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ESSAY 2

# THE GREEN REVOLUTION AND THE ECONOMICS OF PUNJAB AGRICULTURE

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The decade of the 1960s marked a profound change in the "traditional" agriculture of the Punjab. Aggregate growth rates that had been closely related to the rate of population expansion for a quarter of a century began to accelerate rapidly. Instead of an increase of 1.2 percent per annum that characterized the 1930 to 1960 period, the gross value of production increased at a rate of nearly 5.0 percent. To be sure, there were significant year-to-year variations, both in aggregate output and crop composition, but the conclusion that fundamental structural changes had taken place was inescapable.

Because much of the increased output in the late 1960s was related to the introduction of improved varieties of wheat and rice, it became fashionable to speak of the Green Revolution. However, as noted elsewhere, the agricultural growth Pakistan exhibited toward the end of the decade was actually an extension of a trend that had begun several years earlier (*1, 3*). For the anatomy of the Green Revolution in the Indus Basin had it origin, not with improved seeds and fertilizer, but with additional water for irrigation. The principal source of these supplementary supplies was groundwater. As the preceding essay indicated, there were already rather widespread attempts to tap the resources of the acquifer with traditional methods, but the cost of using bullock-powered Persian wheels was too high to make large-scale withdrawals profitable. It was only with the advent of more efficient mechanical technology in the form of tubewells that water could be withdrawn at unit costs that revolutionized the economics of agriculture.[1] Indeed, so profitable were investments in motors, engines, pumps, and wells that from approximately 30,000 tubewells in 1964/65, the total number installed in 1971/72 had risen to 95,000. Most of the wells were approximately one cusec in capacity and they added roughly 50 percent to the available water supply in the Central Punjab between 1960 and 1970.[2]

The increased water supplies were crucial to the expansion of output, par-

[1] The name "tubewell" has been given to bored, as opposed to open wells, in a number of developing countries. In the Punjab, the bore is normally sunk by percussion to a depth of 80 to 100 feet. The efficiency of the attached centrifugal pump is increased by setting it at the bottom of a 15-foot hole. A 20- to 25-horsepower slow-speed diesel engine is connected by belts from the ground level to provide power.

[2] One cubic foot per second (cusec) of water running for 12 hours equals one acre-foot, i.e., an acre covered to a depth of one foot.

ticularly through increases in the intensity of cropping. However, the impetus of this source of growth would surely have waned by the late 1960s without the introduction of technology that increased output per acre. From 1965/66, when the first trials of high-yielding wheat varieties were carried out on farmers' fields, to 1969/70, total wheat output increased by 85 percent. During the same period, national wheat yields, according to official estimates, rose by over 50 percent. Similarly, total rice output increased from less than 1.5 million tons in 1967/68 to 2.4 million tons in 1969/70; rice yields increased by nearly 40 percent.

This brief description of the anatomy of the Green Revolution in the Punjab provides evidence that profound changes have occurred in the area. It also presents a challenge to incorporate some of the new production coefficients into a model of traditional agriculture similar to that developed in Essay 1 and to trace out their impact on the farm enterprise. For example, with increased water supplies it could be expected that land constraints would become binding and that this would significantly affect the optimal cropping pattern. Similarly, the addition of high-yielding varieties should have a substantial effect on the optimal allocation of resources. Not only have the net revenues from wheat and rice been significantly altered, but their associated land, water, and labor requirements have changed as well.

The impact of the new production technology on the model's performance is explored in the paragraphs that follow. It should again be emphasized that the linear programming framework leaves many issues raised by the progress of the Green Revolution untouched. However, this essay suggests that with a little ingenuity, useful insights can be obtained into the impact of new technology on the supply curves of different crops, appropriate incentives for new inputs, and the distributive effects of technical change. These are important problems and justify further elaboration of the basic model developed earlier.

## IMPROVED TECHNOLOGY AND THE BASIC MODEL

The introduction of variables that simulate the Green Revolution technology is fairly straightforward.[3] They consist of (1) water production activities that simulate the tubewell, and (2) crop activities that incorporate data on high-yielding wheat, rice and maize varieties.

### *The Tubewell*

One set of water production activities (simulating a Persian wheel) is already contained in the "traditional" agriculture model. The tubewell activities are similar in that they deliver water to the rows defining water use and availability. However, unlike the Persian wheel, the energy source is an engine whose cost of operation is included in the objective function. In addition, a series of capacity constraints is required to insure that the engine and pump are not operated more than 24 hours a day. (The actual figure used is 22 hours to allow for maintenance and fueling.)

Because of the "lumpiness" of the tubewell investment, farmers having only

[3] The empirical parameters of the model reported in this essay have been drawn from farms lying south of the area investigated in Essay 1. Differences in soil and climate have produced a somewhat different cropping pattern in the "traditional" technology case. The structure of the models is identical.

12.5 acres are unlikely to have a well of their own. Various farm surveys have indicated that most wells in the Central Plains supply approximately 75 acres. A plausible share would therefore be one-sixth. Assuming 22 hours per day, this gives a capacity constraint of approximately 110 hours per month.

### *High-Yielding Varieties*

Eight new activities have been introduced to simulate high-yielding varieties: four for wheat and four for rice. The procedure for determining the relationship between water and yields is the same as that used to determine the steps in the plant-water production function of the "traditional" model (see Essay 1, Appendix). The net revenues of each set are, of course, significantly higher than those associated with local varieties, a difference that reflects the higher yields and lower unit costs of the improved strains.

Other input coefficients have also been changed. The optimum planting date for the new wheat varieties as determined from experimental data, for example, is now November 1 instead of October 15. Land coefficients have been altered accordingly. Higher yields have also meant increased human and animal labor requirements at harvest time, requiring an alteration in the $a_{ij}$'s[4] associated with these resources.

## A NEW BASIC SOLUTION

Table 2.1 describes the impact of the new technology on the primal solution of the basic model. Four separate cropping assumptions have been examined, each of which is further divided by assumptions regarding the presence or absence of a tubewell. For comparative purposes, traditional technology refers to the varieties, levels of fertilizer applications, water and labor requirements used in the basic model. *Improved wheat* technology refers to solutions in which only activities representing high-yielding wheat varieties have been added; *improved rice* technology indicates the inclusion of improved rice varieties, and higher doses of fertilizer.

It is obvious from the table that the introduction of the tubewell with its inputs of additional, flexible water supplies produces a radically different cropping pattern even in areas where it is assumed that year-round canal supplies are available. The acreage under crops like cotton, sugarcane and fruit that have high water requirements increases at the expense of low water-users like wheat and oilseeds.

The adding of activities that simulate improved wheat varieties has little effect on the cropping pattern when historical canal deliveries are assumed. The improved varieties are assumed to have a significantly lower unit cost than the local wheats, but the water constraints so dominate the allocation of land among crops that the cropping pattern remains virtually unchanged.

The combination of tubewells and high-yielding wheat varieties produces a cropping pattern in which, in contrast to tubewells and traditional technology, wheat plays an important role. In addition, net revenue is increased substantially by large acreages under high valued crops like fodder, sugarcane, and orchards.

Introducing improved rice technology points up the interrelationships be-

[4] Input per unit of output.

TABLE 2.1.—OPTIMAL CROPPING PATTERNS AND CROPPING INTENSITIES IN THE CENTRAL PUNJAB WHEAT-COTTON AREA UNDER ALTERNATIVE TECHNOLOGICAL ASSUMPTIONS*

*(Percent except as otherwise indicated)*

| Crops | Traditional technology | | Improved wheat technology | | Improved rice technology | | Improved wheat and rice technology | |
|---|---|---|---|---|---|---|---|---|
| | Without tubewell (1) | With tubewell (2) | Without tubewell (3) | With tubewell (4) | Without tubewell (5) | With tubewell (6) | Without tubewell (7) | With tubewell (8) |
| Winter crops | | | | | | | | |
| Wheat | 43.5 | 8.8 | 45.1 | 42.2 | 42.7 | 31.0 | 44.3 | 34.3 |
| Barley | | | | | | | | |
| Oilseeds | 2.6 | | 2.7 | | | | | |
| Gram | | | | | | | | |
| Fodder | 14.0 | 12.0 | 6.8 | 11.9 | 11.1 | 10.5 | 6.9 | 5.0 |
| Sugarcane | | 6.9 | | 6.9 | 4.8 | 6.1 | 3.7 | 5.6 |
| Vegetables | 1.1 | 1.4 | 1.7 | 1.4 | 1.6 | 1.2 | 1.7 | 1.1 |
| Orchards | | 2.1 | | 2.1 | | 1.8 | | |
| Subtotal | 61.2 | 31.2 | 56.3 | 64.4 | 60.2 | 50.6 | 56.6 | 46.0 |
| Summer crops | | | | | | | | |
| Rice | 2.3 | | 5.2 | | 8.5 | 24.0 | 7.7 | 37.7 |
| Cotton | 25.5 | 50.8 | 27.1 | 16.8 | 15.8 | 9.0 | 20.1 | |
| Maize | | | | | | | | |
| Fodder | 10.2 | 9.2 | 10.6 | 9.2 | 9.9 | 8.2 | 10.4 | 7.5 |
| Sugarcane | | 6.9 | | 6.9 | 4.8 | 6.1 | 3.7 | 5.6 |
| Vegetables | .8 | .6 | .8 | .7 | .8 | .6 | .8 | .5 |
| Orchards | | 2.1 | | 2.1 | | 1.8 | | |
| Subtotal | 38.8 | 69.6 | 43.7 | 35.7 | 39.8 | 49.7 | 42.7 | 51.3 |
| Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Total cropped acreage | 11.8 | 14.5 | 11.8 | 14.6 | 12.2 | 16.4 | 11.5 | 17.7 |
| Cropping intensities | 94.0 | 116.0 | 95.0 | 117.0 | 98.0 | 131.0 | 92.0 | 142.0 |
| Net revenue (*rupees*) | 2,034 | 3,192 | 2,358 | 3,649 | 2,197 | 3,382 | 2,475 | 4,131 |

* Based on 12.5-acre farm.

tween crops that characterize irrigated agriculture. Without a tubewell, the increased profitability of rice results in a larger acreage devoted to rice at the expense of another summer crop, cotton.

When a tubewell is added, rice acreage increases even more. Unlike the traditional technology case, however, where the introduction of a tubewell was accompanied by an increase in the summer crop (cotton) that drastically reduced the amount of wheat grown, the increase in rice acreage has had very little effect on the winter cropping pattern. This is because the growing season assumed for rice is short enough so that a crop of winter wheat, albeit one with a relatively low yield, can follow rice.

The above results are only reinforced when both improved wheat and rice activities are introduced into the model. Again, so long as water is a binding constraint, the major effect of such a change is a "yield effect" as the model maximizes the returns to the seasonal distribution of water. Once this set of constraints is broken, the profitability of improved wheat and rice together, grown one after the other, is sufficient to force cotton from the cropping pattern entirely. The wheat-rice rotation is also sufficiently profitable to remove a perennial crop such as orchards, although it still does not have comparative advantage over sugarcane.

One of the interesting general results that can be derived from Table 2.1 is the complementarity that exists between the new technology and the provision of supplementary water supplies. For example, comparison of column (1) and (7) indicates that without a well the increase in net revenue from high-yielding varieties is approximately 20 percent; a similar comparison of columns (1) and (2) shows that adding well water yields an increase in net revenue of about 50 percent. The sum of these individual changes is 70 percent, well below the 100 percent increase in net revenue that results from adoption of water and the seeds and fertilizer package. This difference, of course, is not the result of the physical complementarities between water, fertilizer, and dwarf varieties of which agronomists speak. Rather, it arises from the opportunity to increase the acreage under profitable high-yielding varieties when a flexible supply of supplementary water is available.

*Scarcity Values of Binding Constraints*

It is well known that the implicit resource and constraint values shown in the "dual" solutions of programming models are frequently of greater interest than the activity levels shown in the primal solution. For one thing, these values are much more stable and unlikely to exhibit the disconcerting flip-flop behavior that sometimes characterizes the primal. Moreover, perusal of the constraint values immediately directs attention to the critical parameters to which the activity levels are sensitive (Table 2.2).

As columns (1), (3), (5) and (7) indicate, without tubewells the cropping pattern is largely determined by the available water supplies and, of course, the constraints that require and limit the production of fodder, and other special crops. The months during which there is an overlap between the summer and winter cropping season tend to have the highest values although values for March are, at least in two cases, also important. The significance of these constraints is

TABLE 2.2.—CONSTRAINT VALUES FOR THE OPTIMAL CROPPING PATTERNS IN THE CENTRAL PUNJAB WHEAT-COTTON AREA
(*Rupees*)

| Resource/Crop constraints | Traditional technology | | Improved wheat technology | | Improved rice technology | | Improved wheat and rice technology | |
|---|---|---|---|---|---|---|---|---|
| | Without tubewell (1) | With tubewell (2) | Without tubewell (3) | With tubewell (4) | Without tubewell (5) | With tubewell (6) | Without tubewell (7) | With tubewell (8) |
| Water (*per acre-inch*) | | | | | | | | |
| April | | 1.00 | | 1.00 | | 1.00 | | 1.00 |
| May | | 1.00 | | 1.00 | 2.30 | 1.00 | | 1.00 |
| June | | 1.00 | | 1.00 | | 1.00 | | 1.00 |
| July | | 1.00 | | 1.00 | | 1.00 | | 1.00 |
| August | | 1.00 | 4.50 | 1.00 | 12.20 | 1.00 | 12.00 | 1.00 |
| September | 17.20 | 1.00 | 5.60 | 1.00 | 12.50 | 1.00 | 14.30 | 1.00 |
| October | 29.70 | 1.00 | 48.90 | 1.00 | 4.60 | 1.00 | 2.60 | 1.00 |
| November | | 1.00 | | 1.00 | | 1.00 | | 1.00 |
| December | | 1.00 | | 1.00 | | 1.00 | | 1.00 |
| January | | | | | | .90 | | 1.00 |
| February | | | | 1.00 | | 1.00 | | 1.00 |
| March | .10 | | 3.80 | 1.00 | | 1.00 | 10.20 | 1.00 |
| Land (*per acre*) | | | | | | | | |
| September | | 16.60 | | | | 128.60 | | 58.80 |
| October | | 159.00 | | 184.90 | | 56.60 | | 196.20 |
| Labor (*per hour*) | | | | | | | | |
| April | .20 | | .40 | .40 | .40 | .40 | | .40 |
| May | .40 | .40 | .40 | .40 | .40 | .40 | | .40 |
| June | | | | | | .40 | .40 | .40 |
| September | | | | | | .40 | | .40 |
| October | | .40 | | | | .40 | | .40 |
| November | | .40 | | | | | | |
| December | | .40 | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Maximum summer fodder (*per maund*) | .60 | .40 | .70 | .40 | .50 | .10 | .60 | .20 |
| Maximum winter fodder (*per maund*) | | .10 | | .10 | | | | |
| Summer vegetables (*per acre*) | 202.70 | 191.70 | 195.40 | 149.00 | 160.00 | 28.50 | 179.60 | 159.90 |
| Winter vegetables (*per acre*) | | 153.20 | 68.30 | 244.80 | 73.20 | 262.00 | 49.40 | 224.70 |
| Fruit (*per acre*) | | 94.50 | | 100.80 | | 56.20 | | |
| Sugarcane | | 209.00 | | 224.40 | | 193.00 | | |
| Minimum summer fodder (*per maund*) | .20 | .40 | .10 | .50 | .30 | .70 | .20 | .60 |
| Minimum winter fodder (*per maund*) | .60 | .60 | .70 | .60 | .60 | .60 | .80 | .80 |

CHART 2.1.—NORMATIVE SUPPLY CURVES FOR WHEAT UNDER DIFFERENT TECHNOLOGIES, 12.5-ACRE FARM, CENTRAL PUNJAB COTTON AREA

to make the cropping pattern dependent on the seasonal distribution of water. This result is underscored by the "shadow prices" or penalties of the crop constraints. Without a tubewell there is no penalty for not being able to increase production of certain high water using perennial crops—such as sugarcane and fruit—beyond their historical average.

The introduction of water production activities that permit the canal flows to be supplemented alters the nature of the constraints that determine the comparative advantage of various crops. As Table 2.2 shows, the focus is now on the competition for land, primarily in the months of September and October. Under traditional technology, the crops that are involved are primarily wheat and cotton. As one increases, the other decreases in almost the same amount. The relationship is altered somewhat with the advent of the new rice technology, since rice matures earlier in the season than cotton and hence shifts the competition for land from October to September.

The scarcity values shown for the water constraints in the presence of a tubewell and for labor constraints in all exercises simply represent the variable costs of operating the pumping and labor hiring activities. Some rather extensive sensitivity analysis indicates that the cropping patterns shown in Table 2.1 are not very sensitive to the values used to weight these activities and hence they are not the subject of further analysis.

## COMMODITY PRICES, IMPROVED AGRICULTURAL TECHNOLOGY AND SUPPLY RESPONSE

Much has been written in recent years about the extent to which farmers respond to changes in the relative prices of crops. The results of various attempts to estimate "positive" supply models have provided convincing evidence that, by and large, farmers in developing countries employ the same economic logic practiced by farmers in more highly developed areas. What is sometimes overlooked, however, is that insofar as farmers employ a calculus of profit maximization, their response is not to relative prices but to relative net revenues. This distinction is of some significance where efforts to promote agricultural growth by introducing new technology have affected crop enterprises differently. By means of parametric programming, the section shows that, as a result of widespread groundwater development, previously calculated supply elasticities for Pakistan crops are probably misleading. This finding is important because commodity price elasticities enter into a number of policy calculations including support prices and buffer stock operations, the utilization of surplus United States commodities under P.L. 480, and so on. Static, normative supply curves can easily be derived from the programming model by varying the price for a given crop, computing the net revenue associated with each new price, and resolving the model.

The new tubewell technology exerts a profound influence on both the optimal level of output at current prices (shifts in the supply curve) and the elasticity of farmer price responses. The two effects are readily discernible from Chart 2.1 where the price of wheat has been varied parametrically under alternative assumptions about the nature of the technology and the availability of supplementary water. Under the traditional technology, the use of supplementary water decreased the comparative advantage of wheat with respect to cotton (the two compete for land during the overlap of the summer and winter seasons), and shifted the wheat supply curve to the left. At the same time the possibility of altering the seasonal distribution pattern of water has made for greater *sensitivity* to the wheat–cotton price ratio. The result is that the two normative curves shown for traditional wheat varieties cross.

### *Resource Allocation at World Market Prices*

The foregoing examination of the effects of alternative prices assumed that only the wheat price varied; all other commodity prices remained constant. While such an analysis is useful in examining the effect of price policies on a single commodity, it cannot come to grips with a situation in which the prices of virtually all commodities are controlled and, to a greater or lesser degree, distorted in comparison with world market prices.

Table 2.3 shows that the effect on the model results of re-valuing all inputs

TABLE 2.3.—OPTIMAL CROPPING PATTERNS AND TOTAL REVENUES AT DOMESTIC AND WORLD MARKET PRICES FOR INPUTS AND OUTPUTS, CENTRAL PUNJAB WHEAT-COTTON AREA

| Crops | Traditional technology[a] | | Improved technology[b] | |
|---|---|---|---|---|
| | Domestic prices (1) | World prices[c] (2) | Domestic prices (3) | World prices[c] (4) |
| Winter crops | | | | |
| Wheat | 5.13 | 1.95 | 5.55 | 5.59 |
| Barley | | | | |
| Oilseeds | .31 | 4.20 | | |
| Gram | | | | |
| Fodder (sale) | .82 | | | |
| Sugarcane | .50 | | 4.63 | |
| Vegetables | .13 | .10 | .20 | .20 |
| Orchards | | | | |
| Summer crops | | | | |
| Rice | .27 | 1.17 | 2.10 | 6.07 |
| Cotton | 3.01 | 3.75 | | 2.03 |
| Maize | | | 1.44 | |
| Fodder (sale) | .78 | | .67 | .67 |
| Sugarcane | .50 | | 4.63 | |
| Vegetables | .09 | .10 | .10 | .10 |
| Orchards | | | | |
| Total cropped acreage[d] | 11.54 | 11.27 | 19.32 | 14.66 |
| Total Revenue I | Rs.2,860 | $ 517.22 | Rs.5,476 | $ 748,03 |
| Total Revenue II | $ 403.55 | Rs.2,454 | $ 558.18 | Rs.4,131 |

[a] Traditional technology is used here to describe yields and costs under historical conditions, including historical water supplies. Unlike the basic solution in Table 2.1, sugarcane acreage is not constrained.

[b] Improved technology assumes high-yielding cereal varieties *and* supplemental tubewell irrigation. Unlike the with tubewell solution shown in Table 2.1, the sugarcane acreage is not constrained.

[c] Exchange rate: $1 = Rs. 9.

[d] Fodder required to maintain bullocks not included.

and outputs to reflect world market prices of the late 1960s, is significant. Columns 3 and 4 (under "improved technology," show, for example, how differently land would be allocated among crops under the two sets of prices. Using domestic prices, wheat, sugarcane, rice, and maize dominate the cropping pattern; when world market prices are used, only wheat retains its position as a dominant crop. Sugarcane and maize, both highly overvalued domestically, are eliminated entirely. Their replacements—rice and cotton—are two crops whose Pakistani price closely approximated world levels.

It is not possible, of course, to describe rigorously the social costs of distorting relative prices within the framework of a single farm. For example, the amount of water that can be pumped by the tubewell has been assumed to depend on its capacity, not on the share of the socially available groundwater that a 12.5-acre farm would command. Moreover, the amount of labor hired has been weighted by prevailing rural wage rates and thus does not take into account the aggregate effect of individual farm labor demands. A similar problem arises on the commodity demand side; the domestic prices used for valuing outputs do not reflect the price adjustments that would occur in the economy if all farmers were to pursue the cropping pattern shown in the domestic model. However, the results can give some indication of the losses to society due to relative price distortions. In columns 1 and 3 of the Net Revenue II row, the optimal cropping patterns generated in response to domestic input and output prices have been evaluated with new revenues calculated from world market prices. As the comparison of these calculations with those in columns 2 and 4 of Net Revenue I show, the opportunity cost of the domestic cropping pattern is quite high; net foreign exchange earned or saved is nearly 25 percent less than it would be if the cropping pattern reflected relative prices obtaining in world markets. As indicated earlier, the principal cause of the discrepancy is the large amount of overvalued sugarcane in the domestic cropping pattern.

Although it may be undesirable on general welfare or development grounds to bring domestic prices in agriculture in line with those prevailing in world markets, it must be recognized that the costs in terms of static efficiency are high. Quantitatively, Net Revenue II shows that if the world price cropping pattern were evaluated at domestic producer prices, it would mean a loss of approximately 15 percent in revenue to the representative farm. Assuming that it was desirable for political and incentive reasons to maintain the terms-of-trade between the agricultural and nonagricultural sectors, this suggests that the government would be well advised to pursue an agricultural price policy that set domestic prices for all crops at some uniform level above world market prices. Operationally, it would mean decreasing sugarcane prices drastically, decreasing wheat and maize prices moderately, increasing rice and oilseed prices significantly and cotton prices moderately.[5] Lest it be misunderstood, such a recommendation in no way suggests that maintaining the current term-of-trade between agriculture and non-agriculture under conditions of advanced technology is an appropriate development objective. Indeed, a comparison of the net revenue estimates associated with traditional technology (column 1) shows that even if the cropping pattern under

[5] Effective devaluation would, of course, accomplish all of these things—provided that the myriad of controls currently in effect went also.

advanced technology at world market prices were used as a basis for calculation, producer prices could be uniformly *reduced* and still provide a net revenue for the representative farmer greater than that earned before the new technology was available.

Two other results of the comparative exercise are worth mentioning. The first is that wheat appears to have a comparative advantage in the winter season regardless of which set of prices is assumed. This is a finding of some relevance since there has been a widespread belief that wheat could not be exported competitively. What is sometimes missed in these calculations is that the position of wheat in the cropping pattern is dependent not only on the price and yield of wheat, but on the prices and yields of competing crops. So long as crops that compete with wheat for land (e.g., gram, chickpea, and oilseeds in the winter and cotton in the summer) return no more per acre than they currently do, wheat will remain the dominant winter crop.[6]

Lastly, the dual of the production model (Table 2.4) suggests a qualification to certain arguments that have been advanced to justify the mechanization of West Pakistan agriculture. It is frequently held, for example, that the Green Revolution, particularly the availability of additional irrigation water, has produced labor and power bottlenecks that inhibit the exploitation of the new technology. Comparison of the shadow prices for labor and bullock power under traditional and advanced technology does indeed show a substantial increase in the amount of human and bullock power used as farmers alter their methods of production. However, it also shows that the precise nature of the so-called bottleneck depends very much upon the set of relative prices assumed to influence the cropping pattern. For example, column 3 shows an extremely high shadow price for bullock labor in May and a bunching of labor hiring activities in April and May and again in the sugarcane harvesting period of January, February, and March. In contrast, where resource allocation is assumed to be in response to world market prices (column 4), no binding constraints exist at all on animal power and hired labor expenditures are now concentrated in the summer months.

It is obvious that if farmers optimizing under these two sets of prices were asked about power and labor bottlenecks, their answers would differ considerably. This suggests that some care must be taken to ascertain that policies aimed at alleviating peak-period power demands through the introduction of tractors and other mechanical devices are actually in response to socially "real" constraints. Otherwise, the response will simply be another all-too-frequent case of a distortion in the economy that called forth further distortions.

## WATER PRICING, THE DEMAND FOR SUPPLEMENTARY WATER, AND GROUNDWATER DEVELOPMENT POLICY

The groundwater reservoir underlying the Indus Basin is one of Pakistan's great natural resources. However, even with its ultimate development and the

[6] Plans are presently under way to step up research on improved oilseed varieties. Pakistan is a large importer of edible oils, and oilseeds would appear to be a natural direction for diversification. The technology for improving cotton yields is also under intensive study. Imported varieties have produced extremely high yields but pest control has been a problem.

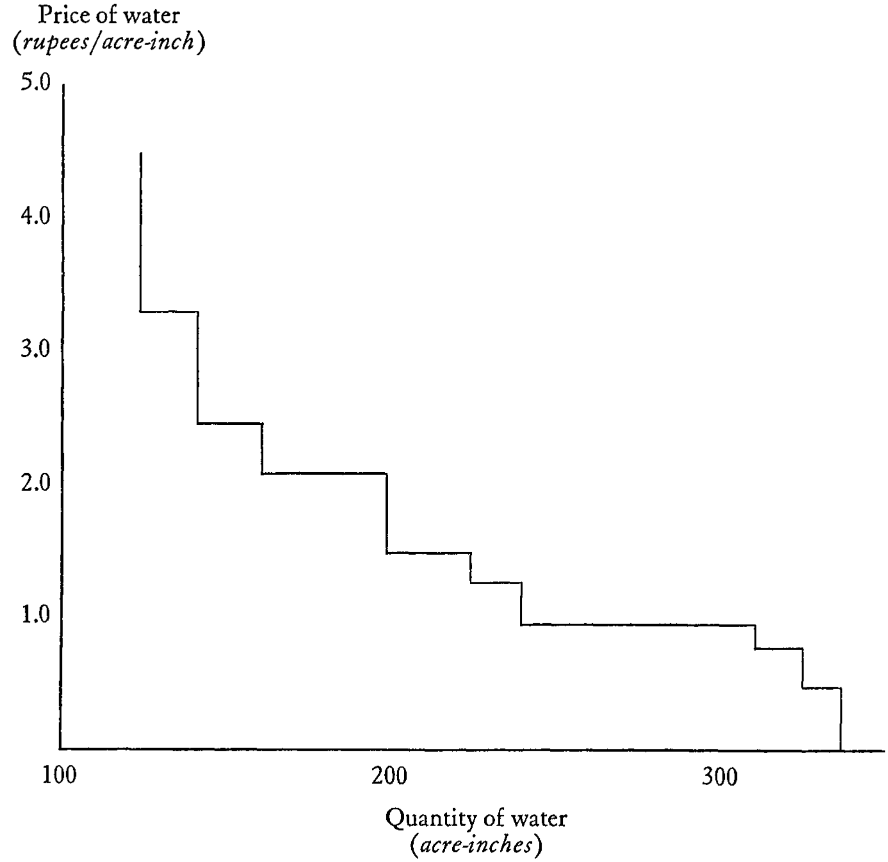
TABLE 2.4.—SHADOW PRICES OF FIXED RESOURCES UNDER TRADITIONAL AND IMPROVED TECHNOLOGY AT DOMESTIC AND WORLD MARKET PRICES FOR INPUTS AND OUTPUTS

| Resources | Traditional technology: Domestic prices (*rupees*) Activity level | Price | Traditional technology: World prices (*dollars*) Activity level | Price | Improved technology: Domestic prices (*rupees*) Activity level | Price | Improved technology: World prices (*dollars*) Activity level | Price |
|---|---|---|---|---|---|---|---|---|
| Water (*acre-inches*) | | | | | (Pumping) | | (Pumping) | |
| January | | | | | 11.4 | 1.0 | 2.2 | .17 |
| February | | | | | 21.3 | 1.0 | 14.1 | .17 |
| March | | | | | 50.4 | 1.0 | 28.3 | .17 |
| April | | | | | 27.3 | 1.0 | 46.1 | .17 |
| May | | | | | 54.0 | 1.0 | 48.2 | .17 |
| June | | | | | 72.3 | 1.0 | 86.0 | .26 |
| July | | | | | 67.2 | 1.0 | 73.8 | .17 |
| August | | 5.1 | | 2.41 | 74.1 | 1.0 | 86.0 | 1.25 |
| September | | 5.6 | | 2.23 | 53.7 | 1.0 | 47.3 | .17 |
| October | | 52.1 | | | 51.6 | 1.0 | 17.3 | .17 |
| November | | 16.9 | | 7.41 | 34.6 | 1.0 | 2.4 | .17 |
| December | | | | | 21.1 | 1.0 | 6.3 | .17 |
| Land (*acres*) | | | | | | | | |
| April | | | | | | 26.1 | | |
| September | | | | | | 219.2 | | 30.28 |
| October | | 38.5 | | 13.32 | | | | |
| Bullocks (*hours*) | | | | | | | | |
| May | | | | | | 5.2 | | |
| Labor (*hours*) | (Hiring) | | (Hiring) | | (Hiring) | | (Hiring) | |
| January | | | | | 180.1 | .4 | | |
| February | | | | | 460.2 | .4 | | |
| March | | | | | 110.1 | .4 | | |
| April | | | | | 208.2 | .4 | 31.3 | .04 |
| May | 66.3 | .4 | 2.1 | .04 | 302.6 | .4 | 428.6 | .04 |
| June | | | | | | .4 | 186.2 | .04 |
| September | | | | | 156.1 | | 84.4 | .04 |
| October | | | | | | .4 | 163.7 | |
| November | | | | | | .4 | | |
| December | | | | | 66.3 | .4 | | |

ultimate development of sources of surface water, land will still be in surplus. When taken together with the decision to permit groundwater exploitation by private individuals, this points to a need to be concerned about resource (water) management. Otherwise, prolonged unmanaged pumping is likely to produce both a rate of use that does not reflect the time preferences of society and the possibility that, at the sweet water–saline water interface, the acquifer will be permanently damaged by the incursion of saline groundwater into the sweet water areas.

One means of regulating individual behavior in this context is to create institutions that can legally control the amount of water that is withdrawn. Another is to devise a cost structure for pumping that indirectly controls the amount of

CHART 2.2.—ANNUAL DEMAND FOR SUPPLEMENTARY WATER AT VARIOUS PUMPING COSTS




water withdrawn. In the exercises below, pumping costs have been varied parametrically to trace out seasonal and annual demand curves for supplementary water. The derived schedules are in turn used for a discussion of the management of groundwater resources.

Chart 2.2 shows the demand curve for supplementary water on a representative farm of 12.5 acres. According to the schedule, diesel tubewell owners with costs of 1.2 rupees per acre-inch should have pumped 230 inches of supplementary water per annum if they equated the value of the marginal water with its marginal cost. Electric tubewell owners with variable costs of 0.8 rupees should have pumped about 320 inches or approximately 40 percent more.

The results of the exercise based on representative farms can be compared, albeit a bit crudely, with the actual withdrawals of a large public tubewell project, Salinity Control and Reclamation Project I (SCARP I), located in the area from which the model's parameters were drawn. By invoking the proportionality assumption of linear models and multiplying the entire vector of resources constraints by $10^5$, the 12.5-acre farm becomes a 1.2 million-acre farm with surface water availability measured in million acre-inches, animal power in million bullock-hours and so on.[7]

Comparison of the optimal withdrawals suggested by the model with the current pumping rate in SCARP I (28 million acre-inches) indicates that if the same area were covered with private diesel-powered wells, profit-maximizing cultivators would probably pump less than is presently being withdrawn; if all farmers owned electric wells, they would probably pump more.

Actually, farmer payments for water from public projects are considerably less than the cost to private tubewell owners of operating their own pumps. Although several difficulties arise in attempting to assess the cost of supplementary water to farmers in SCARP I in a way that is compatible with the assumption underlying Chart 2.2, a crude estimate can be obtained by comparing the land revenue received by the government before and after the installation of tubewells and dividing the difference by the total water pumped. Harza Engineering, in their evaluation of SCARP I supply the numerator for the above computation (*6*). In 1959–60, the Government recovered from the project area 14.5 million rupees from water rates, land revenue, and other taxes assessed on a cropped-acre basis; in 1964–65, this figure had risen to 29.4 million rupees. Dividing the difference by the water pumped yields a figure of 0.5 rupees per acre-inch as payment, direct and indirect, for the supplementary groundwater. Substitution of this result in Chart 2.2 gives an estimate of water demanded of 34 million acre-inches, an amount significantly above the 28 million acre-inches actually being pumped.

One source of the discrepancy between the cost of water and the withdrawals and cropping intensities predicted by the model seems to be related to the installed pump capacity. The per-acre pumping capacity assumed in the model was based on the findings of the farm management studies alluded to earlier, approximately 1 cusec for 80 acres. In SCARP I, on the other hand, the installed capacity is only 1 cusec per 150 acres, substantially limiting the ability of project authorities to respond to peak season water demands.

Monthly capacity constraints effectively limit cropping intensities. However, seasonally constrained capacity is quite consistent with excess irrigation during the total growing season. When water charges are assessed on acreage irrigated and not on cusecs used, the effect of water costs is incorporated only in the planting decision. Thereafter, water becomes a fixed cost and may quite legitimately be used to the point where the value of the marginal product to the farmer is zero.

Charts 2.3 and 2.4 illustrate monthly water demands at different pumping costs and the difference between current pumping practices and the optimal pattern suggested by the model under comparable monthly surface water flow constraints. Caution should be used in interpreting these results since in the model, SCARP I has been treated as a gigantic farm subject to a single decision-maker.[8] Nevertheless, when the comparisons of pumping patterns in Chart 2.4 are considered

[7] Solutions to the problem can then also be multiplied by $10^5$. (For example, the demand for supplementary water at 0.8 rupees per acre-inch would be interpreted as 2.7 million acre-feet.)

[8] This undoubtedly has the effect of overstating the variance in the optimal time distribution of supplementary water. The fact that farmers typically spread their planting dates as a result of labor constraints tends to mitigate the extremes shown in Chart 2.4.

CHART 2.3.—MONTHLY WATER USE AT DIFFERENT PUMPING COSTS AS INDICATED BY THE MODEL

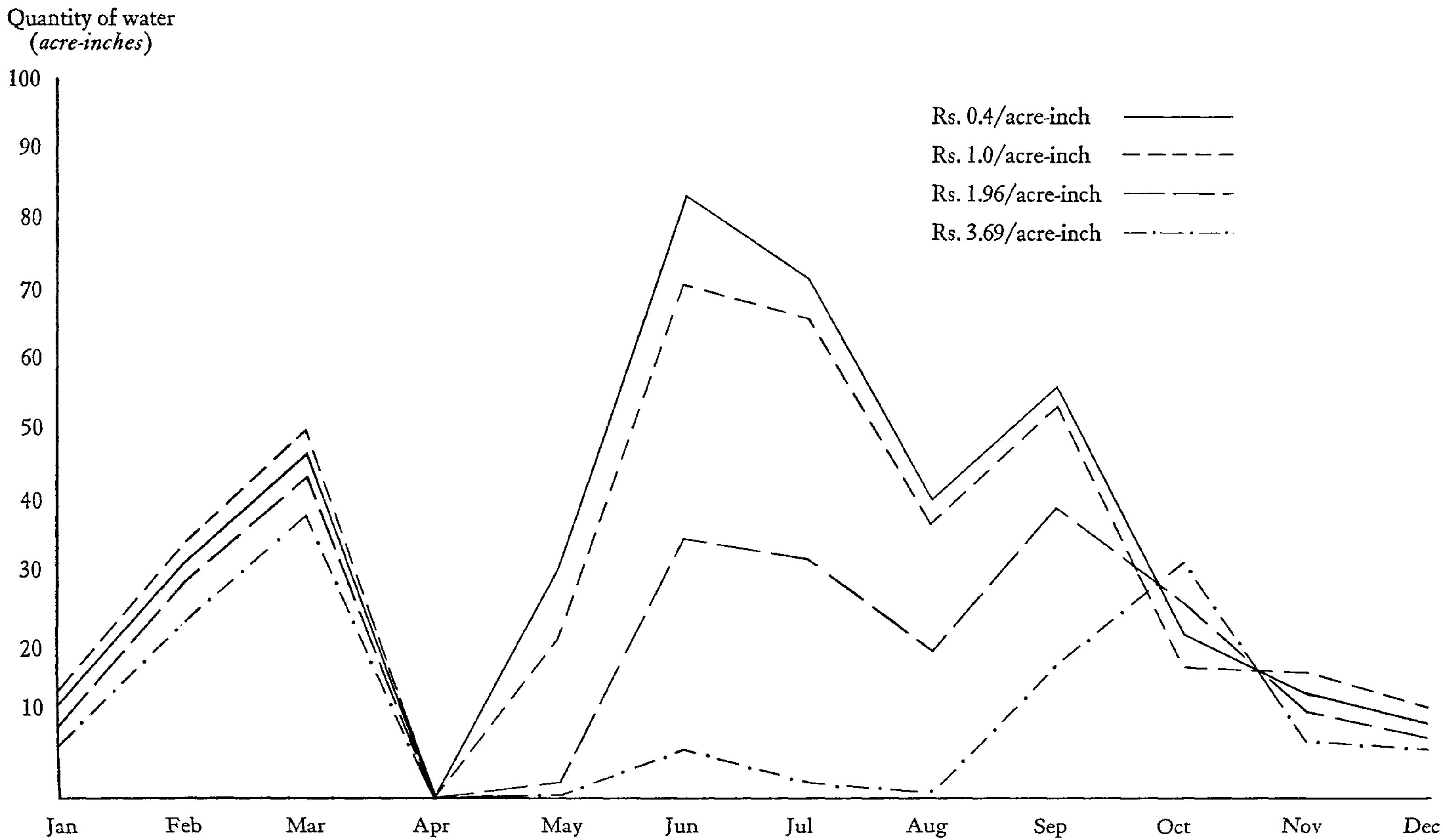
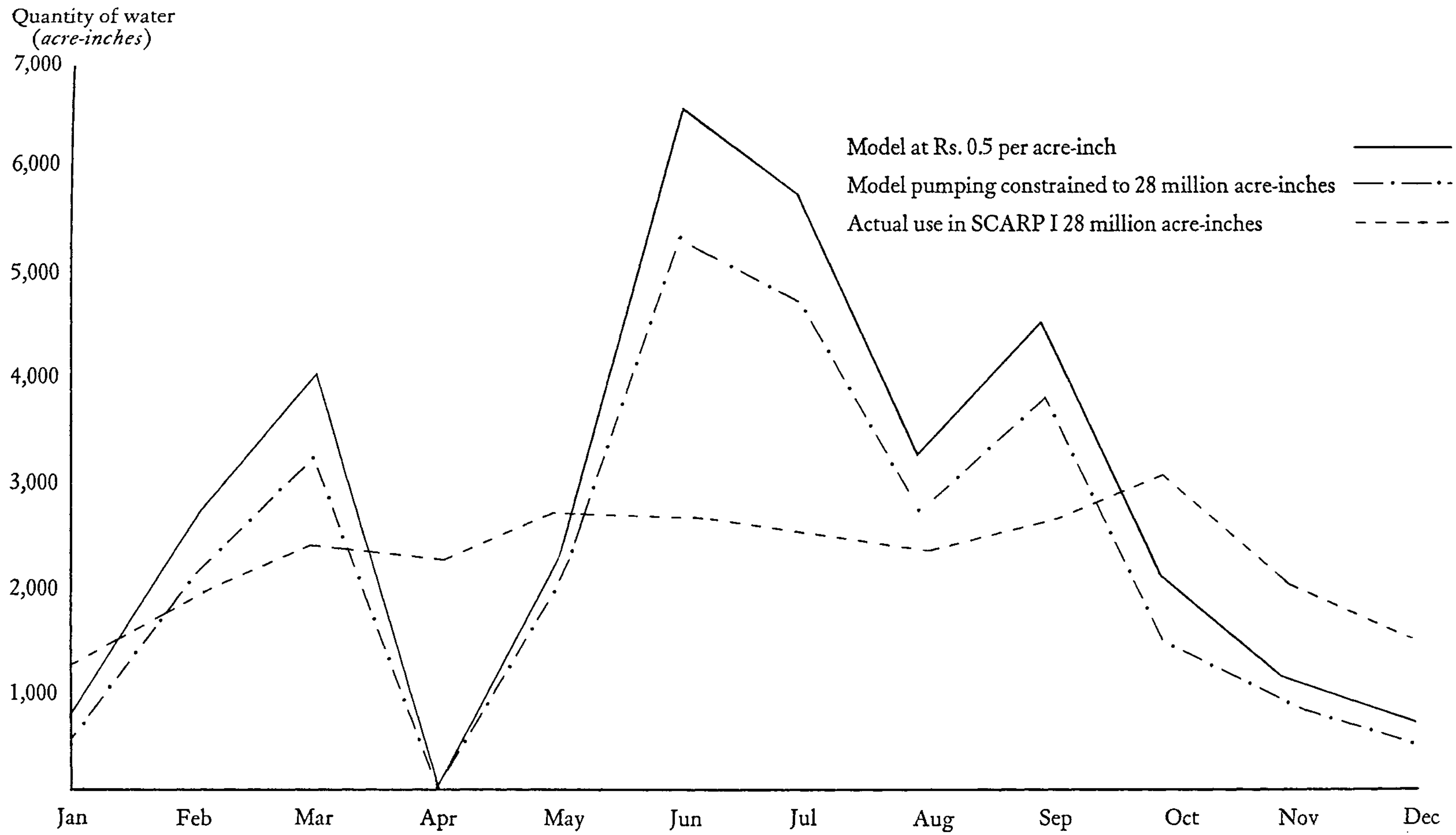


CHART 2.4.—OPTIMAL MONTHLY WATER USE COMPUTED BY THE MODEL AND ACTUAL USE IN SCARP I



in conjunction with the intensities attained in the model and in SCARP I (Model = 142; SCARP I = 125), the evidence points strongly to the conclusion that the additional flexibility associated with greater capacity is an important element in the efficient use of total water supplies.

To reiterate, under present conditions in SCARP I, farmers cannot pump as much water as the price of water would warrant because tubewell capacities are too low to meet seasonal peak demand. At the same time, much water is wasted because once the crop has been sown, additional irrigations are virtually costless. For certain crops that have rather flat response curves at high levels of water application, e.g., rice and Egyptian clover, this can lead to unusually large applications per acre.[9]

It could be argued in rebuttal to the implied case for individually owned tubewells made by this finding, that the result is simply a function of a poorly designed public project. If water were sold on a volumetric basis and sufficient capacity were installed, the needed flexibility could be attained.[10] Unfortunately, the regime-type distribution system in Pakistan allocates water to farmers in rotation. Since groundwater and surface water are mixed at the head of the water course, both are subject to the same rotational scheme. It is difficult to see how this system can be modified to provide the flexibility of individual water control implied in Chart 2.4.

The foregoing paragraphs offer a number of comments on water pricing and the demand for supplementary water. This discussion suggests a further use of the experiment in clarifying certain aspects of the current debate over an appropriate groundwater development strategy for Pakistan.

Some participants in the discussions about groundwater policy argue that the development program must be in public hands. This is the only way, it is held, that the surface and groundwater resources of the province can be used most effectively. Specific arguments include the need to coordinate surface flows and ground water withdrawals, the importance of overall control of the aquifer, the necessity of evening out interseasonal variation in groundwater availability, the need to insure applications of water sufficient to guarantee that the tendency of harmful salts to collect in the root zone is reversed, and the importance of equity in distributing the benefits of groundwater development.

Private development proponents counter by pointing out that another, and possibly overriding, set of considerations has been ignored, namely, that investments in pumps and wells by private farmers add net resources to the country's development program. Moreover, individual farmers, controlling their own water supplies, will use scarce water resources more efficiently than if they are put under public management. Lastly, profit-motivated cultivators, spurred by the returns on private wells, have become a modernizing segment within the agricultural sector that is of great value.

[9] Corroboration of this point is given in (*4*). On the watercourse studied in SCARP I, the following amounts of water were applied per acre (consumptive use requirements at the same point of measurement are given in parentheses): rice 72.6 (46.1); fodder 92.8 (38.3); cotton 30.8 (34.5); wheat 22.8 (23.9). Unlike rice and fodder, wheat and cotton can be overirrigated to the point where yields are seriously affected.

[10] Additional capacity in public projects also has, of course, a cost. But this diminishes sharply as tubewell sizes increase.

The arguments sometimes hinge on differences in opinion about the appropriate time horizon to use in evaluating development proposals. If long-term aggregate water management problems are deemed to be of overwhelming importance, then a predominantly public program appears to be attractive. If, on the other hand, one feels that economic growth has a very high rate of discount, the unavoidable conclusion is that, with present resource availabilities, everything possible must be done to encourage private development.

The conflicting objectives set forth above lead naturally to a search for policies which might reconcile them. Since government resources, particularly foreign exchange, appear to be the most significant constraint currently operating in Pakistan, policies that would make private development an acceptable long-run alternative to public projects need careful exploration.

The most important question to be addressed is the allegation that public projects are needed for proper management of the underground aquifer. Concern on this point originates as much from United States experience as anything else. Developments in the southwestern part of the United States have confirmed that individuals trying to maximize profits will expand irrigated agricultural areas well beyond the long-run yield of the aquifer on which they are dependent, and that they will even permit the destruction of an aquifer by seawater through failure to develop adequate safeguards against overpumping.

Undesirable private exploitation of a common resource may be corrected by direct (institutional) or indirect (pricing) policies. In Pakistan, the latter is particularly attractive because the semi-autonomous Water and Power Development Authority, in addition to being charged with the overall development of the country's water resources, also sets the electricity rates. For example, suppose that the recharge of the aquifer in SCARP I was approximately 26 m.a.i. From Chart 2.3, this much would be pumped at a price per acre-inch of about one rupee.[11] Using Ghulam Mohammad's figure for the variable cost of private tubewells, one rupee per acre-inch implies a cost of electricity of 0.09 rupees per kilowatt hour (*5*, pp. 1–53).

Conversely, the pricing mechanism might be used to increase withdrawals in the interest of promoting reclamation and salinity control. The principal cause of soil salinity is failure to apply enough water to leach the accumulated salts through the root zone. However, as cropping intensities approach 125 to 130, land becomes a binding constraint and applications per acre can be expected to rise and salinity to become less of a problem. The extent to which such increases will occur is, of course, a function of the price of the additional water.[12]

It might be argued that the policy suggested above would be less sensitive in

[11] This is not to argue that such a balance is an appropriate public policy. For an interesting discussion of the complexity of determining optimum rates of groundwater withdrawal, see O. R. Burt (*4*, pp. 632–47).

[12] Some consultants have suggested that a 10 to 15 percent increase in application above the evapotranspiration (maximum yield) requirements is needed for leaching purposes. If the production function in Chart A1.1 is generally valid, this would prove difficult to bring about without a direct acreage control system. One could envisage payments for the use of water beyond the point where short-run MC = VMP, but it would appear that a more convincing solution would be a program of cultivator education about the long-run gains from applying the additional 10 to 15 percent. Unfortunately, this area of investigation is still clouded by a lack of agreement among irrigation engineers regarding the physical requirements of the leaching process.

year-to-year fluctuations than direct government operation. While this is true, it is unlikely that highly sensitive annual adjustments between surface water inputs and ground-water withdrawals are necessary. What is needed is a long-run equilibrium between inflow and outflow and for this, an appropriate energy pricing system would appear to be valid.

The foregoing argument has been centered on countering objections to private water development put forth on water management grounds. It has not tried to add yet another variant to the proposals for an optimal public-private strategy, but has shown that certain technical arguments, thought by many to be central to the problem, are amenable to public policy. Hopefully, greater attention can now be focused on the opportunity cost of the resources involved, on the rapidity with which water resources can be developed, and on considerations of equity, which appear to be more fruitful focal points for the public-private debate.

CITATIONS

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