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Rajan K. Sampath

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Colorado State University
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I. Introduction

Water for irrigation is one of the prime factors for agricultural development in developing countries. Water is a precious input in farming because the potentials of the genetic improvement in crop varieties and agronomic innovations can be fully tapped only if irrigation is made available to the vast areas in which rainfall is inadequate and/or unevenly distributed. Avoidance of risk in farming and stability in productivity are largely ensured through irrigation. Thus irrigation paves the way for alleviating rural poverty, hunger and malnutrition. Since, development of irrigation involves commitment of significant amount of funds, in order to maintain the projects and sustain the growth of irrigation development over time and to ensure their optimal utilization by the users, it is necessary to administer some form of regulatory and/or pricing scheme for allocating irrigation water.

The basic objectives of the existing regulatory and pricing systems in developing countries can be summarized in terms of three categories, namely, (i) the efficiency objective — to allocate available irrigation water among competing users/regions such that it maximizes the total economic returns (however it is measured); (ii) the equity objective — to improve the distribution of income in favor of the poor and small farmers; and (iii) to recover the costs of investment in and

maintenance of irrigation systems [Bowen and Young (1983), Easter and Welsch (1983)].

There are different ways of achieving the above-mentioned objectives — some using purely regulatory systems and others using both regulatory and pricing systems. If the predominant objectives of the government are the efficiency and equity goals, then some might prefer purely regulatory systems of water allocation, though these objectives could also be realized through some form of pricing schemes. But whenever cost recovery objective is also involved, some form of direct or indirect charging for or pricing of irrigation water is a must. In these days of acute shortage of resources, cost recovery is definitely regarded as one of the important objectives along with the other two by almost every country. Also from an equity point of view it is only fair on the part of the farmers as being one of the chief beneficiaries to pay for at least part of the cost of irrigation development.

The regulatory and pricing systems which can be used to allocate irrigation water to achieve one or more or all of the above-mentioned objectives can be classified into purely regulatory (i.e., non-pricing) and pricing systems. The purely regulatory water allocation systems can be further classified into two categories: (i) optimal water distribution regulatory system — this distributes water among farmers, given their resource endowments, such that it maximizes total agricultural income output. This is an ideal system in which each farmer is allocated water without pricing such that the marginal productivity of water across farms is equalized so that the agricultural economy achieves the highest possible production with the given amount of water. This system is almost impractical because of the vast amount of

information and highly complicated regulatory and administrative framework needed to successfully implement it. It will be used in this paper only as a norm for comparison purposes. Under this system cost recovery is not an objective because this method implicitly assumes that since irrigation development benefits both consumers (by lowering prices of agricultural products from increased production due to irrigation development) and producers (by increasing their net income from increased productivity of land), the cost of irrigation development should be borne by both which is accomplished when the cost of investment is met through general income taxation. Under this system, as we will show later, while efficiency objective is always fulfilled, equity objective may or may not be fulfilled depending upon the relative distribution of different factors of production such as land and capital across different farm-size groups.

(ii) Equal water distribution regulatory system — this system distributes water equally among farms according to the size of land cultivated or owned or operated. In other words, a farms' share in water equals its share in land irrigated or cultivated in the command area. This system is used widely either singly or in combination with some form of water pricing scheme. The popular warabandi system in practice in South Asia is a variant of this system [Malhotra (1982)]. This system will achieve the efficiency objective only under rare conditions (whenever the resource endowments across farms are proportional to their land endowments as we will show later) and will promote equity whenever poor farms have relatively poorer endowment of all other complementary inputs to land. Thus in many situations, this system may

achieve neither the efficiency nor the equity objective except that it may prove to be administratively convenient.

The pricing systems currently used in one form or the other in developing countries can be grouped under four categories, (iii) to (vi) the first two being direct charges and the last two being indirect charges for using water.

(iii) Volumetric pricing system — in this system the farmer pays for every unit of water he uses. Several authors [Bowen and Young (1983), Easter and Welsch (1983) and references therein] have noted the practical difficulties in implementing this system. This system achieves the efficiency objective fully and under certain conditions it may also help in achieving the equity and cost recovery objectives as we will show later.

(iv) Acreage pricing system — under this system the farmer is required to pay a fixed price on a per acre basis for the irrigated area. This system, while very easy to administer, will be efficient only rarely, equitable only under certain conditions and can be successful in achieving the cost recovery objective. The share of water received by a farmer, at least in principle, though often not in practice due to a variety of reasons, is supposed to be equal to his share in land irrigated in the command area.

(v) Tax on output produced — under this system a farmer pays a fixed charge per unit of output produced as payment for the irrigation water he receives. Under this system a farmers' share in water equals his share in irrigated area in the command area. This system is also easy to administer.

(vi) Tax on inputs purchased — under this system a farmer pays for the irrigation he receives indirectly through higher prices he pays for the inputs he purchases from the government. Under this system also the farmers' share in water equals his share in irrigated area in the command area. This system is also easy to administer.

II. Objective

The objective of this paper is to study the efficiency-equity-cost-recovery implications of each of the above-mentioned six systems of water allocation and pricing so that we can rank them according to some criteria of relative performance. For our purposes, we will define (i) efficiency in terms of total agricultural output/total net agricultural income, (ii) equity in terms of distribution of agricultural output/income between small and large farms, and (iii) cost recovery in terms of revenues to government from water pricing/charging.

III. Assumptions

(i) The government has already established the irrigation system in the given command area. The opportunity cost of this investment plus the maintenance cost per year is, say, $\overline{C}$ and the water available for irrigation purposes is a fixed quantity, say, $\overline{W}$. The problem the government confronts is how to allocate this water among farmers so as to fulfill the objectives mentioned earlier.

(ii) Efficiency is measured in terms of maximizing total agricultural production through proper allocation of the given quantity of

irrigation water. Equity is measured in terms of distribution of total agricultural output/income between small and large farms. Thus any improvement in the ratio of small farms' income to total agricultural income will be considered an improvement in equity and a decrease in this ratio will be considered a decline in equity.

(iii) The agricultural economy is divided into two groups comprised of small farms and large farms. Both groups have the same production function — a common Cobb-Douglas function subject to constant returns to scale — characterizing the relationship between aggregate output and inputs such as land (L), capital (K), labor (N) and water (W). Further, in the short run with which our paper is concerned, it is assumed that total available land in the command area is distributed between small and large farm groups in the ratio $(\frac{\lambda}{1+\lambda})$ and $(\frac{1}{1+\lambda})$ so that total land with the small farms' (L_s) can be expressed in terms of large farms' land (L_1) as $L_s = \lambda L_1$ and the total land as $L = (1+\lambda)\ L_1$. Similarly capital is fixed in the short run and distributed between small and large farms' in the ratio $K_s = \phi K_1$ and $K = (1+\phi)\ K_1$. Thus the production function pertaining to small and large farm groups can be characterized, respectively, as:

$$Q_s = A(\phi K_1)^{\alpha}\ (\lambda L_1)^{\beta}\ N_s^{\delta}\ W_s^{\gamma} \tag{1}$$

and

$$Q_1 = A\ K_1^{\alpha}\ L_1^{\beta}\ N_1^{\delta}\ W_1^{\gamma}. \tag{2}$$

(iv) The objective of the farmer is to maximize his net income or profit

$$\pi = Q - P_N N - P_W W \quad . \tag{3}$$

where P_N = the unit price of labor and P_W = the unit price of water. For the sake of simplicity we will assume the unit price of output to be unity. Since we have assumed K and L to be fixed in the short run, the farmer will maximize his profit by varying his variable inputs labor and water until their marginal revenue productivities are equal to their respective unit prices.

Model I: Optimal Water Distribution Regulatory System

Under this regulatory system it is assumed that the government has all the necessary information regarding the endowments of resources with the small and large farms and through administrative decree it decides which group will get what share of the available quantity of water. It is further assumed that the government has the necessary administrative framework and political will to implement its decision regarding optimal distribution of water. The objective of the government is to distribute water optimally between the two groups of farmers so that the resulting agricultural production will be optimum. Essentially the government supplies free of charge to the farmers the available supply of water in the ratio x:(1-x) between small and large farms, respectively.

Given the above regulatory water distribution system, the small and large farms' production functions will be, respectively:

$$Q_s = A(\phi K_1)^{\alpha} (\lambda L_1)^{\beta} N_s^{\delta}(x\overline{W}) \tag{4}$$

and

$$Q_1 = A K_1^{\alpha} L_1^{\beta} N_1^{\delta}[(1-x)\overline{W}]^{\gamma}. \tag{5}$$

Since in the short run land and capital inputs are fixed and the share in available water supply is fixed exogenously by the government, the farmers will maximize their agricultural incomes

$$\pi_s = Q_s - P_N N_s \tag{6}$$

and

$$\pi_1 = Q_1 - P_N N_1 \tag{7}$$

by equating

$$\frac{d\pi_s}{dN_s} = \frac{\partial Q_s}{\partial N_s} - P_N = 0$$

$$= \delta A(\phi K_1)^{\alpha} (\lambda L_1)^{\beta} N_s^{\delta-1}(x\overline{W})^{\gamma} = P_N \tag{8}$$

and

$$\frac{d\pi_1}{dN_1} = \delta A K_1^{\alpha} L_1^{\beta} N_1^{\delta-1}((1-x)\overline{W})^{\gamma} = P_N. \tag{9}$$

Now solving equations (8) and (9) for N, we get the optimal quantities of N that farmers will use, respectively, as:

$$N_s = \left(\frac{\delta\ A(\phi K_1)^{\alpha}\ (\lambda L_1)^{\beta}\ (x\overline{W})^{\gamma}}{P_N}\right)^{\frac{1}{1-\delta}} \tag{10}$$

and

$$N_1 = \left[\frac{\delta\ A\ K_1^{\alpha}\ L_1^{\beta}[(1-x)\overline{W}]^{\gamma}}{P_N}\right]^{\frac{1}{1-\delta}}. \tag{11}$$

Now by substituting (10) and (11) into (6) and (7), respectively, and simplifying the resulting expressions we can obtain the total agricultural income in the economy as

$$\pi = \pi_s + \pi_1 = \left[(A^{\frac{1}{1-\delta}}\ K_1^{\frac{\alpha}{1-\delta}}\ L_1^{\frac{\beta}{1-\delta}}\ \overline{W}^{\frac{\gamma}{1-\delta}}\ \delta^{\frac{\delta}{1-\delta}}\ P_N^{-\frac{\delta}{1-\delta}})(1-\delta)\right]$$
$$\left[\phi^{\frac{\alpha}{1-\delta}}\ \lambda^{\frac{\beta}{1-\delta}}\ x^{\frac{\gamma}{1-\delta}} + (1-x)^{\frac{\gamma}{1-\delta}}\right]. \tag{12}$$

The government, to maximize the total agricultural income, should choose x such that

$$\frac{d\pi}{dx} = A_1(1-\delta)\left[\phi^{\frac{\alpha}{1-\delta}}\ \lambda^{\frac{\beta}{1-\delta}}\ x^{\frac{\gamma}{1-\delta}-1} - (1-x)^{\frac{\gamma}{1-\delta}-1}\right] = 0 \tag{13}$$

where $A_1 = A^{\frac{1}{1-\delta}}\ P_N^{-\frac{\delta}{1-\delta}}\ K_1^{\frac{\alpha}{1-\delta}}\ L_1^{\frac{\beta}{1-\delta}}\ \delta^{\frac{\delta}{1-\delta}}\ W^{\frac{\gamma}{1-\delta}}$.

Solving (13) for x results in

$$x = \frac{\phi^{\frac{\alpha}{1-\gamma-\delta}}\ \lambda^{\frac{\beta}{1-\gamma-\delta}}}{1 + \phi^{\frac{\alpha}{1-\delta-\gamma}}\ \lambda^{\frac{\beta}{1-\delta-\gamma}}}. \tag{14}$$

The optimal small farms' share of water as given by (14) will lead to the following quantities for total agricultural output, income, small farms' share in output and income, respectively, as given below:

$$Q^1 = Q_s^1 + Q_l^1 = A_1 \left[\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta}{1-\delta}} \left(\frac{\phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}}{1 + \phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}} \right)^{\frac{\gamma}{1-\delta}} + \left(\frac{1}{1 + \phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\gamma-\delta}}} \right)^{\frac{\gamma}{1-\delta}} \right]$$

$$= A_1 \left[1 + \phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}} \right]^{\frac{1-\gamma-\delta}{1-\delta}} \tag{15}$$

$$\pi^1 = \pi_s^1 + \pi_l^1 = A_1(1-\delta)\ (1 + \phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}) \tag{16}$$

$$\frac{Q_s^1}{Q^1} = \frac{\phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}}{1 + \phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\gamma-\delta}}} \tag{17}$$

and

$$\frac{\pi_s^1}{\pi^1} = \frac{\phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}}{1 + \phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}}. \tag{18}$$

Thus it can be seen that when the government optimally allocates irrigation water between small and large farms, small farms' share in total agricultural output and income in the short run will equal its share in water.

Model II: Equal Water Distribution Model

There are practical difficulties in implementing an optimal water distribution policy (without pricing), some of which are political and others are the problems of lack of availability of information and the requisite administrative and managerial capabilities. So most of the

governments in the developing world follow a simple policy of distributing water equally among farmers in the command area on a per acre basis. In other words, in terms of our example, if total available land in the command area is distributed between small and large farms as $(\frac{\lambda}{1+\lambda})$ and $(\frac{1}{1+\lambda})$, then their respective shares in irrigation water will also be $(\frac{\lambda}{1+\lambda})$ and $(\frac{1}{1+\lambda})$. Substituting $(\frac{\lambda}{1+\lambda})$ and $(\frac{1}{1+\lambda})$ for x in equations (4) and (5) and proceeding through derivations as we did in Model I lead to the following expressions for total agricultural output, income, small farms' share in output and income, respectively:

$$Q^2 = A_1 \left[\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta}{1-\delta}} \left(\frac{\lambda}{1+\lambda}\right)^{\frac{\gamma}{1-\delta}} + \left(\frac{1}{1+\lambda}\right)^{\frac{\gamma}{1-\delta}} \right] \tag{19}$$

$$\pi^2 = A_1 (1-\delta) \left[\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta}{1-\delta}} \left(\frac{\lambda}{1+\lambda}\right)^{\frac{\gamma}{1-\delta}} + \left(\frac{1}{1+\lambda}\right)^{\frac{\gamma}{1-\delta}} \right] \tag{20}$$

$$\frac{Q_s^2}{Q^2} = \frac{\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta+\gamma}{1-\delta}}}{1 + \phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta+\gamma}{1-\delta}}} \tag{21}$$

and

$$\frac{\pi_s^2}{\pi^2} = \frac{\phi^{\frac{\alpha}{1-\delta}} \alpha^{\frac{\beta+\gamma}{1-\delta}}}{1 + \phi^{\frac{\alpha}{1-\delta}} \alpha^{\frac{\beta+\gamma}{1-\delta}}}. \tag{22}$$

Water Pricing Models

Model III: Volumetric Pricing

In this model we will analyze the implications of pricing water under the assumptions that water supply is fixed and water pricing is

done to equate demand to available supply ($\overline{W}$). Thus to fix the price optimally such that D = S, we need to know the derived demand curve for water which we can derive along the lines given below.

Since, now water is priced (P_W), the objective of the farmers is to maximize their modified profit or net income functions. For example, in the case of small farms, given their profit function as

$$\pi_s = Q_s - P_N N_s - P_W W_s, \tag{23}$$

maximum profit will occur when

$$\frac{\partial \pi_s}{\partial N_s} = \frac{\partial Q_s}{\partial N_s} - P_N = 0$$

$$= \delta A(\phi K_1)^{\alpha} (\lambda L_1)^{\beta} N_s^{\delta-1} W_s^{\gamma} - P_N = 0 \tag{24}$$

and

$$\frac{\partial \pi_s}{\partial W_s} = \frac{\partial Q_s}{\partial W_s} - P_W = 0$$

$$= \gamma A(\phi K_1)^{\alpha} (\lambda L_1)^{\beta} N_s^{\delta} W_s^{\gamma-1} - P_W = 0. \tag{25}$$

Since $\delta = \frac{P_N N_s}{Q_s}$, $\gamma = \frac{P_W W_s}{Q_s}$ and K and L are fixed in the short run, letting

$$A_s = A(\phi K_1)^{\alpha} (\lambda L_1)^{\beta}. \tag{26}$$

We can rewrite (1), (24) and (25), respectively, as,

$$\log Q_s = \log A_s + \delta \log N_s + \gamma \log W_s \tag{27}$$

$$\log Q_s + \log \delta = \log N_s + \log P_N \tag{28}$$

and

$$\log Q_s + \log \gamma = \log W_s + \log P_W. \tag{29}$$

Solving the above three equations for the three unknowns Q_s, N_s and W_s results in

$$\begin{bmatrix} \log Q_s \\ \log N_s \\ \log W_s \end{bmatrix} = \frac{1}{1-\delta-\gamma} \begin{bmatrix} 1 & -\delta & -\gamma \\ 1 & \gamma-1 & -\gamma \\ 1 & -\delta & \delta-1 \end{bmatrix} \begin{bmatrix} \log A_s \\ \log P_N - \log \delta \\ \log P_W - \log \gamma \end{bmatrix}. \tag{30}$$

From (30) we can derive, respectively, the optimal small farms' output and the associated derived demand quantity for water as:

$$Q_s = \left[\frac{A_s \ \delta^{\delta} \ \gamma^{\gamma}}{P_N^{\ \delta} \ P_W^{\ \gamma}} \right]^{\frac{1}{1-\delta-\gamma}} \tag{31}$$

and

$$W_s = \left[A_s \left(\frac{\delta}{P_N}\right)^{\delta} \left(\frac{\gamma}{P_W}\right)^{1-\delta} \right]^{\frac{1}{1-\delta-\gamma}}. \tag{32}$$

Similarly we can derive the quantities for the large farms group as:

$$Q_l = \left[\frac{A' \ \delta^{\delta} \ \gamma^{\gamma}}{P_N^{\ \delta} \ P_W^{\ \gamma}} \right]^{\frac{1}{1-\delta-\gamma}} \tag{33}$$

and

$$W_1 = \left[A'\left(\frac{\delta}{P_N}\right)^{\delta} \left(\frac{\gamma}{P_W}\right)^{1-\delta}\right]^{\frac{1}{1-\delta-\gamma}} \tag{34}$$

where $A' = A\ K_1^{\alpha}\ L_1^{\beta}$.

From equations (32) and (34) we can derive the total derived demand (W^D) for water as

$$W^D = W_s + W_1$$

$$= \left[A'\left(\frac{\delta}{P_N}\right)^{\delta} \left(\frac{\gamma}{P_W}\right)^{1-\delta}\right]^{\frac{1}{1-\delta-\gamma}} \left[1 + \phi^{\frac{\alpha}{1-\delta-\gamma}}\ \lambda^{\frac{\beta}{1-\gamma-\delta}}\right]. \tag{35}$$

Now to clear the market we need

$$\text{RHS of (35)} \equiv \overline{W}. \tag{36}$$

Solving (36) for P_W, we get the market clearing price level

$$P_W = \left[\left(\frac{1 + \phi^{\frac{\alpha}{1-\delta-\gamma}}\ \lambda^{\frac{\beta}{1-\delta-\gamma}}}{\overline{W}}\right)^{1-\delta-\gamma} A'\left(\frac{\delta}{P_N}\right)^{\delta} \gamma^{1-\delta}\right]^{\frac{1}{1-\delta}} \tag{37}$$

Now, if the government fixes the price at P_W = RHS of (37), then after substituting RHS of (37) for P_W in the output, income and water demand equations and simplifying the resulting expressions, we derive the following:

$$Q^3 = Q_s^3 + Q_1^3 = A_1\left[1 + \phi^{\frac{\alpha}{1-\delta-\gamma}}\ \lambda^{\frac{\beta}{1-\delta-\gamma}}\right]^{\frac{1-\delta-\gamma}{1-\delta}} \tag{38}$$

$$\pi^3 = \pi_s^3 + \pi_1^3 = A_1(1-\delta-\gamma)\left[1 + \phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}\right]^{\frac{1-\delta-\gamma}{1-\delta}} \tag{39}$$

$$\frac{Q_s^3}{Q^3} = \frac{\phi^{\frac{\alpha}{1-\delta-\gamma}} \cdot \lambda^{\frac{\beta}{1-\delta-\gamma}}}{1 + \phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}} \tag{40}$$

$$\frac{\pi_s^3}{\pi^3} = \frac{\phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}}{1 + \phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}} \tag{41}$$

and

$$\frac{W_s^3}{W^3} = \frac{\phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}}{1 + \phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}}. \tag{42}$$

Comparing (38-42) with Model I equations, we find pricing of water does not affect the levels of output or its distribution, the share of small farms' income in total net income and the distribution of water among farms. It affects only the level of income reaching the farms since there is now a proportional decline in each farms' income level equal to what the government derives as its income from pricing water.

Model IV: Acreage Pricing

This pricing scheme is easy to administer and to collect revenues. A flat rate (t_1) is imposed on every unit of land in the command area. The available water is distributed among farms according to their share

in land. Thus it results in $(\frac{\lambda}{1+\lambda})$ and $(\frac{1}{1+\lambda})$ as shares of water for small and large farms, respectively. Since this becomes a fixed cost in the profit equations of the farms, it does not affect the optimum decisions of the farms with respect to the levels of variable inputs they will use. Thus the total output and its distribution between small and large farms remain the same as under Model II. So is water distribution. What is affected is the level and distribution of total net income.

$$\frac{\pi_s^4}{\pi^4} = \frac{A_1\ (1-\delta)\ \phi^{\frac{\alpha}{1-\delta}}\ \lambda^{\frac{\beta}{1-\delta}}\ (\frac{\lambda}{1+\lambda})^{\frac{\gamma}{1-\delta}} - t_1 \lambda L_1}{A_1\ (1-\delta)\left[\phi^{\frac{\alpha}{1-\delta}}\ \lambda^{\frac{\beta}{1-\delta}}\ (\frac{\lambda}{1+\lambda})^{\frac{\gamma}{1-\delta}} + (\frac{1}{1+\lambda})^{\frac{\gamma}{1-\delta}}\right] - (1+\lambda)\ t_1 L_1}. \tag{43}$$

The question that arises in this context is whether improvement in the distribution of income will result with or without this flat rate. In other words

$$\text{RHS of (43)} \gtreqless \text{RHS (22)}. \tag{44}$$

Simplifying the above in equality (43) leads to

$$\phi \gtreqless \lambda. \tag{45}$$

That is, if capital intensity is higher on small farms, then acreage pricing will actually lead to improvement in income distribution. In contrast if capital intensity is lower on small farms then acreage pricing of water will lead to deterioration in the distribution of income in the short run.

Model V: Tax on Outputs

Sometimes governments impose tax on outputs to recover at least part of the cost of irrigation development. For example, as Bowen and Young (1983) point out: 'currently, the major form of agricultural taxation in Egypt is the commodity tax, imposed on the major crops. The revenue flows into the government's general funds, from which the Ministry of Irrigation must obtain its' revenue for maintaining and expanding the irrigation system.' Let the tax imposed on unit price of output be $\rho(0<\rho<1)$. The modified profit function will be

$$\pi^5 = Q - P_N N - \rho Q$$

$$= (1-\rho) Q - P_N N. \tag{46}$$

Water is distributed equally among farms in the ratio $(\frac{\lambda}{1+\lambda})$ and $(\frac{1}{1+\lambda})$ according to the proportion of land cultivated/owned in the command area. Maximizing (46) for small and large farms, along the lines we discussed earlier, results in the following modified expressions for the economic magnitudes we are interested in:

$$Q^5 = (1-\rho)^{\frac{\delta}{1-\delta}} A_1 \left[\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta}{1-\delta}} (\frac{\lambda}{1+\lambda})^{\frac{\gamma}{1-\delta}} + (\frac{1}{1+\lambda})^{\frac{\gamma}{1-\delta}}\right] \tag{47}$$

$$\pi^5 = (1-\rho)^{\frac{1}{1-\delta}} (1-\delta) A_1 \left[\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta}{1-\delta}} (\frac{\lambda}{1+\lambda})^{\frac{\gamma}{1-\delta}} + (\frac{1}{1+\lambda})^{\frac{\gamma}{1-\delta}}\right] \tag{48}$$

$$\frac{Q_s^5}{Q^5} = \frac{\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta+\gamma}{1-\delta}}}{1 + \phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta+\gamma}{1-\delta}}} \tag{49}$$

and

$$\frac{\pi_s^5}{\pi^5} = \frac{\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta+\gamma}{1-\delta}}}{1 + \phi^{\frac{\alpha}{1-\delta}} \frac{\beta+\gamma}{1-\delta}}. \tag{50}$$

Model VI: Tax on Inputs

Sometimes some governments find it convenient to impose a tax on inputs sold to or hired by farmers to recover at least partially the expenses involved in irrigation development. This modifies the profit equation to:[1]

$$\pi^6 = Q - t_2 P_N N \tag{51}$$

with $t_2 > 1$ and $(t_2 - 1)$ the tax rate. Again, here too, available water is distributed equally on a per acre basis among farms. Maximizing (51) for small and large farms results in the following modified expressions for the economic variables we are interested in:

$$Q^6 = t_2^{-\frac{\delta}{1-\delta}} A_1 \left[\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta}{1-\delta}} \left(\frac{\lambda}{1+\lambda}\right)^{\frac{\gamma}{1-\delta}} + \left(\frac{1}{1+\lambda}\right)^{\frac{\gamma}{1-\delta}} \right] \tag{52}$$

$$\pi^6 = t_2^{-\frac{\delta}{1-\delta}} (1-\delta) A_1 \left[\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta}{1-\delta}} \left(\frac{\lambda}{1+\lambda}\right)^{\frac{\gamma}{1-\delta}} + \left(\frac{1}{1+\lambda}\right)^{\frac{\gamma}{1-\delta}} \right] \tag{53}$$

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[1] In our example the variable input is labor. It can as well be fertilizer or any other agricultural input. While it is common to tax inputs like fertilizer, it is not at all common to put tax on labor hired. But for our purposes it does not matter since our objective here is only to show the impacts of input taxation on the economic magnitudes we are interested in.

$$\frac{Q_s}{Q^6} = \frac{\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta+\gamma}{1-\delta}}}{1 + \phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta+\gamma}{1-\delta}}} \tag{54}$$

and

$$\frac{\pi_s^6}{\pi^6} = \frac{\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta+\gamma}{1-\delta}}}{1 + \phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta+\gamma}{1-\delta}}}. \tag{55}$$

Comparative Analysis

In this section we will make a comparative analysis of the different water pricing/allocation systems in terms of their implications for levels of output/income, small farms' share in them, and cost recovery. Table 1 below summarizes in a convenient format the results we have obtained so far on the implications of different water allocations and pricing systems.

Impacts on Output

Comparing the outputs pertaining to the two nonpricing models we find that the optimum distribution scheme will always produce more output if the following inequality is satisfied

$$A_1 \left[1 + \phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}\right]^{\frac{1-\gamma-\delta}{1-\delta}} > A_1 \left[\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta}{1-\delta}} \left(\frac{\lambda}{1+\lambda}\right)^{\frac{\gamma}{1-\delta}} + \left(\frac{1}{1+\lambda}\right)^{\frac{\gamma}{1-\delta}}\right]. \tag{56}$$

Which will be so, if

$$\phi \gtrless \lambda. \tag{57}$$

Table 1

Efficiency, Equity and Cost Recovery Implications of Water Allocation and Pricing Models

Water Allocation/ Pricing Models	Total Agricultural Crop Output (TACO)	Total Agricultural Crop Income (TACI)	Small Farms' Share in TACO	Small Farms' Share in TACI	Small Farms' Share in Water	Revenues to Government
I. Non-Pricing Models						
1. Optimum Water Distribution	$A_1 (1+B_1)^{\frac{1-\gamma-\delta}{1-\delta}}$	$(1-\delta) A_1 (1+B_1)^{\frac{1-\gamma-\delta}{1-\delta}}$	$\frac{B_1}{1+B_1}$	$\frac{B_1}{1+B_1}$	$\frac{B_1}{1+B_1}$	NIL
2. Equal Water Distribution	$A_1 B_3$	$(1-\delta) A_1 B_3$	$\frac{B_2}{1+B_2}$	$\frac{B_2}{1+B_2}$	$\frac{\lambda}{1+\lambda}$	NIL
II. Pricing Models						
3. Volumetric Pricing	$A_1 (1+B_1)^{\frac{1-\gamma-\delta}{1-\delta}}$	$(1-\delta-\gamma) A_1 (1+B_1)^{\frac{1-\gamma-\delta}{1-\delta}}$	$\frac{B_1}{1+B_1}$	$\frac{B_1}{1+B_1}$	$\frac{B_1}{1+B_1}$	$P_W \bar{W}$
4. Acreage Pricing	$A_1 B_3$	$(1-\delta) A_1 B_3 - t_1 (1+\lambda) L_1$	$\frac{B_2}{1+B_2}$	$\frac{(1-\delta)A_1 \frac{B_2}{(1+\lambda)} \frac{\gamma}{1-\delta} - t_1 \lambda L_1}{(1-\delta)A_1 B_3 - t_1(1+\lambda)L_1}$	$(\frac{\lambda}{1+\lambda})$	$t_1 (1+\lambda) L_1$
5. Output Taxation	$(1-\rho)^{\frac{\delta}{1-\delta}} A_1 B_3$	$(1-\delta-\rho)(1-\rho)^{\frac{\delta}{1-\delta}} A_1 B_3$	$\frac{B_2}{1+B_2}$	$\frac{B_2}{1+B_2}$	$\frac{\lambda}{1+\lambda}$	$\rho (1-\rho)^{\frac{\delta}{1-\delta}} A_1 B_3$
6. Input Taxation	$t_2^{-\frac{\delta}{1-\delta}} A_1 B_3$	$[1-\delta-\delta(\frac{t_2-1}{t_2}) t_2^{-\frac{\delta}{1-\delta}} A_1 B_3$	$\frac{B_2}{1+B_2}$	$\frac{B_2}{1+B_2}$	$\frac{\lambda}{1+\lambda}$	$(t_2-1) t_2^{-\frac{1}{1-\delta}} \delta A_1 B_3$

$$A_1 = A^{\frac{1}{1-\delta}} (\frac{\delta}{P_W})^{\frac{\delta}{1-\delta}} K_1^{\frac{\alpha}{1-\delta}} L_1^{\frac{\beta}{1-\delta}} \bar{W}^{\frac{\gamma}{1-\delta}}; \quad B_1 = \phi^{\frac{\alpha}{1-\delta-\gamma}} \lambda^{\frac{\beta}{1-\delta-\gamma}}; \quad B_2 = \phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta+\gamma}{1-\delta}}; \quad B_3 = \left[\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta}{1-\delta}} (\frac{\lambda}{1+\lambda})^{\frac{\gamma}{1-\delta}} + (\frac{1}{1+\lambda})^{\frac{\gamma}{1-\delta}}\right]$$

Whenever $\phi = \lambda$, that is, whenever the capital intensity is the same with the two farm groups, both equal and optimum distribution models will lead to the same level of total agricultural output.

Since many economists [Bharadwaj (1976), Klein (1970), Berry and Klein (1979), Sampath (1979) and references therein] have noted that the capital intensity is higher on small farms, it appears that the current developing countries' policy of distributing water equally among farms seems to be detrimental to the achievement of economic efficiency in the use of the irrigation water input.

Let us now compare the pricing models with one another. From Table 1 we can infer the following:

(ii) Volumetric pricing leads to the same level of output as the optimum distribution of water scheme. Similarly acreage pricing leads to the same level of output as the equal water distribution scheme. Thus we find in general (except when $\phi = \lambda$) volumetric pricing is superior to acreage pricing in terms of the efficiency criteria. If $\phi = \lambda$, that is, when the capital intensity on small farms equals that on large farms, then we find no difference in efficiency between these two water distribution schemes. But the problem with volumetric pricing is that with the given supply of water, if the productivity of water at the margin is large, then the market clearing price will be such that it will lead to large-scale transfer of income from farmers to government by way of revenues making pricing of water politically infeasible. For example, in the numerical exercise we have in Table 2, setting the volumetric pricing at the market clearing level leads to transfer of 40 percent of the output to

government. Probably this is why many developing countries are reluctant to volumetrically price water.

(ii) Comparing acreage pricing with tax on outputs and tax on inputs, we find that acreage pricing is superior to either of them in terms of the efficiency criteria since[2]

$$\text{RHS of (19)} > \text{RHS of (47)} \tag{58}$$

and

$$\text{RHS of (19)} > \text{RHS of (52)}. \tag{59}$$

Thus, because of (i), we can conclude volumetric pricing is superior to the other three water pricing systems and acreage pricing is superior to the two indirect charges, namely the output taxation and input taxation in terms of the efficiency criteria.

(iii) Comparing output taxation scheme with input taxation scheme we find the superiority of the scheme will depend on the following: If RHS of (47) > RHS of (52), then output taxation is superior; if RHS of (47) < RHS of (52) then input taxation is superior; and if RHS of (47) = RHS of (52), then there is no difference

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[2]This is so because

$$\text{RHS of (47)} = \text{RHS of (19) times } (1-\rho)^{\frac{\delta}{1-\delta}} \tag{58a}$$

and

$$\text{RHS of (52)} = \text{RHS of (19) times } t_2^{-\frac{\delta}{1-\delta}} \tag{59a}$$

and since $0<\rho<1$ and $t_2>1$, we find $(1-\rho)^{\frac{\delta}{1-\delta}}$ and $t_2^{-\frac{\delta}{1-\delta}}$ are less than unity resulting in (58) and (59).

between the two schemes in terms of the efficiency criteria. Thus the relative superiority depends on

$$\text{RHS of (47)} \gtreqless \text{RHS of (52)}. \tag{60}$$

Simplifying (60) we get

$$(1-\rho)^{\frac{\delta}{1-\delta}} \gtreqless t_2^{-\frac{\delta}{1-\delta}}.$$

That is:

$$\rho \lesseqgtr \frac{t_2 - 1}{t_2}. \tag{61}$$

Thus according to (61) whenever ρ is less than RHS of (61), output taxation is superior to input taxation, whenever ρ = RHS of (61), both the schemes are equally good and whenever ρ > RHS of (61) input taxation is superior.

Now under what conditions (61) will strictly hold. Firstly, can ρ be equal to RHS of (61)? If so, then

$$\rho(1-\rho)^{\frac{\delta}{1-\delta}} \bar{A} = (t_2-1)\ t_2^{-\frac{\delta}{1-\delta}}\ \delta\ \bar{A} \tag{61a}$$

since we have assumed that the values of ρ and t_2 will be chosen so as to meet the revenue constraint. Now, if we substitute $\rho = \frac{t_2-1}{t_2}$ for ρ in (61a) we get

$$\frac{t_2-1}{t_2}\left(1 - \frac{t_2-1}{t_2}\right)^{\frac{\delta}{1-\delta}} \bar{A} = (t_2-1)\ t_2^{-\frac{1}{1-\delta}}\ \delta\ \bar{A}. \tag{61b}$$

Simplifying (61b) we get

$$\delta = 1 \tag{61c}$$

which is a contradiction since δ is assumed to be less than unity. Thus it is clear $\rho \nless \frac{t_2-1}{t_2}$ ever. Now, let us see whether ρ can be greater than $\frac{t_2-1}{t_2}$. If so, then we can write

$$\rho = \frac{t_2-1}{t_2} + x, \; x > 0 \tag{61d}$$

and

$$\left(\frac{t_2-1}{t_2}+x\right) \left[1 - \left(\frac{t_2-1}{t_2}+x\right)\right]^{\frac{\delta}{1-\delta}} \bar{A} = (t_2-1)\, t_2^{-\frac{1}{1-\delta}}\, \delta\, \bar{A}. \tag{61e}$$

Simplifying (61e) results in

$$1 + \frac{t_2 x}{t_2-1} (1 + t_2\, x)^{\frac{\delta}{1-\delta}} = \delta. \tag{61f}$$

Since $x > 0$, (61f) implies δ should be greater than unity contradicting the assumption. Thus under the assumption $0 < \delta < 1$, ρ will always be strictly less than RHS of (61) and so, RHS of (47) will always be greater than RHS of (52). Output taxation is thus superior to input taxation in terms of the efficiency criterion for raising revenues to meet project costs.

Thus in terms of the efficiency criteria we can rank the six different water allocation systems in descending order as follows:

(i) Optimum Water Distribution; Volumetric Pricing

(ii) Equal Water Distribution; Acreage Pricing

(iii) Output Taxation

(iv) Input Taxation

Total Agricultural Net Income

This is actually only a variant of the efficiency criteria. In terms of this variable we find again between the two nonpricing schemes optimum water distribution leads to higher level of net income than equal water distribution so long as $\phi \lneq \lambda$. If $\phi = \lambda$, then there is no difference between these two schemes.

Comparing the pricing schemes' impacts we can infer the following:

(i) Volumetric pricing will definitely lead to lower total net income to farmers compared to optimum distribution without pricing exactly equal to γ times RHS of (38). Similarly acreage pricing will reduce farmers' net income by $t_1\ (1+\lambda)\ L_1$, output taxation by $(1-\delta-\rho)$ times the corresponding output and input taxation $[1-\delta-\delta(\frac{t_2-1}{t_2})]$ times the corresponding output. It should be noted here that what farmers lose as net income is what government gains as its revenue from water pricing and as such it is only a transfer payment. Further comparisons of the model impacts show that the inferences drawn with regard to ranking in the last section in output remain the same here also. But if one defines efficiency in terms of impact on producer welfare, then it is difficult to say 'a priori' which scheme, volumetric pricing or acreage pricing, is superior. One has to know the magnitudes of the parameters, equilibriating price

level and the opportunity cost level. For example if $\phi = \lambda$, and water pricing leads to a revenue level $(P_W \overline{W})$ exactly equal to opportunity cost, then the level of net income accuring to farmers as a whole will be greater under volumetric pricing than under acreage pricing whereas if $\phi \neq \lambda$ and $P_W \overline{W} \equiv C$, then both the schemes are equally efficient in terms of net income accruing to farmers. But if $\phi \neq \lambda$ and $P_W \overline{W} \neq \overline{C}$, then one has to know all the relevant values to know which scheme is superior in terms of efficiency as defined here. While it can be easily seen that acreage pricing is superior to input and output taxation schemes to recover exactly the cost of irrigation, it is difficult to say which of the two schemes, input or output taxation, will leave the farmer with higher net income. To do that one has to know the exact magnitudes of all the relevant parameter values.

Small Farms' Share in
Total Agricultural Crop Output (TACO)
and Total Agricultural Crop Income (TACI)

The impact on small farms' share in TACO/TACI will give us a measure of the impact produced on the equity objective. The following inferences can be drawn from an analysis of information contained in Table 1.

(i) Comparing the small farms' share in TACO under the two nonpricing schemes we find optimum water distribution will lead to higher small farms' share if

$$\text{RHS of (17)} > \text{RHS of (21)}. \tag{62}$$

Which gives after simplification the condition

$$\phi > \lambda. \tag{63}$$

In other words, optimum water distribution will improve small farms' share in TACO only if the capital intensity on small farms is greater than that on large farms. If capital intensity is lower, then it will result in lower small farms' share than under equal water distribution rule.

(ii) As far as small farms' share in output is concerned pricing does not affect it at all either adversely or favorably. In other words, pricing is output distribution neutral.

(iii) With regard to small farms' share in TACI, we find volumetric pricing, output taxation and input taxation don't affect it. But acreage pricing affects small farms' share in TACI as compared to equal distribution rule. Let us see under what conditions small farms' share will improve under acreage pricing. That is, under what conditions the following inequality will hold:

$$\text{RHS of (43)} > \text{RHS of (22)}. \tag{64}$$

Which leads to after simplification

$$\phi > \lambda. \tag{65}$$

That is, if capital intensity is higher on small farms, then acreage pricing will improve small farms' share in TACI compared to equal water distribution without pricing rule.

(iv) We also find from Table 1 that optimum water distribution and volumetric pricing schemes lead to small farms' share in water equal to RHS of (14) and the four methods imply a water share of $(\frac{\lambda}{1+\lambda})$. Let us see under what conditions

$$\text{RHS of (14)} > (\frac{\lambda}{1+\lambda}). \tag{66}$$

Simplifying (66) we get

$$\phi > \lambda. \tag{67}$$

That is, whenever capital intensity is higher on small farms, it is preferable to have either optimum water distribution or volumetric pricing because these methods will ensure higher water share for small farms. If $\phi < \lambda$, then equal water distribution will ensure higher water share for small farms.

The ranking of the above six different schemes in terms of their impact on the equity objective in descending order of importance will be as follows under different conditions:

If $\phi > \lambda$, then the ranking according to the equity objective will be:

(i) Optimum Water Distribution/Volumetric Pricing

(ii) All Other Methods

If $\phi = \lambda$, then all the methods lead to the same level in the small farms' share.

If $\phi < \lambda$, then equal water distribution method is superior to the optimum water distribution and volumetric pricing schemes.

Cost Recovery

The nonpricing schemes don't fulfill this objective at all. Of the other four pricing schemes, except the volumetric pricing scheme, the three schemes, namely the acreage pricing, output taxation and input taxation schemes will all achieve this objective since the rates will be so chosen such that the revenue equals cost. With regard to volumetric pricing schemes, there are three possibilities, namely, revenue will equal, exceed or fall short of cost depending upon the magnitude of the market clearing price level. It is reasonable to expect volumetric pricing to result in revenue being greater or at least equal to the cost since in most studies we find the average and marginal water productivity being higher than marginal cost of supplying water [Hussain (1982), Renfro (1983), Young and Bowen (1983)].

Sometimes the objective of the government in pricing water is more than to recover costs, say, to generate revenues to finance further irrigation development elsewhere in the economy. In such cases it might try to maximize revenues. Given the government revenue functions from output and input taxations, respectively, as:

$$R_G^0 = \rho\ (1-\rho)^{\frac{\delta}{1-\delta}}\ \overline{A} \tag{68}$$

and

$$R_G^i = (t_2-1)\ t_2^{-\frac{\delta}{1-\delta}}\ \delta\ \overline{A} \tag{69}$$

where

$$\overline{A} = A^{\frac{1}{1-\delta}} \left(\frac{\delta}{P_N}\right)^{\frac{\delta}{1-\delta}} K_1^{\frac{\alpha}{1-\delta}} L_1^{\frac{\beta}{1-\delta}} \overline{W}^{\frac{\gamma}{1-\delta}} \left[\phi^{\frac{\alpha}{1-\delta}} \lambda^{\frac{\beta}{1-\delta}} \left(\frac{\lambda}{1+\lambda}\right)^{\frac{\gamma}{1-\delta}} + \left(\frac{1}{1+\lambda}\right)^{\frac{\gamma}{1-\delta}}\right]. \tag{70}$$

The optimal output and input tax rates (ρ) and (t_2), respectively, can be obtained by setting

$$\frac{dR_G^0}{d\rho} = \left[(1-\rho)^{\frac{\delta}{1-\delta}} - \rho\frac{\delta}{1-\delta}(1-\rho)^{\frac{\delta}{1-\delta}-1}\right] \overline{A} = 0 \tag{71}$$

and

$$\frac{dR_G^i}{dt_2} = \left[t_2^{-\frac{1}{1-\delta}} - \frac{1}{1-\delta}(t_2-1)t_2^{-\frac{1}{1-\delta}-1}\right] \delta\, \overline{A} = 0 \tag{72}$$

Which result in the revenue maximizing tax rates

$$\rho^* = 1 - \delta \tag{73}$$

and

$$t_2^* = \frac{1}{\delta}. \tag{74}$$

The interesting question that arises now is which one of these two taxation schemes is superior in terms of revenue and output generation. That is,

$$\rho(1-\rho)^{\frac{\delta}{1-\delta}} \overline{A} \gtreqless (t_2-1)\, t_2^{-\frac{1}{1-\delta}}\, \delta\, \overline{A}. \tag{75}$$

Now, substituting in (75) the optimal values for ρ and t_2 from (73) and (74), respectively, we get

$$(1-\delta)(\delta)^{\frac{\delta}{1-\delta}}\,\bar{A} \gtreqless (\tfrac{1}{\delta}-1)(\tfrac{1}{\delta})^{-\frac{1}{1-\delta}}\,\delta\,\bar{A}. \tag{76}$$

Simplifying (76) we get

$$\delta \lesseqgtr 1. \tag{77}$$

Since δ is assumed to be less than unity, output taxation will always result in more revenue than input taxation.

The optimal input and output tax rates will result in the following levels of output reached

$$(1-\rho^*)^{\frac{\delta}{1-\delta}}\,\bar{A} \gtreqless t_2^{*-\frac{\delta}{1-\delta}}\,\bar{A}. \tag{78}$$

That is

$$\delta^{\frac{\delta}{1-\delta}}\,\bar{A} \gtreqless (\tfrac{1}{\delta})^{-\frac{\delta}{1-\delta}}\,\bar{A}. \tag{79}$$

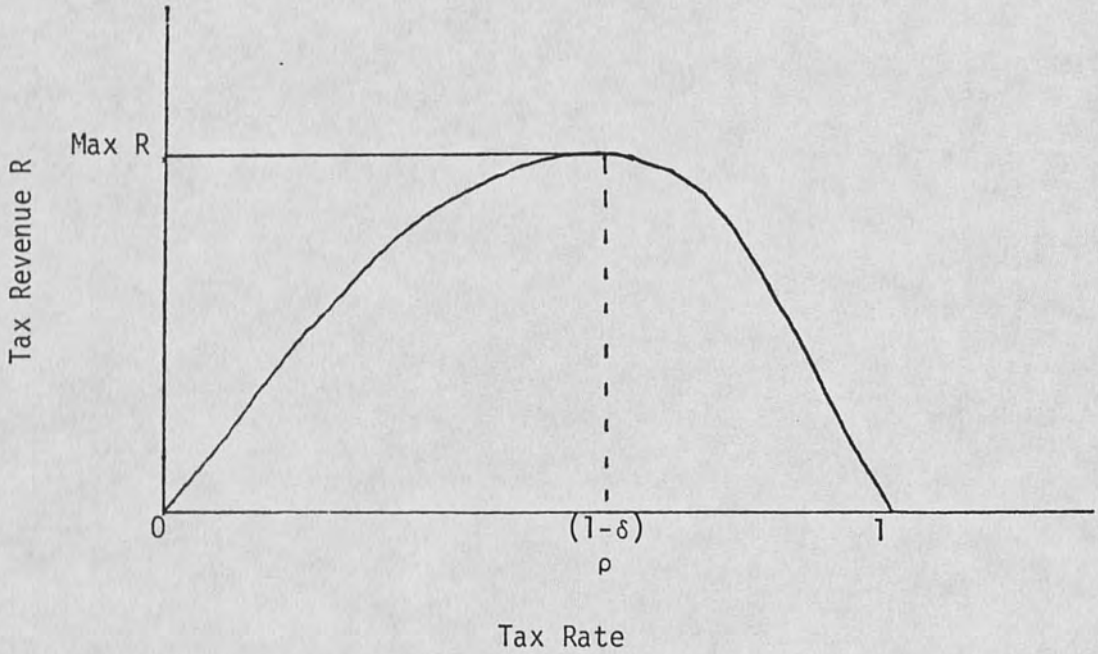
Which, after simplification, results in

$$\text{RHS of (79)} \equiv \text{LHS of (79)}. \tag{80}$$

In other words, the level of output that results from optimal output tax rate which maximizes revenues to government will always be equal to the level of output that results from optimal input tax rate that maximizes government revenues. Thus, since the maximum revenue that

results from output taxation scheme is more than the maximum revenue that results from input taxation without affecting the level of output, output taxation is superior to input taxation in terms of government revenue maximization.

It is worth noting here that ρ takes a unique positive value only when R is at its maximum. For all other values of R, ρ will have two positive values as shown below:



Thus, though for every given revenue constraint (unless the constraint value coincides with the maximum revenue), there will be two solution values for ρ, the lower value ρ will always be chosen over the higher value ρ because the lower value will always result in higher output since

$$\overline{C} = \rho\ (1-\rho)^{\frac{\delta}{1-\delta}}\ \overline{A} \tag{81}$$

and

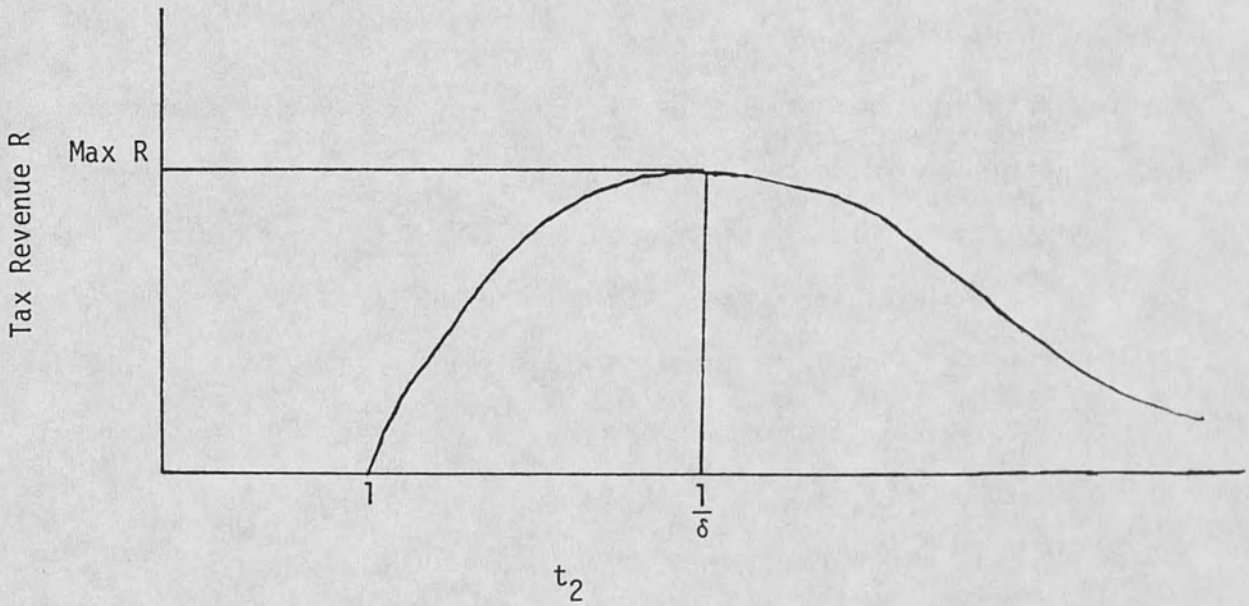
$$Q = (1-\rho)^{\frac{\delta}{1-\delta}} \bar{A} \tag{82}$$

we have

$$Q = \frac{\bar{C}}{\rho}. \tag{83}$$

Thus lower the value of ρ, higher will be the level of output.

Similarly, we have in the context of input taxation, the relation between t_2 and R as shown below:



Here, too, since we have

$$Q = \frac{\bar{C}}{\delta(t_2-1)\ t_2} \tag{84}$$

lower t_2 will always be chosen over higher t_2.

A Numerical Illustration

Table 2 below is a numerical illustration of the implications of different water allocation and pricing systems for efficiency, equity and cost recovery objectives.

Conclusion

Basically in this paper we derived results pertaining to the implications of different water allocation/pricing systems for the equity, efficiency and cost recovery objectives of the government. Using these results we ranked the different systems in descending order in fulfilling these objectives under different conditions. Given the objective reality that capital intensity is higher on small farms in many developing countries, if the goals of the governments are to achieve efficiency, equity and cost recovery, then volumetric pricing is superior to all other methods. If volumetric pricing is not feasible for whatever reasons, then among the three other methods, acreage pricing is superior to output taxation and input taxation. Between the two, output taxation is superior to input taxation.

Table 2

Efficiency, Equity, and Cost Recovery Implications of Irrigation Water Allocation and Pricing

Model	Total Agric. Output	Total Agric. Net Income	Small Farm Share in TACO	Small Farm Share in TACI	Small Farm Share in Water	Revenue to Government	Optimal Tax Rate/Price
	($)	($)				($)	
Optimum Water Distribution	57.47477	51.72729	0.377446	0.377446	0.377446	NA	NA
Equal Water Distribution	57.20368	51.48331	0.335092	0.335092	0.285714	NA	NA
Volumetric Pricing	57.47477	28.73738	0.377446	0.377446	0.377446	22.98990	0.229899
Acreage Pricing	57.20368	41.48331	0.335092	0.346995	0.285714	10	0.142857
Tax on Output	55.99523	50.39571	0.335092	0.335092	0.285714	10.00092	0.17483
Tax on Inputs*	44.29073	39.86166	0.335092	0.335092	0.285714	3.986166	10

Parameters: $A=1$; $\alpha=0.3$; $\beta=0.2$; $\delta=0.1$; $\gamma=0.4$; $P=20$; $W=100$; $L=50$; $K=80$; $\lambda=.4$; $\phi=.8$; and cost to be recovered=$10.

*In the above numerical example even the revenue maximizing input tax rate can not fulfill the cost recovery objective since the maximum revenue that can be obtained from input taxation is only $3.986.

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