ESSAY 3

THE ECONOMICS OF TRACTOR MECHANIZATION IN THE PAKISTAN PUNJAB*

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The diffusion of mechanical technology continues to be one of the most interesting and controversial public policy issues confronting agricultural planners in Pakistan. In an attempt to provide some quantitative information relevant to the issues that have been raised, the model developed in the previous essays has been expanded to include activities that simulate the introduction of tractor power. It has also been updated (1) to reflect the prices of inputs and outputs that existed in 1970, and (2) to incorporate additional farm management data collected by Muhammad Naseem and Ahmed in the intervening period (*1, 3*). Lastly, some additional constraints have been introduced into the structure of the model that embody greater attention to the timeliness with which operations are performed. These changes are reviewed in the section on model structure.

Following the pattern of the preceding essays, presentation of the optimal solution is accompanied by a number of model experiments. First the rate of return on various mechanization packages and farm sizes is calculated. Then, the effect of using world market prices of outputs and inputs instead of domestic values is investigated. Lastly, the benefits of mechanization are examined when the amount of groundwater that may be withdrawn is limited to the level of the so-called safe yield.

MODIFICATION OF PREVIOUS MODELS

The mechanization study involves a substantial modification of the activities, constraints and resource sectors specified in the previous models. However, the basic structure and approach have remained the same and hence only the most important alterations will be mentioned below.

Activity Set

The first change in the tableau involves adding a second set of crop activities that depend on the tractor to provide power for tillage, planting, and other cultural operations. Approaching the problem in this way avoids the need to intro-

* The views expressed in this article are those of the author as an individual and in no way reflect the views of the Planning and Development Board of the Punjab Government.

duce the tractor in terms of bullock-power equivalents. Second, activities have been added to both "bullock-powered" production and "tractor-powered" production to simulate the possibility for double-cropping. That is, wheat-cotton is a year-round activity; water, land, and power requirements are all specified to make such a rotation alternative possible.

Activities have also been added that simulate the availability of tractor services. These have, as entries in the net revenue row, negative numbers representing the fuel and maintenance costs of operating the tractor.

To simplify the matrix, a number of activities have been dropped. For example, variables that represent traditional technology in wheat, rice, and water production by means of a Persian wheel are no longer included. These technologies were not generally used by progressive farmers of the Punjab in 1970/71.

Constraint Set

Several additional constraints have been included in the model. Because of the crucial nature of the "timeliness" question, the number of time periods has been increased by adding additional periods in October and November. There are now 14 rows describing water requirements and availability, 14 describing the way in which crops occupy the land, 14 for bullock power, and so on.

A set of constraints that reflect tractor capacities has also been intoduced into the model. Theoretically, it might be possible for the tractor to work close to 24 hours a day in peak periods. However, this is an unrealistic maximum for a variety of reasons and the model assumes that the tractor can be used for no more than 10 hours a day for 30 days a month.

Resource Availability

For the initial solution and some preliminary observations on cropping patterns and rates of return, the holding size was assumed to be 50 acres. Water availability, bullock-power availability, tubewell capacity, and the like are thus four times those used in the preceding essays for a 12.5-acre farm. Family labor does not increase. However, the figures are slightly different from those used in earlier essays as they were derived directly from a field survey of large farmers in the area.

Special Crop Constraints

Special crop constraints insuring that the bullocks have fodder, that there is some limitation on the fodder that can be grown for sale, and that sugarcane acreage is also limited are slightly different from those shown in the previous essays for a 12.5-acre farm. Again these modifications are the results of data obtained during the survey of large farmers.

ANALYSIS OF THE BASIC SOLUTION

The basic solutions to the programming model provide the net revenue data from which rates of return to various types of investment can be calculated. However, they also deserve detailed study for the insights they provide about how benefits from mechanization are generated.

TABLE 3.1.—CROPPING INTENSITIES: MODEL AND SURVEY RESULTS

Technology	Irrigation system (canal irrigation plus)	Model results	Survey results
Bullocks	No tubewell	99.3	112.5
Tractor	No tubewell	94.3	108.8
Bullocks	Tubewell	144.2	129.1
Tractor	Tubewell	187.0	162.0
Bullocks and tractor	Tubewell		

Cropping Intensities

Table 3.1 gives the model and survey cropping intensities on tractor and bullock farms under different irrigation systems. Insofar as cropping intensity differences between tractor and bullock farms, with and without tubewells, are concerned, the model is generally consistent with the survey results. For example, in the highly progressive Lyallpur area, where supplementary water supplies cannot be developed because the underlying groundwater is saline, the survey results show that tractor farms do not have a higher cropping intensity than bullock farms. Although the absolute levels of intensity differ from the survey findings somewhat, the same consistency of results emerges when the model estimates of bullock and tractor farms without tubewells are compared.

Cropping Patterns

The model estimates given in Table 3.2 show that both with and without a tubewell, the tractor farms have relatively more acreage under high value crops of wheat and cotton than do bullock farms. The explanation lies in the harvest-sowing overlap and the consequent seasonal peak power constraint in May and in November/December. In the model, the tractor farmers are able to overcome the seasonal peak power constraint of these high value crops. Bullock farmers grow relatively more maize and gram. These crops have a relatively low value per acre, but demand less power. Maize is a short-season (July-October/November) summer crop to which the farm operator can turn when constrained in cotton sowing. Similarly, the winter crop of gram is chosen by the bullock farmer because its early harvest in March avoids the May peak power constraint.

The survey shows cropping pattern differences between tractor and bullock farms analogous to those in the model. For example, the tractor farms in the saline groundwater (non-tubewell) area had a relatively higher percentage of their cropped area under cotton than the bullock farms. The latter tended to grow more gram and winter oilseeds. In the sweet groundwater (tubewell) area, there was a similar difference between bullock and tractor farms although in this case high-value crops such as fruits and vegetables enter the tractor farm's cropping pattern in addition to cotton and wheat.

The cropping intensity on survey farms without tubewells is slightly higher than estimated by the model. This is consistent with the commonly acknowledged fact that significant diminishing returns exist with respect to total water applied per acre. The input-output values used in the model assume that each

TABLE 3.2.—OPTIMAL CROPPING PATTERNS AND CROPPING INTENSITIES UNDER ALTERNATIVE TECHNOLOGICAL ASSUMPTIONS, SOUTH CENTRAL PUNJAB, 50-ACRE FARM
(*Percent*)

	Bullocks		Tractor		Tractor and bullocks
Crops	Without tubewell	With tubewell	Without tubewell	With tubewell	with tubewell
Winter crops					
Wheat	29.7	27.6	40.7	40.4	43.0
Oilseeds					
Gram	1.0	31.4		11.5	7.0
Fodder	8.6	5.8			4.0
Sugarcane	3.3	2.2	3.4	1.7	1.5
Subtotal	42.6	67.0	44.1	53.6	55.5
Summer crops					
Rice					
Cotton	14.2	2.0	24.5	21.9	32.5
Maize	31.4	23.1	9.5	5.9	
Fodder	8.6	5.8	9.0	4.4	8.0
Pulses			9.5	12.6	2.5
Sugarcane	3.2	2.4	3.4	1.6	1.5
Subtotal	57.4	33.3	55.9	46.4	44.5
Total	100	100	100	100	100
Total cropped acreage	49.65	72.10	47.15	93.50	96.00
Cropping intensity	99.3	144.2	94.3	187.0	192.0

acre receives in each time period the full consumptive use for the crop being grown. Actually, farmers, being aware of diminishing returns, tend to spread the water more thinly in an effort to maximize returns to a scarce resource. The result, is, of course, a higher cropping intensity.

With a tubewell, tractor power leads to substantially higher cropping intensities. The model results, however, show a greater increase than the survey. Discussions with farmers indicate that double-cropping, i.e., the alternation of wheat and cotton, has been initiated by some—which establishes its potential—but it has not become a standard practice. It is mainly through this crop rotation that the model farms achieve higher intensities (Table 3.2).

Shadow Prices of Fixed Resources

The shadow prices indicated by the programming model identify the scarcity values of the resources available on the farm under alternative assumptions about the sources of power and water. Table 3.3 shows that without a tubewell the bullock farm operator faces both water and bullock-power constraints. The reason for the water constraint is obvious but the shortage of bullock power in this low intensity area (Table 3.2) needs explanation. The scarcity of bullocks appears in May, when bullock power is needed to thresh wheat and to sow cotton and summer fodder. The bullock-pair marginal value product of Rs. 10 per hour (Table

TABLE 3.3.—SHADOW PRICES OF RESOURCES FIXED TO THE FARM, SOUTH CENTRAL PUNJAB, 50-ACRE FARM

Resources	Bullock farm: Without tubewell	Bullock farm: With tubewell	Tractor farm: Without tubewell	Tractor farm: With tubewell	Bullock and tractor with tubewell
Land (*Rs./acre*)					
April					133
August		54			88
September				54	
October I		112			
November I		6		111	99
December					69
Tractor (*Rs./hour*)					
May				53	32
November I				14	
Water (*Rs./acre-inch*)					
September	22				
October I			34		
October II	15		103		
November I	19		43		
November II	16				
December			92		
Bullocks (*Rs./hour*)					
May	10	10			
September		.2			5
November II		1.6			

3.3) when compared to a unit cost of roughly Rs. 1 per hour, indicates the high profitability of additional bullock hours during this period.

The water constraints show high penalties during the months of September, October, and November when the canal flows are low and when water is needed for the preparatory tillage and seeding of winter crops.

When tractors are introduced in an area that has no wells, the power constraint in May is removed (Table 3.3). This enables the farm operator to bring a higher percentage of his area under wheat and cotton. However, the tractor farm operator cannot increase his total crop acreage because the water constraint faced previously is further accentuated.

All aspects of the farming system are altered in areas having sweet groundwater where a tubewell can be installed to supplement the water supplies available from canals. The model indicates that the bullock farm operator in this area no longer faces a water constraint, but is now confronted with both power and land scarcities. The power shortage appears in May and November. It is more severe in May (MVP = Rs. 10)[1] than in November (MVP = Rs. 1.2). This is due to the fact that, while several major winter crops require bullock power for threshing and hence compete for the available power with the sowing of the summer crops in May, the same is not the case with the harvesting of summer crops.

[1] MVP = Marginal Value Product.

Rice, cotton, and maize are all harvested and threshed by hand and hence do not interfere with the preparatory tillage and seeding of the winter crops.

It is evident from the above that with the availability of supplementary water from tubewells, the need for additional draft power increases. When tractors are introduced, the bullock-power shortage in May and November is transformed into a tractor-power shortage in the same months. The intensity of this shortage is indicated by the MVP of Rs. 53 and Rs. 14 per hour of tractor in May and November, respectively.

As shown earlier, tractor power leads to substantially higher cropped acreage and a change in the cropping pattern that consequently creates further power needs. During the field survey it was observed that most of the larger tractor farmers also kept bullocks. Although it will shortly be seen that it would have been more profitable to buy a thresher than to keep bullocks, the model results indicate that even the latter choice makes economic sense. As Tables 3.2 and 3.3 indicate, when bullocks supplement the tractor, further increases in cropping intensity and changes in the cropping pattern in favor of high-value crops occur. The result is an increase in the net farm revenue sufficient to justify the continued maintenance of some animal power. (This issue will be taken up again in the section on rates of return.)

Net Farm Revenue

The above analysis has indicated the effect of tractor and tubewell water on the level of cropping intensity and the cropping pattern. These effects are ultimately reflected in net farm revenue. Table 3.4 shows net revenue obtained by different types of farms. It is evident that the lowest is on a bullock farm without wells. The addition of a tractor or a well increases the net revenue by almost equal amounts (about Rs. 3,500 in both cases). The mechanism through which the additional revenue is generated, however, differs in the two cases. Whereas the addition of a tractor increases net revenue through changes in the cropping pattern from low to high value crops, the tubewell achieves it by enabling the bullock farmer to attain a higher cropping intensity.

As was expected, the acquisition of a thresher is of no value to the tractor farm that does not have a well; cropping intensity, cropping pattern, and net revenue are all unaffected (Table 3.5). The constraining factor for a tractor farm without a well is water, not power. On the other hand, a thresher brings all the benefits

TABLE 3.4.—NET FARM REVENUE: MODEL RESULTS FOR TRACTORS AND BULLOCKS

Technology	Irrigation system (canal irrigation plus)	Net farm revenue (gross receipts less variable costs) (*rupees*)
Bullocks	No tubewell	14,531
Tractor	No tubewell	18,293
Bullocks	Tubewell	18,473
Tractor	Tubewell	30,928
Bullocks and tractor	Tubewell	33,371

TABLE 3.5.—OPTIMAL CROPPING PATTERNS AND CROPPING INTENSITIES WITH AND WITHOUT MECHANICAL THRESHING, SOUTH-CENTRAL PUNJAB, 50-ACRE FARM
(Percent)

Crops	Bullock farm				Tractor farm			
	Without tubewell		With tubewell		Without tubewell		With tubewell	
	Without thresher	With thresher	Without thresher	With thresher	Without thresher	With thresher	Without thresher	With thresher
Winter Crops								
Wheat	29.7	32.8	27.6	48.1	40.7	40.7	40.4	48.4
Oilseeds								
Gram	1.0		31.4				11.5	
Fodder	8.6	7.2	5.8					
Sugarcane	3.2	2.7	2.1	2.0	3.4	3.4	1.6	1.5
Subtotal	42.5	42.7	66.9	55.6	44.1	44.1	53.5	49.9
Summer Crops								
Rice				1.6				
Cotton	14.2	19.7	2.0	26.8	24.5	24.5	21.9	35.5
Maize	31.4	20.2	23.1	8.4	9.5	9.5	5.9	
Fodder	8.6	14.7	5.8	5.5	9.0	9.0	4.4	4.1
Pulses					9.5	9.5	12.6	8.9
Sugarcane	3.3	2.7	2.2	2.1	3.4	3.4	1.7	1.6
Subtotal	57.5	57.3	33.1	44.4	55.9	55.9	46.5	50.1
Total	100	100	100	100	100	100	100	100
Total cropped acreage	49.65	58.9	72.1	76.3	47.15	47.15	93.5	100.0
Cropping intensity	99.3	117.8	144.2	152.6	94.3	94.3	187	200.0

Table 3.6.—Net Revenues and Selected Shadow Prices of Fixed Farm Resources, South-Central Punjab, 50-Acre Farm

Resources	Bullock farm				Tractor farm			
	Without tubewell		With tubewell		Without tubewell		With tubewell	
	Without thresher	With thresher	Without thresher	With thresher	Without thresher	With thresher	Without thresher	With thresher
Land (*Rs./acre*)								
April								
July								88
August			54					
September								
October I			112	346				401
November I			6					
December								
Water (*Rs./acre-inch*)								
September	22						54	
October I		183			34	34		
October II	15	67			103	103		
November I	19	47			43	43	111	
November II	16	183						
December					92	92		
Tractor (*Rs./hour*)								
May							53	32
November I							14	
Bullocks (*Rs./hour*)								
May	10		10					
September			0.2					
November I								
November II			1.6					
December								
Net revenue (*rupees*)	14,531	18,221	18,473	28,446	18,293	18,819	30,928	38,360

that would have been brought by a tractor to a bullock farm that does not have a well. The cropping pattern changes in favor of high-value crops and as a result the net revenue is almost equivalent to that of a tractor farm (Table 3.6). Since the power constraint appears only in May, the wheat thresher, by releasing the bullock power for cotton sowing, accomplishes almost the same results as replacing the bullocks with a tractor.

In the tubewell area, on the other hand, the model indicates that the highest net returns occur when the thresher is combined with a tractor. There the power constraint is binding both when wheat is sown and when it is harvested. While the thresher obviously overcomes the power shortage at the harvest time, it does not help at sowing.

Rate of Return on Mechanization (1970–71 Market Prices)

In this section, the capital costs of mechanization are related to the benefits described above and a rate of return to the farm operator is calculated.

The analysis in the previous section identified higher cropping intensities and higher-valued cropping patterns as potential sources of economic benefits of mechanization. Higher yields per acre are obviously another possible source. The literature suggests, however, that the yield effect of mechanization is still highly controversial. The survey results (referred to earlier) do not provide any consistent evidence of higher yields on the tractor farms. The basic model therefore assumes that tractor and bullock farms have identical yields and inputs per acre for different crops; the only difference in the technology employed is the source of power. If, in actual practice, tractor farms using similar inputs do get higher yields, then to that extent the rate of return indicated by the model will be a lower bound.

It was assumed that the tractor replaces four pairs of bullocks on a 50-acre farm and that it has a life expectancy of eight years. Costs for both equipment "packages" are shown in Table 3.7.

The rates of return to tractor mechanization under several different assumptions about accompanying technology are given in Table 3.8. Where water availability is assumed to be limited by the supplies from the canal, the rate of return is only 3 percent, not enough to pay the interest of 9 percent on the tractor loan charged by the Agricultural Development Bank of Pakistan. Where canal irrigation is supplemented with well water, however, tractor investment brings a return of 46 percent per annum. Thus, in the tubewell areas the farmers have a net benefit of 37 percent (46 − 9) after paying interest on tractor loans. It is no wonder that, as indicated in the Farm Mechanization Committee *Report*, about 63 percent of the tractors have been introduced on the farms having both tubewell and canal irrigation (*4*, p. 98).

Although the net benefits of mechanizing field crop cultivation in the canal irrigated areas without tubewells have been shown to be negative, still, 20 percent of the tractors are reported to have been introduced in this area. The explanation of this seemingly uneconomic behavior may be given by two sources of economic gains not considered in the rate-of-return calculations. First, there are the benefits that accompany the tractor's crucial role in making practical the resumption of land by landlords for self cultivation. With the introduction of high-yielding

TABLE 3.7.—COST OF MECHANICAL AND BULLOCK TECHNOLOGY PACKAGE

I. Mechanical Technology

	Domestic Market Prices[a] (*rupees*)	World Market Prices[b] (*rupees*)
Tractor (1) 45 h.p.	17,500	-29.550
Cultivator/tiller (9 tines)	1,610	2,473
Mouldboard plow	2,500	3,840
Wheat drill (13 tines with fertilizer attachment)	3,730	6,536
Cotton planter	3,000	4,608
Five-ton trailer	4,000	5,072
Total	32,340	52,079
Thresher	5,000	6,340
Fuel and lubricants	3.30	1.90

II. Bullock Technology[c]

	Life (*years*)	Prices (*rupees*)	Salvage price after 8th year	Cost for 8 years
Bullocks (*1 pair*)	12	1,800	600	1,200
Implements (*set*)	10	500	100	400
Total		2,300	700	1,600

[a] The market prices were obtained from (*4*) and discussions with representatives of Rana Tractors Limited, Lahore. The foreign exchange component is valued at Rs. 4.7 = $1.00.

[b] World market prices exclude all taxes and value the foreign exchange component at Rs. 11 = $1.00.

[c] Computed from Muhammad Naseem, "Small Farmers and the Agricultural Transformation of West Pakistan" (unpub. Ph.D. diss., Univ. California, Davis, 1971). In retrospect, the lifetime assumed for bullocks is probably somewhat high. The result of using a more realistic figure of 8 years would be to bias the results toward lower rates of return on tractors.

TABLE 3.8.—INTERNAL RATE OF RETURN TO TRACTOR MECHANIZATION, SOUTH-CENTRAL PUNJAB, 50-ACRE FARM
(*Percent*)

Implement package	Rate of return: Without tubewell	Rate of return: With tubewell
Before: Bullock		
Tractor only	3	46
Tractor plus bullocks	–	43
Tractor plus thresher	–	63
Before: Bullocks plus thresher		
After: Tractor plus thresher	–	35

varieties, substantial increases in the productivity of land occurred—productivity that was shared with tenants under the share-cropping system. By farming the land himself, a strategy made possible by the replacement of a large quantity of low-level managerial inputs with tractors and a few skilled laborers, the entire increase in output can be captured.

Second, the import duties on trucks during the late 1960s were such that tractors and trailers were a competitive means of transporting goods within and close to urban areas. Indeed, many tractor owners found it profitable to consider local short-haul transportation as the primary claimant on tractor time and agricultural tillage as a secondary activity (*4*, p. 99).

The rate-of-return calculations discussed above are based on the assumption that the tractor completely replaces bullocks. However, in the field survey it was noted that many farmers were retaining some or all of their bullocks. When *all* bullocks are retained, the rate of return falls from 46 percent to 43 percent. While the cropping intensity has increased significantly as a result of relaxing the power constraints by keeping the bullocks, the fodder acreage required to maintain the bullocks has an opportunity cost that is greater than the marginal contribution of bullocks to increased output. (The question of the optimal number of bullocks to be retained was not investigated.)

When a thresher is added to the mechanization package, the rate of return goes from 46 to 63 percent. So long as water is not a binding constraint, cropping intensity continues to be constrained by power for tillage and the introduction of stationary power to meet the needs of wheat threshing has appreciable effects on the net revenue of the mechanized farm.

In the last exercise involving the rate of return to mechanization on a 50-acre farm, it is assumed that a tractor-thresher package is being compared to a bullock-thresher package. Given that threshers can be operated with small, stationary engines, there is no technical reason that mechanical threshing be a part of a more general mechanization package.

As indicated previously, the basic difference between the thresher and tractor as sources of additional power is that while the former can be used only for harvest, the latter can be used for preparatory tillage as well. As a result the tractor-thresher combination substantially increases the net revenue over that of the bullock-thresher package. However, as shown in Table 3.8, this before and after comparison, in which only the tractor is added (the "before" package also contains a thresher), cuts the rate of return to 35 percent.

It should be emphasized that the findings shown above pertain only to the areas in the Punjab where supplementary groundwater is available. Introducing a thresher on a bullock farm in the saline groundwater areas having only canal water has a handsome return, but substituting a tractor for bullocks under these circumstances results in an unprofitable investment. Without the water to increase overall intensity by 40 to 50 percent, the only important power constraint has to do with the threshing of wheat, and this the thresher breaks effectively.

Employment Effects of Mechanization

The influence of mechanization on employment, as shown in Table 3.9, varies with the system of irrigation and the package of mechanization used. In the canal irrigated area *without* a tubewell, employment per cultivated acre decreases when bullocks are replaced by a tractor. This is consistent with the results of the field survey (*1*). Adding a thresher to the mechanization package further reduces employment, the reason being that when introduced in this sequence, the thresher displaces labor used in wheat threshing and winnowing without any positive

TABLE 3.9.—EMPLOYMENT EFFECTS OF MECHANIZATION IN THE PAKISTAN PUNJAB: MODEL RESULTS

Technology	Manhours of labor employed per cultivated area (50-acre farm)					
	Canal irrigation with tubewell			Canal irrigation		
	Hired	Family	Total	Hired	Family	Total
Bullocks only	268	131	399	213	131	344
Tractor only	280	122	402	153	103	256
Tractor and bullock	380	130	510			
Tractor and thresher	329	114	443	139	103	242
Bullocks and thresher	305	134	439	227	130	357

employment contribution from increased cropping-intensity and labor-intensive cropping patterns. If, however, a thresher is used with bullocks, labor use increases to 367 man-hours per cultivated acre as compared to 344 with bullocks only. Thus, in addition to offering a high rate of return, the introduction of mechanical threshing on bullock farms with a tubewell is also the best alternative in terms of the demand for labor.

In the tubewell area, all forms of mechanization, i.e. tractor alone, tractor plus thresher, bullocks plus tractor and bullocks plus thresher, lead to increases in employment when compared to traditional forms of cultivation. This is again consistent with the survey results which also indicated positive employment effects in the tubewell area. With no water constraint, mechanical power, through its cropping pattern and intensity effects, tends to create more jobs than it displaces. The model results indicate that, from an employment point of view, tractor plus retained bullocks is the best combination. (As noticed earlier, however, tractor plus thresher yields the highest rate of return.) The combination involving bullocks has an employment bias because of the relative labor intensity of the fodder crops that are harvested several times in the course of a season.

SENSITIVITY ANALYSIS OF THE BASIC MODEL

In the preceding sections, the basic solution of the programming model was analyzed. The following paragraphs will be devoted to a further investigation of the influence on the profitability of mechanization of three factors believed to be critical to the process. These factors are (1) the size of the farm; (2) the prices of the major inputs and outputs; and (3) a constraint on water that a tubewell farmer would be permitted to pump.

The Effects of Farm Size

In any discussion on economics of mechanization, the size of the farm holds a prominent position. The analysis in the preceding chapter assumed a farm size of 50 acres. Here the size of the basic farm will be increased and decreased by 50 percent to study the influence of farm size on rate of return to mechanization.[2]

[2] It could be argued that simply varying the resource availabilities misses much that is important in the size-of-farm issue. That is, the number of technologies in the model is too small to reflect the range of capital-labor ratios that actually exist in most agricultural production systems.

Such a criticism would have the greatest validity if family size farms of 5 to 10 acres were

TABLE 3.10.—RATES OF RETURN TO TRACTOR MECHANIZATION ON DIFFERENT SIZE FARMS
(*Percent*)

Mechanization package	25-acre farm		50-acre farm		75-acre farm	
	Without tubewell	With tubewell	Without tubewell	With tubewell	Without tubewell	With tubewell
Tractor only	—	32	3	46	10	41
Tractor plus bullocks	—	18	1	43	—	48
Tractor plus thresher	—	27	—	63	—	68

Table 3.10 shows the rate of return to tractor mechanization on farm sizes of 25, 50, and 75 acres. As one would expect, the rate tends to increase as the size of the farm expands upward from 25 acres. However, as in all of the previous cases, assumptions regarding the presence or absence of supplementary irrigation water produce different results. Without a tubewell, tillage constraints are not binding at 50 and 75 acres and hence the rate of return increases over this range. Where tractors are introduced on farms having a tubewell, tillage contraints are binding above 50 acres and the rate of return declines.

The analysis in the above paragraphs assumed that mechanization consisted of replacing bullocks with a tractor. This assumption is relaxed in the following exercise to study the influence of mechanization packages consisting of (1) tractor plus bullocks and (2) tractor plus thresher (Table 3.10).

On the 25-acre farm, the rates of return on the tractor-bullock and tractor-thresher package is below the rate of return on the tractor alone. A 45-h.p. tractor has enough capacity to handle all of the tillage and threshing operations on this size holding. At 50 acres, the tractor-thresher package has a high rate of return for reasons discussed previously. On the 75-acre farm, the problem of tillage power in certain periods has become sufficiently acute so that the rate of return on the tractor-bullock package is greater than on the tractor alone.

The number and composition of man-hours used per acre generated by the model also varies by size of farm (Table 3.11). If it is assumed that draft power is supplied entirely by bullocks, it declines by 7 percent from 25 to 50 acres and stabilizes thereafter. This is a reflection of the relatively large amount of family labor with zero opportunity cost on the small farm. As a larger and larger proportion of the labor requirement is hired, total labor used declines. Where the tractor is the sole source of power, man-hours per acre of both hired and family labor decline as farm size increases.

When bullocks are retained or a thresher is included as a part of the mechanization package, farm size has less of an effect on man-hours used per acre. By breaking some of the peak period power bottlenecks, cropping intensities are increased. This in turn leads to an increase in the demand for labor.

included in the calculations. As it is, 25-acre farms in the Central Punjab already require several pairs of bullocks and a number of hired laborers. Under these circumstances, the importance of relatively large amounts of relatively fixed labor resources is minimized and it would appear that the technology would not differ much from a 50-acre farm. These factors are obviously even less important in the 50- to 75-acre comparison and suggest that variations in the resource structure will capture most of what is interesting with respect to holding sizes and mechanization.

TABLE 3.11.—SIZE OF THE FARM AND EMPLOYMENT EFFECTS OF MECHANIZATION IN TUBEWELL AREAS OF THE PUNJAB
(Man-hours per acre except as indicated)

	Size of the farm *(acres)*		
	25	50	75
Bullocks only			
Hired	195	268	307
Family	234	131	92
Total	429	399	399
Tractor only			
Hired	335	280	233
Family	184	122	79
Total	519	402	312
Tractor plus bullocks			
Hired	315	380	433
Family	214	130	92
Total	529	510	525
Tractor plus thresher			
Hired	307	329	326
Family	184	114	84
Total	491	443	410

Input-Output Price Distortion and Profitability of Mechanization

The rates of return on mechanization discussed previously reflect the case where the individual farm operator faces the prices of inputs and outputs prevailing in the domestic market in Pakistan during 1970–71. Some of the market prices critical to mechanization do not reflect the true scarcity value of commodities, however, and it is therefore important to examine the sensitivity of previous conclusions to changes in price parameters. In this section, agricultural machinery equipment and fuel and internationally traded agricultural commodities are entered in the model at their world market values (Table 3.7). (The exercise does not represent a calculation of social rates of return since labor continues to be paid a market wage and no aggregate constraints have been placed on land and water.) The results, calculated for 50-acre farms, simply represent the private rate of return on mechanization that would obtain if certain obvious price distortions were corrected.

Without a tubewell, the rate of return at world market prices, like the rate of return at domestic market prices, is either negative or very low. With a tubewell, however, the rate of return, though less than at domestic prices, still remains quite high, i.e., 32 percent. Even if the interest rate on borrowed capital were increased from 9 to 15 percent to reflect its scarcity value, the private farm operator would still have net benefits of 17 percent.

Given that the cost of the tractor equipment package to the farmer is approximately 40 percent less than the world market prices, the rather modest decline from 43 percent to 32 percent was unexpected. However, the domestic market price of tractor fuels and lubricants was 75 percent over world prices. Also, the

TABLE 3.12.—PRICES OF INTERNATIONALLY TRADED/IMPORT COMPETING AGRICULTURAL CROPS
(*Rupees*)

Crops	Domestic Prices[a]	World Market Prices[b]
Wheat	17	20
Rabi oil	24	58
Maize	15	19
Cotton	50	70
Rice—IRRI (*paddy*)	12	22
Rice—Basmati (*paddy*)	17	50
Sugarcane (*gur*)	40	15

[a] The harvest prices prevailing during 1970–71. Among other things, these prices reflect the government taxation and price policies and the foreign exchange rate of Rs. 4.7 = $1.

[b] These are the prices likely to prevail in the domestic market on the basis of world market prices assuming no taxes and public control over prices and a foreign exchange rate of Rs. 11 = $1. The world market prices were assumed to be the mid-way prices of the minimum and maximum used by Lawrence. "Some Economic Aspects of Farm Mechanization in Pakistan" (2).

prices received by the Pakistani farmer for several of the major crops were substantially less than they would have been had they been sold on the international market. The compensatory changes therefore mitigated the overall impact of the world market price assumption.

The Effect of Changes in the Availability of Supplementary Water

In the analysis of the economics of mechanization, the presence of supplementary groundwater has been shown to be critical to profitable investments in new technology. In this section, the sensitivity of the rate of return on mechanization to the quantity of well water pumped will be investigated. World market prices have been retained to provide a closer approximation to the social rate of return.

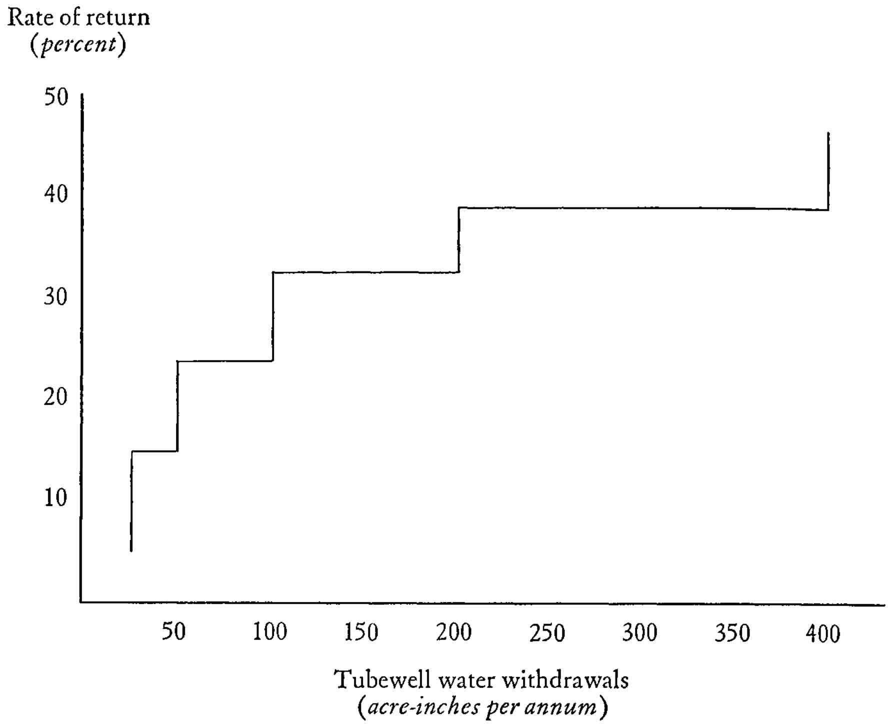
The model's prediction of the total amount of water (canal plus tubewell that would be used by the tractor and bullock farms, and the level of their cropping intensities, is given in Table 3.13. The tractor farm, with a cropping intensity approximately 30 percent greater than the bullock farm, uses about 25 percent more water.

The additional water used on the tractor farm is not drawn entirely from a well. About 55 percent of it comes through increased use of the seasonally fixed water supply from the canal. The total amount of canal water available to the tractor and bullock farms is the same, but the availability of tractor power, by overcoming the seasonal power constraint, increases the planted acreage and

TABLE 3.13.—AMOUNT OF CANAL AND TUBEWATER THAT WOULD BE USED ON A 50-ACRE FARM IF INPUTS AND OUTPUTS WERE VALUED AT WORLD MARKET PRICES

	Tractor	Bullocks	Difference (tractor-bullocks)
Intensity	187	144	
Canal water (*acre-inches*)	1,299	1,112	187
Tubewell water (*acre-inches*)	418	267	151

CHART 3.1.—RATES OF RETURN ON TRACTOR MECHANIZATION AT VARIOUS LEVELS OF PERMISSIBLE GROUNDWATER WITHDRAWALS
(1970 world market prices)



therefore off-peak utilization of canal water. (The excess water supply in the off-seasons is usually dumped onto such crops as sugarcane and Egyptian clover and thus goes to waste.) This contribution of mechanical power to the efficient use of canal water has not been realized by most of the earlier researchers on mechanization.

Tractor power also increases the utilization of water; 418 acre-inches of well water were pumped as compared to 267 inches for the bullock farm. Assuming that the recharge of the acquifer per 50 acres is approximately 1,200 acre-inches per annum, the tubewell water withdrawals by both the tractor and bullock farms are considerably below the socially permissible level.[8] These results indicate that it is not the total withdrawals but the supplies made available at critical times that reflect the true value of the well.

The above point was further investigated through the parametric variation of pumping capacities. Maximum withdrawals were varied from 400 down to 25 acre-inches; the rates of return on tractor mechanization at various levels of tubewell water are given in Chart 3.1.

It is evident from Chart 3.1 that, as expected, the rate of return does fall when total tubewell water is constrained. The proportionate fall in the rate, however, is considerably less than the percentage change in water. For example, a decrease

[8] Based on recent pumping rates in Salinity Control and Reclamation Project No. 1.

of 50 percent in groundwater availability from 400 acre-inches to 200 acre-inches produces an 8 percent decline in net revenue. Even at lower levels of water availability where the effect on rates of return is more pronounced, a 50 percent decline in water availability from 200 inches to 100 inches produces approximately a 30 percent decline in the rate of return.

An examination of the crop activities in the solutions characterized by restricted groundwater supplies shows that cropping intensities in the model have remained high because of the substitution of winter oilseeds, a crop with relatively low water requirements, for winter wheat. As a result, tractor power has continued to yield high rates of return even though water supplies have been curtailed drastically.

Lest this phenomenon be seen as simply a response to altered input-output parameters, however, it should be remembered that world market prices are being used to value output. The result is a set of relative net revenues much more favorable to oilseeds than those obtained when domestic prices are used in the revenue calculations. Increasing the relative profitability of the more drought resistant crops at the same time that water is being made scarcer provides a two-pronged impetus to the shift in cropping patterns that underlies the relationship between tubewell water and the rate of return on mechanization shown in Chart 3.1.

While no one would make the claim that programming models of the type developed in this study are perfect mirrors of reality, the exercise demonstrates once again the interaction problem faced by planners seeking to develop an appropriate policy toward agricultural mechanization. When significant opportunities for substitution within a cropping pattern exist, and when, with the help of an extensive groundwater reservoir, crop shifts between seasons are also feasible, fine-tuning mechanization policies appear to be virtually impossible.

CONCLUSIONS

According to the model estimates, tractors introduced into the areas of the Punjab where sweet groundwater was available earned a rate of return approximating 40 percent. This explains why tractors have been concentrated mainly in areas having sweet groundwater and tubewells.

At the same time, rates of return in saline groundwater areas are predictably low. Indeed, unless there are significant yield effects, it is hard to see why farmers in these areas have invested in mechanization at all. (A possible explanation is the role of mechanization in the eviction of tenants and in the use of tractors for transport.)

The employment implications of mechanization in the model are also linked to the availability of additional groundwater. In sweetwater areas, employment could be expected to increase somewhat, in the saline groundwater areas, to decline. In the former case, however, it is likely that the distribution of income will not improve—and may even deteriorate—as tenants become landless laborers.

In areas underlain with saline groundwater, the thresher rather than the tractor seems to be the appropriate form of mechanization both from the point of view of growth and employment. In sweet groundwater areas, however, tractor plus thresher appears to be the most suitable choice.

The exercise also points to an interesting anomaly between theory and practice. According to the model, the rate of return on mechanizing the threshing operation is extremely high. Yet field investigations confirm that very little mechanical threshing is taking place. This is clearly an important question that merits further research.

Correcting the price distortion for tractor and equipment, if accompanied by an adjustment in output prices in accordance with the world market, is not likely to affect the pace of mechanization.

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