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Micha Gisser

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ECONOMIC POLICY FOR WATER RESOURCES AND PLACEMENT FLOWS

MICHA GISSER[†]

Perennial water pumpage in excess of natural recharge, known as "overdraft" is a problem shared by many important agricultural areas in the Southwest, including the Roswell basin in New Mexico. Perennial overdraft leads to falling water tables, causing a constant rise in the cost of pumping. To illustrate by an oversimplified example, consider an aquifier whose specific yield is 20 percent,[1] and assume the cost of lifting one acre-foot one foot is 5 cents. In such a case, an overdraft of one acre-foot per acre overlying the reservoir will increase the cost of pumping per acre-foot by 25 cents [5x(1/0.20)]. This fact by itself is relevant for policy; Renshaw has shown that storing water in ground reservoirs gives rise to decreasing the cost of pumping. By applying a suitable capitalization factor one obtains a capital equivalent value that should be compared with the investment value of surface reservoirs capable of storing the same amount of water.[2]

This article considers the general economic policy needed to cope with long-run problems of supply of and demand for irrigation water. Short-run problems of reservoir management are not considered. A general case in which natural recharge into the basin is significant is considered. To orient the reader, consider the report of Lansford and Creel[3] describing the annual water balance in the Roswell Artesian Basin in the years 1960-1964: (In acre-feet)

1) Natural recharge	265,000
2) Natural discharge	115,000
3) Net natural recharge (1-2)	150,000
4) Total pumpage	415,000
5) Pumpage consumed	270,000
6) Pumpage returned to aquifier (4-5)	145,000
7) Overdraft (4-3-6)	120,000

This overdraft of 120,000 acre-feet per annum depresses the water

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[†] Associate Professor of Economics, University of New Mexico.

[1] Specific yield is a fraction of an aquifer's porosity. For example, specific yields of allovial aquifers may be in the range of 10 to 20 percent, while those of uniform sands may amount to 30 percent.

[2] Renshaw, *Managing Ground Water Reservoirs,* 45 J. Farm Econ. 285 (1963). *See also* Burt, *The Economics of Conjunctive Use of Ground and Surface Water,* 36 Hilgardia 31 (1964); Buras, *Conjunctive Operation of Dams and Aquifers,* 89 J. Hydraulics Div., No. HY6, Part 1 (1963). More technical aspects of reservoir management have been developed by Burt and Buras.

[3] Lansfor and Creel, *Irrigation Water Requirements for Crop Production, Roswell Artesian Basin, an Economic Analysis and Basic Data,* 5 Water Resources Research 3 (1969).

table, and accordingly leads to a perennial rise in the cost of pumping.

ECONOMIC POLICY IN ABSENCE OF REPLACEMENT FLOWS

Replacement flows are defined to be imported water diverted from resources which are not connected with the basin under consideration. Kelso has analyzed the problem of perennial overdraft and absence of replacement flows.[4] Kelso assumed that (a) water yielding efficiency of the falling aquifer remains constant with depth, (b) pumping cost per acre-foot per foot of lift is constant regardless of depth and (c) the only variable affecting net revenue within any one farming system is pumping cost. In fact, Kelso assumed the demand for irrigation water to be absolutely inelastic: the water use per acre is fixed, regardless of the cost of pumping. Under such assumptions, the problem at hand is similar to the typical problem of mining: all that is left for the policy maker is to calculate the optimal path of water use over time leading to the date of agricultural abandonment. Agricultural abandonment occurs when the cost of pumping water rises to a level which does not leave any profit for farmers. Clearly, agricultural abandonment can be delayed by imposing restrictions on water use. The guiding principle in the process of determining the optimal path over time, which operationally means imposing the correct restriction on water use, is maximizing the present value of future net benefits from water.

Relaxing Kelso's assumption of absolute inelasticity of demand for water results in interesting conclusions. Before going into these results, the reasons why the demand for water can be assumed to have a certain elasticity should be listed. They are as follows:

a) Given a rising cost of pumping, farmers can substitute low intensity crops for high intensity crops.

b) Given a rising cost of pumping, farmers can switch from high intensity to low intensity of water applied to the same crop.

c) Given a rising cost of pumping, farmers can replace water by capital. For example, given the current state of technology, the annual cost of initial investment in sprinklers, assuming a 15 year lifetime and 7 percent interest, is approximately $15.00 per acre. The cost of additional pressure per acre foot of water irrigated by sprinklers is $1.50. Various sources indicate that sprinkler irrigation efficiency is only 67 percent.[5] Thus, investment in sprinklers is to some extent a substitute for water use.

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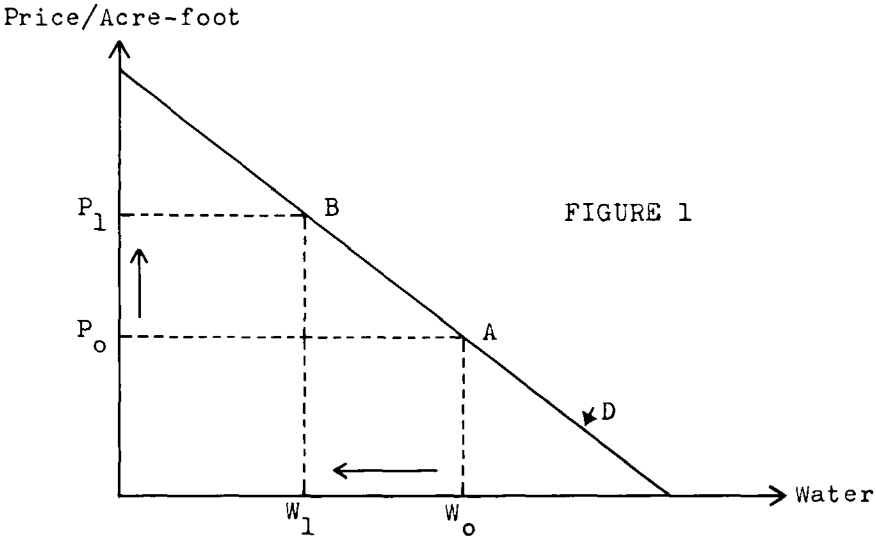
[4] Kelso, *The Stock Resource Value of Water*, 43 J. Farm Econ. 1112 (1961).

[5] M. Gisser, *Applying Linear Programming Models for Estimating the Agricultural Demand Function for Water*, (unpublished preliminary draft of Project No. 3109-33-A-022, The Water Resources Research Institute, New Mexico State University, Las Cruces, New Mexico).



In Fig. 1, the demand curve for irrigation water denoted by D is depicted. Given the depth of the water table the cost of pumping one acre-foot is P_0. Accordingly, as indicated by the demand curve, the amount of water pumped is W_0. Assuming that pumping W_0 gives rise to an overdraft which in turn depresses the water table, leads to a constant rise in the cost of pumping. It is possible that when the cost of pumping (per acre-foot) reaches the level of P_1 pumpage shrinks to a level of W_1 which is consistent with zero overdraft: the agricultural sector reaches a long-run state of equilibrium. In the Roswell example given above, in order to reach long-run equilibrium the cost of pumping will have to increase over time leading farmers to reduce their demand for irrigation water from $W_0 = 415{,}000$ acre-feet to $W_1 = 230{,}000$ acre-feet.

It might appear, on first blush, that the state has no role to play here. This is not necessarily true. In principle there are three alternative policies which can be adopted by the government:

a) Not to interfere and allow the market forces and technological constraints to propel the farm sector from point A to point B.

b) Slow down the process of moving from point A to point B by restricting the total use of water to some quantity which is indicated by some point lying between W_0 and W_1.

c) Restricting farmers immediately to the use of water as indicated by W_1. This will lead to a long-run equilibrium in which the cost of pumping per acre-foot will remain P_0 perennially.

The guiding principle in selecting the optimal policy should be the maximization of present value of future benefits from water.

Clearly, if natural net recharge is negligible, and accordingly W_1 occurs at the origin (or theoretically to the left of the origin), agricultural abandonment in the future is unavoidable.

In order to be able to adopt an optimal policy, the policy maker should have a reliable estimate of the agricultural demand function for water and reliable knowledge of the ground-water reservoir. The Water Resources Research Institute in New Mexico has been investing in this direction, and the research related to the Pecos basin may soon be sufficient for formulating optimal policy for this area.

To be more practical, one does not expect to obtain a linear or any other smooth demand curve like the one shown in Fig. 1. By applying the technique of parametric linear programming one can obtain a step-shaped demand curve for irrigation water which is sufficient for the purpose at hand.[6] Such a demand function can be obtained for any mix of salinity constraints. Also, in reality the assumptions concerning the specific yield of the aquifer as a function of depth can be non-linear. Moreover, salinity may be increasing with depth, thus causing the demand for irrigation water to increase as the water table falls. To complicate things even further, natural net recharge may be functionally related to the depth of water table. All this may technically complicate the process of policy formulation, but it does not change it in principle.

ECONOMIC POLICY IN PRESENCE OF REPLACEMENT FLOWS

Consider a situation in which natural net recharge is insignificant, and accordingly, in order to head off agricultural abandonment the state becomes interested in investing in a project of importing water to the basin. The state is neither inclined to subsidize the project, nor is it interested in deriving profit from the project. In other words, the state serves as the agent of farmers, attempting to provide them with replacement flows at prices which give rise neither to deficits nor to surpluses in the governmental accounts.

Realistically, it may be assumed the supply curve of imported water is perfectly elastic up to a certain point, at which it becomes strictly vertical. The demand for imported water cuts the supply curve where it is still horizontal.

Consider Fig. 2. Assume that currently the cost of pumping water, P_a, is lower than the cost of imported water, P_i. Clearly, the project of importing water to the basin must wait for the overdraft to raise the cost of pumping to the level of P_i. Otherwise, in absence of a subsidy farmers cannot be expected to purchase imported water. Another possibility is a situation in which the cost of pumping, P_b, is

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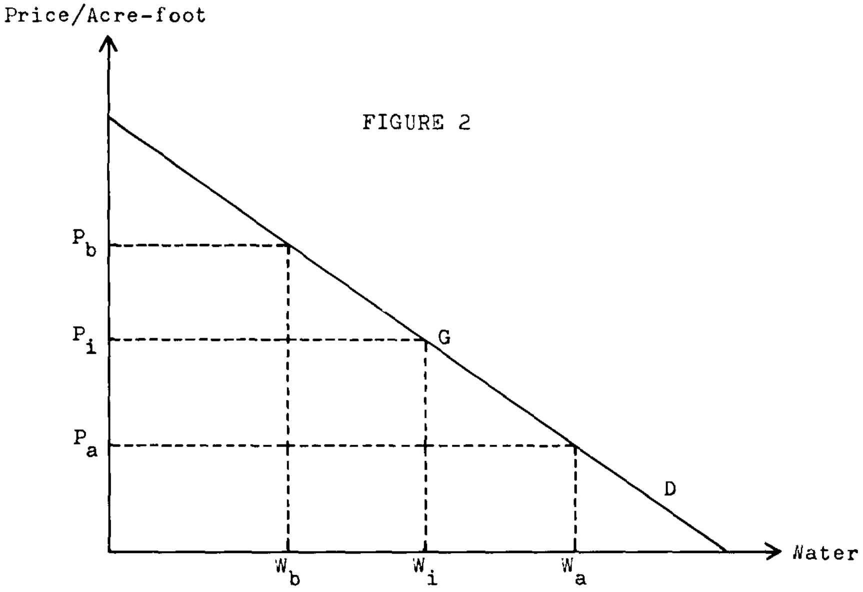
[6] *Id.* Such a demand curve for low salinity water has been obtained for the Pecos Basin.



higher than the cost of imported water. In such a case farmers will switch from pumping to imported water, the overdraft will disappear, in fact the basin will benefit from a net recharge and accordingly the water table will rise and the potential cost of pumping will be falling. In either case, the mechanism of changing water tables will equate the cost of pumping with the cost of imported water. But, there is no guarantee that stability will be established at point G. Adopt the following notations:

Net natural recharge	R
Consumptive use	u
Imported water	M
Pumping	π

where u, consumptive use is the fraction of water diverted for irrigation which does not return to the basin's aquifer. Accordingly, 1-u will be the fraction which returns to the basin's aquifer.

Then the stability condition becomes

$$(1) \ldots\ldots R + (1-u)(\pi + M) = \pi$$

Note that (1-u) (π+M) is the fraction of water pumped and imported which is returned to the aquifer. In order to achieve stability, this quantity plus natural recharge must equal the amount of water pumped.

The market mechanism does not guarantee that equation (1) will be satisfied. In fact, it is possible that farmers will pump too much water and purchase too little of imported water, thus leading to an overdraft which would cause rising pumping cost. A rise in pumping cost will give farmers the incentive to switch in the right direction, but this time there is no mechanism which will guarantee that switching from pumping to imported water will stop exactly when the stability condition is satisfied. Thus, it is possible that the water table will start falling, and in fact will behave like a perpetual pendulum. Switching back and forth from ground to imported water must cause a once and for all increase in the price of imported water. This is true because fluctuations in the use of water would require the construction of reservoirs to synchronize fluctuating water flows. Accordingly, if such fluctuations are to be avoided, some kind of governmental management and regulation is needed.

In order to provide the proper regulation, the policy maker should have a reliable estimate of the agricultural demand function for water and the expected price of imported water, P_i. Given these two the quantity W_i can be determined, and the following equation can be added to equation (1):

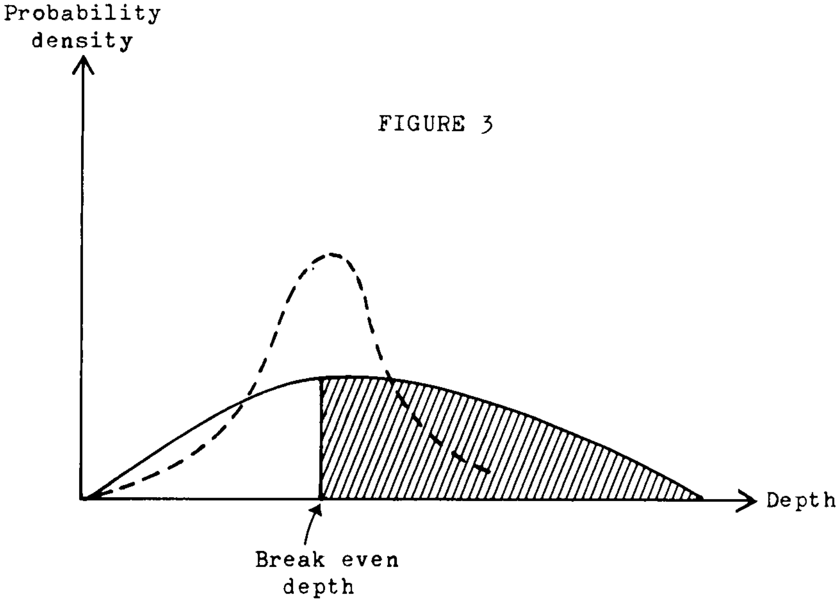
$$(2) \ldots\ldots W_i = \pi + M$$

Equations (1) and (2) together determine π, the quantity of water pumped and M, the quantity of water imported, which are consistent with stability.

The government can regulate the demand for water by allowing farmers to use on the aggregate π acre-feet of ground water and M acre-feet of imported water.

There is one case in which governmental regulation may not be needed. Assume that currently farmers are distributed according to the depth of their wells as indicated by the probability density function in Fig. 3. Introducing imported water to the basin determines a "break-even-depth" below which it pays to pump ground water, above which it pays to switch to imported water. If it is imagined that the current "break-even-depth is as indicated by Fig. 3, the shaded area under the "bell" measures the proportion of farmers already using imported water. If it is assumed that the overdraft still exists, the water table in the entire basin must be falling, leading to an increase in the scale of the horizontal axis (depth), and thus to a leftward shift of the "break-even-depth." Such a shift will decrease the level of pumping (π), and thus will eventually lead to stability as specified by equation (1). If too much density converges on the "break-even-depth," as indicated by the "broken-line-bell," the switch from pumping to imported water may be too abrupt, leading to undesirable fluctuations.

FIGURE 3



CONCLUSION

In absence of replacement flows, and assuming a significant overdraft, the fall of the water table may lead either to a stable equilibrium or to agricultural abandonment. Under such circumstances the role of the state boils down to enforcing the optimal path over time leading either to a stability or to agricultural abandonment.

In presence of replacement flows, and under the assumption that depth of all wells in the basin is practically the same, some governmental regulation is needed. However, if depth is widely distributed among farmers, governmental regulation may not be needed.