (Laffont & Tirole, 1993; Tsur & Dinar, 1995).[4]

Uncertain supply also is related to the choice of water source and irrigation system, which will affect the eventual water price. Small and Rimal (1996) using efficiency and equity criteria evaluated water scarcity effects on irrigation system performance in Asia. They note that optimal conveyance strategies to account for scarcity may reduce economic efficiency and equity marginally. Along these lines, Zilberman (1997) develops an optimal water pricing, allocation, and conveyance system over space to capture different upstream and downstream incentives.

[4] See Tsur (1990, 1997), Tsur and Graham-Tomasi (1991), and Easter et al. (1997) for treatments of intertemporal allocations under scarcity and uncertain supply.

3.5. Other distortionary constraints

There are many other distortionary constraints that make it difficult to achieve *first-best* allocations. We discuss some of the institutional and political constrains in later sections, but before we turn to the practice of pricing and allocating water we should mention that externalities and decreasing returns-to-scale are also factors in achieving efficient and equitable water allocations. Associated with water allocation, there are externalities to the environment (pollution) or to other interest groups (third-party effects), that is, when one person's decisions do not take into account the negative effects on others. Economists have traditionally advocated the use of taxes to address these externalities (Baumol & Oates, 1989). However, the potential for this depends on the nature of the irrigation system (Easter, 2000). Also large-scale irrigation projects typically exhibit increasing returns to water production technology giving rise to a natural monopoly (Spulber & Sabbaghi, 1998). That is the costs for water treatment and delivery per unit decline as the volume delivered increases. Marginal cost pricing in this case will not cover full costs because the marginal cost will always be lower than the average cost (Easter & Welsch, 1986; Dinar et al., 1997; Easter et al., 1997). Two-part tariff pricing can be used in this case to recover both the variable and fixed costs (Tsur & Dinar, 1997). It may also be more efficient for the CWA to price water below its long-run marginal cost when the fixed costs associated with canals, dams, and other infrastructure exceed the variable cost of water supply (Sampath, 1992).

4. Practice

As indicated above there are many components of water pricing which make marginal cost pricing difficult. As a result a variety of methods for pricing and allocating water have arisen, depending on natural and economic conditions that characterize the irrigation project (Table 4). These methods can be placed into four major categories: volumetric pricing, non-volumetric pricing, quotas, and market-based mechanisms.[5] The efficiency, equity and implementation costs associated with these practices are summarized in Table 5.

4.1. Volumetric pricing

Volumetric pricing mechanisms charge for irrigation water based on the quantities of water consumed (Easter & Welsch, 1986; Bandaragoda, 1998). A special case of volumetric pricing is *marginal cost pricing*. Marginal cost pricing equates the price of a unit of water with the marginal cost of supplying the last unit of water. In the absence of implementation costs and scarcity, the marginal cost of supply includes only delivery costs. In this case the resulting allocation is *first-best* efficient (Spulber & Sabbaghi, 1998; Tsur & Dinar, 1997).

One drawback to marginal cost pricing is determining all the marginal costs and benefits when setting the correct price per unit. Costs include the collection of fees and the provision of maintenance (Easter, 1999); costs may vary over months and over years (Tsur & Graham-Tomasi,

[5] There is another allocation method: "user-based allocation", but we do not discuss it here (Dinar et al., 1997).

Table 4

(*a*) *Recent case studies*

Study and country	Allocation method	Description
Musgrave (2000)—Australia	CWA	Decentralization and water price reforms are advanced in the urban sector, but there are many groups opposed to reform in the rural agricultural sector
Bjornlund and McKay (1999)—Victoria, Australia	Water trades	Tradable quotas are used to alleviate the influence of raising water prices and to facilitate a reallocation of water resources to more efficient and sustainable use
Palanisami (1999)—Tamil Nadu, India	CWA	To increase water-use efficiency the following short-term measures are advisable: better management strategies with WUAs, irrigation technology adoption, and use of waste and salt water for irrigation.
Marre, Bustos, Chambouleyron, and Bos (1998)—Argentina	WUA	Due to low collection levels, much of WUA income is spent on fixed costs (e.g., salaries) and little on O&M. This causes further dissatisfaction with paying users
Bandaragoda (1998)—Pakistan	Warabandi	Increasing inequity in water distribution indicates that the balance between infrastructure, water rights, and organizational responsibilities is failing. Adaptability of rules is therefore necessary
Varela-Ortega, Sumpsi, Garrido, Blanco, and Iglesias (1998)—Spain	CWA	Policies are strongly dependent on the distinct regional institutions. Equivalent water charges would then create widespread effects on water savings, farm income, and collections across regions
Rosegrant (1997)	CWA	Water reform is needed to meet growing demands. The most important reforms require establishment of secure water rights, decentralization and privatization

		of water management, the use of market for trading water rights, pricing reforms and reductions in subsidies, and pollution charges
Brewer et al. (1997)—Tambraparani, India	WUA	Inconsistent water rules cause operational problems that may lead to poor efficiency and equity in water distribution. Therefore, water law needs to be flexible to adapt to new problems or demand changes
Isè and Sunding (1997)—Nevada	Water trades	Characteristics such as short-term financial constraints, significantly affect trading decisions. This suggests that agencies may wish to target marginal farmers to attain more efficient outcomes
Kloezen, Garcés-Restrepo, and Johnson (1997)—Mexico	WUA	Comparative indicators for system performance were developed to assess management decentralization
Shumba and Maposa (1996)—Zimbabwe	CWA	Crop yields under small-scale farms are so low as to make irrigation investment questionable. Increased efficiencies can be achieved if farmers form coalitions
Johnson (1997)—Mexico	WUA	Efficiency increases have been realized in fee collection and O&M, however more funds for future investment needs to be put aside. Water law clarifications are necessary as well.
Bilen (1995)—Turkey	CWA	Intersectoral planning of several aspects of water resource management can augment system efficiency. Recommends moving from water resource projects to broader national perspectives
Dahwan (1988)—India	CWA	Factors such as credit availability for the purchase of fertilizer at low rates of interest adversely affect the chances of small farmers in India to fully realize benefits of irrigation. This compounds inequality problems inherent in this system. Land redistribution is cited as one possible solution

Table 4 (*continued*)

(*b*) *Extended summary of several successful projects*

Country/study	History	Reformed mechanism	Result/comments
Egypt (1986–2002) (Wichelns, 1998)	Movement from cotton to rice following agricultural reform is stressing capacity	Improve tertiary canals and install monitored pumping stations for volumetric pricing	Capital cost recovery + O&M estimated to be 15–25% of increased income generation
Mexico (1990–1996) (Johnson, 1997)	The percentage of O&M paid by users declined from 95% in 1950 to 37% in 1990. Management transfers to WUAs in two stages have reversed this trend	The first stage transfers O&M responsibility for secondary canals; the second stage incorporates main canals	From 1989–1996, 86% of service had been transferred to WUAs. Autonomy increased from 37% to 80% by 1994. Costs as a % of production have remained constant
Argentina (1985–1994) (Marre et al., 1998)	To increase efficiency of water allocations, there has been considerable consolidation in Argentina's WUAs	To maintain WUA autonomy, correct water rates are needed	Farmers in small WUAs pay, respectively, more than those in large WUAs. Low fee collection is correlated with low O&M expenses
Chile (1986–1993) (Hearne & Easter, 1998)	Chile has a tradition of private development of water resources and private rights to shares of river and canal flows	National Water Code of 1981 established permanently tradable water rights	Analysis reveal that water marketing produces significant gains to trade between and within sectors. One caveat being that there may be benefits to storage and delivery investment in reducing transactions costs, which must be weighed against the use of water marketing as an alternative to large-scale storage projects
Vietnam (1993) (Small, 1996)	Following economic reform, examined ability of irrigation districts to cover O&M	Former agricultural coops used as WUAs to distribute water provide O&M, and collect fees	Per area fees by crop, season and gravity/pump. Pegged to rice. Resulting collection rates $\approx$90%
Texas (1981–1985) (Chang & Griffen, 1992)	Water marketing data indicate significant volumes of agricultural water have been sold to municipalities	1967 Water Rights Adjudication Act provided the water right specificity necessary for water marketing	Water cost to agriculture range from \$249 to \$1894 per 1000 m^3. Municipal benefits range from \$5000 to \$17,000 per 1000 m^3

NB: CWA = central water authority; WUA = water user association.

Table 5
Comparison of pricing methods (efficiency/equity/implementation costs)

Pricing scheme	Potential efficiency	Time horizon of efficiency	Equity	Implementation costs	Characteristics
Single-rate volumetric	First-best	Short-run	User-pays fairness principle	Complicated	Requires water use monitoring
Tiered	First-best	Short-run	Can be used to target income groups for subsidy or tax	Relatively complicated	As above
Two-part	First-best	Long-run	As above	Relatively complicated	As above
Output/input	Second-best	Short-run	As above	Less complicated	Requires input/output monitoring
Per area	Second-best	Short-run / long-run	As above	Easy	Requires cropping patterns by season
Quotas	First-best (when tradable)	Short-run	As above	Easy	Requires cost and benefit information for efficient allocations
Water markets	First-best	Short-run / long-run	Depends on type of market	Difficult	Requires developed water institutions and infrastructure

Source: Adapted from Tsur and Dinar (1995).

1991; Sampath, 1992); costs also include environmental externalities (Biswas, 1997);[6] and costs may need to account for future supply scarcity (Dosi & Easter, 2000).[7] In addition, marginal cost pricing ignores equity concerns (Seagraves & Easter, 1983; Tsur & Dinar, 1997). For example, if the volume of water delivered by the water source were to decrease throughout the cropping season, then the effective price per water unit (marginal cost of providing water) should rise proportionally (e.g., Maharashtra, India—Easter et al., 1997). This price increase may adversely affect lower income groups (Dinar et al., 1997).

4.2. Non-volumetric pricing

Non-volumetric methods charge for irrigation water based on a per output basis, a per input basis, a per area basis, or based on land values. In their global survey, Bos and Walters (1990) found 60% of farmers on 12.2 million HA face per unit area water charges. This method is easy to implement and administer and is best suited to continuous flow irrigation, which may explain its prevalence (Easter & Welsch, 1986; Easter & Tsur, 1995). Due to the high costs of implementing a

[6] There have been several recent economic reviews of the management for groundwater systems (Gisser, 1983) and for conjunctive management with surface water (Tsur, 1997; Zilberman, 1997).

[7] Conservation technology in irrigation has been reviewed and developed for water price and land quality and asset quality (Caswell, Lichtenberg, & Zilberman, 1990); for variable resource qualities (Caswell, Zilberman, & Casterline, 1993); for land allocation (Green & Sunding, 1997); and for underinvestment due to subsidized water (Zilberman et al., 1997).

meter system it is often times more efficient to use per unit area pricing than volumetric pricing when allocating water (Smith & Tsur, 1997).

4.3. Quotas

We know that it is efficient to base prices on the marginal cost of acquiring more water plus its scarcity value. However, prices based on marginal costs are often too high for low farm incomes (Dinar & Subramanian, 1997; Saleth, 1998). This is especially true when the scarcity value is such that marginal cost pricing would drive smaller, less productive farms out of production. Quota allotments often are used in these situations to mitigate equity issues (e.g., warabandi system in India and Pakistan—Bandaragoda, 1998) or resource management issues (e.g., water quality—Dinar, Hatchett, & Loehman, 1991; water conservation—Yaron, Dinar, & Voet, 1992) that arise with a water market or marginal cost pricing. By allowing quota allotments to be traded, the water authority can address equity concerns while promoting efficient allocations (Seagraves & Easter, 1983; Wichelns, Houston, & Cone, 1996; Dinar, Balakrishnan, & Wambia, 1998).

4.4. Water markets

Market-based mechanisms can address allocation inefficiencies found in traditional irrigation institutions (Easter et al., 1999). It has long been recognized that markets provide a means to allocate water according to its opportunity cost, resulting in efficiency gains (Gardner & Fullerton, 1968; Hartman & Seastone, 1970). Water markets, which rely on market pressures to determine the price for irrigation water, are also more flexible than centrally controlled, allocation mechanisms (Mariño & Kemper, 1999). For formal water markets to work there first needs to be well-defined, tradable water rights and the appropriate infrastructure and institutions for distributing water (Zilberman, Chakroavorty, & Shah, 1997; Thobani, 1997). Such things as return flows, third-party effects, and instream uses have to be considered (Easter et al., 1997), which can prove difficult especially when public water agencies are unwilling to relinquish control of the water rights (Howitt, 1998; Wilson, 1997).

Informal water markets often develop when water is scarce (Shah, 1993; Anderson & Synder, 1997) or when governments fail to respond to rapidly changing water demands (e.g., South Asia—Shah & Zilberman, 1991; Pakistan; Mexico—Thobani, 1998). However, given the institutional structure necessary for market-based policy, external effects across users, temporal interdependencies, large fixed investments costs, and uncertain supplies, the prospect of attaining first-best allocations via markets alone are unlikely (Ahmed & Sampath, 1988; Rosegrant & Schleyer, 1996; Easter & Feder, 1998). Though as with non-volumetric pricing, second-best market allocations may surpass volumetric pricing in efficiency even when distorted (e.g., Morocco—Diao & Roe, 2000).

5. Water institutions

Noting the importance of institutional structure to achieve efficient or equitable water allocations through the mechanisms discussed earlier, we now turn our attention to the recent literature on water institutions. The term "water institutions" broadly refers to the interrelated legal, administrative, and policy spheres necessary for allocating water (Global Water Partnership, 2000). There is a renewed interest in the evolution of institutions managing natural resources (Ostrom, 1990; Easter & Tsur, 1995; Ostrom, Gardnet, & Walker, 1994; Merrey, 1996; Saleth & Dinar, 1999) reflecting how essential institutions are in allocating water. Table 6 documents several relevant studies examining legal and administrative institutions.

6. Legal institutions

The laws and rules that define water distribution will naturally affect the performance of the system (e.g., Asia—Small & Rimal, 1996; Spain—Garrido, 1998; Tamil Nadu—Brewer, Skathivadivel, & Raju, 1997). The evolution of water law and property rights is intrinsically linked to politics and the changing climate of water regulation. It is important to integrate conscious design of institutional rules and economic incentives to achieve efficient and/or equitable water allocations (Dinar & Loehman, 1993; Spulber & Sabbaghi, 1998). Unclear definitions and uncertainties in water laws are often cited as the limiting factor to achieve a sustainable and efficient system of irrigation management (Hunt, 1990; Ghosh & Lahiri, 1992; Anderson & Synder, 1997).

Rights for water use have evolved through custom or bodies of law and regulation in most countries. Water rights specify how water will be divided between sectors (industrial, domestic, and agricultural consumption) and also within sectors, as might be the case between individual farmers (Holden & Thobani, 1996). In most countries water rights are based on one of three current systems (Sampath, 1992; Holden & Thobani, 1996): riparian rights link ownership to adjacent land ownership; public allocation based on priorities of use determined by government; and prior allocation determined by actual historical use. For the free market to determine fully the development and allocation of irrigation water, there would have to be a system of pure private property rights. In the absence of such rights, government intervention will be required to enforce private rights or to allocate scarce water resources, using another mechanism. The movement from water rights to water markets is not always optimal, but depends on the associated political and economic costs (Saliba & Bush, 1987; Shah & Zilberman, 1995). As in the case of Mexico, there is often considerable tension between market transferability and highly regulated trading (Rosegrant & Schleyer, 1996).

7. Water administration

The primary role of a water administrator is to facilitate irrigation water management by reducing implementation costs and promoting efficient, equitable, and sustainable water allocations. The type of water administration can vary substantially, ranging from centralized government water agencies to water user and supplier associations. This sphere of the water sector includes the following administration-related institutional aspects: spatial organization, organization features, functional capacity, pricing and finance, regulatory and accountability mechanisms, and information, research and technological capabilities (Saleth & Dinar, 1999).

Table 6
Water institutions

Author(s)	Description	
Legal institutions		
Brewer et al. (1997)	Water law	Review studies linking system performance to water rules
Johnson (1997)	Water law	Link deficiencies in decentralized system performance to recent legislation
Zilberman et al. (1997)	Water rights	Studies that examine water rights generally extend their analysis to the corresponding water markets associated with those systems
Rosegrant and Schleyer (1996)	Water rights	Note several trends that encourage the transition from water law and rights to market trades: continuing macroeconomic reform, growing non-agricultural, and continued lobbying efforts from farmers for transferable water rights
Feder and Noronha (1987), Feder and Feeny, 1991).	Water rights	Examine the effects of uncertain property rights
Water administration		
Easter and Feder (1998)	CWA	Note that CWA failures include: misallocated project investments, overextended government agencies, inadequate service delivery to the poor, neglect of water quality and environmental concerns, and the underpricing of water resources
Roumasset (1987)	CWA	Outlines necessary incentive-compatible relationships between the different units in an irrigation system (manager, supplier, and user) to insure sustainable irrigation services
Small (1996)—Vietnam	Supply co-ops	Financial autonomy of irrigation systems is enhanced by supply cooperatives that act as an intermediary between farmers and the central water authority
Kloezen et al. (1997)	WUA	Discuss how WUAs both increase supply efficiency and production efficiency
Meinzen-Dick, Mendoza, Sadoulet, Abiad-Shields, and Subramanian (1997)	WUA	Show that institutions are not always in place or strong enough affect efficiency via WUAs
Easter and Welsch (1986)	WUA	Note that the strength of these collective action institutions is directly related to water scarcity. Water must be sufficiently scarce as to provide the incentive to organize

7.1. Government institutions

Historically, governments have provided defacto subsidies to the agricultural sector by not fully recovering capital costs and achieving partial recovery of O&M costs (Wichelns, 1998). Reform efforts targeted towards decentralizing government provision of irrigation water services are largely aimed at fixing these government inefficiencies in water allocation (Parker & Tsur, 1997). Easter (1993) provides examples of how government management can affect the efficiency of irrigation services: assurances that water fees will be used for O&M, commitment to efficient water allocation, and fairness of setting water fees. For example, water markets can achieve efficient allocations, but to be successful they require institutional components from the local, regional, or national government. Government intervention is often necessary to define and enforce water rights for the successful functioning of water markets (Gisser & Johnson, 1983; Meinzen-Dick, 1997) as in the case of water banks (Howitt, 1994; Archibald & Renwick, 1998) or with water-basin management models (Briscoe, 1996).

7.2. Water supply organizations

Countries have begun to recognize the functional distinction between centralized mechanisms needed for coordination and enforcement and decentralized reforms needed for user participation and decision-making (Wichelns, 1998). Specifically, supply reforms stem from three main reasons (Vermillion, 1997): CWAs lack incentives and responsiveness to improve management performance; management transfers to users or private sector coupled with supportive social and technical support will result in improved system quality and efficiency; and management transfers will save the government financial resources in terms of reduced O&M responsibilities.

7.3. Water user associations (WUAs)

These organizations are responsible for a wide range of management activities, some with more responsibilities than others (Martin & Yoder, 1987; Meinzen-Dick, 1997). WUAs are managed and operated with the interests of water users in mind and so they tend to substantially reduce the costs of implementing water pricing, such as monitoring and enforcement costs (Easter & Welsch, 1986; Wade, 1987; Zilberman, 1997; Meinzen-Dick & Rosegrant, 1997). For example, the *warabandi* system in Pakistan and India, a relatively complex rotational method for equitable allocation of irrigation water, fixes flows by day, time, and duration of supply proportional to irrigated area (Bandaragoda, 1998).

Many factors affect the viability of WUAs; property rights are a crucial factor (Easter & Welsch, 1986; Meinzen-Dick et al., 1997). Obviously, user groups cannot make decisions regarding water if they have no rights over that water (Meinzen-Dick & Mendoza, 1996; Johnson, 1997). The creation and ownership of irrigation property (water, conveyance structures, and pumping equipment) form the basis for relationships among the irrigators; i.e. the "... social basis for collective action by irrigators in performing various irrigation tasks" (Coward, 1986). Well-defined water rights give farmers incentives to participate in the O&M of their water supply system. These rights can be assigned to individuals or to groups of farmers, such as WUAs (Wade, 1987; Feder & Noronha, 1987).

8. Water policy

The water policy sphere of water institutions includes the following policy-related institutional aspects: project selection criteria, pricing and cost recovery, interregional/sectoral water transfer, private sector participation, user participation, and linkages with other economic policies (Saleth

& Dinar, 1999). These can be determined in a number of ways. On the one extreme lie centralized allocation methods, where prices and/or allocations are determined at the outset (Qingtao, Xinan, & Ludwig, 1999); on the other extreme are decentralized methods based solely on market mechanisms (e.g., spot and options markets in California—Howitt, 1998). In between lies the entire policy spectrum of water allocation methods, as touched on earlier, characterized by levels of decentralization. We have noted how the decentralization in water allocation mechanisms can address these aspects and enhance efficiency and address equity. However, there are obstacles to decentralization and reform, which may be environmental, economic or political in nature. Zilberman et al. (1992) posit that the availability of new technology or institutional design may not be sufficient for overcoming obstacles to policy decentralization and that to hurdle these barriers reform may require large random shocks (e.g., the California drought of the late 1980s). Economic factors that may affect policy reform include: level of development (GDP per capita), per capita water availability, and size of the budget deficit (Dinar & Subramanian, 1997). The political obstacles to decentralization and reform are many, so we devote the next section to their discussion.

9. Political economy and water allocations

Increased water scarcity and quality concerns have generated new approaches to water management and reform.[8] However, reforms in practice often do not result in first-best allocations. As mentioned, this is due to a variety of additional constraints. Political obstacles to reform efforts, special interest pressures, and rent-seeking can be thought of as implementation costs (Shah & Zilberman, 1995), which result in second-best or third-best outcomes (de Gorter & Tsur, 1991; Dinar, 2000).

10. Theory

Interest groups will form to impact the allocation process so that the end results best serve their constituents. Similarly, reform efforts in water allocation, which result in a redistribution of economic benefits, will generate significant political opposition. For example, it is particularly difficult to induce a movement from a situation where farmers have historically internalized the scarcity value of water (e.g., because they were granted quotas of water at low prices) to one where they must now pay the scarcity value (e.g., Morocco—Diao & Roe, 2000). Political groups via lobbying efforts or rent-seeking may slow, divert, or stop reforms that seek to increase the efficiency (Roumasset, 1997; Reisner, 1993; Dinar et al., 1998) or equity (Briscoe, 1992) of water use.

Three main approaches to the political economy of allocations can be identified. The first is the interest group approach, where political decisions are viewed as the outcome of a struggle between pressure groups (Becker, 1993; Panagariya & Rodrik, 1993). Second is the politician–voter interaction approach, where the interaction between voters and support-maximizing politicians

[8] See OECD (1999), Dinar and Subramanian (1997), and Ahmad (2000) for recent OECD water pricing reforms.

result in policy (Peltzman, 1976; Hillman, 1989; de Gorter & Tsur, 1991). Lastly are the bargaining process models, where policies are determined via a bargaining process with players of different power (Jordan, 1995, Finkelshtein & Kislev, 1997; Zusman, 1997; Ruasser & Zusman, 1998).

11. Practice

Recent studies looking at irrigation water reform often will employ one or more of these approaches to model the political economy (Rucker & Fishback, 1983; Gardner, 1983; Cuzán, 1983) or are couched in game theory (Ostrom et al., 1994). Some recent extensions to these approaches to incorporate improved water management include: incentives for individuals to participate in management schemes (Bardhan, 1993; Hurwicz, 1998), the exploitation of common property resources (Ligon & Narain, 1997), environmental regulation (Chen, Tomasi, & Roe, 1998; Loehman, 1998), and game theory approaches to international water management (Frisvold & Caswell, 1997). However, as a framework for describing this literature, it is useful to understand the reasons for reform, the institutions undergoing reform, who is supporting/opposing the reform, and compensation mechanisms (Dinar, 2000). This framework traces reform efforts from its initial stages to post-reform effects.

11.1. Reasons for reform

In many cases reform efforts directed at water pricing are simply the results of financial crisis, low cost recovery percentages, deteriorating facilities, and increasing water demand (Easter, 1999; Wichelns, 1998; Wambia, 2000). However, there are often other motives such as linking water sector reform to other macroeconomic reforms that are indirectly related (e.g., Krueger, Schiff, & Valdés, 1991; Diao & Roe, 2000; Ward, 2000).

11.2. Institutions and reform

As previously mentioned, the institutional framework and its changing nature are intrinsically linked to political economy considerations (Dinar et al., 1998; McCann & Zilberman, 2000). These considerations include rent-seeking existing institutions (Wilson, 1997; Zusman, 1997; Rausser & Zusman, 1998), the power system (Rausser, 2000), and the electoral system (Boyer & Laffont, 1996). Often it is necessary to engage existing bureaucracies in the reform process (de Azevedo & Asad, 2000) or to induce farmers to view water management as a public good (Garrido, 1998; Bromley, 2000). The strengths of the various groups depend on such things as informational power, which can lead to second-best allocations, and are thus important when planning and implementing water pricing reform (Tsur, 2000; Renzetti, 2000).

11.3. Support and opposition

As touched on earlier, water pricing and reform creates a dynamic interaction between existing institutions and the political establishment (Dinar, 2000). In many cases (Musgrave, 2000; de

Azevedo & Asad, 2000; Kemper & Olson, 2000; Ward, 2000) the reform efforts stem from existing inefficiencies in pricing policy (i.e., subsidized irrigation water). However, environmental quality can also be a motivating factor (Wambia, 2000; Moore, Gollehon, & Hellerstein, 2000).

11.4. Compensation mechanisms

Opposition to water sector reform can be overcome if there exist payoff mechanisms to reimburse negatively affected parties (Zusman, 1997). Such mechanisms might include sharing of reform benefits and costs (Diao & Roe, 2000). In addition to including existing institutions, it is also necessary to weigh equity and environmental concerns when compensating for water pricing reform (Boland & Whittington, 2000).

12. Conclusion

Increased population pressures, improved living standards and growing demands for environmental quality have all prompted governments to find better ways to manage their available water resources. While it is agreed that if water users pay the marginal cost and scarcity rent of supplying that water, significant movements towards more efficient water use would be made, implementing such policies is far from trivial and in many cases impossible. It is for this reason that we note a growing emphasis on decentralization, on policy reform, and on the importance of efficiency in water allocation mechanisms. Many argue that water markets are a useful means to improve efficiency when perfect information is not available to policymakers. But the circumstances under which water markets are viable remains an open question, due to the necessary institutional and physical structures that may or may not be available.

While efficient allocations will help meet increasing water demands, debate continues regarding the role of irrigation and farming as a development tool and as a means to redistribute wealth to both producers and consumers via cheaper staple food prices. Marginal cost pricing and water markets will serve to increase the cost of irrigation water for most farmers globally, and when the scarcity value of water is high, may force subsistence-level farmers out of production. In such cases (tradable) water quotas, which can be better tailored to equity considerations, may be the preferred mechanism of allocation. The trade-offs between efficiency and equity and the use of water allocations to address poverty in many areas of the world are important questions that require further inquiry.

There also are questions regarding long-run (sustainable) water allocations between users in agriculture and other sectors of the economy that remain insufficiently answered. To what extent are water markets long-run solutions to water scarcity when environmental concerns are incorporated? What effect will decentralization have on farm production and the rest of the economy? What are the forces that are moving towards decentralization or (re)centralization?

The answers to these questions are difficult to generalize. Each country or region has specific institutions, geography, and history that bear consideration when examining such issues and when prescribing policy alternatives. For this reason we have summarized a parsimonious list of recent case studies which have developed approaches and analysis relevant to this discussion (Tables 5 and 6). However, while there are many case studies focusing on particular aspects of water allocation, there are too few theoretical or empirical GE studies that consider the broader, economy-wide implications of changes in the allocation irrigation water. These broader analyses would be invaluable when weighing the benefits and costs, to different sectors of the economy and to different segments of the population, of developing more efficient and equitable allocations of irrigation water.

Acknowledgements

The opinions expressed are those of the authors' and not necessarily those of the US Department of Agriculture or the Economic Research Service. Robert C. Johansson is an economist with the Economic Research Service of the US Department of Agriculture. This analysis was conducted while he was a graduate research assistant at the University of Minnesota. This review is an outcome of the "Guidelines for Pricing Irrigation Water Based on Efficiency, Implementation, and Equity Concerns" research project, funded by the World Bank Research Support Budget, DECRG, and the Rural Development Department. Ariel Dinar is a Lead Economist in the Rural Development Department of the World Bank. Yacov Tsur is a Professor in the Department of Agricultural Economics and Management at the Hebrew University of Jerusalem and Adjunct Professor in the Department of Applied Economics at the University of Minnesota. Terry L. Roe is a Professor in the Department of Applied Economics at the University of Minnesota. Rachid M. Doukkali is a Professor in the Department of Social Sciences at the Institut Agronomique et Veterninaire Hassan II in Morocco.

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