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American Journal of Agricultural Economics, Vol. 81, No. 4. (Nov., 1999), pp. 928-941.

EVALUATION OF PRICE POLICY IN THE PRESENCE OF WATER THEFT

ISHA RAY AND JEFFREY WILLIAMS

Mathematical programming models of "representative" farms are commonly used to evaluate policies such as input subsidies and output price supports. On canals in India, upstream farmers routinely use more irrigation water than allotted. In such circumstances, the programming model should encompass farmers' locational heterogeneity. Here, a representative watercourse with thirty farms is calibrated to the eight crops, fifteen irrigation turns, yield responses to water, and seepage in Maharashtra. Not only does water "theft" increase the social cost of price policies, but the policies' increased inducement to theft by upstream farmers leaves those downstream with less water and lower incomes.

Key words: canal irrigation, India, mathematical programming, price policy.

The agricultural sector of most countries is a complex web of support prices for some crops, low procurement prices for others, trade restrictions, subsidies for inputs, and minimum wages for hired labor. The interactions within this policy regime determine a farmer's input use and cropping patterns, and therefore the private profits from farming. In Maharashtra, India, where canal irrigation is critical to the productivity of agriculture, subsidies to water interact with low domestic prices for wheat and high support prices for water-intensive sugarcane. As a result, farmers prefer to grow cane. To evaluate such a price regime, analysts ask: What is the estimated social cost of this set of private prices? To what extent do particular policies compensate for other distortions? What are their distributive consequences if farmers are not homogeneous?

The simplest way to evaluate a price regime is to compare the revenues generated on a "representative" farm with, and then without, the output and input price interventions. On a canal, however, farmers are never homogeneous, because even if they are identically endowed with land and labor, they cannot be identically located. As water flows from the head of a canal to its tail, each successive farmer loses more and more water to percolation, evaporation, spills, and seepage. This locational heterogeneity suggests that a price regime could have significant efficiency and distributive consequences. More important, the link between a farmer's water use and his or her neighbor's water supply implies that a single farm ought not to be the unit of analysis.

The with-and-without comparisons of farmers' revenues could be carried out for a canal system, with the farms on it differentiated by position. To maximize the aggregate producer net revenue, the water would be allocated such that the marginal value to farm $k + 1$ is just high enough to offset the seepage loss from farm k to $k + 1$ (Chakravorty and Roumasset). But net revenue maximization is not the intention, let alone the reality, on any canal in India. In theory, the irrigation department (ID), motivated by equity rather than efficiency, rations out water to each irrigable acre in accordance with some predetermined rule. In practice, individual farmers who want more than their allotted water simply take it—often with the connivance of the ID-employed canal inspector. Location is a key determinant of such "theft" because it is much easier for upstream farmers to siphon off extra water during downstream farmers' irrigation turns.

The true deadweight loss of a price regime is the difference between farm incomes at social prices and under efficient allocation, and

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The authors thank Carl Gotsch for his help with the farming system model and his insights into irrigation practices in South Asia.

Amer. J. Agr. Econ. 81 (November 1999): 928–941

those under private prices and water theft. Canal water theft is considered a major problem and, in the literature, institutional changes rather than relative price changes are usually recommended to reduce it (Coward, Meinzen-Dick and Mendoza, Wade). Yet a particular price policy could encourage or discourage theft, or even determine how damaging theft actually is. Similarly, it is seldom acknowledged that farmer behavior, such as stealing or not stealing water, could determine the social cost of a price regime.

This article uses survey data from a typical canal in drought-prone western Maharashtra to develop a mathematical programming model of a representative watercourse. The underlying structure of the farming system is quite general, so the model's usefulness is not regionally confined. Distinct versions of the model represent different institutional arrangements for water allocation and different relative price regimes. In each case, the model's numerical solutions reveal the spatial allocations of canal water and therefore of crops down the watercourse. Quantitative relationships are derived between the institutional arrangements for water allocation and the deadweight loss from price interventions, and between relative prices and the deadweight loss from unauthorized irrigation. The solutions demonstrate that a detailed farming system model, incorporating these richly complex interactions, is essential to estimate the need for, and the effects of, water policies or price policies.

Irrigated Agriculture in Maharashtra

The canals of the Deccan Plateau, which includes the state of Maharashtra, consist of a Left Bank branch and a Right Bank branch on either side of the dammed river (figure 1). The canals are run on an "on and off" basis with a subset of watercourses full of water at any given time. In a normal year, the ID provides up to fifteen irrigations, with a dry interval of fourteen to twenty-one days between them. Each watering turn is called a "rotation." When a watercourse has its rotation due, a steady discharge is maintained through the outlet, the entire delivery is (usually) given to one farmer at a time, and for a fixed number of hours per acre irrigated. The *patkari,* or ID-employed canal inspector, is responsible for opening and closing the outlets and for monitoring the irrigating farmers. This is how a canal is operated "officially" (Gandhi).

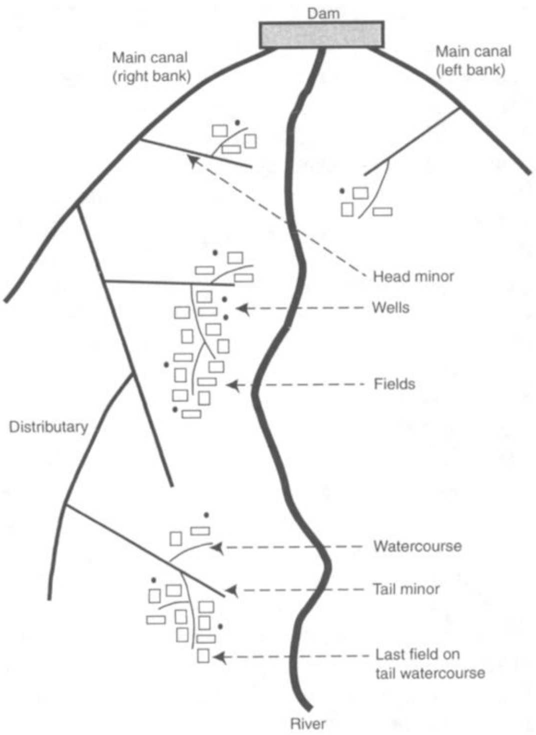

Figure 1. Layout of a canal system

The cost to farmers of the heavily subsidized canal water is extremely low, varying between 5% and 15% of the canal's operating costs. For most seasonal food and cash crops, a flat fee per acre is levied, implying a zero marginal cost for water. Except for sugarcane, there is no evidence that existing water fees have any allocative effect on the average farmer.

Farmers in the head reaches of a canal and its minors have a more assured flow to their fields. Water in open channels is lost in transit to seepage, evaporation, and theft as it flows from the head to the tail. Theft is usually a simple matter of a farmer making an unauthorized breach on his field channel, siphoning off the water, and then closing up the breach again. Sometimes an attempt to use water illegally is seen and stopped by the *patkari.* Alternatively, the farmer and the *patkari* can "arrange" not to have the theft reported (Datye and Patil). On a watercourse, the advantage bestowed by a farm's location rivals, and may even dominate, wealth or "influence" in determining access to water.[1]

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[1] In an active land market, this locational advantage would be

With year-round irrigation, the same piece of land can support two, or even three, successive crops in one year. Because many crop growth periods overlap, farmers must consider sets of crops each year. In most of Maharashtra, farmers grow pearl millet or sorghum in the monsoon season, wheat, sorghum, and some gram in the winter, and groundnuts in the short summer season.[2] By far the most lucrative, sought-after, and water-consuming option is sugarcane, a twelve-month crop raised with the conjunctive use of wells and canal water (Lele and Patil).[3] Canal seepage recharges the wells, but the wells draw down the water table over the year.[4] From April to June the water column is low everywhere, with no recharge from percolation and no stored moisture in the cracking soil. During these months the need to keep the sugarcane alive, legally or illegally, is especially urgent.

The price the farmer receives for his cane crop is set by the processing mills in the region. The mills receive a subsidy per ton crushed from the Government of Maharashtra, so it is in their interest to encourage raw cane production through a high support price. In 1991/92, when the survey data were collected, the effective nominal protection coefficient (NPC) for sugarcane was almost 1.5.[5] The fine cereal, wheat, is partly procured by the government and partly sold on the open market. The Indian Government's decision to restrict exports kept the domestic prices for wheat depressed; its NPC was approximately 0.7. For the coarse grains, sorghum and millets, there were no effective support prices. Pearl millet is not traded internationally. Sorghum is traded, but the government has never purchased substantial quantities of either of these foodgrains. The other major crops in Maharashtra, and in the model, are gram and groundnuts. Groundnuts, especially the confectionery variety that is eaten rather than pressed for oil, are quite competitive on the export market. Its NPC was estimated as 1.1 for the period between 1990 and 1994 (Gulati, Kohli, and Sharma). The NPC of gram was also very close to 1, so the prices for groundnuts and gram are not modeled as supported or taxed.[6]

The Model of a Watercourse

The watercourse in the model has thirty farms, identical but for location, and 120 acres in its command. Each 4-acre farm is endowed with a male adult and a female adult,[7] its share of canal water, and a well to which a 5 horsepower motor is attached. These are treated as fixed and allocatable inputs on each farm, making the model a "restricted-equilibrium" one (Schaible). Complexities of risk, economies of scale, soil heterogeneity, etc., are ignored to isolate the effect of a farm's position along the watercourse.[8]

The model is written in the GAMS programming language, as a sequence of representative farms over space, within a time period of one agricultural year. Each farm is a linear programming problem over eight crops, and eight variable inputs, besides the endowed factors. The technical coefficients and supply constraints for male and female labor, land, and well and canal water are separately specified for each of fifteen canal rotation intervals, to accommodate the seasonal nature of the agriculture.

The numerical parameters and coefficient values are based upon detailed cost-of-cultivation data, obtained through extensive interviews with sixty-five farm households, on two watercourses of a major canal in Maharashtra (Ray). The households were located all over the watercourses, and their land holdings varied from 1 acre to 40 acres. The farmers were interviewed over two agricultural seasons (from November to May) in a year with slightly above average precipitation. Some inputs,

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capitalized into the value of the land. Land sales are infrequent in most parts of India, Maharashtra included. In this article, the market for land sales or leases has not been considered.

[2] The other major cash crop is cotton, which is not grown in the study site. Sunflowers, lucerne grass, and vegetables such as onions occupy less than 5% of the land in canal-irrigated Maharashtra.

[3] The soils in Maharashtra are clay or clay loams above consolidated hardrock, an impervious layer below which water cannot penetrate. Most of Maharashtra's wells are dug wells and not bore wells (Dhawan 1986). Dug wells empty out after a few hours of pumping and slowly fill up again. Pumping water from these wells does not produce the "cone of depression" of bore wells, so mutual interference is not a major problem (Hauser).

[4] Wells are privately owned in Maharashtra, and though it is understood that they are entirely dependent on canal recharge, it has been politically impossible to charge farmers for groundwater, or to remove the subsidies for rural electricity which powers the pumps.

[5] No international price exists for cane, which has to be processed within a few days of being cut. Its NPC was computed through the procedure followed by the World Bank to estimate the unsupported price of cane as a fraction of the international price for raw sugar. We are grateful to Donald Larson at the World Bank for his help.

[6] All NPCs are at shadow exchange rates. We thank Mandar Jayawant of the Asian Development Bank for his help with sources for, and explanations of, agricultural price policy in India.

[7] Male and female wages are typically different in rural India, and the range of tasks performed by them is not the same. The model solutions, however, are not sensitive to this differential.

[8] Other than location, land size and soil types could also be sources of heterogeneity. In this region, over 70% of the plots are between 3 and 5 acres, and soils are generally clay or clay loam.

such as seeds or irrigation labor per acre, varied little from farmer to farmer. Others, such as labor for harrowing, or fertilizers applied, did vary. In these cases, the input levels reported for each crop were averaged to yield the "representative" input uses per acre employed in the model.[9]

Key Features of the Farming System

The water requirements of the individual crops, the supply to the top of the watercourse, seepage, and the recharge captured by wells are central to the farming system model.

As more water is made available per acre, the yields of most crops increase, but at diminishing rates (Levine, Hillel). The maximum yield is achieved when a crop receives its full water supply, through effective rainfall plus its net irrigation requirement (NIR).[10] The water response function for each crop was derived from experiments carried out at the major agricultural stations in India (IARI). To keep the model as linear as possible, the concave water response functions are broken up into between four and six linear segments. A crop with a lower water availability than its NIR is treated, in effect, as a separate activity with a lower water requirement, and so a lower yield and lower labor use. The final model has forty-two crop activities from which the GAMS solver can choose.[11]

The water requirements for each crop activity are specified not only as annual totals, but are further divided into rotations. Crops have critical periods when water shortages cause a disproportionate fall in yields, which cannot be reversed by adequate irrigation at other times. For wheat, for example, the most water-sensitive stages are crown root initiation and preflowering. To reflect plant physiology as accurately as the data allow, the rotation-wise water requirements take into account any critical growth stage a crop might have.

The model assumes that a known volume of canal water, W, is delivered to the head of the watercourse during each rotation, that farms receive water one at a time starting at the top, and that the water used at each farm can be measured:[12]

$$(1) \qquad W = N\bar{A}r^q$$

where N is the number of farms on the watercourse; $\bar{A}$ is the farm's land endowment (the same for all the farms); and r^q is the amount, in acre-inches, of water, before seepage, that a farm is entitled to in a rotation. The amount r^q is set administratively by the ID; it is not the quantity of water every farmer actually receives. For this model, $r^q = 3$ acre-inches, and therefore $W = 360$ acre-inches per rotation.

In addition to canal water, each farm has a well. The base water column in the representative well, and therefore the water available from it (w_r^b), varies by rotation, dropping to its lowest point during April and May and then rising with the onset of the monsoon rains.[13] The natural aquifer of the Deccan Plateau is extremely poor, and shallow dugwells themselves lose water to seepage and evaporation. Therefore, the potential for rolling over unused water from season to season is quite limited (Dhawan 1986).

Because some canal water is lost to seepage, the model includes these losses as water flows past each farm to the one below it. Part of the seepage on farm k's segment of the watercourse is captured as recharge into its well:

$$(2) \qquad w_{kr}^a = as(w_{kr}^{rem})^{1.5}$$
$$\forall\ k = \text{farm } 1, \ldots, 30$$
$$\forall\ r = \text{rotations } 1, \ldots, 15$$

where w_{kr}^a is the additional recharge into farm k's well in rotation r (in acre-inches); a is the

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[9] The information in the model about the mode of water theft and the behavior of the ID's field staff was revealed by farmers and engineers in confidence. To respect this confidence, the name of the canal where the fieldwork for this research was carried out has been withheld.

[10] The NIR figures for the crops are from the Water and Land Management Institute, Aurangabad, and Mahatma Phule Agricultural University, Rahuri. They are unpublished. We thank Professor J.R. Pawar and the staff of MPAU for their assistance in obtaining them.

[11] The model was initially run with additional crop activities incorporating lower levels of weeding and tilling labor, associated with correspondingly lower yields. These made no difference to any of the optimal solutions.

[12] W, the total water supply, is modeled as a parameter. It is the maximum volume the watercourse could receive when each farmer uses his or her full entitlement. In an ideal system, with storage capacity above the head of this watercourse, W would surely vary by rotation.

[13] The dimensions and pumping capacity of the representative well in the model, and the base water column by season, were compiled from Lal, and from unpublished measurements made in 1988/89 by the Directorate of Irrigation Research and Development, Pune, Maharashtra. The annual water availability from an average canal-tract well in Maharashtra is 250 acre-inches.

recharge factor, set at 0.25 in the model[14]; s is the seepage constant, set at 0.002,[15]; and w^{rem}_{kr} is the canal water passed down from farm k to $k + 1$ in rotation r (acre-inches). The recharge is added in each rotation to the base level of the well. Therefore, the total well water available in rotation r to farmer k is equal to $w^b_r + w^a_{kr}$.[16]

Equation (2) shows that, assuming that all water applied to field crops is consumptively used, each farm's seepage loss and well recharge is a function of the volume of water that is let go down the channel.[17] The functional form of equation (2) is itself a hydrological model, calibrated to the fluid flow and transit loss assumptions used by engineers to construct unlined canal segments through clay soils in India (India, Ministry of Agriculture). The seepage, and therefore recharge, relationship is the only nonlinearity in the farming system model. Transmission losses increase nonlinearly down the watercourse: seepage reduces the rate of flow toward the tail-end, and an even higher proportion of water is lost to seepage at these lower flows (Chow).[18]

Institutional Variations in the Model

Three institutional versions of the model are presented. Each version represents a different decision maker for allocating and monitoring the distribution of canal water. In each version, the farming system relationships are the same, as is the canal water available to the watercourse, W, the base well levels, w^b_r, and the recharge function. The canal water supply equations—that is, the equations of motion linking one farm to the next—are specified separately, however. In other words, the "versions" are not parametric variations of one another.

The first institution is efficient water allocation—or a social planner concerned only with the maximum attainable net revenue over the entire watercourse:

$$(3) \quad Z = \sum_k \sum_j C_j A_{kj} - \sum_k \omega l^h_k - \sum_k (c^w_k + c^c_k)$$

subject to per-rotation family labor, canal water, well water, and land constraints, where C_j denotes the gross margins for an acre of crop j (revenues minus variable input costs); A_{kj} denotes the acres of crop j planted on farm k; ω is the wage rate per day (in rupees);[19] l^h_k denotes labor days hired on farm k; c^k_w denotes repair and electricity bills for operating farm k's well (in rupees);[20] and c^c_k is the cost of canal water (acre-inches used × fee per acre-inch). The equations of motion linking the planner's allocative decisions are

$$(4) \quad W^{rem}_1 = W - w^c_{1r} \quad \forall\, r$$

$$(5) \quad w^{rem}_{k+1,r} = w^{rem}_{kr}(1 - s(w^{rem}_{kr})^{0.5}) - w^c_{k+1,r} \quad \forall\, r \quad \forall\, k = 1, \ldots, N-1$$

$$(6) \quad w^{rem}_{Nr} \geq 0 \quad \forall\, r$$

where w^{rem}_{kr} is the canal water passed down from farm k to $k + 1$ in rotation r; w^c_{kr} is the canal water used by farm k in rotation r; and W is the total water supply at the start of the rotation. Equation (6) is the terminal condition which ensures that more water is not used up along the watercourse than is released at the head to start with. Comparable inequalities constrain the allocatable inputs on each farm.

In programming terms, the "efficient mod-

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[14] The irrigation department estimates that about 25% of the seepage loss is recaptured as groundwater, and that soil permissivity conditions are such that farms with more water passing through their field channels capture more seepage. No firm data are available on how seepage and recharge may vary from season to season. The geohydrological assumptions in this model are, of necessity, best estimates.

[15] According to field measurements on the surveyed watercourse, in the absence of any (discernible) water theft, the flow of water at the last field falls to some 50% of the starting flow. The constant s has been set so that, without theft, the last farm on the watercourse receives a flow of ½ cusec, compared to a starting flow into the channel of 1 cusec (28.3 liters per second).

[16] Gisser and Mercado explicitly include natural and artificial recharge in their replacement flow model, where they analyze optimal water use from an aquifer in steady state. The natural recharge to the aquifer in this model is implicit in the seasonal variations of the base well level, w^b_r. The aquifer is assumed to be at steady state from year to year, but not from season to season within the year.

[17] By allowing a farm to capture all the recharge from seepage along its segment of the watercourse, equation (2) imagines that farmers make their irrigation breach on their farm's upstream boundary.

[18] Ideally, equation (2) should model seepage and recharge as a function of flow rather than of volume. Flow is composed of volume and velocity, so the model implicitly holds the velocity of water constant.

[19] In 1991/92, Rs 30 = U.S.$1 approximately. Male and female labor are assumed available at their respective "going" wages each season. All hiring is from a reserve army of labor, and not from underemployed family labor on other farms. As an experiment, the model was run giving each family member a choice of family farm work or outside employment. Work on the family farm was always chosen, regardless of the farm's location.

[20] The pumping costs are constant per acre-inch pumped. The water table in the Deccan Plateau is high, which keeps the pumping costs low enough to make this a reasonable approximation.

el" is a dynamic optimization over space (Quiggin),[21] with the seepage rate as the analogue of the discount rate in time models. Efficiency requires a balance between sending water downstream because of diminishing increases in yields, and keeping it upstream because of seepage losses. The efficient planner allocates water such that its marginal value to farm $k + 1$, compared to its use on farm k, is just high enough to offset the seepage loss beyond farm k minus the recharge to k's well.

The second institution is the equitable irrigation department (ID), which gives each farmer a fixed number of hours of flow per irrigated acre but is unable to adjust for seepage losses.[22] Given the equal-time rule, seepage, and a farm's location, each farmer's canal water share is now predetermined, independent of any other farmer's water use. The actual water supplies are still connected, because the water not used by one farmer determines the water available downstream from him. No stealing is allowed. This "ID model" conforms to the official allocation policy.

The third institution is the individualistic farmer, concerned only with his own welfare, and prepared to steal extra water if he needs it. The fixed-hours-per-acre rule is still in operation. However, once the water comes to his field, he simply takes it until the marginal benefit of the last unit used equals its marginal cost to him. Then he sends the unused water, if any, down to the next farmer. If his theft is noticed by the canal inspector, he knows how much he has to pay to remain officially undetected.[23] If he wants only a small amount of water, and the subsidies to pumping are sufficiently generous, he may rely on recharge alone, forgoing both his official allotment as well as theft. This "theft" version is a simplification of the truth on the ground, at least on the Deccan Plateau.

Officially, the irrigation department fines a farmer for water theft, but this fine is fixed per acre and does not change with the rotation. As a result, the unofficial bribe stays within a narrow range.[24] Theoretically, the equilibrium bribe can be looked at as a bargained outcome between a farmer and the *patkari.* The farmer would rather have the water at a price lower than the official fine, and the canal inspector does not want to ask for so much money that the farmer becomes indifferent to paying him and paying the official fine.

There is nothing, on the ground or in the model, to prevent downstream farmers from stealing water, or from trying to pay off the canal inspector. Some downstream farmers, especially wealthy or influential ones, successfully do so. Canal inspectors rarely have enough control over the water to act as discriminating monopolists, selling each unit of water to the highest bidder regardless of location. Thus most theft takes place along the upper reaches of a canal system, because it is much easier for those upstream to take the extra water when they need it.

In both the ID and theft versions each farmer maximizes his individual profits, so these models cannot be solved as collective optimizations over space. In the mathematical program, the model is first solved for farmer 1 alone. The starting water supply for farmer 2 is known only after farmer 1 has taken out his optimal amount, w_1^c, and has released the remaining w_1^{rem} back into the system. The model is solved iteratively, farmer by farmer, by reassigning the water supply parameters to take account of increasing seepage losses after each iteration. The linear program, through a series of static optimizations, arrives at a sequential equilibrium for the watercourse.[25] The objective function for an optimizing farmer is

$$(7) \qquad Z = \sum_j C_j A_j - \omega l^h - c^w - c^c.$$

In the theft version, c^c, the cost of canal water, has an illegal component made up of the water stolen and a per-unit bribe. In the model, the bribe is exogenous, the same for all the farmers, and unrelated to the marginal value of the water. It is above the charge for the legal allotment.

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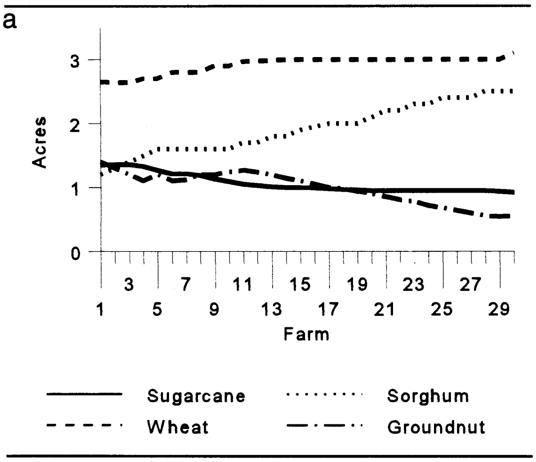
[21] For a control theoretic rather than programming approach to efficient allocation over space, see Chakravorty, Hochman, and Zilberman.

[22] The irrigation department does take into account seepage along the main, branch and minor canals (figure 1). But within a watercourse, which is a small hydraulic unit, the administrative resources do not exist to monitor seepage (or theft) effectively. So an equal number of hours per acre is the common practice.

[23] Water theft is usually not as blatant as this. Although influential farmers and large sugarcane growers steal water almost openly, others try to steal discreetly, so they can avoid being fined by the canal inspector or being embarrassed by their field neighbors.

[24] On the canal studied, the expected bribe worked out to between one-half and two-thirds of the official penalty. During the peak stealing period, the average bribe was much lower than the marginal value of water, as was the official fine.

[25] Gisser analyzes the problem of mining groundwater under different property rights laws. The "institution" of theft here corresponds most closely to Gisser's competitive equilibrium among a finite number of farmers above the aquifer, with "absolute ownership," or the right to pump any amount of water.



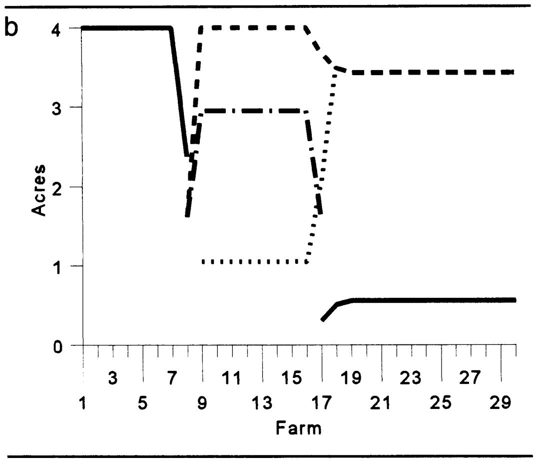


Figure 2a. Cropping patterns with ID, private prices
Figure 2b. Cropping patterns with theft, private prices

The canal water supply passed down from one farmer to the next is given by

$$(8) \quad w^{rem}_{kr} = w^{rem}_{k-1,r}(1 - s(w^{rem}_{k-1,r})^{0.5}) - w^{c}_{kr}.$$

In the model incorporating theft, farmer *k* can use all the canal water coming down to him, if he is prepared to pay the necessary bribe. In the ID version, an additional "legitimate water allowance" constraint ensures that he can use only his predetermined share. This constraint is the main distinction between these otherwise identical versions.

Price Regimes

With the three versions in place embodying different institutional assumptions, parametric variations represent three different price regimes. Of course, an infinite number of price regimes is possible. The three regimes in this analysis were chosen because they represent the "real world" during the study period, the world considered in a major policy debate among water economists, and the "ideal world" without price interventions, respectively. The first regime is one with the prices prevailing in the study region in 1991/92. To recapitulate, water and electricity are heavily subsidized, sugarcane has a high support price, winter wheat has a low market price, and hired labor receives legislatively set minimum wages.[26]

The second price regime keeps intact the private output and labor prices but removes the water subsidies substantially. Canal water is now priced so that the operational cost, including maintenance and monitoring, of the canal infrastructure would be recovered from the water users' fees. Electricity for the wells is not subsidized, and the water from them is no longer free.

Finally, the third price regime represents social prices for all the inputs and outputs: the procurement price for wheat is removed, the prices of all three coarse cereals are raised slightly because their demand is expected to rise if wheat becomes more expensive, the sugarcane price is dropped to its free-market rate, water is priced to recover the irrigation department's annual operating costs, and labor wages are allowed to drop below the state-set minimum. The version with social prices and under the allocation mechanism of the efficient planner is the benchmark against which all the other versions can be evaluated.

The Consequences of Price Policies

Among the nine price-institution combinations, reality on most canals lies between ID and theft at private prices, but closer to theft. Figure 2 shows the cropping patterns down the watercourse in the relevant model solutions. In each case, the crops chosen are the same, but their distributions along the watercourse are sharply differentiated. When the irrigation department succeeds in enforcing its allocation rules (figure 2a), all the farmers

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[26] In 1991/92, the legislated daily wage rates were Rs 25 (just under U.S.$1) for males and Rs 15 for females. Informal surveys showed that, in this labor-surplus region, the "market" rates would have been about Rs 15 and 10 respectively.

have some land permanently under sugarcane, and the rest is in a three-season rotation of sorghum, wheat, and groundnuts. When the ID cannot enforce its rules and farmers steal water (figure 2b), the upper third of the watercourse is dominated by cane, and the middle grows a small amount of monsoon sorghum and a winter-summer rotation of wheat and groundnuts. Tail-end farmers grow a half acre of sugarcane, although at a lower yield level, and place the rest of their land in a monsoon-winter rotation of sorghum and wheat.

In the theft version at private prices, sugarcane occupies 19.5%, sorghum 28%, winter wheat 38%, and hot weather groundnuts 14% of the gross cropped area. From surveys conducted on four canal systems of Western Maharashtra—the Mula, the Girna, the Pravara, and the Nira—between 1984 and 1989, the average land use was sugarcane 16%, sorghum 22%, millets 5%, winter sorghum 20%, winter wheat 20%, and summer groundnuts 12% of gross cropped area (WALMI; Dhongade, Suryawanshi, and Deshmukh 1986a,b; Rath and Mitra).[27] With the exception of sorghum, a food crop, the crops and their cropped areas are not far from those in the model solution.[28] Many canals in Maharashtra, including the one where the survey was conducted, display a marked crop differentiation along their lengths.

It is interesting to relate the farmers' crop choices to the shadow price of water. The water supply constraints are separately specified for each of fifteen rotations, so the model solutions have fifteen sets of shadow values, per farmer, in one year. The solutions reveal how the adequacy or inadequacy of a single irrigation turn can drive a farmer's cropping pattern for the entire year. They also indicate that, if the farming system model is sufficiently disaggregated by season, there may not be a simple correspondence between the shadow price of water and its marginal revenue product. As an example, figure 3a plots the marginal value of water (MVW) in one rotation in May, under the social planner, the irrigation department, and theft, with the prices prevailing in 1991/92. May is a tight water month in Maharashtra—the clay soils are cracking, the well levels are low, and the net irrigation requirements of standing crops are high. Figure 3b shows the canal water stolen, farmer by farmer, during the same rotation.

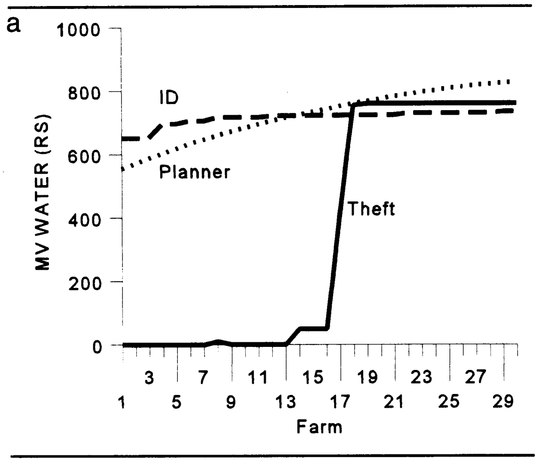

Figure 3a. Marginal value of water under private prices and three institutions, rotation 13 (May)

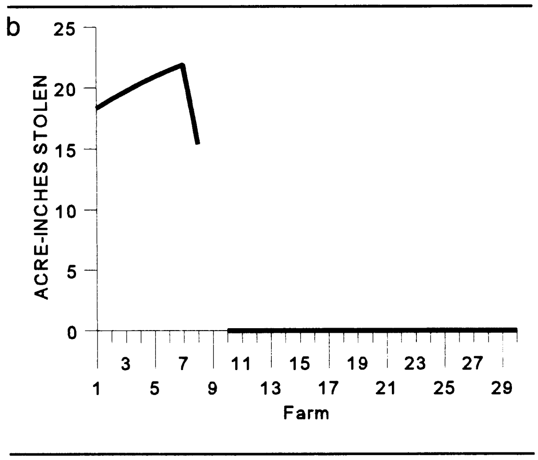

Figure 3b. Water stolen in rotation 13 (May), under private prices

When the social planner distributes water down the channel, farm $k + 1$ receives its first unit of water only when its MV is just high enough to offset the seepage (minus recharge) losses in transit from farm k. Figure 3a shows the resulting steady increase in the shadow price of water from farm 1 to farm 30. With the ID in control of the channel, every farmer has to stop irrigating while the shadow price of water is still high—it increases down the canal from Rs 652 to Rs 735. With theft, the shadow price rises as a step function. Farmers 1 to 7 steal canal water (see figure 3b)—for

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[27] On the Girna sugarcane was not raised. Cotton occupies 14% of this black soil region.

[28] Wheat is much more lucrative and water-sensitive than sorghum, so where the water supply is predictable, as in this certainty model, more wheat is raised. On the lower third of actual canal systems, sorghum is common (WALMI).

Table 1. A Comparison of Price and Water Allocation Regimes

Price and Allocation Regime	Social Planner (Efficient)	Irrigation Dept. (Equitable)	Individual Farmer (Theft)
No water subsidies; No minimum wage; No support prices	Revenues: 895,778[a] *Social surplus*: 895,778	Revenue: 873,281 *Social surplus*: 850,784[b] DWL: 22,497[c]	Revenues: 847,118 *Social surplus*: 798,458 DWL = 48,660; Water stolen: 299.2 acre-inches out of 1,800 supplied between April and June. All stealing is for groundnuts.
Crop price supports; Minimum wages; No water subsidies	Revenues: 888,308 *Social surplus*: 759,688 DWL: 136,090	Revenues: 862,467 *Social surplus*: 752,887 DWL: 142,891	Revenues: 840,038 *Social surplus*: 699,205 DWL = 196,573; 605.7 acre-inches of water stolen out of 1,800 supplied. All stealing is for sugarcane.
Prevailing private prices (1991/92)	Revenues: 961,916 *Social surplus*: 702,246 DWL: 193,532	Revenues: 938,447 *Social surplus*: 729,067 DWL: 166,711	Revenues: 925,023 *Social surplus*: 679,439 DWL = 216,339; 605.7 acre-inches of water stolen out of 1,800 supplied. All stealing is for sugarcane.

[a] "Revenues" means the net revenues on the entire watercourse, minus variable costs, and before taxes and subsidies have been netted out. All figures are in rupees.

[b] "Social surplus" is the net revenue on the watercourse minus the lump-sum taxes necessary to finance the price regime.

[c] "DWL" is deadweight loss from the relevant policy regime, compared to box 1 with efficient water allocation and no price interventions.

them, the land constraint is binding and the MVW is zero. Farmer 8 is the last to steal, but he does not get quite enough for 4 acres of sugarcane. His MVW is positive but small. Farmers 9 to 13 have switched out of sugarcane to a less water-intensive winter-summer rotation of wheat and groundnuts. Their MVW is Rs 1.5—the cost of pumping additional water from their own wells, which still have water in them.[29] The shadow price of water for farmers 14 to 16 is Rs 50—the cost of one unit of (illegally obtained) canal water. This means that they have exhausted their wells. They could have stolen a unit of canal water rather than let it go downstream, but they chose not to.[30] Farmer 17 is the last one on the watercourse to get any canal water during the May rotation; its shadow price is high at Rs 418. From farmer 18 down no one gets any canal water at all. They exhaust the entire supply available from their wells, and the value of one more unit of water here is at it highest, at Rs 761.

Under the theft regime, although the desire to steal is evenly distributed along the channel, the opportunity to steal is concentrated upstream. Farmers 1 to 8 simply "buy" extra water from the canal during the critical months of April, May, and June. All of this extra water is used for sugarcane. The farmers lower down do not steal, not because they are law-abiding, but because not enough canal water comes down to them when the marginal value of the water is highest. This pattern of stealing only in the warm weather months and only for sugarcane was exactly as reported by most of the interviewed farmers in the study villages.

The key results from the nine combinations are shown in table 1. Each "box" of the table indicates the net revenues earned by all thirty farms on the watercourse and the deadweight losses (DWL) from a particular price-allocation regime. By definition, the efficient allo-

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[29] As long as well water is available to supplement canal water, the shadow price of canal water will never exceed the cost of pumping groundwater, regardless of its actual revenue product. The shadow prices vary sharply because the model does not allow water to be stored in the wells from one season to the next.

[30] It may appear surprising that these farmers do not expand their acreage by using a little more canal water, rather than pass it along to their neighbors. This is because their water supply was more severely constrained in a previous rotation (rotation 10), which locked them into cultivating only a part of their land for the April to June season. A farmer's MVW in one rotation is strongly dependent on his or her water supply in all rotations.

cation at social prices is the social optimum. If allocation and price interventions cause deadweight losses, the theft-private prices combination ought to be particularly inefficient. Table 1 confirms that this is indeed the case, after the total net revenues have been adjusted through lump-sums for the expenditure on subsidies and the revenue from taxes in the system.[31]

Each row of table 1 represents a distinct price policy. The different figures for the deadweight loss in each box show the extent to which the true cost of price interventions is influenced by how farmers use water. In row 2, water and electricity are not subsidized, but sugarcane is. If the analyst assumes that the water is efficiently allocated, the DWL from this price policy alone is 15% of the social optimum. However, if water is rationed and then siphoned off, the DWL from the price and allocation distortions rises to 22%—a significant difference. Row 3 compares the institutional regimes under private prices. Again, if the analyst assumes that the efficient allocation of water is the norm, or even the intent, the DWL from the price policy is 21.6%. If the analyst knows that theft is the norm, the DWL would be 24.2% of the social optimum—a smaller additional cost than might have been expected.[32]

The DWL figures in row 2 under all three allocation rules are lower than in row 3, principally because the farmers have lost the highly wasteful incentive to let surface water seep into their wells to be pumped up again at a lower charge. Yet a comparison of the two rows shows that the additional social welfare from removing water subsidies differs with the method of allocating canal water.

It should be noted that, under private prices, the most socially beneficial regime is not the planner but the equitable irrigation department. With artificially high sugarcane prices, the "efficient" planner allocates too much water, especially during the hot-weather rotations, to upstream farmers growing cane (figure 4). The forced equality of the ID rules compensates to some extent for the price distortions.

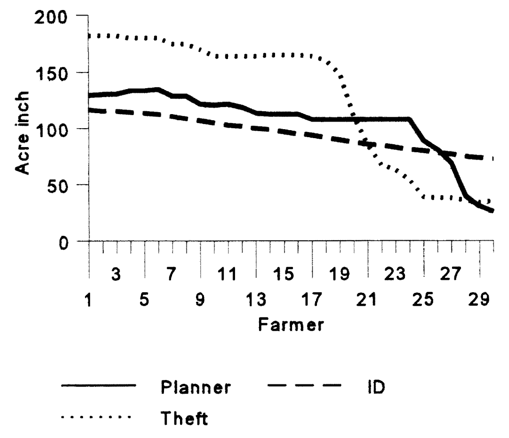

Figure 4. Annual canal water allocation, private prices

Estimating the social cost of price policy demands an understanding of when and why farmers steal water. Similarly, estimating the social cost of water theft requires understanding the role of relative prices. The model solutions show that when sugarcane is subsidized, the top seven or eight farmers grow exclusively sugarcane and steal water for this crop. Because of this concentration of sugarcane, theft is more inefficient than the irrigation department rules within both the no-water-subsidy and private price regimes.

Could the government eliminate theft by removing output price supports, and/or by taxing them? The theft box of the social prices row in table 1 indicates that when sugarcane is no longer supported, farmers switch from stealing for cane to stealing for groundnuts. The amount of water stolen drops because groundnuts need less water than sugarcane in the critical hot weather months. If the government now tries to lower groundnut prices, figure 5a shows that as groundnut prices drop from Rs 650/q (an 18% subsidy) to Rs 450/q (an 18% tax), less and less water will be stolen. Through such a price policy it is feasible only to contain theft, not to eliminate it. Once groundnut prices fall below Rs 450/q, even unsubsidized sugarcane becomes relatively attractive, and so the water stolen rises sharply. The amount of water that farmers steal, at least over this range, is strongly related to the relative prices and the water requirements of crops.

The social cost of price interventions for groundnuts, relative to the efficient allocation–social prices box of table 1, follows a pattern

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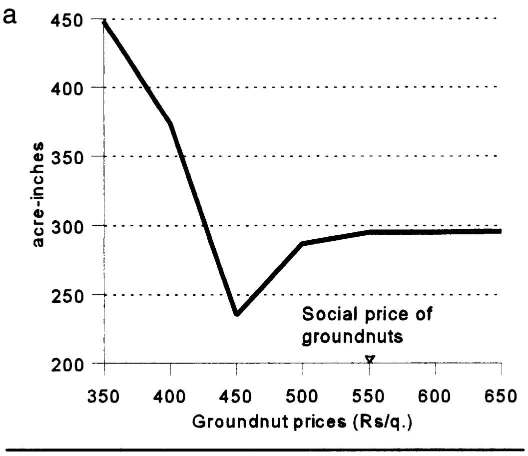
[31] The deadweight loss calculations for the theft column treat water paid for with a bribe as water with a smaller subsidy than legally provided water. It is probable that if the official price of water rose, so would the unofficial price of theft. In the model, however, the bribe is the same for all the price regimes.

[32] Seepage also matters. On a well-maintained watercourse, theft is more inefficient than on a leaky one, because the effect of diminishing returns would quickly overcome the effect of seepage.



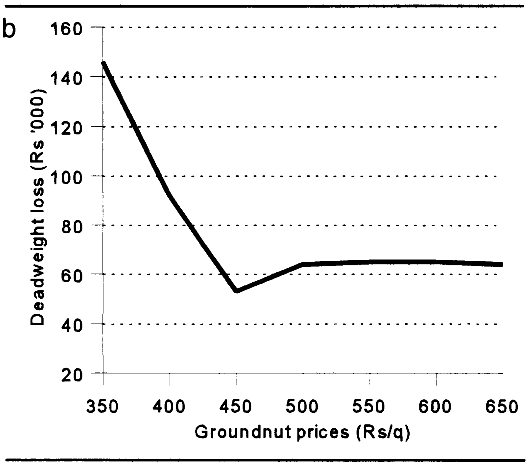


Figure 5a. Canal water stolen, April–June, out of 1,800 acre-inches supplied, if no sugarcane support price
Figure 5b. Social cost of groundnut taxes and subsidies, no sugarcane support price

very similar to the water stolen (figure 5b). As groundnut prices drop from Rs 650/q to Rs 350/q, the deadweight loss function drops gradually, reaches its lowest point at Rs 450, and then rises sharply. Theft causes upstream farmers to use more water than is efficient, so a small tax on the commodity they steal for—groundnuts in this case—moves the watercourse closer to the social optimum. But the deadweight loss from theft never falls to zero by using price policy as an instrument.

Heterogeneity on the Watercourse

Changes in taxes or subsidies or relative prices have distributive consequences for heterogeneous rural interest groups. The political economy of price policy is concerned with questions of distribution: Who will be better off if the price regime changes, and who is likely to resist the change? Even when the changes under consideration are geared toward social efficiency, their differential impacts on heterogeneous farmers may make them politically infeasible. Much of the literature on inequality has been preoccupied with landholding size, and this is indeed the most prominent face of heterogeneity in rural India (de Janvry and Subbarao, Dhawan 1988, Pant).[33] On a canal, however, the core heterogeneity stems from the physical feature of the resource itself. The flow of water from the head to the tail imposes asymmetry on the farmers. Even if they are identical in their landholdings and their farming practices, they are unlikely to win or lose from relative price changes in the same way.

From the equity point of view, theft is always more skewed than the irrigation department's water allocation, for any set of prices. Whether theft is more or less equitable than the efficient planner depends upon the price regime. Table 2 shows the ratio of net revenues from farming between farmers 1 and 30 (π_1/π_{30}) for each price-allocation combination. If the government removed all price supports and input subsidies, theft is not any more inequitable than the social planner. Sugarcane is the most water-intensive crop and, at social prices, it is not worth stealing water for. At the prices prevailing in 1991/92, in contrast, theft is much more inequitable than the other two allocation regimes.

Figure 6 compares the distributive consequences on the watercourse of a change from private prices to social prices, assuming that farmers observe the ID rules of allocation (figure 6a), and under the more realistic premise of theft (figure 6b). With the irrigation department in charge, every farmer gets equal irrigation time but not an equal amount of canal water; the net revenues from farming decline steadily down the watercourse. All farmers would have the same reaction to a change in the price regime, because the curve under private prices (e.g., with sugarcane subsidies) lies everywhere above the curve under

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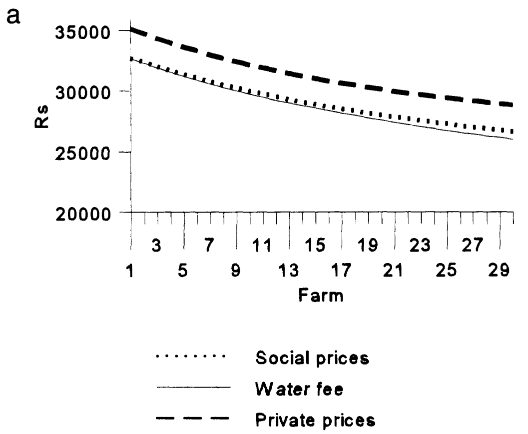
[33] Other sources of heterogeneity, such as differences in skills, risk aversion, or political influence, have generally been tied to the difference in asset ownership.

Table 2. Net Revenues at Head and Tail of Watercourse

Price and Allocation Regime	Efficient	Equitable	Theft
No price supports	π_1/π_{30} = 1.54	π_1/π_{30} = 1.23	π_1/π_{30} = 1.5
Crop price supports; No water subsidies	π_1/π_{30} = 1.94	π_1/π_{30} = 1.26	π_1/π_{30} = 1.91
Private prices	π_1/π_{30} = 1.68	π_1/π_{30} = 1.22	π_1/π_{30} = 1.91

social prices.[34] If the government imposed higher water fees, or removed supports and subsidies altogether, the entire channel would be worse off, but there would be no conflicts within it.



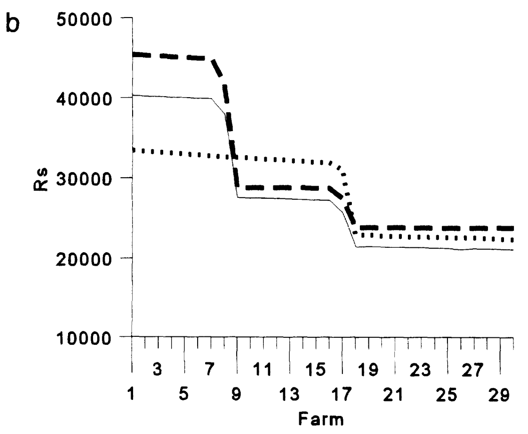


Figure 6a. Net revenues under ID rules, three price regimes

Figure 6b. Net revenues with water theft, three price regimes

When monitoring on the canal is lax and the farmers subvert the allocation rules, the change from private to social prices is no longer uniformly unwelcome. The top eight farmers are much better off with sugarcane subsidies than with social prices, and the bottom twelve farmers are slightly better off too, and no doubt would resist the change in relative prices.[35] The middle farmers would prefer a shift to social prices. When farmers steal for groundnuts, which use up less summer water than cane, the land constraint binds for the upstream farmers. They pass down some water, and with it, some stealing opportunities, to the middle third, which is therefore better off without any output price supports. Without a model that explicitly incorporates location and theft, it would be hard to see why some farmers could gain from a fall in the price of a crop they do not even grow.

Conclusions

Agricultural prices, taxes, and subsidies are powerful policy tools for a government that wants to advance its production or welfare goals. For its policies to be effective, it must predict how heterogeneous groups of farmers will alter their chosen crops and water use. A key determinant of a farmer's response is his or her access to water, especially where agriculture depends on irrigation from a canal. Other things being equal, downstream farmers on a canal suffer disproportionately from upstream seepage. They also lose more water to theft, a widely observed phenomenon on canals in India and elsewhere. A government concerned about the welfare implications of existing prices should explicitly acknowledge that many farmers steal water. Conversely, a government concerned about the social cost of water theft must understand the contribution of its own price distortions.

In the empirical literature on irrigation

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[34] The curves have not been adjusted downwards for the lump-sum of the costs of subsidies. If figures 6a and 6b are adjusted, the qualitative analysis remains unchanged. Nor is any compensation being considered in the change from one set of prices to the other.

[35] Figure 1b shows that the tail third raises a small amount of sugarcane in the private price regime.

management, the importance of location in a farmer's access to water has frequently been observed and documented. The analyses have mostly been descriptive, for example, survey results of water scarcity at the tail-end of a channel, or records of the changing crop patterns down a canal (Chambers, Wade). But such knowledge does not tell the analyst how farmers would respond to major changes in price policy. To quantify the nature and magnitude of these price-allocation interactions, we developed a location-centered, mathematical programming model of a canal, with a number of farms in sequence. The model's central features are the spatial flow of surface and subsurface water, seepage, the seasonal interlocking of year-round agriculture, and farm-level optimization. With a realistic range of crops, technical coefficients, and water response functions, the data-driven model determined each farmer's water deliveries, actual water use, and optimal crop choices, and how these varied with the price regime. More important, the model made the water deliveries to downstream farms endogenous to the choices made by individually optimizing upstream farmers.

Solutions that emerge for a wide choice of inputs and outputs are believable and can be used with confidence to make policy decisions in particular instances. Specifically for the state of Maharashtra, welfare losses from the price regime in place in 1991/92 were much higher than those from theft alone, although theft is undoubtedly both inefficient and inequitable. The deadweight loss from theft under private prices was 24% of the revenues earned in the efficient water allocation–social price regime, which is a very high annual cost. An effective way to counter theft is to reduce the minimum prices guaranteed to farmers for sugarcane so that other, less water-consuming, crops such as groundnuts become more attractive. Sugarcane subsidies, moreover, are a greater cause of social inefficiency than water subsidies, whose removal is often debated among resource economists (Repetto, Datye).

Of course, changes to the price regime can lead to political upheaval. Higher wheat prices would make urban consumers and marginal farmers, who are net buyers of food, unhappy. The sugar mills, which benefit from cane-crushing subsidies, are organized and vocal, and would rally against their removal (Rosenthal). In the presence of water theft, farmers along a canal might also have strong, and location-specific, views on price policy, even when they do not raise the crop or use the input whose price may be about to change.

Perhaps the only viable management option for the direct control of theft—other than turning the watercourse over to the farmers themselves—is to step up the quantity and the quality of the irrigation department's own monitoring efforts. Even so, at the distorted output prices of 1991/92, the deadweight losses from theft are only slightly higher than those from a socially efficient distribution. The resultant efficiency increase might not justify the increase in canals' operating costs.

[Received May 1998;
accepted January 1999.]

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