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Appraising Alternatives for Allocating and Cost Recovery for Irrigation Water in Egypt

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Abstract

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Alternative approaches to allocating and recovering costs for water on Egyptian farms are proposed and evaluated in accordance with the societal objectives of allocative efficiency, equity of income distribution and cost recovery. A linear programming model of a study area in Egypt's northern Delta predicts farmers' response to the proposed cost-sharing instruments over a range of water supply conditions. Transactions costs for each charging instrument are estimated and incorporated into the allocative efficiency analysis. Flat land charges, supplemented by water quotas in the event of increasing water scarcity, best achieve societal objectives in the current and prospective Egyptian situation. Volumetric charging instruments were judged to be somewhat less desirable, due to higher tangible and intangible costs of implementation. The results highlight the importance of transactions costs, the degree of water scarcity and other governmental revenue raising policies in determining an appropriate charging mechanism.

Introduction

Changing water supply and demand conditions point to an eventual need to revise the revenue base and allocation procedures for Egypt's irrigation water delivery system. The topic is extremely important to Egypt, because the majority of the population continues to derive its livelihood from irrigating crops from the Nile River.

Because of the extreme scarcity of irrigable land in Egypt and limited up-

river agricultural development, water supply to the agricultural sector has been relatively plentiful and stable since the completion of the High Aswan Dam. However, growing conflicts with hydroelectric power demands (Oven-Thompson et al., 1982), increasing urban and industrial demands for water and the plans to irrigate new lands in the Sinai desert and elsewhere (Gotsch and Dyer, 1982) have raised the possibility of a need to reallocate water away from the existing irrigated areas (the "old" lands). Waterbury (1979) has suggested that water shortages might appear in Egypt before the end of the century.

On the supply side, the lengthy drought in the Nile's headwaters regions had, by mid-1985, necessitated a substantial drawdown of water stored in Lake Nasser. Meanwhile, a cooperative water supply augmentation project undertaken with upstream neighbor Sudan is behind schedule, in part due to political unrest in the latter country. Nations containing the Nile's headwaters, particularly Ethiopia, have recently made claims to a much larger share of the river's flows than had been previously recognized. These general trends indicate that hard choices regarding water allocation and management may be forced upon Egypt much sooner than expected.

Achieving adequate funds to properly operate and maintain the irrigation system is also a problem. Concern has been expressed about the extent of deferred maintenance. Currently, the major form of agricultural taxation in Egypt is the commodity tax, imposed on the major staple crops. The revenues flow into the Government's general fund, from which the Ministry of Irrigation must obtain the bulk of its budget for operating, maintaining and expanding the irrigation system. Inability to obtain a desired level of funding through the competitive annual budget process, combined with the expectation that direct water pricing would have a large potential for effecting water conservation, have prompted the Ministry to consider more direct methods of recovering costs from farmers.

Research objective and approach

The purpose of the research reported in this article is to propose some feasible alternative methods of allocating and charging for irrigation water, and to develop a preliminary assessment of these alternatives. Allocating and charging for water may be accomplished in a number of ways. A full volumetric charging system could achieve rationing as well as provide revenues, while non-price allocation would require an additional revenue mechanism. Whatever policy approach is in effect will have impacts on the efficiency of resource allocation, the distribution of income and government revenue collection. Thus the general problem becomes one of designing allocative and revenue devices to satisfy multiple societal objectives.

The general approach of the research follows the policy design of Tinbergen (1967), incorporating: (a) a posited set of social objectives or criteria, (b)

policy or controllable variables, (c) non-controllable variables, and (d) a predictive model which relates controllable and non-controllable variables to the social objectives. Methodologically, the study attempts to wed the neoclassical research program (with its self-interested rationality and equilibrium system axioms) with the Institutionalist concern for studying the effect of alternative social institutions on achieving multiple social goals (Schmid, 1972; Randall, 1985).

The social objectives hypothesized to be important for this case include allocative efficiency, equity of income distribution, and fairness in cost recovery. The policy variables analyzed include alternative farm-area-based and volumetric charging mechanisms and quota systems. The non-controllable variables include behavioral assumptions regarding farmer response to the policy alternatives, technology, government regulations and price controls. In order to reflect the more important conditions under which irrigation water charging policy might occur, each policy variable is analyzed under several alternative scenarios. The scenarios include: (i) administered versus hypothetical market prices for commodities, (ii) head, middle, and tail locations on the watercourse, and (iii) five water supply situations, ranging from full supply to a 40% reduction from that level.

The predictive model is based on a linear programming formulation of resource allocation options in farm situations in Egypt's northern Nile delta. The model reflects potential allocations of water, land and other resources among a number of alternative crops and irrigation levels, consistent with animal nutrition requirements. Transactions costs of implementing the various charging systems are explicitly considered, in addition to the more conventional resource costs.

Previous literature

Milliman (1972) synthesized the three major strands of economic literature which deal with public pricing. The public finance literature has historically stressed the equity (fairness) and long-run efficiency benefits of beneficiaries paying for the benefits received from government projects. But little attention has been devoted to how payment should be extracted. The public utility literature, on the other hand, has been concerned with designing rate structures appropriate to the financial and legal constraints of privately-run, publicly-regulated utilities. As a result, utility rates are generally designed to recover historical costs and tend to reflect average historical cost of services rather than marginal cost of supply (Coase, 1970).

The welfare economics literature emphasizes that for maximum economic efficiency, public prices should be set equal to marginal (opportunity) cost (see Meier, 1983, for a useful survey). The allocative efficiency objective is concerned with the classic economic problem of allocating scarce resources to

maximize social welfare, including the provision of appropriate signals for investment and innovation. The achievement of greater efficiency in irrigation requires increased administrative effort to yield more precise measuring, monitoring, policing, and price differentiation with respect to place, time, and quality (Bromley et al., 1980). Incremental administrative costs have usually been assumed to be trivial in studies of pricing of publicly-supplied goods. However, when the value of water at the margin of use is low, as it has been in Egypt (Bowen and Young, 1985), the transactions cost of bringing about increased economic efficiency may exceed the social benefits, suggesting so that no institutional change is needed (Randall, 1983).

The income redistribution impact is an additional objective usually considered in establishment of water charges. Policymakers may wish to influence the distribution of income by either subsidizing or overpricing the services provided to certain groups.

Tinbergen (1967) has shown that the problem of satisfying multiple objectives can be solved by the use of multiple policy instruments, where there are at least as many instruments as objectives. Some of the policy instruments available to irrigation administrators are prices (including alternative rate structures), quotas, permits, and transferability in water rights. Given the likelihood for conflict among efficiency, equity and cost recovery objectives, it may be desirable to use two or more instruments for allocating and charging for irrigation water.

In the literature on irrigation pricing, Ansari (1968) investigated irrigation rates in India, while Davis and Hanke (1971) describe and evaluate water pricing systems used in the U.S., including those for public irrigation. Methods for pricing irrigation water in Iran were proposed by Gardner et al. (1974). Maass and Anderson (1978) have presented perhaps the most detailed examination of water allocation rules used in various arid regions of the world. J.A. Seagraves and various associates have developed conceptual and empirical studies of the use of water prices and other instruments to achieve multiple objectives in irrigation (Neghassi and Seagraves, 1978; Seagraves and Ochoa, 1978; Seagraves and Easter, 1983). Randall (1981) has integrated the literature on property rights with that on pricing. Carruthers and Clark (1981) deal with both charges and allocation in a broad study of irrigation economics.

In general, the cited studies have been prescriptive without providing empirical analyses of the effects of policies on societal objectives (Seagraves and Ochoa (1978) being the exception). Little consideration has been directed to location (e.g. head, middle, and tail reaches of the canal system), an important factor affecting achievement of both allocative efficiency and equity objectives. Transactions costs in implementing water pricing policies are often acknowledged, but we are not aware of any studies which provide empirical support of its importance.

Other considerations in selecting cost recovery methods

Rural–urban differences in income distribution are found to be an important factor in recommendations for irrigation system cost recovery. Egypt’s revenue and pricing policies have served to extract a large part of the agricultural surplus. Farmers have been required to produce certain prescribed crops and sell them to government marketing boards at fixed prices. We estimate the effective transfer to government to be approximately 40% of pretax net income in the study area. When the transfer to consumers (from lower food prices) is included, the estimated burden is 46% (Bowen, 1982).

For the economy as a whole, the average tax rate as a percent of gross national product (GNP) is about 25% (Cuddihy, 1980). The farm tax rate in the study area is therefore as much as 60–80% higher than the economy-wide rate. Agricultural incomes, moreover, are reportedly 25% less than the economy-wide average.

The potentiality for corruption is an important factor to consider in administering public programs, particularly for revenue collection in developing countries (Goode, 1984). Evidence that the problem may be significant in irrigation systems is provided by Wade (1982).

Farmers may be reluctant to accept institutional changes requiring explicit measurement or charging for irrigation water. Boulding (1980) has noted the special spiritual and symbolic role water plays in human affairs, which may account for the often-expressed feeling that water should not be priced as if it were a standard commodity. In this regard, perhaps the most common objection to charging for water in Egypt is that such a policy might conflict with specific Islamic teachings. Waterbury (1979) asserts that the attitude is more Egyptian than Islamic. This issue is not perceived to be insurmountable for several reasons. The policy instruments proposed in this study seek to recover delivery costs, rather than charge for the water itself. Private sales of water already occur in Egypt, although farmers may consider it as the cost of using a neighbor’s pump.

A model of farmer response to water charging instruments

The Abu Raia cooperative, located in the Kafr El Sheikh district, was selected as the study area because it is thought to be typical of a large portion of the Nile delta and because data were readily available. Cotton, rice and maize are the major summer crops and wheat, berseem (Egyptian clover), flax and broadbeans are common in the winter season. Farms are small, averaging about two hectares.

Irrigation delivery to the area is on a rotational basis among the major branch canals but operates as a continuous flow system within any given area during “on” periods. Egypt’s Below Grade System (BGS) delivers water below field

level, forcing the farmer to lift the water (approximately one meter) onto his fields. Lifting costs serve as a rationing mechanism and discourage extreme waste.

To simulate the impact of alternative water charging and allocation instruments on farm production and water use, a programming model of the study area was developed. The watercourse model consists of three linked linear programming models of representative farms at different locations along the watercourse. The three farm models use an identical objective function and technical coefficients and differ only in right-hand-side water constraints.

The prototype farm model assumed farmers to have considerable flexibility in allocating water under scarcity and is designed to be reasonably sensitive to the impacts of alternative policies. For each crop, there are from 7 to 24 different production activities. The model assumes that farmers can respond to higher water costs or restricted supply by shifting planting dates, by stressing the crops at different stages of plant growth, or by increasing on-farm irrigation delivery efficiency.

The farmer is assumed to maximize net returns to fixed and unpriced resources (land, management and water). Family labor is priced at a reservation wage rate. Prices of farm output and fertilizer inputs are recognized under two institutional scenarios. One scenario (Government Model) uses actual prices received by farmers in 1980. The Egyptian government controls prices for staple commodities through an extensive system of marketing and production controls. The other scenario (Market Model) corresponds to a hypothetical market system of price determination and uses border prices for internationally traded commodities.

The farm model is an otherwise standard linear programming formulation of an integrated cropping and livestock operation. The energy and protein requirements of the livestock inventory require the production of a minimum amount of forage crops. Limited market potentials impose assumed production limits for minor perishable crops. Land is seasonally constrained to the model farm size of 4.5 feddans (approximately 1.9 ha or 4.7 acres) and reflects a one-year planning horizon. For further details of model formulation, see our earlier related paper (Bowen and Young, 1985).

Fixed monthly constraints are used for water supply, reflecting assumed inflexibility in reallocating water among months and between the summer and winter season. Fixed monthly water constraints imply that the farmer knows what monthly quantities of water are available to him, even though Egypt's continuous flow system of delivery does not formally assign water rights to farmers. To reflect the allocation of water under shortages in a continuous flow delivery system, unless otherwise indicated, it is assumed that head farms will be able to divert up to 50% of the water flowing past their headgate. Middle farms can divert 60% of the remaining water and tail farms can use all of the residual. These percentages are based on considerations of conveyance losses

and legal restrictions on blocking the flow of water, as described in Wolfe et al. (1979).

Potential charging and allocative methods and associated institutional costs

Our research effort is aimed at helping to determine which combination of cost recovery and allocative instruments would be appropriate for Egyptian conditions, as evaluated under the concerns for allocative efficiency and equity in income distribution. The full range of instruments that could be considered is quite large, consisting of different combinations of allocative rules, quotas, water charges, and water markets. We have evaluated two broad types of water charges: area-based taxes and volumetric charges. The use of quotas is also considered in conjunction with area-based charges.

Non-economists such as Etzioni (1985) have criticized the predilection of neoclassical economists for pricing and incentive systems, arguing that idealized incentive systems are compared with actual implemented, and imperfect, command and control systems. In partial recognition of this point, we explicitly consider transactions and administrative costs of the water pricing systems.

Area-based charges. One broad category of water charges are area-based. The “flat” land charge would be based on cultivable area while crop charges are based on feddans actually cultivated. A flat land tax is the easiest area-based pricing instrument to administer, since only the existing knowledge of the farmers’ landholdings is needed. Crop taxes require information on the number of feddans by crop for each farmer. Crop information is currently collected by the Egyptian government, so that area charges would require little incremental expense.

The use of water quotas in conjunction with area-based charges would entail changing the method of water delivery from the present continuous flow to a rotational delivery system. At the meska (branch canal) level, such a system could be managed privately, through cooperatives, or publicly. Maass and Anderson (1978) and Malhotra (1982) describe and evaluate various forms of quotas in use.

Volumetric charges. This broad category of water charge instruments requires the ability to measure water with a reasonable degree of accuracy. In Egypt’s Below Grade System (BGS) of delivery, water must be lifted from the ditch to the field, usually via a *sakia* (Persian water wheel), but a low-price measuring mechanism may be feasible. The method selected for analysis assumes the use of a counting device on the sakia. This water measurement proxy is simple and relatively low in cost. A counter meter would record the number of revolutions. An initial calibration test would be needed for each sakia to convert the rota-

TABLE 1

Estimated annual cost of administering water charging instruments for a branch canal (serving 1700 feddans)^a in 1980 Egyptian pounds (L.E.)^b

Type of cost	Area-based charges			Volumetric charges		
	Flat land tax	Crop taxes	Flat land with land tax quotas	Flat, annual charge	Dual, annual charge	Dual, seasonal charge
Annualized capital cost						
Meters and control structures	0	0	160	1440	1440	1440
Annual administrative costs						
Meska operation and monitoring	0	0	3600	3600	3600	3600
Revenue assessment	500	1500	500	3500	4500	6000
Total institutional cost	500	1500	4260	8540	9540	11040
Average cost per feddan	0.30	0.90	2.50	5.10	5.70	6.60

^a1 feddan = 0.42 ha or 1.04 acres.

^b1 L.E. = US \$ 1.43 (in 1980).

tion count into volumes of water. The formula would reflect the size, design, and degree of submergence of the sakia. Slack (1981) studied the problem of measuring the discharge of a sakia in Egypt and estimates that discharge measurements with this method would be accurate within a 20–30% range. The counter would need to be read at least once a year and the readings converted to volumes for tax assessment. Administrative complexity and costs will increase with more sophistication in volumetric pricing. Among the potentially more complex approaches considered in this research are seasonal pricing and the use of “dual” or “two-part” prices.

Estimating transactions costs

From an economic efficiency perspective, benefits from institutional change ought to exceed the costs necessitated by the change (Ruttan, 1978). Due to the difficulties involved, our attempt to develop quantitative estimates of transactions cost of various pricing must be recognized as preliminary and speculative, and rather wide confidence intervals for the estimates must be assumed.

The annual cost estimates reported in Table 1 are based on interviews with knowledgeable engineers, supported by data from the research literature, including Slack (1981), Maass and Anderson (1978), and Coward (1980). The estimated incremental administrative costs ranged from less than one Egyptian pound (L.E.) per feddan to over 6 L.E. per feddan (1 L.E. = US \$ 1.43 in

1980; 1 feddan = 0.42 ha or 1.04 acres). (Our inability to measure the *intangible* costs associated with a pricing scheme implies that transactions costs are underestimated.)

The estimated tangible transactions costs (Table 1) are not trivial. For the most elaborate form, volumetric pricing, they amount to 4% of net farm income for the typical family. This would be a 33% increase in the historical level of charges for providing irrigation water, or, from another perspective, two weeks of a typical family's income just for the ability to measure and charge for irrigation water use.

Evaluation criteria for water charging instruments

Single charge instruments (area-based taxes without quotas or flat volumetric prices) can only guarantee the attainment of one objective. To simultaneously optimize upon two objectives, two instruments (area-based taxes with quotas or dual volumetric prices) are required. We assumed that the cost recovery objective must be satisfied prior to other objectives.

Two levels of cost recovery were evaluated. One level recovers all capital and operating outlays, including estimated administrative cost of the pricing instruments. The alternative cost recovery objective includes the above but does not seek recovery of capital costs. ("Capital" costs here refer to major system improvements but do not include any amortization of the dams at Aswan.)

When two instruments are considered, the second-order objective to be optimized is allocative efficiency. The optimal pricing instrument, judged by the efficiency criterion, is the instrument that maximizes social returns to land and water in the study area, net of the social cost incurred in providing and charging for the irrigation water. The proposed water rates which meet these cost recovery and efficiency objectives are reported in Tables 2 and 3.

There are two income concerns considered: (1) the distribution of farm income along the watercourses (locational equity), and (2) the distribution of farm income by income class. The former deals with inequality in income derived solely from unequal access to water due to location on the watercourses (farm size is held constant). The evaluation criterion is the ratio of income of tail-reach farms (the most disadvantaged group) to income of head-reach farms (the most advantaged group). The possible value of the criterion ranges from the social optimum of one, representing equality, to zero, representing extreme inequality along the watercourse.

Unlike the allocative efficiency and locational equity objectives there is no objective basis for defining an optimal criterion for the second equity objective. We therefore only attempt to measure the estimated impact of water charges on different sized farms, leaving the definition of an optimum income distribution by farm size to policymakers. Assuming constant returns to scale and

TABLE 2

Area-based water rates (L.E. per feddan)^a designed to meet cost recovery objective^b, government (Gov.) and Market (Mkt.) Models

Area-based charging instrument	Model	Crop							
		Long berseem	Short berseem	Broad beans	Cotton	Flax	Maize	Rice	Wheat
Flat land charge ^c	Both	0	0	0	0	0	0	0	0
Flat crop charge	Both	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Water requirements-based crop charge	Gov.	11.10	6.00	7.10	13.50	6.20	9.40	12.90	7.50
	Mkt.	10.90	5.90	6.90	13.20	6.10	9.20	12.60	7.30
Gross revenue-based charge	Gov.	9.90	3.30	11.80	17.10	12.70	11.20	9.60	8.50
	Mkt.	5.80	1.90	6.90	18.20	9.00	7.70	11.70	9.20
Net revenue-based charge	Gov.	12.80	3.70	14.40	15.40	14.00	14.50	8.50	8.00
	Mkt.	6.10	1.80	6.80	17.90	8.70	8.40	12.00	9.20

^a1 L.E. = US \$ 1.43 (in 1980); 1 feddan = 0.42 ha or 1.04 acres.

^bCharges are designed to generate 10 L.E. per feddan per crop which is the estimated full budgetary cost of providing irrigation water. Rates designed to recover only operating cost would be approximately 50% of the above rates.

^cThe change is assessed on the basis of land area, not crop area.

TABLE 3

Marginal volumetric water rates (L.E. per 1000 m³)^a designed to meet cost recovery^b and allocative efficiency objectives under alternative water supply scenarios, Market Model

Volumetric pricing instrument	Water supply				
	Actual	Reduction by 10%	Reduction by 20%	Reduction by 30%	Reduction by 40%
Flat, annual (1)	1.20	1.20	1.25	1.45	1.70
Flat, annual (2)	3.20	3.20	3.20	3.70	4.20
Dual, annual	0.00	1.70	8.70	27.60	46.60
Dual, seasonal					
Winter	0.00	1.70	3.10	23.00	30.00
Summer	0.00	1.50	19.60	42.00	50.00

^a1 L.E. = US \$ 1.43 (in 1980).

^bTwo cost recovery objectives were evaluated. The flat, annual (1) rates recover only operating costs while the flat, annual (2) rates recover full cost. The dual (two-part) rates reported above are the charges for water used in excess of a base quota. Cost recovery objectives are met by adjusting the base quota charge.

household size estimates from Haider (1982), the characteristics of two farm sizes are considered:

Farm size	Household size	Farm income	Per capita income
3 feddans	7 persons	420 L.E.	60 L.E.
8 feddans	12 persons	1120 L.E.	93 L.E.

The relative income effect of subsidized water rates for the smaller farms will be estimated.

Results

Table 4 summarizes the predicted allocative efficiency and (locational) equity impacts of alternative types of water charges. Water charging instruments are ordinaly ranked for each criterion. No overall ranking of instruments is made since this would require knowledge of the social weights attached to each objective and the intangible costs of each instrument must be considered.

Since the analytic results and water policy implications of the Government and Market models were similar, the subsequent discussion reports only the findings derived from the Market model. Comparison of the results of the two models does reveal the extent to which current government pricing policies extract much of the farmers' surplus (see Bowen and Young, 1985). This is a source of concern for long-run economic efficiency and equity (Schultz, 1978; Peterson, 1979; Cuddihy, 1980). These inefficiencies and inequities would only be worse if water pricing were merely another means of extracting more surplus from agriculture. Therefore, we advocate the water charges evaluated in this

TABLE 4

Evaluation and ranking of water pricing instruments under alternative water supply scenarios on the basis of allocative efficiency and equity criteria^a, Market Model (rank given in parentheses)

Water supply: Evaluation criterion:	Unrestricted		Reduction by 10%		Reduction by 20%		Reduction by 30%		Reduction by 40%	
	Ef	Eq	Ef	Eq	Ef	Eq	Ef	Eq	Ef	Eq
Policy instrument										
Area-based charges										
Land tax	323 (1)	100 (1)	318 (1)	93 (6)	306 (4)	80 (6)	272 (6)	43 (7)	223 (6)	12 (7)
Crop taxes ^b	322 (2)	100 (1)	317 (3)	93 (6)	305 (7)	80 (6)	271 (7)	45 (6)	222 (7)	14 (6)
Land tax with quotas	320 (3)	100 (1)	318 (1)	100 (1)	313 (1)	100 (1)	295 (1)	100 (1)	261 (1)	100 (1)
Volumetric prices										
Flat, annual (1) ^c	318 (4)	100 (1)	313 (7)	94 (5)	306 (4)	86 (5)	272 (5)	50 (5)	232 (5)	24 (5)
Flat, annual (2) ^c	316 (6)	100 (1)	316 (4)	100 (1)	307 (2)	94 (4)	279 (4)	55 (4)	235 (4)	27 (4)
Dual, annual	317 (5)	100 (1)	315 (5)	100 (1)	307 (2)	96 (3)	287 (3)	83 (3)	249 (3)	69 (3)
Dual, seasonal	316 (6)	100 (1)	314 (6)	100 (1)	306 (4)	99 (2)	288 (2)	84 (2)	253 (2)	80 (2)

^aAllocative efficiency criterion (Ef): social returns to land and water per feddan net of tangible institutional costs of pricing water (in L.E.; 1 L.E. = US \$ 1.43 in 1980).

Locational equity criterion (Eq): (after-tax) farm income of tail farms as a percent of head farm income.

^bFlat crop tax, water requirements based crop tax, gross income-based crop charge, and net income-based crop charge.

^cFlat annual (1) charges recover operation costs only; flat annual (2) charges recover full (budget) capital and operating costs.

study be regarded as replacement rather than additional forms of government taxation.

Allocating and charging for water under non-limiting supply conditions

The first column of Table 4 shows the summary results under non-limiting water supply conditions. [While aggregate irrigation water supply in Egypt has been adequate to meet demand in the agricultural sector, shortages occasionally occur in certain areas during peak demand periods due to such problems as improper canal design or high conveyance losses on sandy soils. These problems are reportedly not widespread and were not observed in the study area.]

Without considering the transactions cost of charging for water, net social returns to irrigation are estimated to be 323 L.E. per feddan under non-limiting conditions. Water charge instruments do not increase social returns when water is not scarce, since no improvement in water allocation can be effected. Most of the evaluated instruments cause reductions in social welfare solely due to the transactions cost of measuring and charging for water. The non-zero marginal charge of the flat volumetric instrument produces an additional welfare loss.

Because of lower transactions cost, area-based charges are more efficient than volumetric charges under non-limiting water supply. The flat land tax is the least expensive instrument and has the advantage of being allocatively neutral. Although crop taxes theoretically can produce allocative distortions, no misallocations were predicted by the model under the range of conditions tested. This result follows from the fact that the demand for water in the linear programming model is a step function. In this case, the demand was perfectly inelastic with respect to price (or price proxies) within the range of water charges examined.

There were also no differences among the water charging instruments under current water supply according to the locational equity measure. Income equality along the branch canals was achieved by all the instruments. Under constant returns to scale, distribution of income per unit of land along a watercourse will be equal when water is not limiting.

Using both criteria, land taxes without quotas (the existing policy) are the highest-ranked pricing instrument and can be recommended as appropriate for Egypt, so long as water continues to be plentiful. Subsidies to particular groups, such as to small-hold farmers or poorer regions, might be accommodated by charging different rates for different groups. Differentiation of rates to groups of farmers will not detract from allocative efficiency and is an inexpensive method of redistributing income among farmers. However, because water costs and therefore water rates are a small fraction of farm income and because political considerations are likely to constrain the size of subsidy

allowed, water charges can be used to achieve only a modest redistribution of income. For example, the per capita income of a three-feddan farm is 65% of that of the eight-feddan farm; a 33% subsidy of irrigation water to the smaller farm would only increase the income equity ratio to 69%.

Allocating and charging for water under hypothetical water shortages

The rationale for including hypothesized water shortage scenarios is that accelerated development of new lands (in Egypt or in upriver countries), increased hydropower and urban/industrial demands, and/or a series of low Nile flows could necessitate a reduction in water available for agriculture. The study of water pricing under shortages also has implications for specific areas in Egypt and other countries that currently experience severe water shortages.

Table 4 reports our analytic predictions of how alternative water pricing instruments perform for each proposed water scarcity. The second through fifth columns summarize the social returns and locational equity ratings for four hypothesized water shortage conditions.

The allocative efficiency measure declines from the high of 323 L.E. per feddan (under unrestricted water supply) to, at worst, 222 L.E. per feddan (under crop taxes), or, at best, 261 L.E. per feddan (under land taxes with quotas). These are 31 and 19% reductions in social welfare caused by a 40% decline in water availability at the farm headgate. The relatively inelastic response of social net income to changes in the supply of water is partly due to the numerous possibilities for substitution of other resources for water reflected in the programming model.

A significant improvement in efficiency benefits can be achieved by using quotas in conjunction with area-based charges. For example, in the 20% reduction scenario an increase in net social benefits of 7 L.E. per feddan is achieved by the use of quotas. Given the assumptions of the model, i.e. homogeneous production functions and fixed monthly water constraints, the quota system would be the preferred policy instrument for effecting an efficient distribution of water along the watercourse, prior to considering transactions costs. When transactions costs are explicitly considered then the efficiency benefits must be net of the increased social cost of administering the quota system. With a 10% reduction in water supply, the additional benefits of using quotas in conjunction with land taxes just equals the transactions cost of the quotas. Beyond a 10% reduction, quotas are clearly a potentially efficient instrument.

Area-based water charges without quotas would cause considerable inequity of income, even under a scenario of modest water shortage. With quotas, however, a perfect rating under the locational equity criterion is achieved because the even distribution of water leads to an even distribution of income under the assumed homogeneous production conditions. From the equity criterion perspective, the present continuous flow delivery system would require modi-

fication or replacement if even modest aggregate water shortages were to occur in Egypt.

The various area-based charging instruments did not produce any changes in the model's predicted optimal cropping patterns. The result was unexpected for crop taxes, since this type of taxation alters the relative profitabilities of the crops and theoretically should reproduce some difference in cropping patterns. It can be inferred that, at the level of charge likely to be considered, area-based taxes will have little effect upon the allocation of water in the continuous flow method of delivery. Crop charges based on the water requirements of crops have been decried in the literature as being a suitable proxy for volumetric pricing (World Bank, 1976). Yet our results show that this instrument is neither more efficient nor more equitable than other area charges.

Volumetric pricing is predicted by the model to be less economically efficient than quotas under all scenarios considered. This is partly due to the higher transactions cost of volumetric pricing. Another reason is the model's fixed monthly water constraints, which are based on assumed inflexibility on reallocating water at Aswan to satisfy agricultural demands only. With the opportunity cost of water varying monthly, annual or seasonal pricing will not satisfy the equimarginal principle. It would probably be unrealistic to assume that water prices could vary from month to month.

The analysis reveals volumetric pricing to be inappropriate for the likely near-term conditions in Egypt. But it is informative to examine the efficiency and equity ratings among the alternative forms of volumetric pricing, which have implications for areas where water is valuable enough to be measured, priced and delivered on demand. The dual (two-tier) form of volumetric pricing is most efficient and equitable under the severe water shortage scenarios (where volumetric pricing is most likely to be considered). Flat annual volumetric charges are inefficient because the marginal rates designed to recover historical costs were generally much lower than the opportunity cost of water, especially in the peak demand season. However, if the rates were set to maximize the efficiency objective, farmers would be overcharged in relation to the cost of providing water. Whether an annual or seasonal form of dual pricing is more desirable depends upon the degree of variation in the value of water over the year, which depends on the ability to store water in the low value (in agriculture) season for use in the high value season. Seasonal prices were predicted by the model to better meet water pricing objectives in Egypt than an annual price.

Conclusion

Egypt's supply-oriented water management policies of the past have successfully met aggregate irrigation demands without a need for rationing. If plentiful water supply conditions continue, the analysis has shown area-based

water charges to a suitable method for recovering cost. In particular, the flat land tax is the highest ranked instrument, using both economic efficiency and locational equity criteria.

Should planned future supply conditions not live up to expectations, land taxes would continue to be an appropriate method of raising revenue but would need to be supplemented with a non-price rationing method, such as a quota system. Quotas require somewhat less administrative effort, incur less farmer opposition, and avoid an additional drain on already low farm incomes.

Subsidizing water rates for the smallest farms can be an inexpensive method of income redistribution and allocative distortions would be small. However, water rates are a small fraction of production cost and the impact of a water subsidy on income distribution would not be large.

Marginal cost pricing is allocatively efficient assuming zero transactions costs. This study shows that transactions costs are non-trivial and need to be explicitly accounted for in irrigation pricing policy analysis. The benefits of marginal cost pricing must exceed the transactions cost of measuring the water. In Egypt, small farm size is an important factor in the estimated high transactions cost of volumetric pricing.

Volumetric water charges are found to produce an acceptable distribution of income along a watercourse (where all variables save water supply are held constant) but are not preferable to quotas in the scenarios analyzed. Greater sophistication in structuring volumetric rates, i.e. dual and seasonal pricing, will lead to greater equity in income along the watercourse, but the higher cost of sophistication would probably detract from economic efficiency.

Limitations and directions for future research

Metering the sakkia is an untried method of measuring water, and farmer response would be uncertain. To some extent this is a management problem, requiring a sound system of monitoring and enforcement. Yet if tampering and destruction of counters were to be widespread, the problem may be unmanageable. Any decision to use metering devices, either for implementing quotas or volumetric pricing, needs to be preceded by experimental trials. The potential effectiveness of public agencies in managing volumetric pricing would also need to be assured. The above empirical analysis ignored these potentially large intangible costs.

The findings that only limited allocative efficiency gains can be achieved by alternative charging systems under present conditions may not be relevant outside the Egyptian context. The "Below Grade System" of delivery, which requires the farmer to lift water from the canal to field level, serves as a rationing measure. The lifting cost discourages extreme wastage and places limits on the potential for further efficiency gains through water charging.

The assumptions of fixed monthly constraints used in formulating the model

are important to the analytic results for volumetric pricing. The model predicts that farmers on the tail of the watercourse will not always receive all the water they demand. This is because the marginal opportunity cost of water fluctuates over the year and annually or seasonally set prices cannot allocate water efficiently in certain months. Further research into the potential for reallocating water from the Aswan High Dam from the low demand winter months to the high demand summer months would allow the nature and magnitude of the water supply constraints to be better defined. Owen-Thompson et al. (1982) considered the possibility of reallocating Nile River water from summer to winter under present conditions. The range of reallocation possibilities studied should be expanded to include winter to summer reallocation and hypothetical water reduction scenarios.

Administrative cost is not considered in measuring equity as it is in measuring economic efficiency. As a result, a trade-off often exists between efficiency and equity objectives. The results of the analysis show that the conflict between efficiency and equity objectives can be resolved with the use of more than one instrument. The use of quotas combined with area-based charges best resolved the conflict when water was constrained; for volumetric rates, the proposed dual pricing method produced an acceptable resolution.

Research into alternative methods of administering a quota system should be encouraged. This study did not recognize the entire potential range of approaches and the corresponding transactions costs. Some major distinctions among potential quota systems applicable to Egypt's delivery system are quantity vs. time-share basis and government vs. user controlled. Converting the delivery system from below grade to gravity feed is an option currently being considered for some areas. This approach would require a quota system even if direct cost recovery was not desired.

Finally, our conclusions rest upon the assumption that water charges would not add to the current agricultural tax burden in Egypt but would be balanced by tax reduction elsewhere. The government's share of farm income in the northern delta study area were found to be high and further increases would worsen long-run distortions in agricultural incentives.

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