Appendix 1

Allocation and Pricing at the Water District Level

C-097467

Allocation and Pricing at the Water District Level

Eyal Brill, Eithan Hochman, and David Zilberman

Eyal Brill and Eithan Hochman are, respectively, Ph.D. student and professor in the Department of Agricultural Economics and Management at Hebrew University. David Zilberman is professor and chair in the Department of Agricultural and Resource Economics at the University of California at Berkeley, and member, Giannini Foundation of Agricultural Economics, University of California at Berkeley.

The authors would like to thank P. Zusman, I. Finkelstain, O. Hochman, A. Dinar, and M. Gisser for their helpful remarks. This paper was supported by BARD Project US-2507-94C and a U.S. Bureau of Reclamation Challenge Grant.

Allocation and Pricing at the Water District Level

Eyal Brill, Eithan Hochman, and David Zilberman

Efficient water pricing schemes are introduced for nonprofit water agencies, where members have property rights based upon historical usage. The existing average cost rate design is compared with the proposed designs, "active trading" and "passive trading." Both schemes lead to efficiency, but "passive trading" has operational advantages since it generates less transaction costs than "active trading." Blockrate pricing is shown to be suboptimal and inferior to "passive trading." An example from the Israeli water economy is used as an empirical illustration.

Key words: blockrate pricing, efficient allocation, transferable rights, water agencies, water pricing

Allocation and Pricing at the Water District Level

In many countries, nonprofit water agencies are responsible for obtaining and delivering water to farmers. Water pricing by water agencies is based on average cost pricing and is likely to lead to economic inefficiency. The costs associated with this inefficiency are likely to increase as water availability declines. Block rate pricing (Wichelns 1991a, 1991b) and various water marketing schemes (Howe, Schurmeier, and Douglas) have been important components of water reform proposals. This paper analyzes policy options of water agencies to reduce water supply. These policies are (i) average cost pricing with the administration of quota allocation; (ii) block rate pricing; and (iii) a transferable water rights regime.

The main obstacle to efficient water allocation within a water agency is asymmetric information. Aggregate available water is known to the central decision maker, whereas at the farm level individual farmers know (but tend not to reveal) the efficient amount of water for each crop (see Zusman 1991). The analysis shows that a reduction in overall water use accompanied by a reformed transferable water rights system may lead to welfare improvement with minimal information requirements. It also shows that tiered pricing does not necessarily lead to an efficient outcome. The properties of these three policy options are compared and illustrated with a numerical example based on data from Israel.

Some of the literature on water pricing (Burness and Quirk; Gisser and Sanchez; Gisser and Johnson; Howe, Schurmeier, and Douglas; Tsur and Dinar; Zilberman and Shah; and Chakravorty, Hochman, and Zilberman) recognized the suboptimality of a traditional water rights system and recommended transition to market-like allocation of water, although the analyses did not include a revenue constraint relevant to nonprofit nature water agencies. The water pricing policies considered in this paper are subject to the balanced budget constraint of the water agencies. Furthermore, it is assumed that water rights are defined by the water use level prior to a water supply reduction—rights which must be considered by the water agency in response to supply cuts. Historical usage patterns are of crucial importance in allocating water with prior appropriation and other water rights systems. We expand Zusman's (1988) model of cooperative behavior to obtain optimal water pricing and allocation as well as income distribution taking previous water use levels into account. We also explicitly incorporate heterogeneity among farmers in the analysis.

We have the following theoretical results. A Hicksian barter market will result in Pareto efficiency if the following conditions exist: information is perfect, trading is costless, and the management allocates "initial endowments" of water according to the historical rights of the farmers. When trading is not costless and information is imperfect, an alternative policy option of "passive trading" with an internal price quotation by the management achieves Pareto efficiency. It is also shown that, under realistic assumptions, tiered pricing results in a second-best allocation. Finally, an empirical example illustrates the theoretical framework.

Modeling the Existing and Optimal System

Let us assume that a regional water agency consists of N farmers. The supply of water is generated from two origins: local underground water from wells within the area and surface water imported from outside. Water used by the region is subject to government regulation. Local ground water pumping is restricted by an upper bound (Q_L in figure 1) while the rest of the water, Q - Q_L, is purchased from outside the region. It is assumed that water from both sources are of the same quality. However, the cost per unit of local water, w_L, is fixed and lower than w_e, the cost per unit of imported water. Thus, the region faces a two-step supply function (depicted as MC in figure 1) with the following properties:

$$MC(Q) = \begin{cases} w_L > 0 & 0 < Q < Q_L \\ w_e > 0 & Q_L < Q \end{cases}.$$

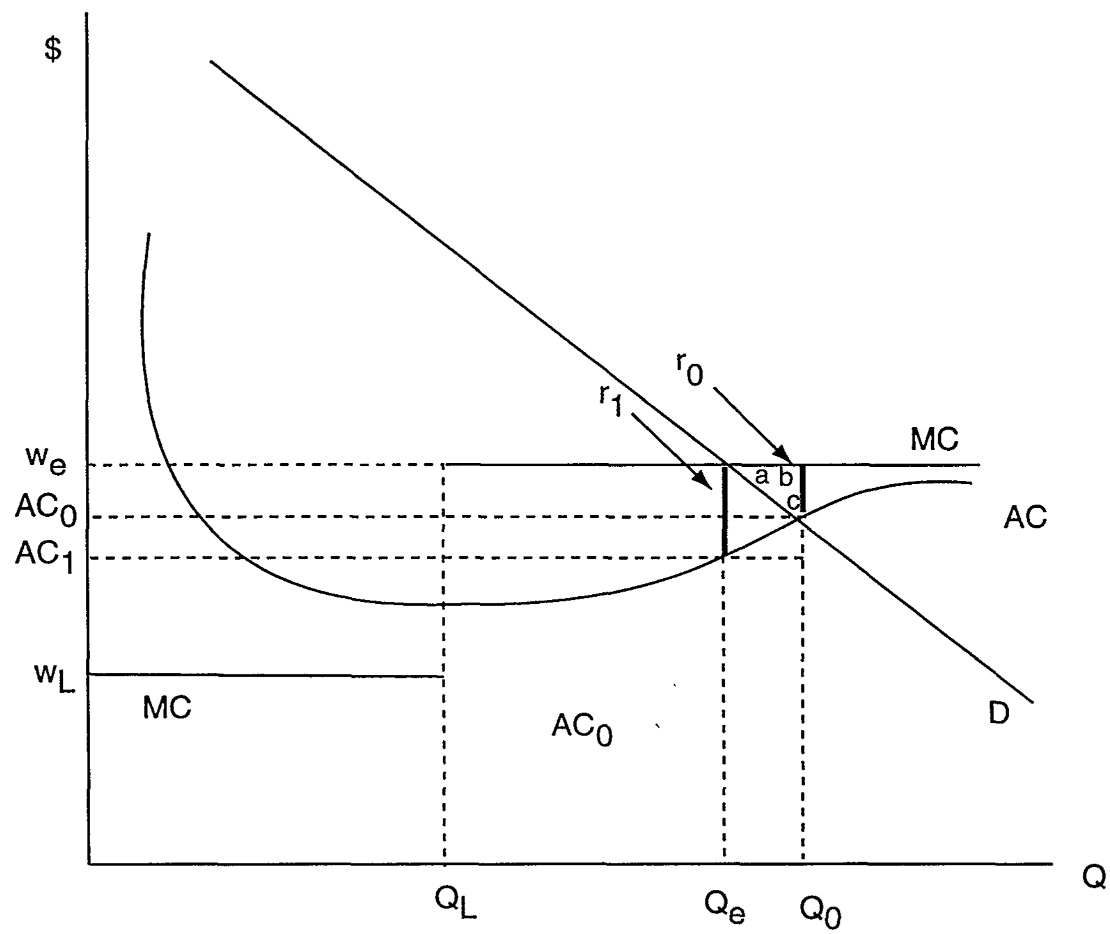

Figure 1. Resource Allocation Under Average Pricing and Trading

The average cost function of generating water to the region (depicted as AC in figure 1) decreases at the range $0 < Q < Q_L$ and increases asymptotically towards w_e at the range $Q > Q_L$.

Let $f^n(q_n)$ be the nth individual benefit from water use, measured by the dollar value obtained by application of q units of water. This benefit function may represent gross revenue, if water is the only scarce input, or net revenue of fixed input, assuming that water is the only scarce variable input. The function $f^n(q_n)$ is well behaved with $f_q^n(q) = \partial f^n / \partial q > 0$, $f_{qq}^n(q) < 0$. Note that the water demand function of the nth individual is given by $f_q^n(q)$.

The aggregate demand curve for water consists of the horizontal summation of the N individual water demand curves (see D in figure 1). For each given price, the aggregate quantity is the sum of the quantities demanded by the individuals.

Inefficient Allocation with Average Cost Water Rates

Assume that, under the initial system, the water agency sets a price for water that will both satisfy farmers' demands and balance the water agency budget (Rosen, Smith). The equilibrium conditions in this case are

(1a) $f_q\left(q_n^0\right) = w_0$ for $n = 1, 2, ..., N$

(1b) $w_0 = AC(Q_0)$

where w_0 is the initial price of water, q_n^0 is the quantity of water used by the nth farmer under the initial system, and $Q_0 = \sum_{n=1}^{N} q_n^0$ is the aggregate water used under the initial system. Equation (1a) states that water used for the nth individual is where the marginal benefit from water (inverse demand) is equal to the water price. Equation (1b) states that, under the initial system, average cost pricing is used for the price of water. It is almost trivial to say that such a policy results in inefficient resource allocation, i.e., the quantity, Q_0, is greater than the optimal quantity, Q_e, which is a result of the intersection between the MC curve and the aggregate demand curve, D. (It is assumed that the intersection point occurs at the upper segment of the MC curve.)

Optimal Allocation

Suppose that the water agency has central management which aims at developing an optimal pricing policy with the following criteria: (a) efficient water allocation, (b) balanced budget, and (c) equity-rent distribution in proportion to historical water use.[i]

Studies of water allocation design suggest that water reform seems more equitable and, therefore, politically acceptable if the reform recognizes historical rights (Colby). An efficient resource allocation of water in the region is obtained by maximizing the aggregate welfare function of the farmers in the region, i.e.,

$$(2) \qquad \underset{q_1,\ldots,q_n}{Max} \sum_{n=1}^{N} f^n(q_n) - C(Q)$$

where $Q = \sum_{i=1}^{n} q_n$. The necessary conditions which ensure the maximization in (2) consist of the n equations,

$$(3) \qquad f^n_{q_n}(q_n) = MC(Q) \quad \forall n.$$

These equations imply that each farmer equates the value of the marginal product of water to the marginal cost of generating Q units of water.

Let $h\left(q_n, q_n^h\right)$ denote the payment function, i.e., the rule which determines the amount of payments by each farmer where q_n is the amount of water delivered to the farmer and q_n^h is the historical water use right. At the micro level each farmer maximizes quasi-rent,

(4) $$\underset{q_n}{Max}\, f^n(q_n) - h(q_n, q_n^h) \quad \forall n.$$

The necessary conditions for solving the individual farmer's optimization problem are that each farmer equates the value of the marginal product of water to the marginal payment charged for water,

(5) $$f_{q_n}^n(q_n) = h_{q_n} \quad \forall n.$$

Thus, (3) and (5) result in

(6) $$MC(Q) = h_{q_n} \quad \forall n,$$

which implies marginal pricing.

Now, for simplicity, assume that the payment function has a linear form and depends on the actual use of water and the historical rights. Thus,

(7) $$h(q_n, q_n^h) = Aq_n + Bq_n^h \quad \forall n.$$

The zero profit constraint implies that the sum of payments of the N farmers equals the total costs of generating Q units of water, i.e.,

(8) $$\sum_{n=1}^{N}\left[h(q_n, q_n^h)\right] = C(Q).$$

Substituting (7) into (8), and using (6), B results in

(9) $$B = \frac{C(Q) - MC(Q)Q}{Q^h} = [AC(Q) - MC(Q)]\,\frac{Q}{Q^h}.$$

where $Q^h = \sum_{i=1}^{N} q_n^h$ and $AC(Q)$ are average costs. Since average costs are less than marginal costs ($C' > 0$), B is negative; thus, under optimal pricing, farmers are paid for their historical water use rights. The per unit rent of historical water use rights is $-B$.

Rewriting equation (7),

$$(10) \qquad h\left(q_n, q_n^h\right) = MC(Q)\, q_n + \left[\frac{C(Q) - MC(Q)Q}{Q^h}\right] q_n^h.$$

The payment function (10) depicts the two goals of the optimal policy: (1) efficient water allocation, i.e., each farmer pays the marginal costs of water for the actual quantity used by him and (2) water rent distribution is in proportion to the historical water use rights.

The pricing rule (10) can be written differently. Let $s_n = \frac{q_n^h}{Q^h}$ be the share of the nth individual in the historical rights. Then, his/her "adjusted" water right is obtained by calculating his/her share in the total quantity used, i.e., $q_n^r = s_n Q$. Thus, the allocation rule can be presented as follows:

$$(11) \qquad h\left(q_n, q_n^h\right) = MC(Q)\left[q_n - q_n^r\right] + AC(Q) q_n^r.$$

According to equation (11), the individual pays average costs for his/her adjusted rights; when $q_n > q_n^r$, he/she also pays the marginal costs for the difference between actual use and adjusted rights. When $q_n < q_n^r$, he/she receives this difference. Several payment schemes can be based on equations (10) and (11).

Policy Options

Assume that the policymaker knows aggregate demand and supply but not individual demands; thus, two policies are optional. The first option is the "active trading" policy. At the beginning of each time period (e.g., a year or season), the water agency determines the optimal aggregate quantity Q_e at the intersection of aggregate demand and supply (figure 1) and allocates individual annual rights in proportion to the historical rights $q_n^r = s_n Q_e$. Each farmer pays the price $AC(Q_e)$, i.e., the average cost of generating the aggregate quantity Q_e, for each unit of "initial endowment" of water rights. This ensures a balanced budget, and farmers are allowed to trade their water rights. Assuming a perfect competitive market with costless trading, the market will determine the equilibrium price w_e (figure 1). At this price each farmer may have an excess demand (supply) according to whether the sign of $f_q^n\left(q_n^r\right) - w_e$ is positive (negative).

Assuming also that trading is conducted at a given place and time, price w_e will clear the market with a rent per unit of water rights: $w_e - AC(Q_e) = r$. Note that such a market, which follows the description of a barter market as described by Hicks, results in characteristics of the optimal system described in the second section.

The second option is called the "passive trading" policy. At the beginning of each time period, the water agency determines and announces the optimal price, w_e, at the intersection of the aggregate demand and supply (figure 1). Each farmer applies the amount of water, q_n^e , according to his/her individual demand at w_e. The summation of all the quantities, q_n^e, used during the time period will result in an aggregate quantity $S_n^r Q_e$ of water rights that equals $r = w_e - AC(Q_e)$. The water agency also calculates the periodical individual water right as $S_n^r Q_e$. For each period, the farmer will be entitled to receive $s_n^r Q_e r$. Thus, the total water expenditure of the nth farmer will be

(12) $$q_n^r AC(Q_e) + r\left(q_n^e - q_n^r\right).$$

Note that, by the end of the period, a farmer is an "*ex post* buyer" ("*ex post* seller") of water according to whether the sign of $\left(q_n^e - q_n^r\right)$ is positive (negative), and he/she pays (receives) the amount $r\left(q_n^e - q_n^r\right)$. Thus, the "passive" market has the characteristic whereby the participant buyer (seller) does not have to pursue a matching seller (buyer).

For the passive trading policy, a unique marketplace is not needed. Each farmer determines his/her water use at the price determined by the central management. In both cases, the distribution of the water use rights is predetermined according to historical shares (e.g., for riparian rights along a river, see Anderson). For the active trading policy, the periodical water rights result from the policymaker's *ex ante* estimation of Q_e, while, for the passive trading policy, the periodical water rights result from the *ex post* summation of the quantities used by the individual farmers at a unique price, w_e, as announced by the water agency.

Water markets exist in some localities, e.g., the water law in New Mexico allows trading in consumptive use of surface water rights but is absent almost everywhere else. Creation and operation of active trading require substantial transaction costs, including the cost of new trading channels, legislative framework, and detailed registration of the bilateral transactions. Central decision making by water agencies may be less costly, explaining the absence of water markets in some localities (Coase 1988). However, the inefficiencies resulting from administrative allocation under asymmetric information may be higher than "active trading" transaction costs.

Distributional Effects

A policy reform from average pricing to either active or passive markets increases aggregate economic surplus, and the increase in surplus is depicted by the area *abc* in figure 1. If farmers are identical and the industry is price taking, the reform will result in no trading and improvement in the welfare of <u>all farmers</u>. However, when farmers are heterogeneous, the reform will result in trading and income redistribution and result in gainers and perhaps some losers. To investigate the impacts of heterogeneity on the distributional effects of the policy reform, denote outcome of average cost pricing with a 0 subscript and outcome of the policy reforms with a 1 subscript. Furthermore, assume that all farmers used equal amounts of water under average cost pricing and initial water rights of each of them is denoted by q_0^r; however, assume that farmers are divided equally into two groups according to their water demand functions.

Figure 2 depicts f_q^1 and f_q^2, the demand curves of two farmers, one for each group. The curves intersect where water price is AC_0 (water price under average pricing) and water use is q_0^r. Farmers of group 1 are assumed to be more efficient for $q < q_0^r$;

therefore, f_q^1 is above f_q^2 for $q < q_0^r$. Given the equal initial share, after the reform, the water rights of all farmers are equally reduced from q_0^r to q_1^r. The water price after the reform increases from AC_0 to w_e and the average cost of water decreases from AC_0 to AC_1.

The quantities q_1^1 and q_1^2 in figure 2 denote the post-reform water use levels of all farmers of group 1 and group 2, respectively. The farmers of the more efficient group demands more water at the post-reform market price, and he/she will be a buyer of water. The farmer of the less efficient group will be a seller. The quantity bought by a buyer in figure 2 is q_1^1 minus q_1^r, and the quantity sold is q_1^r minus q_1^1. Since we have an equal number of buyers and sellers, q_1^1 - $q_1^r = q_1^r - q_1^2$.

To compare the impact of the reform on the well-being of the buyer and seller, note that both gain from a reduction of price of their water quota, and this gain is depicted by the area AC_0ghAC_1 in figure 2. Both the buyer and seller lose economic surplus because of lower output. The area a^1d^1c depicts the surplus loss of the buyer because of lower output. The purchase of water from the seller also contributes to the buyers' cost of the reform, and the area ea^1d^1g depicts this extra cost. Thus, the net effect of the reform on the buyer is gain measured by AC_0ghAC_1 and loss measured by ea^1cg.

The surplus loss of the seller because of reduced production is measured by the area a^2d^2c in figure 2. However, the seller gains d^2gea^2 from selling water. Thus, the net impact of the reform on the seller is gain of AC_0ghAC_1, loss of fgc, and gain of a^2ef To simply the notation, let

$$A \equiv \text{area } AC_0ghAC \qquad B = \text{ area } a^2ef$$
$$C \equiv \text{area } fkd^1g \qquad D = \text{ area } ea^1cf.$$

The impact of the reform on the welfare of the buyer and seller is denoted ΔW_1 and ΔW_2, respectively,

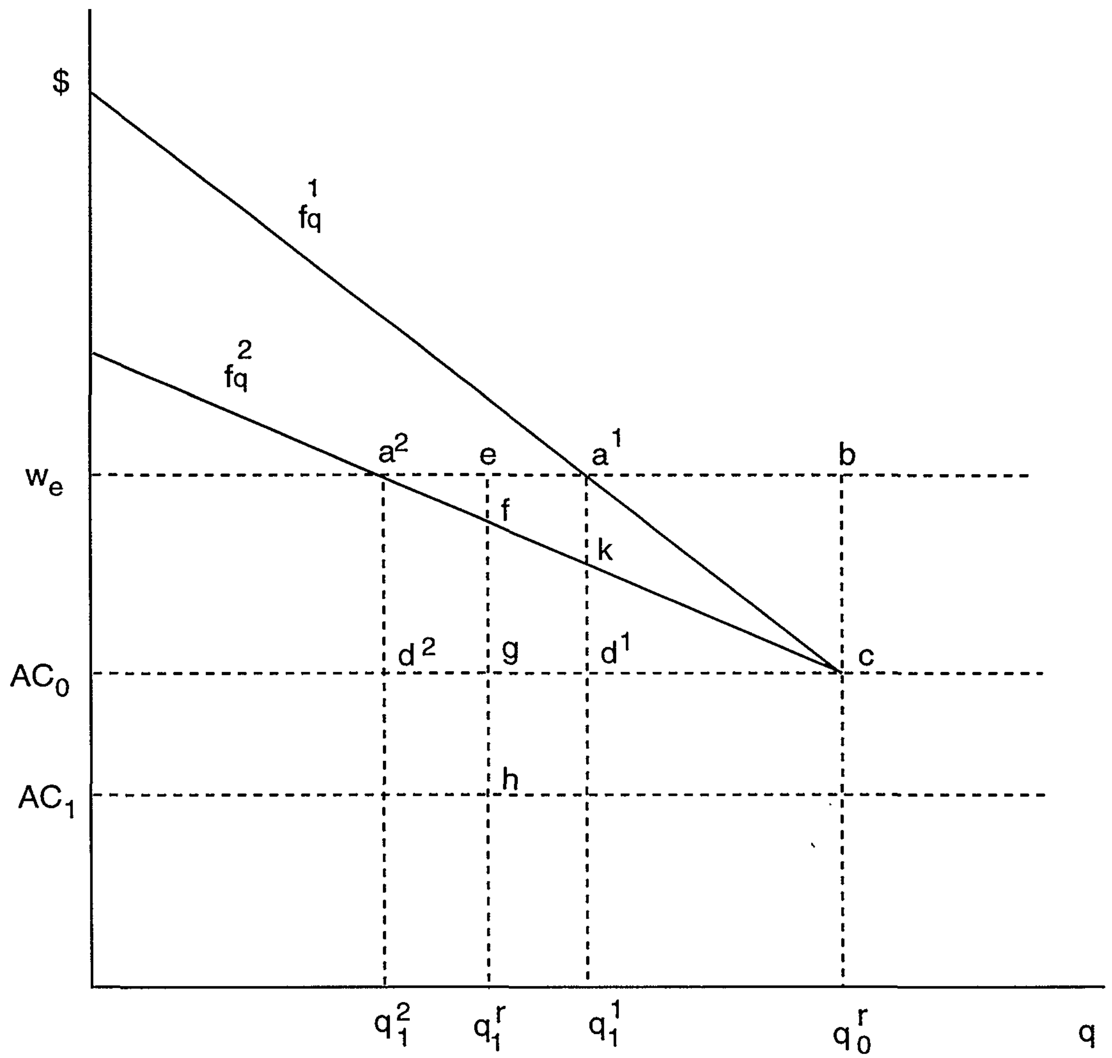

Figure 2. Distributional Effects of Water Policy Reform

C-097480

(13.a) $\Delta W_1 = A - C - D$

(13.b) $\Delta W_2 = A - C + B$.

Equation (13.a) and (13.b) show that the *seller gains more from the reform than the buyers.* The impact of the reform on the benefit of sellers and buyers is

$$\Delta W_1 + \Delta W_2 = 2(A - C) - D + B > 0$$

since the reform improves overall welfare. Thus, (13.b) suggests that

$$\Delta W_2 = A - C + B > \frac{\Delta W_1 + \Delta W_2}{2} = A - C - (D + B)/2 > 0$$

which implies that *the seller always gains from the reform.* On the other hand, $\frac{\Delta W_1 + \Delta W_2}{2} > \Delta W_1$, which implies that the *buyer does not necessarily gain from the reform.*

The buyer may actually lose from the reform as heterogeneity increases. Comparing situations with the same AC_0, AC_1, w_e, and two groups of farmers all having the same q_o^r and q_1^r, the differences in production technology between farmers increase as f_q^1 in figure 2 rotates to the right and as f_q^2 in figure 2 rotates to the left (keeping $a^1 e = a^2 e$). Increase in heterogeneity will increase q_1^1, reduce q_1^2, and increase trading between the two parties. The increase in heterogeneity will not affect A but will increase the area $C + D$, increase the area B, and reduce the area C. Thus, using (13a) and (13b), an increase in heterogeneity will reduce the welfare of the buyer and increase the welfare of the seller. If as heterogeneity increases $C + D$ becomes greater than A, then the reform will make the buyers worse off. Thus, there may be situations where a reform from average pricing and trading may improve welfare but may make the more efficient farmers worse off and that may lead to their objection of this reform.

An Alternative Pricing Policy: Tiered Prices

Block pricing, a common pricing method of electrical and gas utilities, was introduced recently as tiered pricing in some water agencies in Israel and California. A two-block rate design[ii] consists of a two-step payment function as follows,

$$(14) \quad h\left(q,q^r\right)=\begin{cases} w\left(q-\gamma q^r\right)+\delta w\gamma q^r & \text{if}\left[q(w)\geq \gamma q^r\right] \\ \delta wq & \text{if}\left[q(w)<\gamma q^r\right] \end{cases}$$

where q_n^r, w, γ, and δ are determined by the water agency. The first two parameters, q_n^r, and w, respectively, measure the assigned water quota of the nth individual farmer and the price of water, and the two last parameters are between 0 and 1.

This payment function is linear in q in two segments with a discontinuous jump at γq_n^r. The farmer pays a reduced price, δw, for the first γ percent of his/her water quota, q_n^r, and full price, w, for additional water, $\left(q_n-\gamma q_n^r\right)$.[iii] This payment function should be compared to the payment function described by equation (10), which is linear over the whole range of q_n. Note that some farmers may not use water efficiently for some values of q_n^r, w, γ, and δ. This can be verified by applying the individual optimization conditions (see equations 5 and 6) to the case of tiered pricing, deriving three types of behavior by the farmers:

(15a) Type j: $f_q^j\left(\gamma q_j^r\right)<MC(Q)$, where $q_j^e<\gamma q_j^r$

(15b) Type k: $f_q^k\left(\gamma q_k^r\right)\geq MC(Q)\geq f_g^k\left(q_k^r\right)$, where $\gamma q_k^r<q_k^e<q_k^r$

(15c) Type i $f_q^i\left(q_i^r\right)>MC(Q)$, where $q_i^r<q_i^e$

where q_j^e, q_k^e, and q_i^e are the economically efficient quantities for each type of farmer. Figure 3 depicts three representative members of the corresponding behavioristic groups. While the individual farmers in groups of type k and i apply their water efficiently, i.e.,

$f_q^k\left(q_k^e\right)=MC(Q_e)$ and $f_q^i\left(q_i^e\right)=MC(Q_e)$, those in group type j apply their water inefficiently, i.e., $f_q^j\left(q_j^t\right)=\delta MC(Q_e)$. Thus, the inefficient allocation of water by the representative member of type j in figure 3 results in a waste of $\left(q_j^t-q_j^e\right)$ and a welfare loss measured by the triangle *abc*. In general, the corresponding losses of water and welfare by the farmers of type j group can be calculated from

(16a) $$\sum_{j=1}^{J}\left(q_j^t-q_j^e\right)$$

and

(16b) $$\sum_{j=1}^{J}\int_{q_j^e}^{q_j^t}\left[MC-f_q^j(q)\right]dq.$$

As was discussed in the second section, the regional water agency management follows the efficiency rule $w = MC$, which determines the efficient aggregate quantity Q_e subject to the balanced budget constraint. The water quotas q_n^r of each of the individual farmers are determined exogenously by the management relative to the historical water rights subject to

(17) $$Q_e=\sum_{n=1}^{N}q_n^r.$$

$$0\le\delta\le\frac{AC(Q_e)}{MC(Q_e)} \text{ and } \left[1-\frac{AC(Q_e)}{MC(Q_e)}\right]\le\gamma\le 1.$$

Maximum reduction of inefficient use of water by type j farmers can be achieved by choosing either:

(a) $\delta=0$ and $\gamma=\left[1-\frac{AC(Q_e)}{MC(Q_e)}\right]$.

or

(b) Allowing trading in water rights.

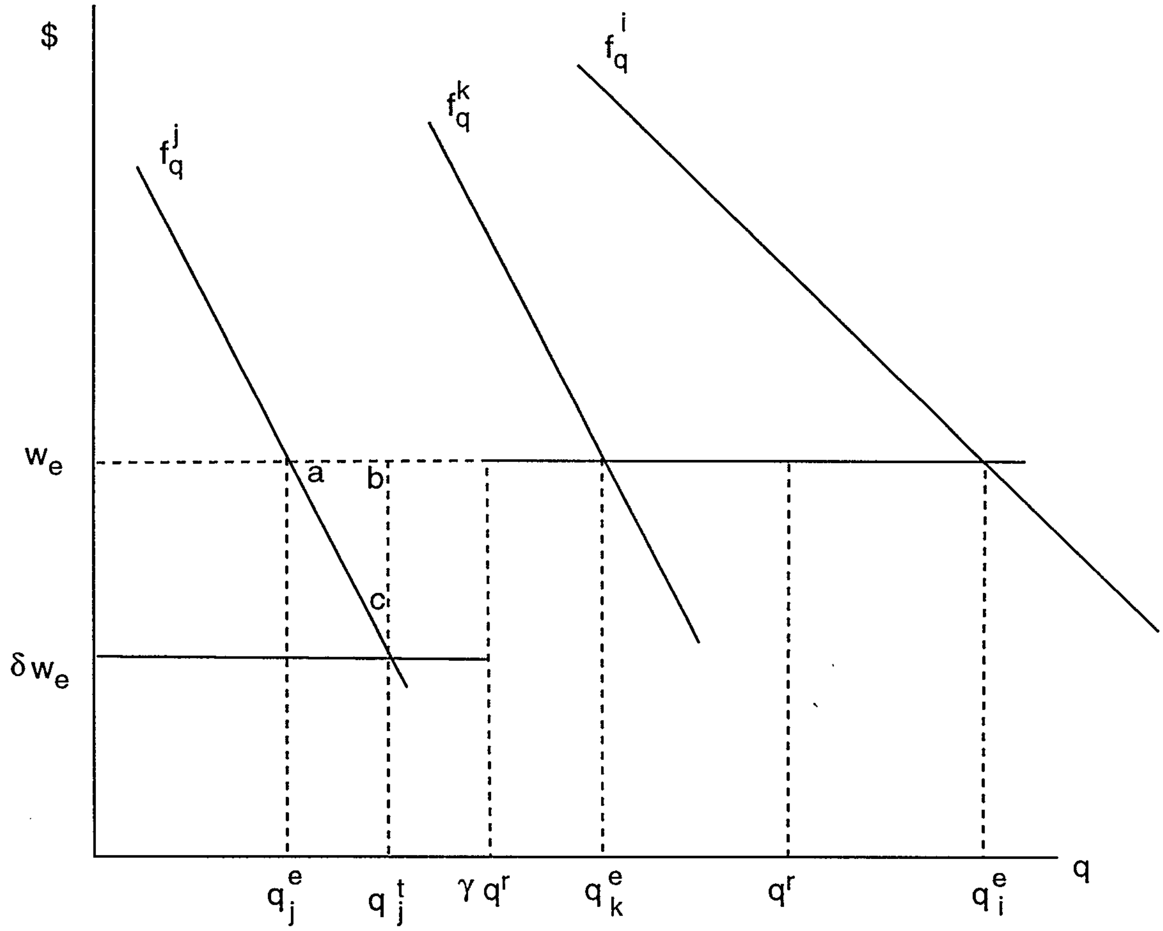

Figure 3

C-097484

The choice of the parameters is subject to the balanced budget constraint in (8), i.e.,

Note that the effectiveness of condition (a) is reduced as the heterogeneity of water requirements among crops and among farmers is increased.[iv] Hall and Hanemann argued that a policy based on (a) may not be politically feasible due to equity considerations.[v]

In the case of water trading (b), efficient allocation implies

$$(18) \quad \sum_{j=1}^{J}\left(\gamma q_j^r - q_j^e\right) = \sum_{i=1}^{I}\left(q_i^e - q_i^r\right).$$

The quantities scheduled for sale by type j farmers must equal the quantities scheduled for purchase by type i farmers. Note that, for the type k farmers, the following inequality holds

$$(19) \quad \sum_{k=1}^{K} q_k^r > \sum_{k=1}^{K} q_k^e.$$

Therefore, by using (18) and (19), it can be verified that

$$(20) \quad \sum_{n=1}^{N} q_n^r > \sum_{n=1}^{N} q_n^e$$

which contradicts (17). Note that information on the distribution of type j, k, and i is needed for complete efficient allocation given the constraint in (20). Thus, more information is needed for efficient implementation of tiered pricing than the information needed for the implementation of a market mechanism.

An alternative policy for reducing the loss caused by type j farmers is to abandon historical rights and to design a block rate on a crop basis. Such a policy requires detailed information concerning the production functions of each crop and, as pointed out by Hall and Hanemann, involves a tradeoff between efficiency and transaction costs.

An Application

Empirical data collected from a region in Israel (Hasharon region) are used for an application of the transferable rights mechanism presented in this paper. The table in appendix A contains 1991 data for 40 major crops in the region. Each row in the table depicts the data for one crop. The crops are listed in descending order according to the average rent per m^3 of water, based on data made available by the Israeli Ministry of Agriculture. Since information on the individual demand curves is not available, the empirical application assumes fixed water-land ratio per crop and uses the water quasi-rent as a welfare measurement.

The farmers in the Hasharon region are organized as a water cooperative. Of a total consumption of 65 million m^3 per year, approximately 30 million are generated by wells within the region. The average cost of pumping a cubic meter of water from a local well is 0.43 NIS (New Israeli Shekel). Surface water is imported from outside the region via the national aqueduct at the price of 0.65 NIS per cubic meter of water.

The quasi-rent, which results from the application of one m^3 water to a given crop, is profit derived by deducting the average costs from the average revenue of a given crop. The obtained quasi-rent is multiplied by the total amount of water applied to the crop and is registered in column 6 of table 1. The welfare generated by the current policy (33,894 thousand NIS in table 1) is obtained by summing up the crops in column 6 in appendix A.

In the following analysis, we assume a fixed water-land ratio for each individual crop. We examine simulations of three policies aimed at achieving the optimal use of 31,000 thousand m^3 of water: water quotas, passive trading, and tiered pricing.

Water Quotas

The allocation of water in the region (31,562 thousand m^3) is obtained through administrative allocation of water quotas. In order to achieve this goal, the amount of water for each of the crops is reduced by a fixed proportion. This yields a total irrigated area of 47,691 dunams and a total welfare of 19,877 thousand NIS (see policy 1 in table 1).

Tiered Pricing

Assume that with a tiered pricing policy all crops with a value of marginal product less then 0.65 NIS will reduce the amount of water by 20%. Using equation (14) in section 4, γ = 0.8 and δ = .05, which concurs with the policy adopted recently by the Water Commissioner in Israel. The total amount of water used under this scenario equals 58,219 thousand m^3 and the total welfare equals 37,538 thousand NIS. If the reduction of water usage among low value crops is 30%, i.e., $\gamma = 0.7$, the total amount of water usage equals 54,887 thousand m^3 and the total welfare equals 39,360 thousand NIS. Although the tiered pricing policy doubles the aggregate welfare compared to the initial allocation, it still remains considerably below the first-best allocation achieved by passive trading. The inefficiency in the allocation of water by tiered pricing results in a waste of 26 million cubic meter and a low profit rate of 0.64 NIS per cubic meter compared to the optimal profit rate of 1.65 NIS with passive trading.

Passive Trading

With passive trading, an efficient allocation results in a quantity demanded equal to 31,562 thousand m^3 of water at a price of 0.65 NIS. The total irrigated area of 48,119 dunams yields a total welfare of 52,116 thousand NIS. Each unused cubic meter of water use right is compensated by 0.21 NIS, while the cost of a cubic meter of water less than the water use right equals 0.44 NIS. Thus, the reservation price of each applied cubic meter within the water use rights is equal to 0.65 NIS, which is also the efficient price.

Passive trading results in a Pareto optimal allocation, and it is superior to the other two policies. It yields the highest aggregate water profits and land rents and results in the lowest aggregate quantity of water demanded. Therefore, it is plausible that passive trading generates the least political resistance.

C-097488

Table 1. Different Policies of Water Allocation

		Current situation	Policy 1: Administrative quotas	Policy 2: Tiered prices	Policy 3: Passive trading
Total water used	($1000*m^3$)	64,884	31,562	58,219	31,562
Irrigated area	(dunam)	98,040	47,691	88,056	48,119
Welfare	(1000*NIS)	33,893	19,877	37,538	52,116
Profit / m^3	(NIS)	0.52	0.62	0.64	1.65
Average costs	(NIS)	0.55	0.44	0.54	0.44

However, hydrological constraints can impose reduction in the use of local water. When this occurs, the reduction in the water rents endangers the acceptance of the reform, i.e., some of the farmers will be worse off by the reform. Resistance to the reform is likely correlated to the relative decrease of the farmer's income. Let $\alpha = r_1 Q_1 / r_0 Q_0 < 1$ denote the relative decrease of the farmer's income. Table 2 depicts the percentage of crop area whose income is reduced by more than a certain value for a given reduction of water rents. To illustrate, for a share of 4.33% of the crop area, a reduction of 20% in water rents (α = 0.8) will result in a reduction of more than 5% (the critical value) of income.

Concluding Remarks

This paper compares policy options to allocate water in response to reduced water supply. Average cost pricing with quota reductions results in administratively inefficient pricing and allocation.

Economists have suggested water markets as a remedy, but the absence of well-defined property rights and high transaction costs remain barriers to this solution. According to Coase (1992), "if the costs of making an exchange are greater than the gains which that exchange would bring, that exchange would not take place, and the greater production that would flow from specialization would not be realized." The "passive trading" policy developed in this paper enables a trade of water use rights with low transaction costs. The passive trading enables an efficient allocation with minimal losses by farmers and, therefore, minimal political resistance by them. This is made possible by increasing the welfare resulting from the use of water and establishing quasi rights related to historical use. The greater the "pie," the easier it is to redistribute it among the farmers. In the long run the increased "pie" enables the diversion to higher value products and water-saving technologies.

Table 2. Percentage of Crop Area Adversely Affected Under Several Scenarios

	Critical values			
Reduction in rents	1%	5%	10%	20%
α = 0.9	21.7%	1.76%	0%	0%
α = 0.8	29.13%	4.33%	1.76%	
α = 0.7	46.38%	7.64%	4.33%	0.17%
α = 0.6	47.83%	20.83%	4.37%	2.65%

A detailed description of the calculations from which table 2 is derived appears in appendix B.

Water institutions and their laws in many states, for example, in Israel and California, do not allow trading in water use rights. Tiered prices have recently been suggested as an efficient pricing method. It is shown in this paper that, under reasonable assumptions, tiered prices lead to a "second best" solution. Passive trading results in a Pareto efficient allocation and does not require new water legislation. Such a policy could also be useful in other price pooling systems, such as production and marketing boards.

Appendix A

Table A1. Individual Crops Budget Data, Hasharon Region, 1992

Crop	(1)	(2)	(3)	(4)	(5)	(6)
Wax flower	4.90	920	600	552	552	2,392
Roses	4.41	920	1,000	920	1,472	3,536
"Almog" Peaches	3.31	89	400	36	1,508	98
Potatoes	2.99	17,130	630	10,792	12,300	26,154
"Grand" Apple	2.98	121	750	91	12,390	219
Miniature Mango	2.82	228	600	137	12,527	308
Mango	2.60	228	600	137	12,664	278
Ruscus	2.56	920	900	828	13,492	1,651
"Babcock" Peaches	2.14	89	500	45	13,536	70
"Delicious" Apple	2.13	121	750	91	13,627	142
Carnation	1.83	920	1,600	1,472	15,099	1,860
Groundnuts	1.80	1,001	400	400	15,500	494
Gypsophila	1.77	920	965	888	16,387	1,068
Sunflowers (Type A)	1.67	406	150	61	16,448	67
"Reed" Avocado	1.63	1,476	700	1,033	17,481	1,099
Orange	1.52	121	750	91	17,572	87
"Hof" Groundnuts	1.44	1,000	500	500	18,072	437
Easy Peeling Citrus	1.35	9,253	750	6,940	25,012	5,437
"Swilling" Peaches	1.31	89	500	45	25,056	33
"Armoza" Peaches	1.30	89	550	49	25,105	36
Persimmons	1.29	1,781	650	1,158	26,263	838
Sunflowers (Type B)	1.23	405	100	41	26,304	27
Seed Tomatoes	1.23	861	350	301	26,605	200

"Hass" Avocado	1.09	1,476	700	1,033	27,638	541
Chickpea (Garbonzo beans)	1.07	672	120	81	27,719	41
"Horshim" Avocado	0.96	1,476	700	1,033	28,752	407
"Ettinger" Avocado	0.85	1,476	700	1,033	29,785	293
Bulgarian Chickpeas	0.81	672	120	81	29,866	20
Corn	0.80	1,111	500	556	30,421	130
"Nevel" Avocado	0.74	1,476	700	1,033	31,454	179
"Port" Chickpea	0.68	672	160	108	31,562	12
Seedlings Tomato	0.62	71	350	25	31,587	1
Pecan Nuts	0.60	2,124	750	1,593	33,180	53
Sorghum	0.51	672	100	67	33,247	-4
"Pima" Cotton	0.40	1,042	520	542	33,789	-90
Irrigated Cotton	0.39	1,042	400	417	34,206	-74
"Jonathan" Apples	0.38	121	750	91	34,296	-17
"Acala" Cotton	0.35	1,042	480	500	34,797	-108
"Fuerte" Avocado	0.33	1,476	700	1,033	35,830	-244
Spanish Chickpeas	0.26	672	200	134	35,964	-41
Wheat	0.23	504	220	111	36,075	-37
"Shamouti" Oranges	0.05	41,155	700	28,809	64,884	-14,880

Column definition.

(1) Average rent per m^3 (NIS).

(2) Total cultivated land for each crop (dunams).

(3) Applied water for 1 dunam of crop (m^3).

(4) Total applied water for each crop (m^3 x 1000), [(2)x(3)].

(5) Accumulated water for the region (m^3 x 1000).

(6) Income per crop. (NIS x 1000), [(1) x (4) - water costs].

Appendix B

TheDerivation of the Results in Table 2 Using Data in Appendix A.

To demonstrate the use of the data in appendix A to derive the results in table 2, consider the case of $\alpha = 0.8$ (second row in table 2). Let us start with crop 1 in appendix A: Water rent per cubic meter is 4.9 NIS. Average cost pricing results in a profit per crop of 2.4 million NIS. This number is derived by using $AC = 0.55$ NIS, deducting it from the water rent (4.90), and multiplying it by the amount of water used by the crop (552 thousand of cubic meter), i.e., [(4.90 - 0.55) x 552 = 2401 thousand NIS].

The transition to passive trading will result in the same profits, 2.402 million NIS, if $\alpha = 1$. These profits are obtained from two sources: (1) from (4.90 - 0.43) x 268.51 = 1200.25 thousand NIS and (2) from the water use in excess of the reduced 268 thousand cubic meter water rights, i.e., 552 - 268 = 283.

Thus, the profits from the second source are equal to (4.90 - 0.65) x 283 = 1,204 thousand NIS. Note that 1200 + 1204 = 2,404.

For $\alpha = 0.8$, AC is increased from 0.43 NIS to 0.46 NIS, and the profits for the above individual crops are reduced to 2,396 thousand NIS, i.e., a reduction of 0.2% in the crop profits.

The same calculations are illustrated for all crops. Then, in table 2, the percentages of crop area whose income was reduced by 1, 5, 10, and 20% are reported in the corresponding columns in the second row. Thus, for example, in the second row (α = 0.8) 4.33% of the cultivated area consists of crops that suffered a reduction of at least 5% in income.

Footnotes

vi

References

Anderson, T. L. *Water Rights, Scarce Resource Allocation, Bureaucracy and the Environment.* San Francisco: Pacific Institute for Public Policy Research, 1983.

Burness, H. S., and J. P. Quirk. "Appropriative Water Rights and the Efficient Allocation of Resources." *Amer. Econ. Rev.* 69(March 1979):25-37.

Chakravorty, U., E. Hochman, and D. Zilberman. "A Spatial Model of Optimal Water Conveyance." *J. Environ. Econ. and Manage.* 29 (May 1995):25-41.

Coase, R. H. *The Firm, The Market, and the Law.* Chicago: University of Chicago Press, 1988.

________. "The Institutional Structure of Production." *Amer. Econ. Rev.* 82 (September 1992):713-19.

Colby, B. "The Economic Incentives and Agricultural Drainage Problems: The Role of Water Transfers." *The Economics and Management of Water and Drainage in Agriculture,* ed. A. Dinar and D. Zilberman. Norwell, Massachusetts: Kluwer Academic Publishers, 1991.

Fundenberg, D., and J. Tirol. *Game Theory.* Cambridge: The MIT Press, 1993, pp. 268-75.

Gisser, M., and R. N. Johnson. "Institutional Restrictions on the Transfer of Water Rights and the Survival of an Agency." *Water Rights, Scarce Resource Allocation, Bureaucracy, and the Environment.* New York: Harper & Row Publishers, Inc., 1984.

Gisser, M., and D. A. Sanchez. "Competition Versus Optimal Control in Groundwater Pumping." *Water Resour. Res.* 16(1980):638-42.

Hall, D. C., and W. M. Hanemann. "Urban Water Rate Design Based on Marginal Cost." *Advances in the Economics of Environmental Resources*, Vol. 1. Greenwich, Connecticut: JAI Press Inc., 1996, pp. 95-122.

Hicks, J. R. *Value and Capital.* New York: Oxford Press, 1939.

Howe, W. C., D. R. Schurmeier, and W. Douglas. "Innovative Approaches to Water Allocation: The Potential for Water Markets." *Water Resour. Res.* 22(1986): 439-45.

Rosen, M. D. "Property Rights and Public Choice in Water Districts: An Application to Water Markets." Ph.D. dissertation, University of California at Berkeley, 1989.

Smith, R. T. "The Economic Determinants and Consequences of Private and Public Ownership of Local Irrigation Facilities." *Water Rights, Scarce Resource Allocation, Bureaucracy, and the Environment.* New York: Harper & Row Publishers, Inc., 1984.

Tsur, Y., and A. Dinar. "Efficiency and Equity Considerations in Pricing and Allocating Irrigation Water." World Bank, Policy Research Working Paper No. 1460, 1995.

Wichelns, D. "Increasing Block-Rate Prices for Irrigation Water Motivate Drain Water Reduction." *The Economics and Management of Water and Drainage in Agriculture,* ed. A. Dinar and D. Zilberman. Norwell, Massachusetts: Kluwer Academic Publishers, 1991a.

________. "Motivating Reductions in Drain Water with Block-Rate Prices for Irrigation Water." *Water Resour. Bulletin* 27(1991b):585-92.

Zilberman, D., and F. Shah. "Queuing vs. Markets in Water Resource Allocation." Department of Agricultural and Resource Economics, University of California at Berkeley, unpublished paper, 1994.

Zusman, P. "A Conceptual Framework for a Regulatory Policy of the Israeli Water Resources." The Center for Agricultural Economic Research, Hebrew University Working Paper No. 9108, 1991.

_______. *Individual Behavior and Social Choice in A Cooperative Settlement.* The Magnes Press, The Hebrew University, 1988, pp. 58-64.

[i]Fundenberg and Tirol identify properties a-c as necessary to obtain an efficient sustainable rate design.

[ii]The implementation of tiered pricing may be much more complex. Here we use a simple general form. Most of the results obtained here are preserved for other forms of tiered pricing.

[iii]The payment function may include a third segment where water use in excess of the water quota q_n^* will be charged an extra fine.

[iv]This can be verified by examining the table in appendix A.

[v]Under policy (a), the average charge per unit of water for farmers who use small amounts of water is significantly lower than the average for those who use large amounts of water.