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"Relative Price Response, Economic Efficiency and Technological Change: A Study of Punjab Agriculture

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I. INTRODUCTION

Since World War II, agricultural economists throughout the world have given increased attention to the factors that influence the production decisions of farmers. Ironically, the major reasons for this interest have come from two widely different policy dilemmas: the desire on the part of several developed countries to limit agricultural production, and the desire of most underdeveloped nations to expand agriculture as a part of their development effort.

Analyses of farmer decision making in the United States have produced many important theoretical and empirical results.[1/] In recent years, the techniques developed in the United States have also been used successfully in less developed countries

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1/ See, for example, Cochrane (1), Johnston (18), Nerlove (24), and Heady (15).

with, often surprisingly, similar results. Such studies have done much to move the discussion of peasant response to economic incentives from speculation, based largely on apriori assumptions of peasant behavior, into the realm of "positive" economics. In both the developed and less developed worlds, however, only a nominal amount of work has been done on the differential effects of technological change on various agricultural activities. Although it is generally agreed that agricultural development hinges critically on an ability to infuse rural areas with new types of inputs such as fertilizer, improved seeds, tubewells, etc., little thought has been given to the way in which these radically new inputs are likely to affect the overall composition of the cropping pattern. The result, of course, is the distinct possibility that price policies carried over from earlier periods may produce a socially undesirable mix of commodities.

Before many predictions can be made about the interaction of technological change and supply elasticities, however, historical experience must convincingly show that farmers do, in fact, exhibit a significant amount of economic rationality. In Pakistan, some attention has already been given this question and, in general, researchers have given an affirmative verdict.[2/]

2/ See Falcon (4), Ghulam Mohammed (21), Hussain (16), and Qureshi (25).

However, all of the previous studies have assumed simpler farmer decision rules than is probably warranted. Hence, even though there is little question that West Pakistan farmers do respond to price, the magnitudes of such adjustments are still very much open to question.

In examining the above range of issues, the discussion presented here is broadly divided into two parts. The first of these examines the historical experience in some detail. Section I provides some initial background on the former Punjab,[3] the major agricultural region of West Pakistan; Section II uses distributed-lag models to extend some of the earlier work on historical price responsiveness; and Section III deals with relative prices and the historical allocation of scarce water supplies. The latter Section introduces a programming model which permits a normative examination of the relationship between water supplies, agricultural output, and prices.

In the second part of the paper, technological change is introduced into the programming model via activities which produce additional water supplies. Normative supply curves are generated and then compared with the long-run historical elasticities derived in the first part of the paper.

3/ In October, 1955, the Provinces of West Pakistan were consolidated into one unit. Strictly speaking, therefore, the Pakistan "Punjab" should always be referred to as "former Punjab."

The major conclusion which evolves from the econometric analyses is that there is a high degree of farmer sensitivity to economic variables even in the low-income agriculture of West Pakistan. The relative-price relationships appear to be of the same magnitude as those found in the United States; moreover, the water analysis in Part V suggests that the supply curves will both shift and increase in elasticity as a result of the technological change embodied in the water development program now being undertaken in the Indus Plain. Both these observations have a significant bearing on a broad range of issues, including input subsidies, export taxes, price supports, rural taxation and food imports.

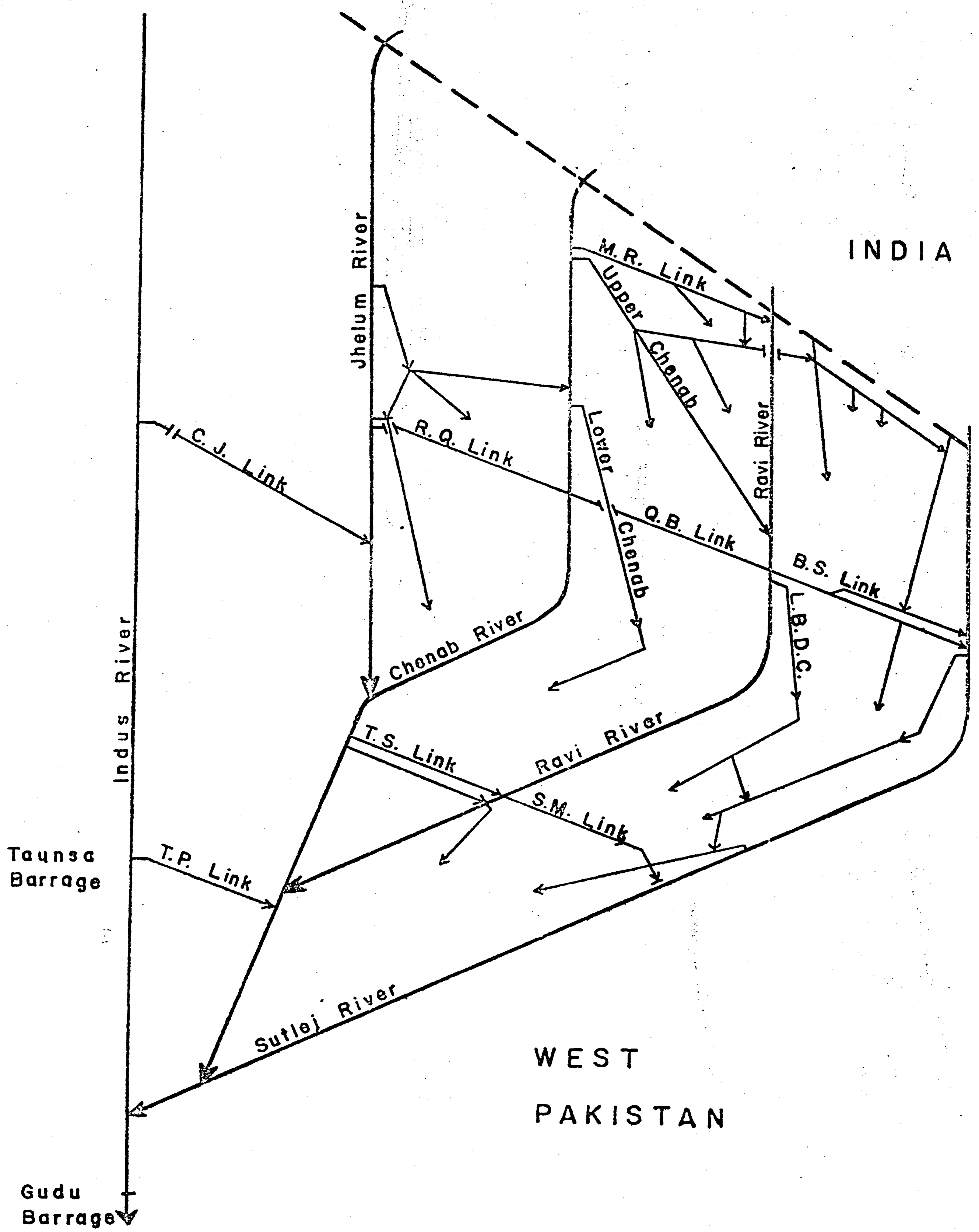
II. DECISION MAKING IN THE TRADITIONAL AGRICULTURE OF PUNJAB

To appreciate the amazingly complex nature of rational decision making in Punjab agriculture, it is necessary to understand several important details of the rural environment.4/ Of particular significance is the irrigation system which serves some 13 million cropped acres of the Northern Zone of the Indus Basin. This vast system of perennial and non-perennial canals is one of the world's largest irrigation networks, with approximately 30 million acre feet per year presently diverted from the five rivers that flow into the area. (See Figure 1) Most parts of the Northern canal network were installed between 1880 and 1920, and they have one important element in common: the areas commanded by these canals are large relative to the water they deliver. Thus in both the <u>kharif</u> (spring-planted) and <u>rabi</u> (fall-planted) seasons, over 50 percent of the cultivable land usually lies fallow. Moreover, that area which <u>is</u> cropped receives only a relatively small water application.5/ Since, in addition, the canal supplies vary greatly throughout the year and between years, canal water supplies are both a critical and uncertain input in large agricultural areas of West Pakistan. Clearly water, not land, is the most binding constraint for the majority of farmers in West Pakistan.

4/ For a fuller discussion of agriculture in West Pakistan, see Roberts (26), the Food and Agriculture Commission Report (11), and the Revelle Report (29).

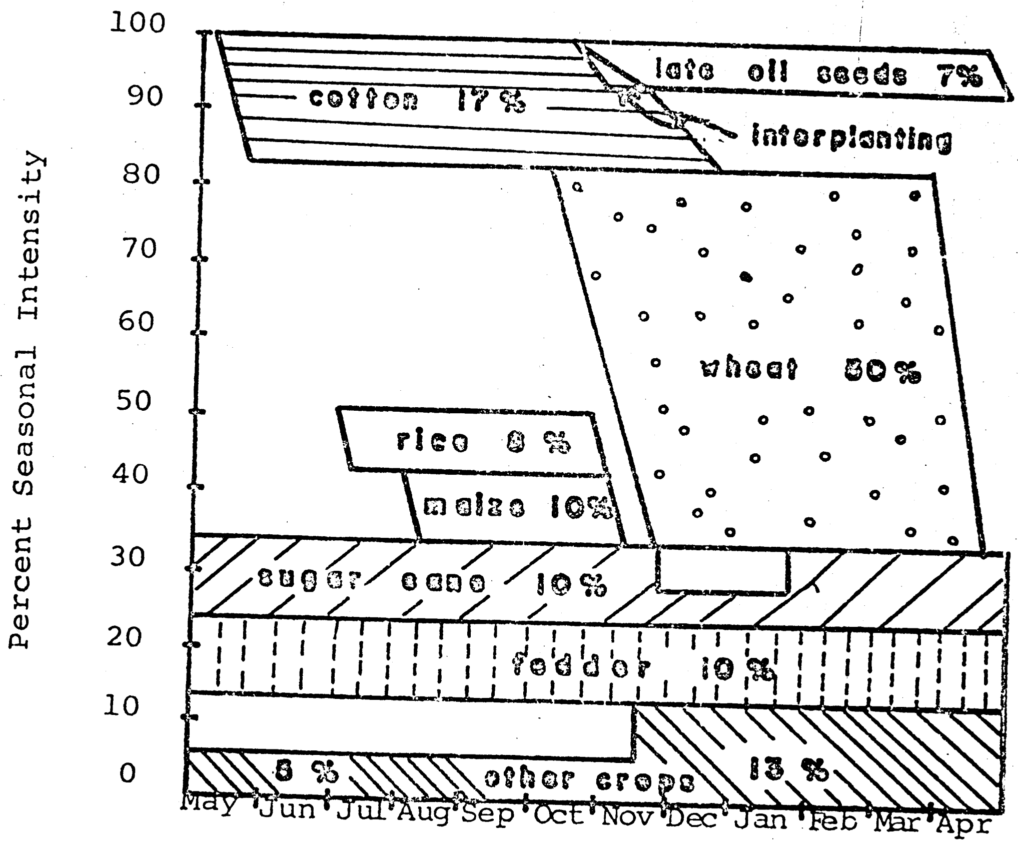
5/ Water applications per acre in West Pakistan are only 1/3 to 1/2 of those found in comparable areas of California.

Figure 1. SCHEMATIC DIAGRAM OF PUNJAB IRRIGATION SYSTEM

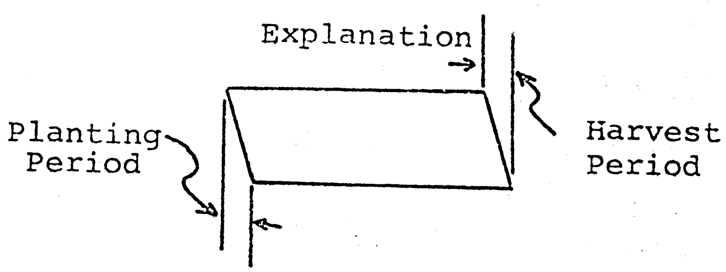


SOURCE: Harza Engineering Co. (13)

FIGURE 2. Illustrative Cropping Pattern, Punjab, West Pakistan



TYPICAL CROP PATTERN



INDUS PLAINS

TYPICAL CROP PATTERNS

SOURCE: Harza Engineering Co. (13)

A second general feature of West Pakistan agriculture involves the complicated crop calendar. (See Figure 2). Unlike most portions of the United States, where there is one season with rather clearly defined planting and harvesting dates, cultivation in Punjab can be carried on throughout the year. Because of the large number of crops that are commonly grown and because of the overlapping of seasons, the Punjabi farmer is faced with an extraordinarily large number of decisions concerning his cropping alternatives.

A third significant characteristic of West Pakistan has to do with its <u>average</u> scale and level of technology. To a considerable extent, agriculture in the Indus Basin is poor and traditional. Average farm size is approximately 8 cultivated acres, and rural per capita income is only about Rs. 350 ($74) per year. Farming is generally non-mechanized, and while cultivators are now beginning to use commercial fertilizers and pesticides, many farming practices are as they have been for centuries.

On the other hand, the averages presented above are misleading. While about 60 percent of the West Pakistan farmers have "subsistence" farms which are less than 7.5 acres, approximately 20 percent of the cultivated land is in "economic" units of more than 25 acres.[6/] While the dualism in West Pakistan agriculture is not as great as in many other countries, there is definitely

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6/ Agricultural Census (12), p. 13.

a dynamic commercial segment composed of larger farms. It is this group, for example, that has been mainly responsible for the recent installation of more than 30,000 private tubewells for irrigation.

A final characteristic of the irrigated agriculture of West Pakistan involves the industries and institutions which serve it. Marketing, processing, storage, extension, and credit services are all rather rudimentary, and rural prices exhibit great seasonal and inter-year variation. As a result of these and other factors, foodgrain self-sufficiency has been an historic key to survival, and is a major factor in farm planning for the majority of small farmers.7/

7/ This point is developed at length in Falcon (3), Chapter 1.

III. PRICE RESPONSE IN WEST PAKISTAN -- THE HISTORICAL EXPERIENCE

With the type of agriculture described in the short sketch above, it is not surprising that early opinions varied on the decision making behavior of farmers -- particularly whether or not they responded to changes in relative prices.[8/] In part, the different viewpoints arose because various protagonists failed to distinguish between cash and food crops, between production and marketing elasticities, and between acreage and yield responses. However, several recent commodity studies have concluded that West Pakistan's farmers are in fact price and income conscious. In large part, the discussion has now shifted from "if" to "how much".

The Relative-Price Estimation Model[9/]

The extent to which farmers react to changes in relative prices between crops has an important bearing on public policy towards agriculture. The Government, through such instruments as export bonuses, taxes, import of agricultural products, etc., can (and did) alter significantly relative prices between the major crops of West Pakistan. Thus, the first empirical question of this study concerns how much these changes affected the level and the composition of output.

8/ In this essay, the concern is with the relative profitability among crops. How farmers have responded to changes in factor prices, i.e., the terms of trade for agriculture, is deferred to a subsequent paper.

9/ Readers more interested in the empirical results than the model may prefer to go directly to the estimates given on pages 14 ff.

To answer this question, it is first useful to approach the problem with a simple model for a "typical" cotton farmer of the Punjab. The model postulates that the farmer behaves as an "economic" man, so that the statistical results of the next section can be used to verify or to modify this central hypothesis.

For the profit-maximizing cultivator, the production of cotton in any year is related to his expectations of its relative profitability. This idea is expressed more formally in equation (1).

$$(1) \quad O_{c.t} = f(P_{c.t}, P_{s.t});$$

Where:

$O_{c.t}$ = the output of cotton in year t.

$P_{c.t}$ and $P_{s.t}$ = the expected prices in year t of cotton and of the other crops which are production substitutes for cotton, respectively.

Further specification of the model is not an easy task. One crucial problem centers on the definition of "expected" prices. Clearly, it is inappropriate, because of the identification problem, to use the actual price in the same year as an approximation. For with the prevailing trends and variations in canal water supplies, a regression of quantity on price is more likely to trace out some hybrid function rather than a supply curve.

One possible alternative is to assume that the relative prices of the previous period are used by the farmer as the best estimate of expected sale prices. Thus for the case of cotton:

$$(2) \quad O_{c.t} = f\,(P_{c.t-1}, P_{s.t-1})$$

Where:

$O_{c.t}$ = Output of cotton in year t.

$P_{c.t-1}$ and $P_{s.t-1}$ = Historical prices of cotton and production substitutes in year t-1, respectively.

This equation, or variations of it, has been used successfully in several recent studies.10/ It provides a useful approximation, and has given estimates with relatively small standard errors. Nevertheless, the assumption that expected prices are determined solely by the previous year's prices is an unnecessarily restrictive one, and the distributed-lag technique, first adapted to agricultural supply analysis by Nerlove,11/ offers a more appealing alternative.

With the distributed-lag approach, expected prices (P^*_t) are assumed to be a function of actual prices in a series of preceding years:

10/ See Falcon (4), Ghulam Mohammed (21), Qureshi (25), and Hussain (16).

11/ See Nerlove (23), and (24), Koyck (19) and Krishna (20) for a fuller discussion of the assumptions and technicalities of the distributed-lag approach.

(3) $P^*_t = f\ (P_{t-1}, P_{t-2}, P_{t-3} \ldots\ldots P_{t-n})$ 12/

In other words, it is assumed that farmers form an impression of the expected relative profitability of a given crop, not only on the prices they received in the immediately previous year, but in earlier periods as well. Such an assumption has great intuitive appeal, and it is also of operational significance.

Beginning with the assumption in equation (3), the function for cotton output might then be fitted with the following model:

(4) $O_{c.t} = \alpha + \beta_1 \cdot P_{t-1} + \beta_2 \cdot P_{t-2} + \ldots\ldots \beta_n \cdot P_{t-n} + \varepsilon$

In this formulation, the parameter β_1 could be thought of as the short-run response to price, while the sum of β_1 to β_n would represent the long-run price response.

Without further assumptions, however, it is difficult to use equation (4).13/ It can be shown, however, that if β_1 to β_n

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12/ In this formulation, the prices can be thought of as the ratio of cotton to cotton substitutes prices. By making this ratio, it is possible to keep the idea of <u>relative</u> profitability and yet remove one dimension of the equation.

13/ This difficulty results from the high inter-correlations which are likely among the lagged price variables. Also, with data available for only relatively short periods, using prices with long lags requires that several observations be discarded.

are related in a particular way, estimation becomes much simpler. For example, suppose that the betas of equation (4) are linked by an expectations coefficient lambda (λ), which may have the value of $0 \leq \lambda \leq 1$, and which gives an indication of the influence of a particular past price on the formation of farmer price expectations. Specifically, suppose that the output of cotton in year t is a function of expected price in year t, with the latter being defined as follows:

$$(5) \quad Q_{c.t} = \alpha + \beta_1 P_{t-1} + \beta_2 \lambda . P_{t-2} + \beta_3 \lambda^2 P_{t-3} + \ldots + \beta_n \lambda^{n-1} P_{t-n} + \varepsilon$$

It is obvious from this equation that if $\lambda = 0$, the expected price in year t is established solely on the basis of price in year t-1. Thus with a λ value of zero, Equation (5) is of the same form as Equation (2). However, if λ equals 0.5, then prices of preceding years also have an effect on expected prices. This influence is greatest for the years nearest t, because $(\lambda)^{n-1}$ approaches zero as t minus n decreases.

Even though the above form of the distributed-lag has a restrictive assumption about λ, it is still much more general than equation (2), which can be regarded as one of its special cases. Furthermore, with the above assumption about the relationship between the betas, a simple estimating equation (6) can be derived which provides estimates of the long and short run responses to price.[14/]

(6) $O_{c.t} = a + b.P_{t-1} + d.O_{c.t-1}$

Where:

b_1 = The short-run price response

$b/_{1-d}$ = The long-run price response

$O_{c.t}$ = Output of cotton, year t.

P_{t-1} = Actual cotton price, year t-1.

It is thus possible to develop a rather complicated formulation of expected prices with only two directly observable historical variables. Because of this advantage, equation (6) is the model used for the empirical work of the next section.

14/ (i) $O_{c.t} = \alpha + \beta_1 P_{t-1} + \beta_2 \lambda . P_{t-2} + \beta_3 \lambda .^2 P_{t-3} + \ldots \beta_n \lambda .^{n-1} P_{t-n} + \epsilon_1$

(ii) Similarly:

$O_{c.t-1} = \alpha + \beta_2 P_{t-2} + \beta_3 \lambda . P_{t-3} + \beta_n \lambda^2 P_{t-4} + \ldots + \epsilon_2$

(iii) Multiplying (ii) by λ and subtracting from (i)

(iv) $O_{c.t} - \lambda O_{c.t-1} = (1-\lambda)\alpha + \beta_1 P_{t-1} + (\epsilon_1 - \lambda \epsilon_2)$

(v) or:

$O_{c.t} = (1 - \lambda)\ \alpha + \beta_1 P_{t-1} + \lambda . O_{c.t-1} + (\epsilon_1 - \lambda \epsilon_2)$

The Estimates

In analyzing the effects of relative price on the production of different crops, there are several reasons for disaggregating output into its yield and acreage components. First, there is no particular reason why farmers should react with their land input in the same manner as with their labor, fertilizer, water and other non-land resources. While it might be expected *a priori* that an increased relative price would result in both a large acreage and a higher yield, the two types of responses may be of entirely different magnitudes. As discussed in Section IV, this is especially likely to be the case when there is fallow land and a general "shortage" of irrigation water. Second, weather effects are likely to create more variation in yields per acre than in acreages planted. Hence, by eliminating the yield component, and by using acreage rather than output as the dependent variable, many of the estimation problems involving weather can be avoided. These acreage responses can be thought of as a lower bound of the supply elasticity, since any price-induced changes in yields from non-land inputs would be in addition to the acreage effect.

Acreage Effects

The acreage supply functions for the various crops of the former Punjab are shown in Table 1. The equations, all of which were fitted in logarithmic (constant elasticity) form, are of the distributed lag variety described previously. In addition,

TABLE 1. Acreage Response Functions, Former Punjab

CROP	Equation No.	Lagged Relative Price	Lagged Acreage	Water Supply	Constant Term	Variance Explained	Durbin Watson Statistic	Years Included
A		P_{t-1}	A_{t-1}	W_t	a	R^2	D.W.	
Rainfed Wheat	1	-.09[a] (.08)	.51 (.11)	.07[b] (.01)	6.99	.64	2.70	1932-61
Irrigated Wheat	2	.06[c] (.03)	.81 (.09)	.12[d] (.06)	1.59	.90	1.80	1932-64[e]
Rice	3	.16[f] (.09)	.61 (.14)	.63[g] (.26)	-1.10	.91	2.40	1932-64[e]
Cotton	4	..29[h] (.08)	.92 (.14)	.29[i] (.15)	-1.50	.67	2.20	1932-56
Sugarcane	5	.14[k] (.08)	.88 (.06)	.89[l] (.37)	-8.4	.98	1.60	1940-64[e]
		P_{t-2} .30[k] (.08)						

a) Wheat price ÷ gram price
b) Sept. plus Oct. rainfall
c) Wheat price ÷ weighted average cotton and sugarcane prices
d) Rabi Water supplies, 8 major canals
e) Excludes 1950/51, 1951/52 and 1952/53. Data unavailable because of the Indus Basin dispute
f) Rice price ÷ weighted average cotton and sugarcane prices
g) Rabi Water Supplies Preceding Year, 8 Major Canals
h) Cotton Price ÷ weighted average rice and sugarcane prices
i) May plus June Water Supplies, 8 Major Canals
k) Sugar cane (gur) Price & Weighted Average Cotton and Oilseed Prices
l) Rabi plus Kharif Water Supplies, 8 Major Canals

a water variable has been added to each equation to take into account the critical nature of that input in the region. (Availability of relevant water data was also the determinant of the particular years that were included in each equation.)

The results are strikingly consistent. They indicate supply elasticities at least as large as those found for the United States. In addition they collectively indicate a high correlation between the price elasticity magnitudes and the extent to which the crops are grown for sale rather than subsistence.

Each of the commodity equations has special features which are worth noting briefly. In the case of wheat, the main foodstuff of West Pakistan, the difference in price responsiveness between the rainfed and the irrigated areas gives one indication of the interrelated nature of historical price response and water supplies. In the rainfed areas of former Punjab, climatic conditions are virtually the only determinant of acreage. Relative prices play almost no role, since the other crops that are feasible under the moisture conditions are extremely limited. For example, it would seem from acreage statistics that gram (chick-pea) is the largest potential competitor. But in fact, these figures are misleading because gram and wheat are often sown together as a contingency against low-rainfall, -- gram being an even more drought-resistent crop.

These characteristics of wheat production are summarized in Equation (1). A crude estimate of September-October rainfall is an extremely significant variable, while the price variable is insignificant and even of the wrong sign.

The contrast between rainfed and irrigated wheat (Equations 1 and 2) indicates an increased price responsiveness when the water constraint is partially relaxed. Though irrigation supplies in the fall season remain an important determinant, relative price now enters the equation in a significant way. While the short-run price elasticity is low (.06), it is still important given the absolute magnitude of wheat acreage. With some 6 million irrigated wheat acres in West Pakistan, a 10 percent variation in relative wheat prices has a short-run effect of approximately 200,000 tons.[15/] Since annual price changes to farmers of 10 and even 20 percent are not uncommon, the price responsiveness in wheat clearly has important implications for food policy.[16/]

The equation for rice (3) indicates the intermediate character of that commodity in the former Punjab. Although rice is an important foodstuff, many of the finer varieties are grown as a cash crop for eventual export. The fact that irrigation water supplies is again a significant determinant, and that the price elasticity of .16 falls about half way between wheat and a "pure" cash crop such as cotton, is encouraging on

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[15/] Average wheat yields about 0.5 ton per acre, thus .06 x 6,000,000 acres x .5 tons per acre is approximately 200,000 tons.

[16/] The average absolute change in annual wheat prices at Lyallpur was 11.2 percent for the 10 years ending in 1964/5. Seasonal fluctuations were of course even larger.

consistency grounds.[17/]

For cotton and sugarcane (Equations 4 and 5), the two major cash crops of the area, price elasticities are both higher and more significant in a statistical sense.

The .3 price elasticity for cotton is slightly lower than was found in two earlier studies, though it is still of the same order of magnitude.[18/] The water variable in cotton also created some difficulties in estimation since acreage was uncorrelated with total canal flows over the season. However, canal flows for the "planting months" of May and June proved significant. Regrettably, these data were available only through 1956 and thus it was not possible to examine how well the equation "explained" the recent years which are of most relevance for policy purposes.

The sugarcane equation adds a final point to the questions of magnitude and methodology. Sugarcane is, at a minimum, a year-long crop. In West Pakistan it is usually cut-back (ratooned) and allowed to produce a second crop as well. Thus, "short-run" for cane is really two years. These technological observations are reflected in Equation (5) where lagged

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17/ The price elasticity of .16 is similar in magnitude to the .12 estimate of Hussain's (16) for Aus Rice in East Pakistan. It is significantly lower, however, than the .3 estimate of Krishna (20) for an earlier period in undivided Punjab.

18/ See Falcon (4) and Ghulam Mohammed (21), whose estimates using different types of equations were .4 and .5, respectively.

prices for years t-1 and t-2 have both been included. The sum of these price coefficients (.44) can be regarded as the short-run price response. The size of this elasticity, the largest of all those computed, serves to underscore the potential importance of price and import policies for sugar.

The summary picture that emerges for former Punjab is that when climatic and technological conditions permit, farmers allocate acreages in response to changed relative prices. While all of these short-run elasticities are less than 1.0, and hence inelastic by the usual definition, they are of sufficient magnitude to be of importance in agricultural planning. The specific policy implications of these estimates, as well as an interpretation of the long-run elasticities implied by the equations, is deferred to Section V.

Yield Effects

Just as a farmer might react to price by allocating his land input, so might he respond with non-land inputs to alter yields per acre. By substituting yield for acreage variables in the previous equations, it was possible to obtain estimates of these effects.

The yield response equations proved just as consistent as the previous acreage estimates -- but in a startlingly different way! None of the yield equations contained statistically significant price variables, nor did several variations in the form and structure of the yield formulation provide results that were any more significant.

An explanation of these yield results rests on a combination of theoretical, empirical, and statistical factors. As mentioned previously, it is generally agreed that climatic factors affect yields more than acreages. Hence, it may be that the price effects on yields were simply "swamped" by other factors -- thus making it impossible to estimate the price reactions.

Secondly, during most of the three decades under study, there were few technical possibilities for altering yields. Between 1930 and 1960, yields were virtually stagnant; fertilizers, pesticides, etc., which might have been altered in response to changed prices, were virtually unknown.[19/] There was of course the possibility of altering the relative amounts of labor used in cultivation processes of different crops. However, a number of writers have commented on the seemingly fixed nature of cultivation practices for particular crops in different regions.[20/] Thus without going into an extensive discussion of whether the marginal product of labor was zero (or epsilon) in different crops, whether labor was a free good as seen by the farmer, or whether there were some minimal shifts in the allocation of labor among crops, the conclusion is clear. The reallocation of labor as well as

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19/ The general features of Punjab agricultural technology during this period are discussed at length in Gotsch (9).

20/ See Falcon (3) for more details.

fertilizer, pesticides, etc., in response to changed relative prices were not important variables in explaining variations in former Punjab yields during the last three decades.

Finally, there remains the puzzling case of irrigation water. One might have expected that as relative prices of a particular crop increased, two reactions would have occurred: (a) more acres of the crop would have been grown and (b) that a larger volume of water *per acre* would have been applied, thus giving a yield response. However, the empirical evidence suggests that only the area response appeared significant. As the discussion in Section IV will indicate, this asymetry in response represented optimizing behavior on the part of the farmers. Thus, in spite of the limited number of estimates presented above, the historical evidence on the effect of relative prices in former Punjab seems fairly conclusive. While they were an important determinant of acreage, especially for crops grown primarily for sale, they were unimportant as an explanation for variations in yields.

IV. ALLOCATION OF IRRIGATION WATER - A FURTHER INDICATION OF FARMER RATIONALITY

In the preceding section, it was argued that land allocation in response to relative prices indicated that West Pakistan farmers behaved as if they were profit motivated. Several price models, in which acreage was treated as the dependent variable, were tested and found significant.

In comments made earlier, however, it was pointed out that land is generally not the limiting factor in West Pakistan. In this respect, the region is no different from other arid zones of the world where the decision to grow a certain amount of a crop is usually a decision about the allocation of limited amounts of irrigation water. In the following section, the water allocation problem is developed at some length because it permits a fuller explanation of the significance of the area models and the insignificance of the yield models attempted in Section III.

Water Allocation under Certainty

In examining the relationship between price response and water availability, one of the simplest ways of visualizing the problem of allocating water between crops is with the aid of a conventional linear programming tableau. The illustrative cropping pattern shown in Figure 2 can be translated easily into a matrix of land and water requirements, such as the one for a typical Gujranwala farm shown in Table 2. The water coefficients, given in acre inches, refer to the monthly water "requirements" per acre under crop; the land coefficients, given in acres, refer to the area occupied by a crop during a given time period. The constraints in the right hand column refer to water and land availability, respectively, while the net revenue figures of the last row indicate the income per acre from each crop.

From the matrix presented above, it is clear that a rational response to changes in relative prices will require a fairly complex set of calculations. The farmer, in attempting to maximize profits, must bear in mind not only the changed price relationship among crops, but also their relative water requirements and the time distribution of the available water supplies. For example, a small increase in the price of cotton might be expected to increase its production relative to rice, the other major kharif crop. However, there is also some overlap in the growing periods of cotton and wheat. If water is in "short" supply during the month of October, it may not pay the farmer to grow more cotton. To do so would mean a reduction, not only of rice, but also of wheat. Indeed, for sufficient price changes, profit maximization will lead to an entirely new set of critical water periods. As some of the solutions to the programming problem presented in a later section indicate, it is this result which serves to link closely the magnitudes of price response with irrigation-water availability.

Although the model presented in Table 2 provides considerable insight into the trade-offs involved in distributing water efficiently among crops, it still does not reflect fully the difficult water allocation problem. The choice between using water to increase yields or to extend acreage has been sidestepped entirely thus far. In the linear programming context, the crop-water activities which were used assume that a particular yield would be obtained from a crop if, and only if, the monthly water delta indicated by the matrix was applied. Numerous researchers have reported, however, that such an assumption is a gross oversimplification of the relationship between water applications and yield. Delta-yield ratios can vary widely and some thought must be given to the most likely shape of the yield function of crops with respect to water.

Water/Yield Relationships

In recent years, agriculturists have shown increasing interest in crop/water relationships. Unfortunately, the problem has nearly always been attacked with the intention of ascertaining the amount of water "required" by plants. Often called "consumptive use", this parameter is generally measured under conditions that ensure very limited moisture stress on the plant during the growing season and hence is more or less synonymous with the amount of water needed to maximize plant yields.

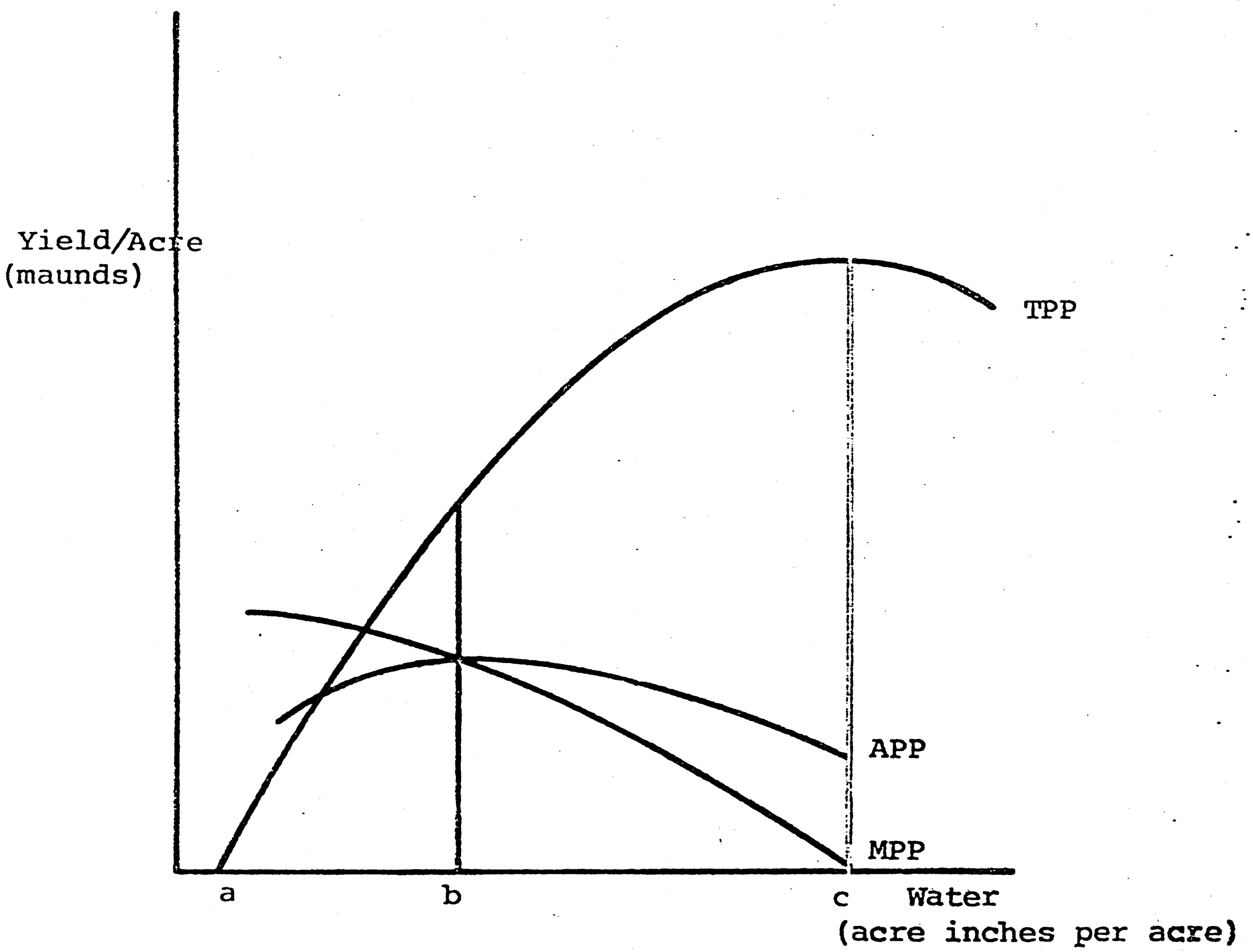
No attempt will be made in this paper to examine in detail the literature regarding the characteristics of the crop production with respect to water. However, a substantial amount of evidence, both theoretical and empirical, is accumulating which suggests that a function of the general form shown in Figure 3 is most appropriate for relating yield to successive increments of water.[21/]

21/ The interested reader should refer to Eke (2) and Ilaco (17) for comprehensive reviews of the work that has been done in this area. Also the 2500 trials reported by Fox suggest that 2/3 of the field capacity for water will produce 90% of maximum yield and that about 1/2 of the full requirement will produce approximately 2/3 of the maximum yield. In West Pakistan, work done by Gill (8) also indicates strongly diminishing returns to wheat, cotton, sugarcane and gram.

Figure 3.

Diminishing Returns Water

Response Curve



a = wilting point

b = optimal allocation when land is a free good

c = field capacity

TABLE 2 LINEAR PROGRAMMING MATRIX

(Gujranwala Rice Tract, Typical 12.5 Acre Farm)

Column	1	2	3	4	5	6	7
	Fine rice	Coarse rice	Kharif fodder	Kharif vegetables	Cotton	Wheat after fallow	Wheat after rice
Water							
WAPR			1.7	1.7	1.7	.8	
WMAY		8.5	3.8	3.8	5.5		
WJUN	8.0	14.9	6.9	6.9	3.7		
WJUL	11.4	11.6	4.3	4.3	2.7		
WAUG	9.5	4.7	1.8	1.8	6.3		
WSEP	13.2	2.4	.8	.8	11.7	1.3	
WOCT	3.5				7.7	4.2	
WNOV	.5					1.6	2.1
WDEC						1.9	2.0
WJAN						2.2	2.3
WFEB						4.8	4.3
WMAR			1.3			7.1	7.3
Land							
LAPR			1.0	1.0	1.0	1.0	1.0
LMAY		1.0	1.0	1.0	1.0		
LJUN	1.0	1.0	1.0	1.0	1.0		
LJUL	1.0	1.0	1.0	1.0	1.0		
LAUG	1.0	1.0	1.0	1.0	1.0		
LSEP	1.0	1.0	1.0	1.0	1.0	.5	
LOCT	1.0	.5	1.0		1.0	1.0	
LNOV	.5		1.0		.5	1.0	.8
LDEC						1.0	1.0
LJAN						1.0	1.0
LFEB						1.0	1.0
LMAR						1.0	1.0
Net Revenue	161.6	122.6	219.6	320.0	79.6	159.1	85.6

Cont'd on next page

Table 2 (Cont'd)

LINEAR PROGRAMMING MATRIX

(Gujranwala Rice Tract, Typical 12.5 Acre Farm)

Column	8 Gram	9 Oil-seeds	10 Berseem	11 Rabi Vegetables	12 Sugarcane	13 Fruit	14 Resource Availability
Water							
WAPR			6.3		8.0	7.0	32.7
WMAY					13.9	9.4	39.0
WJUN					15.4	8.5	43.2
WJUL					9.3	4.5	42.4
WAUG		.8	1.3		7.3	4.2	42.0
WSEP	3.4	2.5	3.4		10.7	9.3	43.2
WOCT	2.4	3.6	3.8	6.9	10.0	7.7	35.7
WNOV	2.5	3.5	4.2	4.2	3.6	3.8	24.4
WDEC	2.7	3.3	3.1	3.1	3.1	2.0	21.8
WJAN	2.1	2.1	2.7	2.2	1.6	1.3	22.7
WFEB		.1	5.0	3.6	8.7	2.4	29.0
WMAR			8.5	5.6	3.5	3.9	35.2
Land							
LAPR			1.0		1.0	1.0	12.5
LMAY			1.0		1.0	1.0	12.5
LJUN					1.0	1.0	12.5
LJUL					1.0	1.0	12.5
LAUG		.5			1.0	1.0	12.5
LSEP	.5	1.0	1.0		1.0	1.0	12.5
LOCT	1.0	1.0	1.0	1.0	1.0	1.0	12.5
LNOV	1.0	1.0	1.0	1.0	1.0	1.0	12.5
LDEC	1.0	1.0	1.0	1.0	1.0	1.0	12.5
LJAN	1.0	1.0	1.0	1.0	.5	1.0	12.6
LFEB	1.0	1.0	1.0	1.0	.5	1.0	12.7
LMAR	.5		1.0	1.0	1.0	1.0	12.8
Net Revenue	86.1	88.3	321.0	420.0	550.0	520.0	

Diminishing Returns to Water and Rational Irrigation Practices

The foregoing discussion has indicated that farmers can respond in terms of either acreage or yield (or both) to changes in the relative price structure. How is it then, that only the acreage models in Section III were statistically significant? With the comments on the shape of the crop-water relationship as background, it is possible to offer a partial explanation for this result and at the same time, to provide some insight into the causes of the serious soil-salinity problem in the Indus Basin.

Assume that the input-output relationship between crop yield and water exhibits diminishing returns as indicated in Figure 3. Under such conditions, what would the optimum allocation of water per acre (delta) be?

As is well known, production functions which include ranges of increasing, decreasing and negative marginal returns can be divided into three segments.[22] The function in Figure 1 has been truncated approximately at its inflection point but it still exhibits the three so-called "stages." Production in any stage except 2 is economically irrational.[23] In the special case where the economic value of an input is zero, rational resource use requires that production take place at the appropriate border of Stage 2. For example, if the variable resource were "free", (its opportunity cost were zero) profit maximization would require that it be added to the fixed resource until its marginal product is also equal to zero. A similar argument holds for the fixed resource and the edge of Stage 2 marked by the point of maximum average production. Hence, in Figure 1 above,

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22/ See, for example, Heady (14).

23/ Heady (14), chapter 4.

if land is a "free resource", production would be carried out at point "b". Alternatively, this point may be thought of as maximizing the productivity of the variable resource, water.

Many studies of the Indus Basin confirm that farmers are indeed applying deltas substantially below those associated with maximum yields. Harza Engineering estimates,[24/] for example, that of the average full crop requirement of 2.7 acre feet per acre required during the kharif season, only about 80 percent, or 2.2 acre feet per acre, are supplied by the canal system. They also report that even more extensive "under-watering" occurs during the rabi season.

Tipton and Kalmbach, in preliminary studies for the Feasibility Report on Salinity and Reclamation Project No. 5,[25/] have also noted that application of less than the consumptive use requirement is a standard agricultural practice. Present cropping intensities in the project area, according to their estimates, are in the neighborhood of 125%. If the full consumptive use requirements of the crops were to be met, irrigation supplies are available for only about 100% intensity.

The profit maximizing nature of "underwatering" is evident from the nature of the crop-water production function. In situations where large acreages are left fallow each season for want of water, land is virtually a "free" input to the farmer and hence one can expect little increase in the amount of water applied per acre.

24/ Harza Engineering Company (13).

25/ Tipton and Kalmbach (28).

The failure of the earlier yield models to give significant results is therefore consistent with the foregoing conclusion. As farmers increased or decreased acreages they have tended to hold deltas -- and hence yields -- constant. It is only when the land constraint, or what might be called a "feasible intensity" constraint becomes binding that increased yields can be expected as a result of increased water applications per acre.

The short-run rationality embodied in spreading scarce water thinly has had, however, serious side effects for the Indus Basin in the long run. The failure to supply enough water per acre to ensure a continual downward movement of the salts in the soil profile has resulted in a salinity problem which each year reduces yields and forces abandonment of thousands of irrigated acres.26/

It is thus ironic that "rational" economic actions by farmers have led to the severe salinity problem of West Pakistan. Although they have been roundly criticized for "underwatering", few critics have appreciated the time horizon or the extent of knowledge required by cultivators to act otherwise. Soil salinity takes years, even decades, to develop and the decreases in yields resulting from the buildup in salts is almost imperceptible in the short run. Moreover, given the low level of

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26/ Soil salinity can arise in two ways, both of which, except in extreme cases, can be treated by consistent downward percolation of water through the soil profile. The simplest case results when salts have been left in the root zone by many years of "under" irrigation, but the groundwater level is still 10 feet or more below the surface. The second case results when groundwater tables rise to the point that capillary action causes the water to move upward into the root zone, there to be evaporated. The latter problem is the more difficult to treat since, in addition to higher deltas per acre, drainage is also required.

consumption and income of the average farmer, and hence his preference for present over future production, it is unlikely that he would have acted differently even if he understood the relationship between "underwatering" and salinity. Even from a social or national point of view, it would have taken a very low social discount rate to justify a behavior other than that which was employed.

A Linear Programming Model Incorporating Diminishing Returns

Although there is a growing recognition that water response curves are non-linear, very little empirical work exists which permits or includes non-linear functions. As the previous discussion indicated, however, non-linear relationships between yields and the per acre application of water are fundamental to a quantitative understanding of the water allocation problem in Pakistan. Hence an attempt must be made to incorporate this concept into the programming model shown in Table 3.

It is well known that convex functions can be approximated to any desired degree of accuracy by a series of straight line segments. When applied to the production function for a particular crop, these linear segments may be interpreted as activities which produce the same commodity but with different input-output coefficients. For example, if the water response curve for wheat has the form shown in Figure 4, activities can be constructed at points a, b, c, and d.

Choice of any one of these segments corresponds to the choice of a point on the production function. Choice of two would indicate an optimal point on the non-linear function somewhere between the specific points indicated by the activities and could be approximated by interpolation.

Table 3

ACTIVITIES APPROXIMATING A NON-LINEAR WATER RESPONSE CURVE FOR WHEAT AFTER FALLOW[27/]

Column	(1) WHF1	(2) WHF2	(3) WHF3	(4) WHF4
	D	C	B	A
WAPR	.8	.7	.5	.4
WMAY				
WJUN				
WJUL				
WAUG				
WSEP	1.3	1.1	.9	.7
WOCT	4.2	3.6	3.0	2.3
WNOV	1.6	1.4	1.2	.9
WDEC	1.9	1.6	1.3	1.0
WJAN	2.2	1.9	1.6	1.2
WFEB	4.8	4.1	3.4	2.7
WMAR	7.1	6.0	5.0	3.9
LAPR	1.0	1.0	1.0	1.0
LMAY				
LJUN				
LJUL				
LAUG				
LSEP	.5	.5	.5	.5
LOCT	1.0	1.0	1.0	1.0
LNOV	1.0	1.0	1.0	1.0
LDEC	1.0	1.0	1.0	1.0
LJAN	1.0	1.0	1.0	1.0
LFEB	1.0	1.0	1.0	1.0
LMAR	1.0	1.0	1.0	1.0
Net Revenue	159.1	154.3	141.6	117.7

27/ For methods of monthly estimating coefficients, see Gotsch (9). A major difficulty in obtaining monthly coefficients is the lack of experimental data on the effects of moisture deficits on the plant at various points on the plant growth stage curve. The estimates presented above for Columns 2-4 assume that the deficit (consumptive use minus availability) is distributed in proportion

Figure 4.

APPROXIMATED WATER RESPONSE

CURVE FOR WHEAT

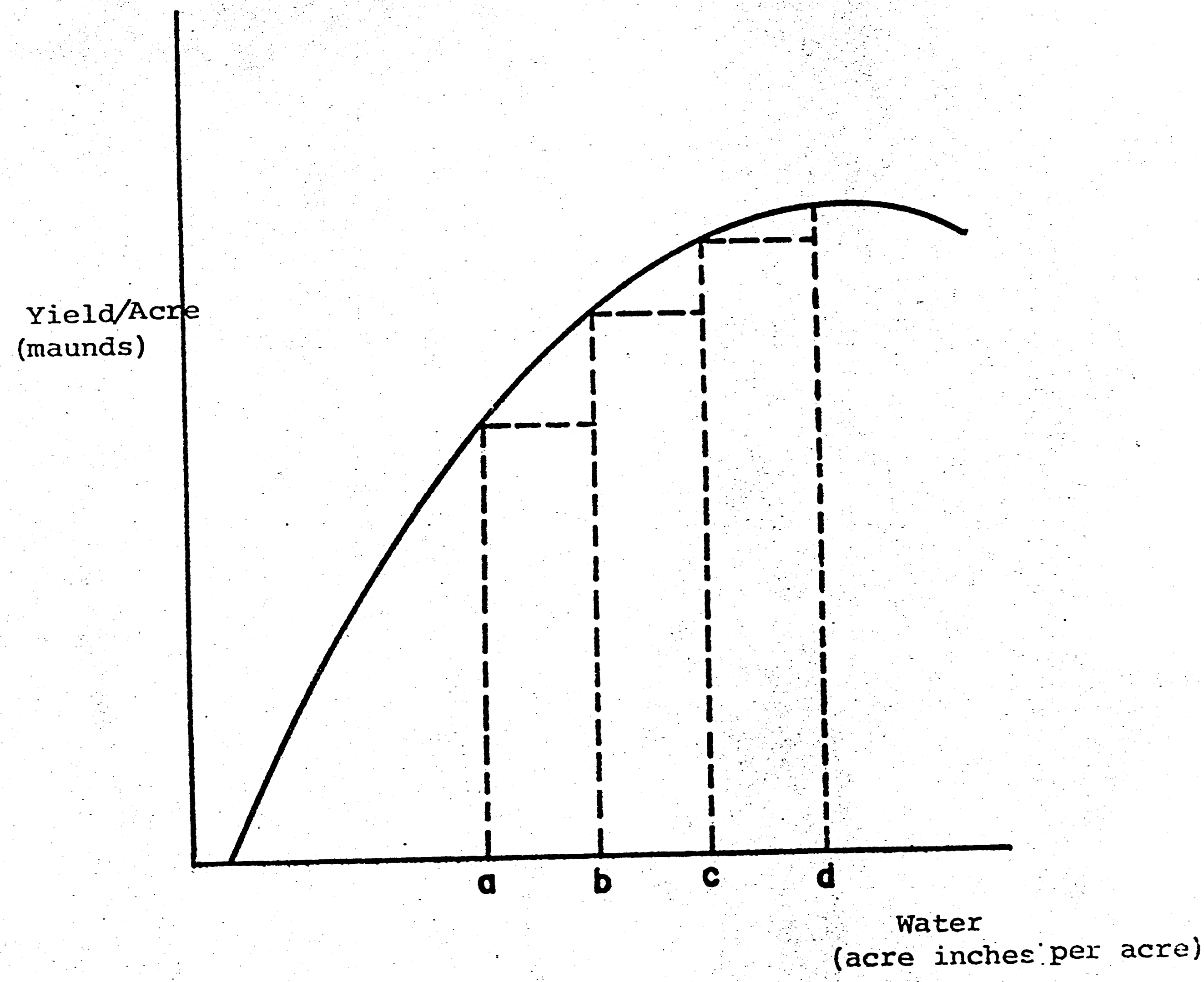


Table 4 presents solutions to the linear programming models both with and without the assumption of non-linear water response curves. The comparison clearly emphasizes the quantitative importance of incorporating non-linear functions into any examination of decisions regarding water allocation in West Pakistan.

Table 4

CROPPING PATTERNS, CROPPING INTENSITIES AND YIELDS UNDER LINEAR AND NON-LINEAR WATER RESPONSE CURVES (12.5 acre farm - Gujranwala rice tract)

Crops	Model I Linear Response Curves (consumptive use)		Model II Non-Linear Response Curves	
	Acreage	Yield	Acreage	Yield
Fine rice	1.14	18.0	1.23	17.1
Coarse rice	.63	23.0	1.07	21.8
<u>Kharif</u> fodder	.80	250.0	.80	250.0
<u>Kharif</u> vegetables	.10		.10	
Wheat-after-fallow	1.36	12.5	2.99	9.2
Wheat-after-rice	.68	6.8	.98	5.2
Gram	.52	7.0	2.43	6.2
Oilseeds	1.24	6.0	1.56	5.6
Berseem	1.60	450	1.60	450.0
<u>Rabi</u> vegetables	.20		.20	
Sugarcane	1.00	500.0	1.00	429.0
Fruit	.30		.30	
Total Acreage	9.57		14.26	
Cropping Intensity (based on cultivated acreage)*	79%		116%	
Net Revenue	Rs. 1857		Rs. 2097	

*Fruit counted twice

Use of input-output coefficients which imply that consumptive use requirements are met (Model 1), produces a cropping intensity well below that observed historically. Incorporation of non-linear functions, on the other hand, results in a significant decrease in yields and an increase in acreage under crop, both of which are consistent with available empirical material. In addition, net revenue has increased by Rs. 240 (13%) indicating that the farmer may have been wiser than those who accused him of "underwatering" and those who insist on full consumptive-use coefficients for planning.

V. EFFECT OF SUPPLEMENTARY WATER SUPPLIES ON FARMER PRICE RESPONSE

It is evident from the foregoing discussion that there is a strong relationship between the ability of West Pakistan farmers to alter their cropping patterns in response to a change in relative prices and the availability of irrigation water supplies. In view of the magnitude of the proposed water development program planned for the Indus Basin, one can question whether the elasticity calculations based on the earlier time-series data will be appropriate guides for future agricultural price policy. In the following section, the linear programming model developed earlier is used to explore this hypothesis from a normative point of view.

As a first step, the new technology (tubewells) for producing water must be incorporated into the model. This is done by adding a series of activities that deliver water to the water using rows, i.e., they make additional water available for crop use. The operation of such activities incurs a cost (the variable cost of running a tubewell) and the objective of the program now becomes the maximization of the sum of net crop revenues minus the cost of pumping.

Table 5 indicates that the introduction of "tubewells" into the linear programming tableau radically alters the agricultural picture presented by the optimal solution of the model. Cropping intensities have increased to the extent that land is now binding, yields are higher, and the composition of the cropping pattern has changed substantially. The total net revenue for the representative farm has grown by nearly 40% indicating the strong incentive for farmers to invest in the new technology.

TABLE 5

Cropping Patterns with and without Supplementary Water from Tubewells (12.5 acre farm, Gujranwala Rice Tract)

Crops	Without Tubewell		With Tubewell	
	Acreage	Yield	Acreage	Yield
Fine rice	1.23	17.1	5.53	18.0
Coarse rice	1.07	21.8	2.01	23.0
Kharif fodder	.80	250.0	.80	250.0
Kharif vegetables	.10		.10	
Wheat after Fallow	2.99	9.2	2.21	12.5
Wheat after Rice	.98	5.2	5.76	6.8
Gram	2.43	6.2		
Oilseeds	1.56	5.6		
Berseem	1.60	450.0	1.60	450.0
Rabi Vegetables	.20		.20	
Sugarcane	1.00	429.0	1.00	500.0
Fruit	.30		.30	
Total Acreage	14.26		19.51	
Cropping Intensity (based on cultivated acreage)*	116%		158%	
Net Revenue	Rs. 2097		Rs. 2877	

* Fruit counted twice

Of primary interest for the present study, however, is the effect of an increased, highly flexible water source on the supply curve of various crops. Such curves are defined as the amount farmers should be willing to supply of a particular crop at varying prices when the prices of other crops, other technology and weather are held constant. They can easily be derived from the programming model by varying the price for a given crop, computing the net revenue associated with each price and then re-solving the model for each variation. The linear programming model is, of course, an optimizing model, and hence, the supply curves derived by parametrically varying prices are normative in nature. That is, they describe what farmers should do at varying prices in order to maximize profits, and thus they differ conceptually from the supply estimates presented in Section III, which show what farmers have done. Nevertheless, the conclusion that the new tubewell technology can be expected to exert a profound influence on (1) the optimal level of output at current prices (shifts in the supply curve) and (2) the elasticity of farmer price responses appears unmistakable.

Figure 5.

NORMATIVE SUPPLY CURVES FOR SUGARCANE

(12.5 acre farm, Gujranwala area)

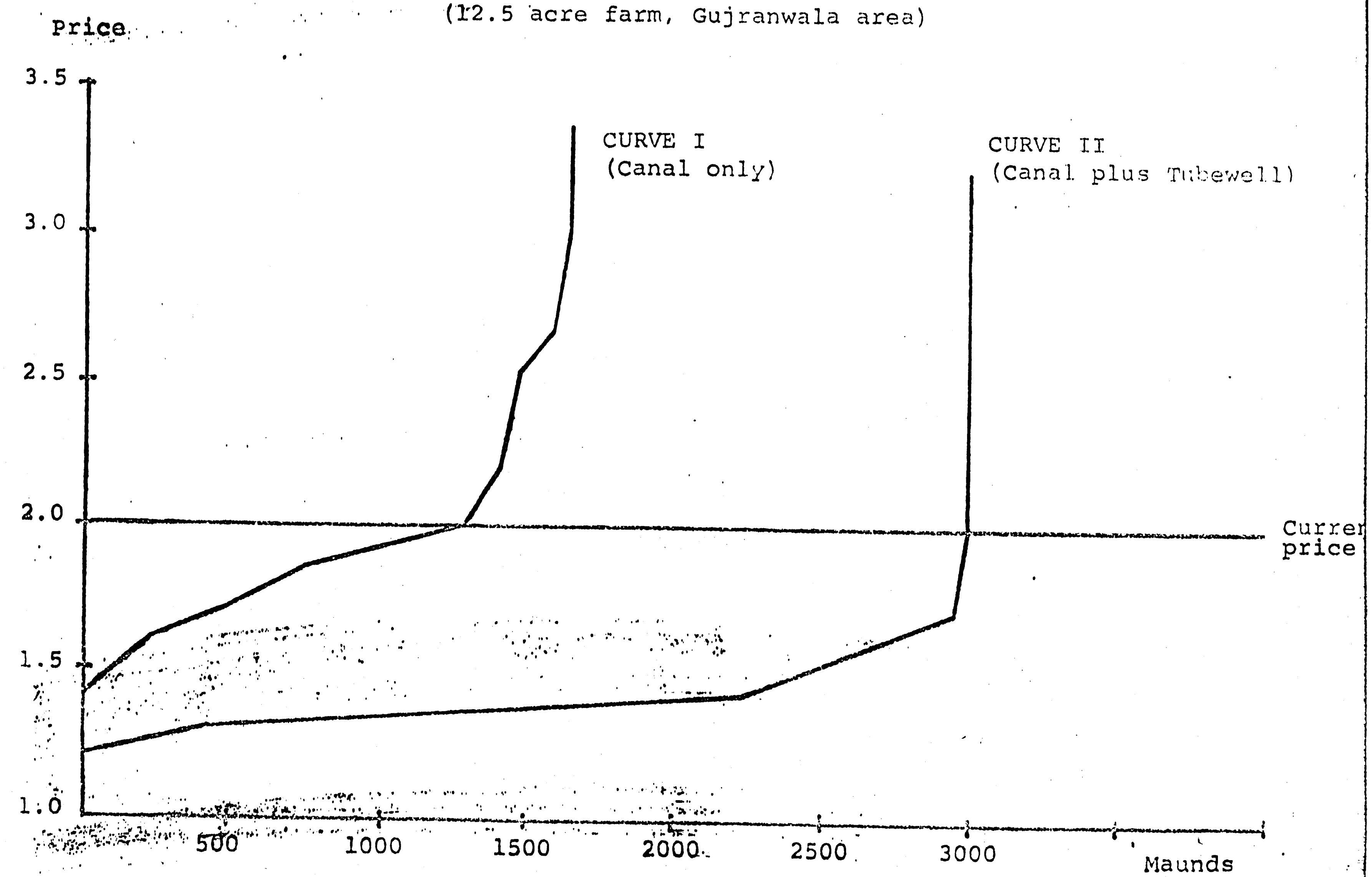


Figure 6

NORMATIVE SUPPLY CURVES FOR WHEAT

(12.5 acre farm, Multan - Montgomery area)

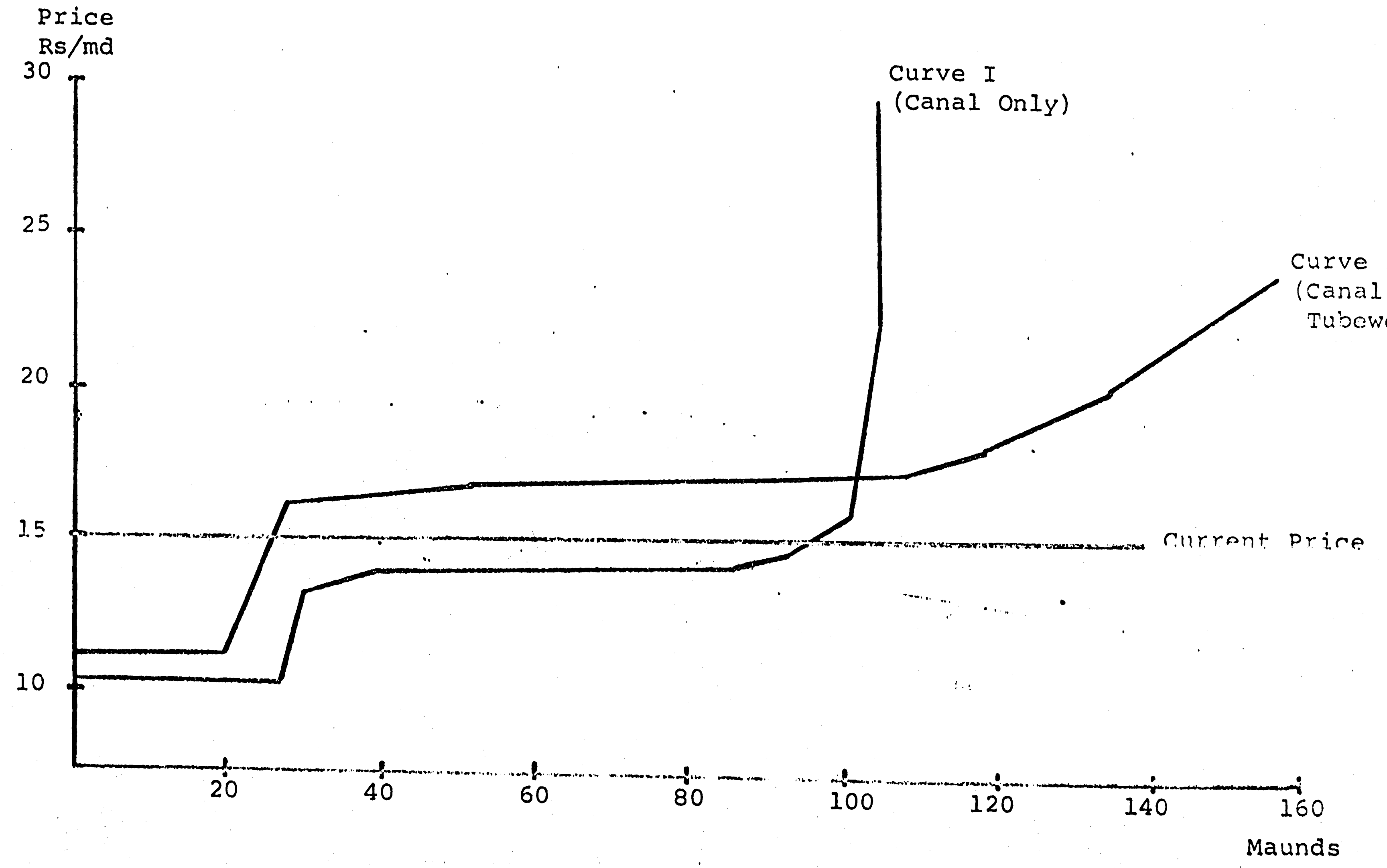


Figure 7.

NORMATIVE SUPPLY CURVES FOR COTTON

(12.5 acre farm, Multan - Montgomery area)

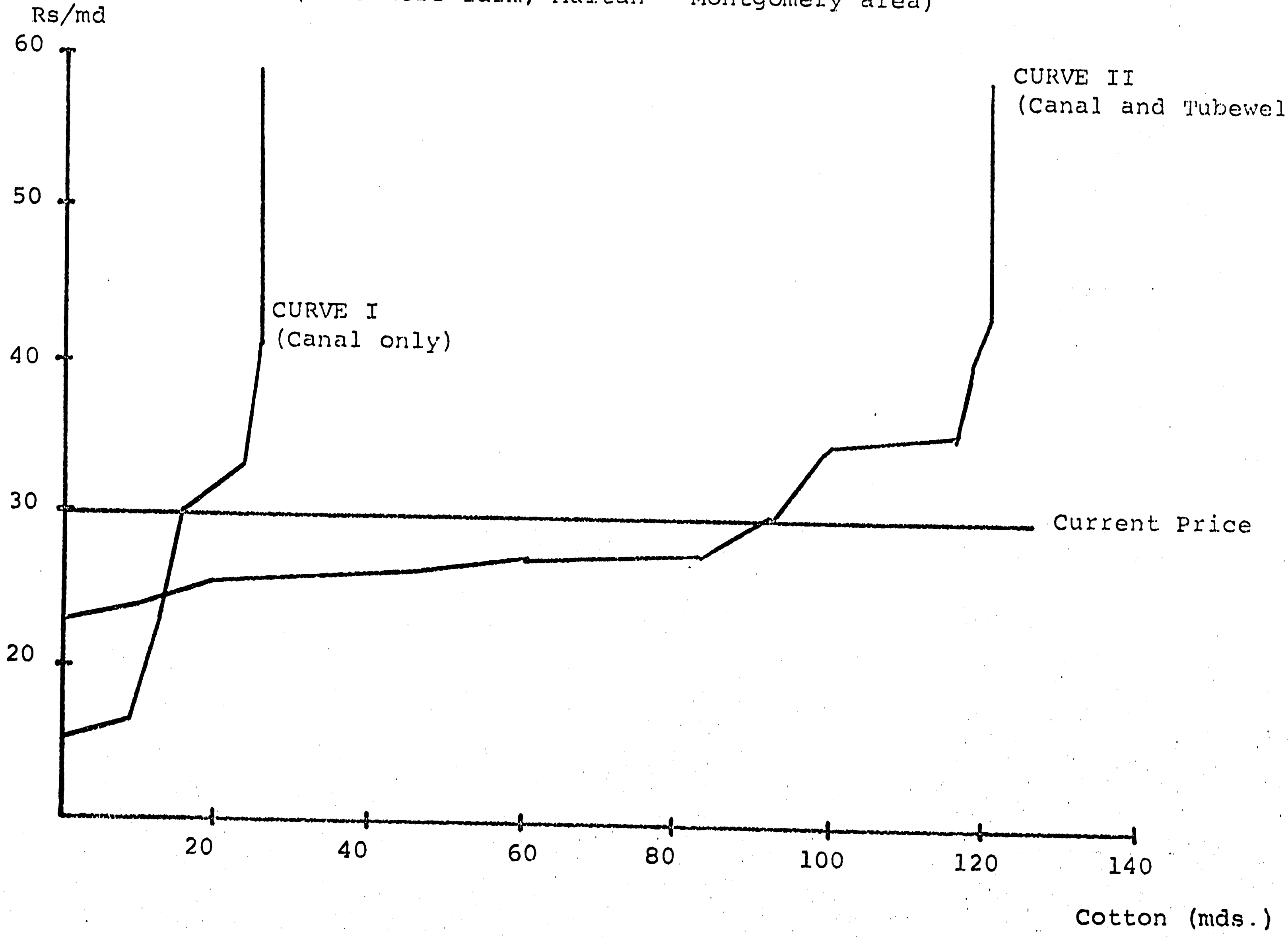
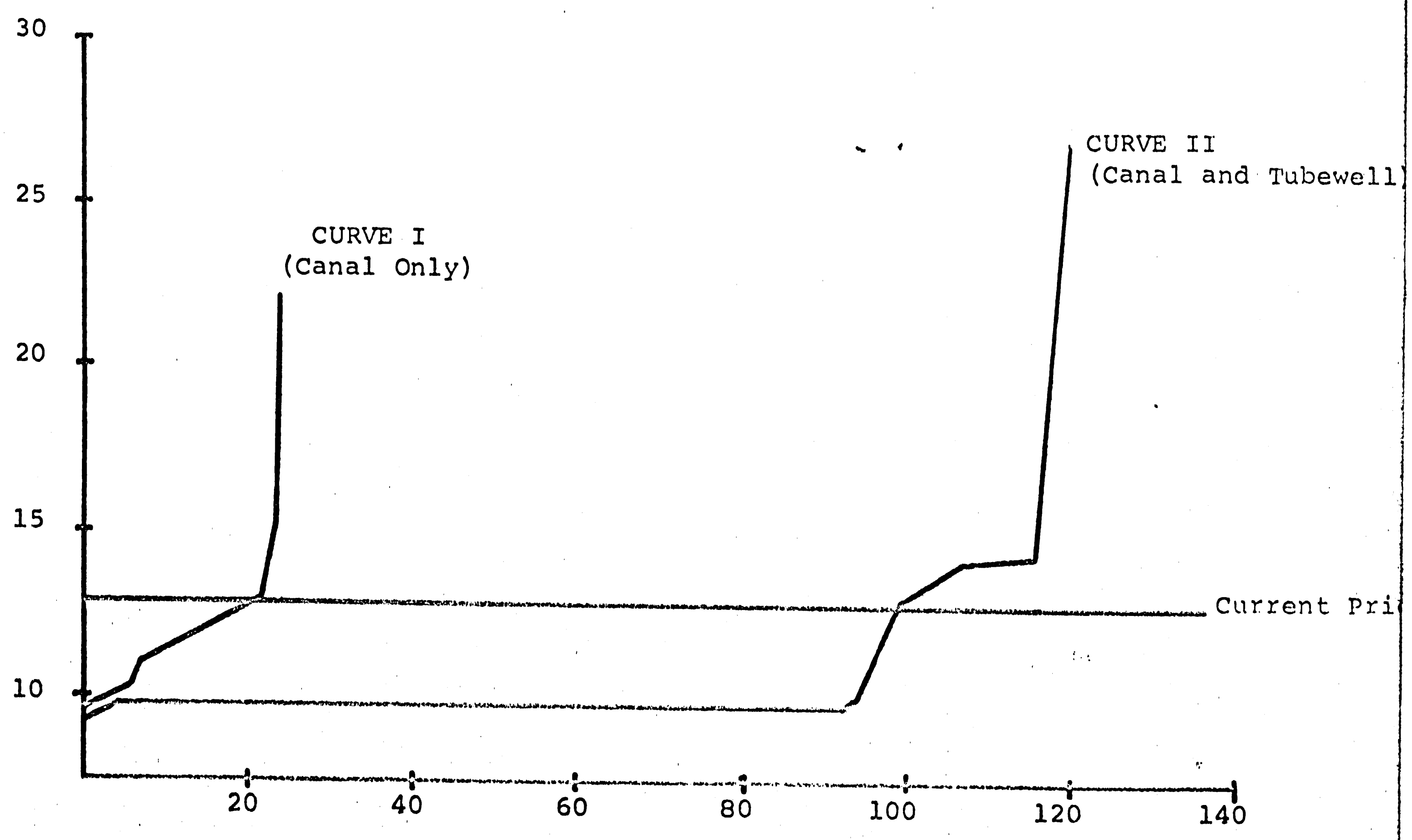


Figure 8.

NORMATIVE SUPPLY CURVE FOR FINE RICE

(12.5 acre farm, Gujranwala area)



The two effects described above are readily discernable in Figure 5. The equilibrium level of cane output at current prices has more than doubled under the impact of a flexible supply of supplementary water. Moreover, over the relevant range, Curve II is much more elastic than Curve I. This comparative increase in price elasticity is significant in that Curve I is in some sense analagous to the long-run supply elasticities derived in Section III.[28] The link is that the latter estimates assume a time lapse sufficient for farmers to have made all the adjustments implied in the normative curve.

The choice of sugarcane as an example is not without reason. Present cane prices to growers are substantially above world market prices and are held there by factory price guarantees and a restrictive Government import policy.[29]

Historically, the distortion of cane prices has been minimized by the extremely high water requirements of sugarcane. In fact, many areas served by non-perennial canals, grow virtually no cane at all. As Figure 5 indicates, however, and as evidence from SCARP I and other high tubewell density areas corroborates, large scale groundwater development has substantially

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[28] Indeed, for sugarcane, the relationship is remarkable. A crude calculation of the elasticity of Curve I gives a value of approximately 2.7. The estimate based on time series data is slightly greater than 3. The normative and long-run historical elasticities for cotton and rice are also of similar magnitudes. Wheat, however, presents an anomaly since the normative elasticity is much greater than the long-run response indicated from Table 1.

[29] For a fuller discussion, see the Sugar Commission Report (10).

altered the relative profitability of the sugar crop. Hence, if the Government does not want further inroads into land which might be devoted to export crops such as rice and cotton, or into food crops, some adjustment will be required in its present sugar policy. A failure to make these alterations may prove quite costly, both in terms of budget expenditure and national income foregone. Quantitatively, it would appear that maintenance of the status quo in sugarcane output in the face of a wide-spread increase in water availability, would require a decrease in the guaranteed mill price (Rs. 2.0 per maund) of 25-30 percent -- at least in the Gujranwala area for which the tableau is apropros.

Other examples of the effects of additional water supplies on the cropping pattern are given in Figures 6, 7 and 8. Figure 6 indicates that at the prevailing wheat price of approximately Rs. 15 per maund, farmers who installed tubewells would be likely to reduce wheat production substantially! This result is due to the profitability of growing cotton which competes with wheat for land. Figure 6 also indicates that only a small price (or yield) increase is required for wheat to overcome the comparative advantage of cotton production. On the basis of the derived curves, one could expect wheat output under tubewells to be substantially greater at Rs. 17.5 per maund than when only canal water was available. Such a possibility is, of course, of special importance if the substantial imports of wheat supplied under concessional terms (P.L.480) were to be cut off.

An even more significant effect of additional water supplies on the historical wheat-cotton relationship may come as a result of the introduction of the new "dwarf" wheats. Yields of the new varieties have been reported to be 2-3 times that normally achieved with indigeneous varieties.30/ Such yield increases depend, in part, however, on several additional irrigations during the growing season -- which could easily be supplied with tubewells.

Figures 7 and 8 illustrate other major cash crops for which substantial increases in supply at current prices can be expected once supplementary water becomes available. As in the case of sugarcane, surveys of farmers who have already installed tubewells strongly support the conclusions obtained from the normative analysis. For example, based on a relatively large sample of tubewell and non-tubewell farmers, Ghulam Mohammed 31/ shows that in Gujranwala District, tubewell farmers have increased the percentage of area under rice from 36 percent to 62 percent; he also reports that in the Multan-Montgomery area cotton has been increased from 27 percent to 38 percent. At the same time, wheat acreage has remained essentially stagnant in both areas.

The fact that the curves in Figures 5 to 8 are static is, of course, a major shortcoming. Large increases in the supply of wheat, for example, might be expected to reduce prices, which in turn would affect relative net revenue. What is required for further exploration of the model is (1) the introduction of demand schedules for various crops, and (2) dynamic macro

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30/ Ford Foundation (6) and (7).

31/ Ghulam Mohammed (22).

variables assumed to represent the growth in consumer incomes. Even without these considerations, however, the conclusion that large scale water development programs can be expected to change radically the supplies and the price elasticities for most agricultural commodities appears to be well substantiated.

VI. CONCLUSIONS AND WARNINGS

Many of the conclusions of this study have been noted in passing. However, three points seem worthy of re-emphasis, as do some words of caution.

The first theme of the paper has been that historical responses to changes in relative prices have been large by world standards. The short-run supply elasticities, mostly within the .1 to .5 range, indicate the potential power of price policy as an instrumental variable in Pakistan. This is particularly true for cash crops whose elasticities are clustered at the upper portion of the scale. As an historic example, one might cite in this category the recent series of reductions in export duties for cotton which have probably increased the relative price received by cotton farmers by about 20 percent.[32/] This reduction, and the long-run acreage response it induced, was undoubtedly a factor in the rapid growth of cotton production and exports.

A second theme, demonstrated by the empirical estimates of supply responses as well as by the models on water use, has emphasized the efficiency with which Punjabi farmers have allocated inputs. These general conclusions add to the growing literature on the "poor but efficient" view of peasant agriculture.

32/ For a fuller discussion, see Falcon and Gotsch (5)

33/ This idea is most succinctly stated in Schultz (27).

Methodologically, the programming approach appears to offer a useful approach for verifying the efficiency of farmer actions, for assessing the differential effects of changing technology, and for examining the interaction between technical change and price policy.

Finally, the specific calculations for the normative supply functions have indicated the sensitivity of supply elasticities to changes in technology. Although the specific calculations presented in the paper should only be regarded as suggestive because of their static and regional character, they do offer a partial explanation for certain recent commodity developments in West Pakistan. For example, the general rightwar <u>shifts</u> in the curves for cotton, rice and sugarcane, as a result of breaking the water constraints via tubewells, are consistent with recent historical growth rates of 7.1, 7.8 and 10.6 percent per annum respectively. These shifts are in marked contrast to the leftward movement indicated by the models for wheat supply (at current prices) and the recent actual stagnation in wheat output. The normative wheat curves indicate, however, that with higher relative net revenues per acre (through higher prices and/or yields) wheat production would be likely to expand significantly, though at the expense of the other crops. Perhaps above all else, however, this set of curves indicates the necessity of constant review of agriculture price policy under conditions of rapidly changing technology.

With regard to the changes in slope (as opposed to shifts in the curves) the normative supply curves indicate that the price elasticities of supply for most crops will probably increase in West Pakistan as a result of the water development program. To be sure, this is a statement of what farmers "should do" to maximize incomes; however, the historical models have indicated that they have generally behaved in a rational manner. These changes in elasticities indicate the increased potential for altering future cropping patterns through policies which affect the prices of agricultural commodities.

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