The Use of Pricing and Markets for Water Allocation

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Abstract: This paper will argue that increased demand for water resources and higher cost of development of new water resources require a transition toward water systems that enhance conservation by adoption of efficient irrigation and application technologies, improving water delivery systems, and improving the efficiency of water allocation. This can be done by a transition from systems of water queuing based on historical water rights to systems of trading and efficient pricing. The design of water pricing has to consider political-economy and equity considerations and therefore we present alternative approaches — including active and passive trading with water markets, and various institutions including tiered pricing. Incentives to adopt cleaner and "greener" technology is essential for the improvement of water quality and we will present a framework for pricing water and inputs that affect water quality taking into account heterogeneity among water users and across locations. The analysis will use illustrations from various case studies including the California water market.

Résumé :

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Introduction

The complexity of water and its crucial value to society make the design of management and pricing rules that are simple, transparent, efficient and equitable a formidable task. This paper provides an economic perspective for determining water allocation rules and pricing. First we will present a general framework for the pricing of water. Then we will discuss the issues of water reform that will allow better use of water pricing and finally, we will address some of the particular issues associated with water pricing and allocation in the municipal, agricultural and environmental sectors.

Determining Water Pricing Within a Market

Despite the infrequent use of markets for the allocation of water, we first introduce such an analysis to illustrate the forces shaping supply and demand for water and the resulting prices within a market. This approach follows the applied welfare economics approach (Just *et al.,* 1982) which views the competitive market outcome, corrected for externalities and market failures, as the benchmark for optimal resource allocation and pricing.

There are several types of agents who interact in the water market. One type is water suppliers, who may be owners of wells or reservoirs, or who have access and rights to flowing river water. The suppliers have time-dependent private costs for obtaining the water, which we will refer to as private cost (*PC*). These costs may be the cost of pumping the water or the opportunity cost of the water in use by the supplier. The suppliers are assumed to be located away from the market and each supplier has a conveyance system (a canal), which may require energy, equipment and labour. The conveyance costs are denoted by *CC*. The diversion of water from its source region may negatively affect the environment, yet the water at the source may generate benefits to individuals other than their owner. These external benefits (externalities) include environmental and other third party benefits. If the water is applied to grow crops, some of the runoff water is used to feed wetlands and recharge groundwater, both of which are environmental benefits. If the water originated in a lake or reservoir its removal may harm fish or dependent wildlife. The net environmental cost of diverting water is denoted by *EC*, where this refers to the environmental benefits subtracted from the costs.

All of the cost categories are functions of the quantity of water diverted, which we denote as *X*. The marginal changes in the private costs, conveyance costs, and the environmental costs with respect to a change in water quantity are denoted by *MPC*, *MCC* and *MEC*, respectively, and are all assumed to be dependent on the quantity *X*. In addition, it is generally assumed that all of these marginal cost functions are increasing (or at least non-decreasing) with *X*. In addition to these temporal cost categories, the extraction and supply of water may impose economic costs on the system in future years because of the dynamic nature of water systems and the randomness of precipitation. The discounted dynamic costs of water extraction and supply are denoted by *FC*, which depends on *X* (these costs are analyzed in detail by Tsur *et al.,* 2004). The marginal changes in these dynamic costs (sometimes referred to as user costs) are denoted by *MFC*. Examples of these costs include the reduction in future productivity due to accumulation processes such as soil salinity or waterlogging.

Water buyers obtain economic benefits from the water they purchase. These marginal benefits, measured in monetary terms, are denoted by the *MB* curve (see Figure 1), and are dependent on the quantity of water, *X*. We assume that these water users are competitive economic agents (a large number of firms or consumers, each with no monopolistic power). The intersection of demand (*MB*) with the sum of the marginal private costs, marginal conveyance cost, marginal environmental costs, and the marginal dynamic costs, denoted by *A* in Figure 1, represents the socially optimal outcome (Just *et al.,* 1982). The resulting optimal price and optimal quantity of water are P_A and X_A, respectively. This suggests that the optimal price of water is denoted by

$$P_A = MPC(X_A) + MCC(X_A) + MEC(X_A) + MFC(X_A) \quad (1)$$

When there are multiple water providers who share a common aquifer, they will not consider the future or externality costs of their sales (presumably they incur the conveyance costs and consider it) and thus their supply will be captured by the sum of the MPC and MCC curves in Figure 1 leading to an equilibrium represented by point B in Figure 1 where the price is

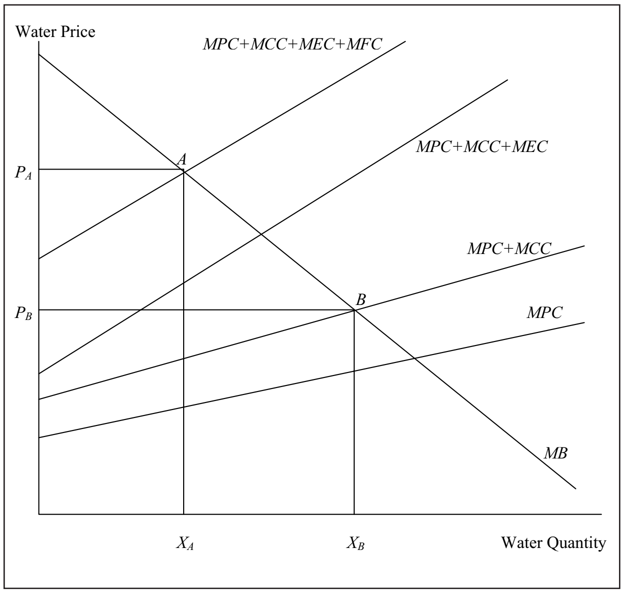

Figure 1. Marginal Costs and Benefits in a Water Market.

$$P_B = MPC(X_B) + MCC(X_B). \quad (2)$$

Equations (1) and (2) suggest that when a water market exists among competitive buyers and sellers there may be a role for government intervention that will require the sellers to consider the externalities and, when appropriate, the future costs of their activities. The regulators may set an extra tax, equal to $MEC(X_A) + MFC(X_A)$, or set a limit on water trading, equal to X_A, and introduce a system of tradable permits that will result in point *A*. The price of water in this case will be equal to $MPC(X_A) + MCC(X_A)$ and the price of the permit will be $MEC(X_A) + MFC(X_A)$. Under the assumption that transaction costs are zero, these two options will result in the same outcome. However, when the transaction costs of water trading are large, as is generally assumed, these two mechanisms may lead to very different outcomes.

The model above assumed that conveyance costs are only a function of the quantity of water diverted. However, in reality those costs are driven by location as well. For example, the cost to pay for the energy required to lift water from a valley to the top of a mountain is much greater than the cost to transport water down the mountain. In this case, the cost difference between locations is driven by the cost of energy necessary for delivery. In another example, the cost difference between locations can be driven by factors such as evaporation and loss in transmission. When water is released from a reservoir, there is always some level of loss and evaporation as it moves through the conveyance system. Because of this, it might be necessary to release two volume units of water from a reservoir for every volume unit used 80 km downstream, and to price the water accordingly.

In addition to the need to adjust conveyance costs by location, the model presented above also neglects the importance of fixed costs. While marginal cost pricing provides the optimal allocation of water in the long-run, when water projects are initially built, the fixed costs of construction and development can be very large. For a water project to be worth building, the present value of lifetime benefits of the project should be greater than the sum of the present value of fixed costs and the marginal costs of operation and maintenance. However, depending on the shape of the marginal cost curve, it might be difficult for a utility to collect their incurred fixed costs using marginal cost pricing. The graphs in Figure 2 show this more clearly.

In both graphs, the surplus is given by the area below the price and above the marginal cost (*MC*) curve. In the left graph, the use of marginal cost pricing, with a price of *P*, leaves a water utility very little surplus to pay its fixed costs of development. In cases such as this, it might be necessary for a utility to initially charge an additional fee above the marginal cost of providing water, until the fixed costs are paid. In the right graph, the use of marginal cost pricing provides a utility with much larger surplus revenue,

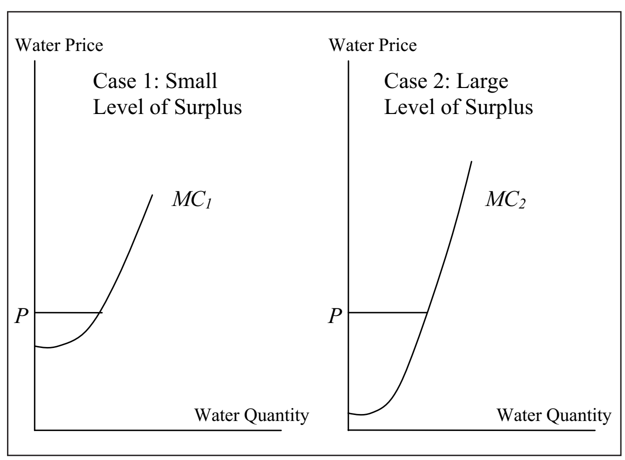

Figure 2. Two Surplus Outcomes with Marginal Cost Pricing.

and therefore no additional fee may be necessary to fully pay the fixed costs of development.

The stylized models presented above separate water buyers and sellers into two distinct groups, but the reality is more complex. Major water users are also owners of water resources and may sell or buy water depending on the circumstances. Historical ownership of rights plays a major role in determining access to water and establishing water trading patterns. Water allocation and pricing are also affected by the characteristics of water conveyance and management capital and the capacity to modify it. In addition, water users are diverse and pricing and trading may vary in different sectors. The value of water not only depends on when and where it is used, and who is using it, but also on the quality of the water. In the next sections we will address how these various factors affect water pricing and policies.

The Transition from Water Rights to Water Markets

Allocation of water by markets or other trading mechanisms is quite infrequent. Water is generally allocated by queuing systems that have seniority rules that determine entitlement. The prior appropriation system is a queuing system used in the western part of the United States. Many other systems follow similar rules. In this system, rights are determined according to historical use. Earlier users have more senior rights, but rights are lost if use of the water is discontinued ("use it or lose it"). In addition, utilities supply water to water rights owners using average cost pricing, which is frequently based on unrealistically low maintenance and operation costs. Water rights in many districts are fully appropriated and highly productive individuals may be denied access to the water. The water allocation under these situations is inefficient. Trading bans and low water prices do not provide the owners of senior rights with the incentive to adopt water conserving technologies to reduce their water use and sell the extra water to highly efficient individuals with junior or no water rights.

A water reform based on a transition from queuing to trading is likely to increase and improve overall economic efficiency (Brill *et al.,* 1997). This occurs since both the population of water users and the allocation of water according to marginal cost pricing expand. The gains in efficiency result from the expansion of water use by highly efficient junior rights owners, adoption of water conserving technologies and elimination of inefficient uses of water. Water use may actually increase with a water reform that allows trading and transition from average to marginal cost pricing. This occurs when the added demand by water users, who were denied access under the prior appropriation water rights regime, is greater than the reduction in demand due to a higher price for water after a shift from average to marginal cost pricing, since marginal cost is higher than average cost (see Figure 3).

In this case, even though the water price increases as a result of the reform, water use increases as well. In other cases, when the added water demand of the junior rights owners is not sufficient to overcome the effect of supply reduction under marginal cost pricing, the transition from average cost to marginal cost pricing will reduce aggregate water use.

Simulation analysis suggests that the introduction of water trading among cotton growers in the Central Valley of California can maintain the same level of aggregate profits while field level water applications are reduced by more than 25% (Shah *et al.*, 1993). One caveat to this finding is that due to recharge, the basin-wide applications may not be reduced as significantly. The idea that a transition to a market system allows welfare gains to compensate for losses associated with reduction in water supply is behind the *Central Valley Project Improvement Act* (CVPIA) of the United States.

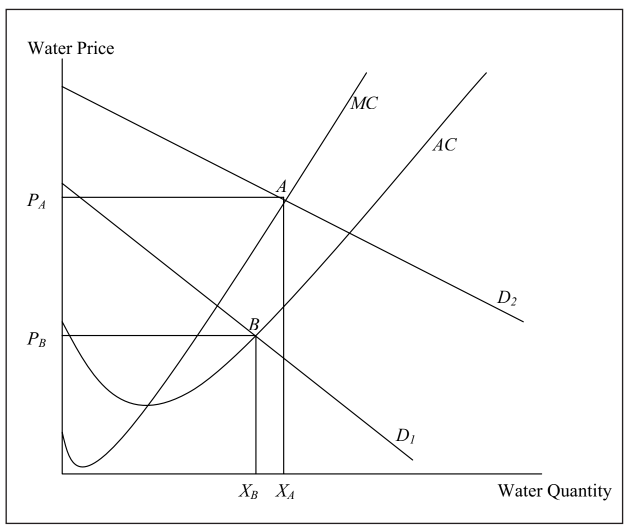

Figure 3. Comparison of Water Use and Price Pre- and Post-Market Reform.

This Act reduced the water rights to agricultural users of the Central Valley Project in California by 10% but allowed them to sell some of their water rights.

The transition from a queuing system to water trading is likely to be costly. It requires that water rights are clearly defined and the establishment of mechanisms to facilitate and monitor trades. Trading allows more flexibility and expands the networks of water users, and thus requires investment in infrastructure. When deciding whether to introduce a reform that allows water trading the efficiency gains from trading must be weighed against the transaction and capital costs required by the reform. A water reform may not be economical in situations when water is abundant, however the gains from a trading regime are greater as water scarcity increases, thus increasing the marginal value of a unit of water.

A transition to water trading may encounter political opposition. The owners of water rights will lose and may oppose a reform that will "nationalize water" and allow the state to be the seller of the water. However, these owners are more likely to support a system of transferable rights, as they will be the beneficiaries of such a system (Shah *et al.,* 1993). The range of trading activities allowed determines the welfare gains and political economy of reform. Both the gains and political economic constraints are smaller when the water reform allows annual transfer ("renting of water rights") rather than permanent sale. For example, the electronic water market in California's Central Valley (Olmstead *et al.*, 1997) operates to modify temporal allocations of water in response to changes in climatic and economic conditions, but it does not allow large realignment of resources and new regional development initiatives.

Water trading, and in particular permanent sale of water rights, may be constrained within a geographic area (a hydrological basin), and this may limit its impact. Allowing permanent water sales across regions may provide the foundation for new development efforts. Such changes have been observed with the introduction of water markets in Chile and South Africa. The net gains from these changes vary widely by region. In Chile, few sales of water have occurred that are separate from the sale of land. However, there have been a large number of transactions establishing property rights to water, many of which were poorly defined before the change in law (Bauer, 1998). In South Africa, variation in the response to water trading has been observed due to heterogeneity in a region. Regions such as the Lower Orange River area have seen an active water market due to heterogeneity between water users, while the Nkwaleni Valley has seen few trades despite water scarcity (Nieuwoudt *et al.,* 2001).

The adoption of water trading might entail large economic costs to the region of origin. These costs are a reason for suggestions that sellers of water rights be required to transfer a fraction of the water (up to 25%) to a regional agency to compensate for the environmental and third party losses the transfer may cause.

Pricing in Heterogeneous Water Systems

Water services are provided under diverse circumstances that give rise to a variety of water allocation and management regimes. It is useful to distinguish between three major categories of applications of water: municipal, agricultural and environmental. Here we will address some of the features of water allocations and pricing water for each of these application categories.

Municipal Water Systems

Water applications within municipalities can be roughly divided into residential and commercial applications. Some applications (drinking purposes and some industrial uses) require a very high quality of water while others (car washing and gardening) require a lower quality. Some applications of municipal water systems require a very high degree of reliability and availability on demand. Thus the cost of water to municipal systems has to include water quality cost (QC), water reliability costs (RC), and pricing and quantity of water for applications that require extra quality and reliability, and which should be determined according to

$$\begin{aligned} &MB(X) = P = MPC(X) + MCC(X) \\ &+ MEC(X) + MFC(X) + MQC(X) + MRC(X) \end{aligned} \quad (3)$$

where MRC and MQC are marginal quality and reliability cost, respectively.

The extra quality requirements of major categories of municipal water and the need to provide them on demand (reflecting a high level of reliability) may result in municipal water being more expensive than water used in other applications, such as agriculture. Some municipal water users with extra quality and reliability requirements should be charged extra for their water. Such pricing for reliability has been used in electricity markets, where certain users pay a premium to guarantee uninterrupted service, while others are subject to blackouts. Discriminatory pricing may actually lead to enhanced efficiency in these cases. Similarly, it may be economical to maintain more than one system of water distribution, and water of lower quality will be distributed to water lawns, golf courses and other similar activities, charging the user a lower price. These dual distribution systems are more commonly observed for the use of reclaimed water in agriculture. While these systems are beginning to be used more frequently, due to the high cost of developing dual distribution systems, they are only seen in locations where the gains are substantial. The costs will be higher in places where the existing systems have to be retrofitted, instead of new service areas where the dual distribution system can be installed with greater ease.

Municipalities should not always strive to meet the water quality demands of their entire constituency. Zivin and Zilberman (2002) argue that when purification of drinking water to meet the needs of a small section of the population is very expensive, it may be worthwhile to subsidize the purchase of bottled water for vulnerable individuals. If the fixed cost of purification is high, the optimal water quality levels of water sources serving a small community will be lower than the optimal water quality standards of larger communities, and the smaller communities may rely more heavily on bottled water.

Agricultural Water Systems

Agriculture tends to be the largest user of water wherever irrigated farming is practised. Much of the water available for farming is subsidized, as water projects were once a favourite form of pork-barrel public investments. Growing financial and environmental concerns, as well as falling farm product prices, have been major causes for the reduction in public investments in irrigation and other water projects since the 1970s. The introduction of formal cost benefits analysis (codified in Principle and Guidelines (1983)) used to evaluate proposed water projects has also contributed significantly to the decline in their number and magnitude.

While both cheap water and commodity subsidies have led to the establishment of irrigated agricultural activities that are not economically viable, much irrigated agriculture can be competitive in a market economy. High value crops such as fruits and vegetables can still be profitable with a water price of several hundreds of dollars per 1000 m^3. Irrigated field crops in many regions are economically viable as well. The subsidization of irrigated farming has led to the appreciation of land prices and deterred the adoption of water-saving irrigation technologies. It has also led to overdraft of groundwater aquifers and excessive diversion of water from bodies of water. Examples of this include the Eastern San Joaquin sub-basin in California, where groundwater levels have declined by an average of 0.5 m/year over the last 40 years (DWR, 2003). In the past, government support for the development of agricultural water supplies has been embodied in the reliance on queuing rules and water right regimes for the allocation of water, and these systems have been very effective in attracting settlers to frontier regions. Currently, the challenge in agriculture is to have a transition from queuing to trading. Brill *et al.* (1997) suggest distinguishing between two forms of water trading, active markets and passive markets, where each is appropriate for certain sets of agricultural water organizations.

Active markets occur when each water user has a given amount of water rights and the various parties interact to trade and negotiate prices. A passive market occurs when a central organization announces a water price and everyone trades with this organization. In this case, it is expected that prices will be established so that the market will clear. Passive markets are especially appropriate for trades within water districts, as water districts are established to obtain water and manage the distribution of water within a geographical area. However, a major difficulty with passive markets is that a water agency often doesn't know the true value of water. For a passive market to work may require the ability of the agency to adjust the stated price until a market clearing condition is found. Active trading is more appropriate for trade between water districts. Large distances and difference in elevation between farms suggest that the market clearing price will serve as a benchmark and prices paid by particular farms will be adjusted for the extra conveyance costs.

Environmental Services

The justification for allocation of water for environmental purposes is that water has been relocated away from natural systems and restoring or sustaining these ecosystems requires a sufficient quantity of water. Evaluating the environmental services provided by this water transfer is a major challenge but is important for allocation of water among alternative applications. Ideally, the value of water in the natural environment can be derived with good information about the production and generation of environmental amenities from water, and reliable quantification of the value of those amenities. Unfortunately, information on both water productivity and the value of environmental amenities is limited and are both areas for future research. Some applications of travel cost methods and contingent valuation provide valuations of environmental benefits of water (Bergstrom *et al.,* 2001; Bockstael *et al.,* 1987), but it is not clear to what extent policy makers will fully embrace these approaches.

An alternative to explicitly pricing the environmental quality of water is the development of purchasing funds, which enable environmental agencies to purchase water and water rights for environmental purposes. These purchasing funds are an indicator of social willingness to pay for the environmental benefit of water resources. Since these environmental benefits have public good properties it is appropriate that the public sector at least partially finance the purchase of them. Mechanisms such as matching funds that combine public resources to purchase environmental amenities may also be very useful; both for indicator purposes and to provide resources that allow protection of water for environmental purposes.

Difficulties in Implementation

Many of the recommendations included in this paper can only be implemented under ideal conditions. We now discuss some of the practical difficulties to qualify the suggestions contained in this paper.

One difficulty is the quantification of the true value and costs of water, including the environmental value. Several methods are used to determine such information, including the use of travel-costs studies, hedonic valuation and contingent valuation methods. However, when these types of studies are poorly done, valuation estimates can be inaccurate and misleading. A correct estimate of these values is necessary to determine optimal water allocations, information which is necessary to design appropriate water policy.

In addition, water supply is inherently stochastic in nature, a fact that affects the optimal value and allocation of water, in addition to the management of water resources. The value of water is determined in part according to its scarcity and will be greater during times of drought than in seasons with high precipitation. An optimal water policy will have to be flexible enough to take account of this seasonal or annual variation in supply. Finally, we mentioned the role of transaction costs above, but their importance in water allocation and the potential to develop water markets must not be ignored. Water is difficult and expensive to move, and the inclusion of these costs will result in otherwise welfare improving water trades no longer being beneficial.

Conclusions

The valuation of water resources is very challenging, as the value of water varies over space and time according to quality and use. This paper suggests that in pricing water it is important to take into account the provision costs of the water, the cost of dynamic adjustment associated with water supply, conveyance costs and environmental costs. The main challenges in water policy are not limited to pricing water but also reforming the systems to facilitate transition from a reliance on queuing to the use of trading, more effectively introducing benefit-cost methods with the establishment of new water projects, and better assessing the environmental value of water resources.

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