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Output Effects of Tubewells on the Agriculture of the Punjab: Some Empirical Results

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1. Introduction

It is now established that the encouraging performance of the agriculture of West Pakistan during the Second Plan period took place largely as a result of water resource development, in which private tubewells were particularly important. According to the pioneering study by Ghulam Mohammad, additional water made available by the tubewells enabled the farmers to: (i) increase the depth of irrigation of existing crops; (ii) increase the intensity of cropping by eliminating fallowing and by double cropping; (iii) grow more valuable crops like cotton, rice, fruits and vegetables; (iv) increase the use of fertilizer; (v) increase the efficiency of bullock use; and (vi) increase the output per manual worker.[1/] There were 34,400 private tubewells in 1964/65. 9,100 were added in 1965/66 and 9,500 in 1966/67, thus raising the number of private tubewells in West Pakistan to some 53,000 by 1967.[2/]

[1/] Ghulam Mohammad, "Private Tubewell Development and Cropping Patterns in West Pakistan," Pakistan Development Review, Vol. 5, No. 1 (Spring 1965), pp. 1-53.

[2/] Mohammad Ghaffar and Edwin H. Clark II, "Installation of Private Tubewells in West Pakistan, 1964-67", Research Report No. 71 (Karachi, Pakistan Institute of Development Economics, 1968).

The short-stemmed varieties of wheat and rice imported from abroad and the increased use of fertilizers have dramatically increased the agricultural output of West Pakistan. This recent break-through in foodgrain production is sometimes referred to as the "green revolution", or as the "seed-fertilizer revolution." There is no question that additional supplies of irrigation water which preceded the dawn of the "green revolution" played the role of catalyst in introducing the yield-increasing innovations. By making it possible to grow more crops, more lucratively, per acre of cultivated area tubewell water, new seeds and increased applications of fertilizers have increased the aggregate output as well as the incomes of farm workers.

This study draws data primarily from a survey conducted in the winter of 1967 by Mohammed Ghaffar under the direction of Edwin H. Clark II and the late Ghulam Mohammad. About 125 farmers were interviewed in six districts of the former Punjab: Multan, Sahiwal (Montgomery), and Jhang referred to as "cotton area" and Gujranwala, Sialkot, and Lahore designated in this study as "rice area" on account of their major Kharif crops. These six agricultural districts rank highest in the number of private tubewells in existence, accounting altogether for more than 70 percent of the total number of private tubewells in West Pakistan (Appendix Table 1). Moreover, excepting for Sialkot district in which agricultural output stagnated, the remaining five districts experienced remarkably high average rate of growth in gross value of production during the period of 1960-65. These six agricultural districts produced some 51 percent of the gross value of the agricultural output of the Punjab.[3]

Essentially, this is an extension of Ghulam Mohammad's pioneering study of tubewells in the Punjab. However, in two important respects this study attempts at improving the results obtained by the previous study. The first distinguishing characteristic of the present study is that it uses the later survey data more carefully selected from wider areas.[4] In contrast to Ghulam Mohammad's study, this study includes not only relatively less developed districts but also tehsils that are comparatively more representative of the whole district. The

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[3] Multan grew at 5.7 percent, Sahiwal at 6.4 percent, Jhang at 5.1 percent, Gujranwala at 4.3 percent, and Lahore at the annual rate of 4.0 percent during 1960-65. See: Carl H. Gotsch, "Regional Agricultural Growth: The Case of West Pakistan," Asian Survey, Vol. 7 (March 1968), pp. 188-205.

[4] One of the important considerations in the selection of the sample was to cover less developed areas in these relatively well developed districts so as to balance the choice of the districts ranking high among those in the Punjab. The tehsils covered within cotton area are Mailsi and Khanewal in Multan district, Sahiwal and Pakpattan in Sahiwal district, and Jhang of Jhang district. The tehsils in rice area are Gujranwala and Wazirabad of Gujranwala district, Sialkot and Daska of Sialkot district, and Ghunian and Kasur of Lahore district. Again, an attempt was made to choose representative Union Councils and villages in these tehsils with the help of the agricultural assistants and field assistants. The survey covered all the tubewell farmers in a selected village. In contrast, Ghulam Mohammad's study relies on the sample drawn from Multan and Sahiwal districts, and Gujranwala from rice area which are the best districts in the two agricultural areas included here. This study includes not only relatively less developed Jhang district in cotton area, but also tehsils that are comparatively more representative of the whole. While all the areas selected by Ghulam Mohammad are situated on perennial canals, the present sample includes areas commanded by semi-perennial canals as well (e.g. Pakpattan tehsil).

second characteristic of this study is its emphasis on statistical analyses of the effects of tubewells on productivity. We shall attempt, with the use of some regression models, to analyse the independent effects of tubewells on productivity isolated from the effects of increased inputs of cropped area and labor. It is one thing to state that additional supplies of water from tubewells brought forth the increased inputs of land, labor, and other factors to produce a greater amount of output. It is quite another to ask whether such increases in the quantities of inputs could have produced the increased amount of output, in the absence of changes which brought forth additional supplies of water to start with, or how much of that increase could be attributable to the changes in water supplies alone. This study aims at answering this question in a greater detail.

Effects of Tubewells on Cropping Patterns and Cropping Intensitites

Given the natural characteristics of a locality, cropping patterns are dependent on the relative net profitabilities of crops that can be grown (which in turn depend on their yield performances, prices and costs of production), weather conditions (granted that this factor is less binding for farmers with tubewells), and the availability of additional supplies of water. Additional supplies of water and the possibility of better control of their use represent the relaxation of one of the most binding constraints on the farmers' ability to exploit and expand the economic opportunities in West Pakistan.

Table 1 presents cropping patterns and cropping intensities of tubewell and non-tubewell farmers separately for the two selected areas in the former Punjab. It is evident that there is a general increase in the area of crops grown with the additional supplies of water made available by tubewells. Significant increases are observed in the acreage under cotton, sugarcane, rice and wheat in cotton area and rice and sugarcane in rice area. Noteworthy is the decrease in the acreage of cotton in rice area. Owing to the yield disadvantage of cotton and to the government price support policy for foodgrains, rice provides comparatively greater returns per acre in this area than cotton as soon as additional water becomes available. Competitive strength of rice vis a vis cotton reflects a recent trend in the Punjab which calls for an urgent attention to the nation's fiber supply problem.

The cropping intensity of the tubewell farmer is higher than that of the non-tubewell farmer. In cotton area the former averaged 127 percent and the latter 81 percent. In rice area the corresponding figures were 147 percent and 108 percent, respectively. It is obvious, therefore, that additional supplies of water from tubewells enable the farmer to increase the intensity of land use during the course of year. It is interesting to observe that the cropping intensities during the Kharif season tend to be higher for tubewell farmers than during the Rabi season, while the opposite is the case for non-tubewell farmers. A lower intensity of Kharif cropping before the installation of tubewells is mainly due to the relatively unreliable supplies of water from the canals. The

Table 1

Cropping Patterns and Cropping Intensities of Tubewell and Non Tubewell Farmers, 1967 [a]

(Percent)

	Cotton Area		Rice Area		Both Areas	
	Tubewell Farmers	Nontubewell Farmers	Tubewell Farmers	Nontubewell Farmers	Tubewell Farmers	Nontubewell Farmers
KHARIF CROPS						
Cotton	31.6	19.8	1.8	4.9	19.7	13.9
Rice	4.4	0.6	41.0	17.5	19.1	7.3
Maize	1.3	1.5	0.5	1.0	1.0	1.3
Fruits	4.4	1.3	2.0	0.6	3.4	1.0
Kharif Fodders	14.1	11.9	16.0	13.5	14.9	12.5
Sugarcane	6.0	3.1	7.6	4.8	6.6	3.8
Other Kharif Crops	0.5	0	0	0	0.3	0
Sub total Kharif	62.3	38.2	68.9	42.3	65.1	39.8
RABI CROPS						
Wheat	39.1	27.1	42.9	45.5	40.6	34.4
Oil seeds	1.0	1.0	3.5	1.6	2.0	1.2
Rabi Pulses	1.0	1.3	0.1	0.5	0.6	1.0
Potatoes	0.6	0.1	5.9	2.0	2.8	0.9
Fodders	10.9	8.7	13.5	10.7	11.9	9.5
Other Rabi Crops	1.3	0	2.9	0	2.0	0
Sub total Rabi	53.9	38.3	68.8	60.4	59.9	47.0
Sugarcane	6.0	3.1	7.6	4.8	6.6	3.8
Fruits	4.4	1.3	2.0	0.6	3.4	1.0
Sub total	10.4	4.4	9.6	5.4	10.0	4.8
GRAND TOTAL (Cropping intensity)	126.6	80.9	147.3	108.1	135.0	90.0

Source: The 1967 Survey conducted by PIDE.

[a] 1967 denotes Robi crop of 1966/67 and Kharif crop of 1967.

[b] Cropping intensity is defined as the ratio between the area cropped and the area cultivated.

cropping intensity during the Kharif season rises, once additional water becomes available, because of the relative profitability of Kharif crops compared with the Rabi crops.

Essentially the same picture emerges when we compare the cropping intensities of tubewell and non-tubewell farmers by the size of operating acreage. Table 2 reveals, moreover, some additional information regarding the economic impact of tubewells by the size of operating acreage. First, for both tubewell and non-tubewell farmers the cropping intensity of the larger size farm is lower than that of the smaller size farm. This is what the 1960 agricultural census of Pakistan revealed and is confirmed here by the 1967 data. Second, although the cropping intensity of a larger tubewell farm tends to remain lower than that of a smaller tubewell farm, the disparity in the cropping intensities between large and small farms is narrowed after the installation of tubewells as compared with the previous situation. The tubewells appear to raise the cropping intensity of the larger farms proportionally more than the smaller farms. This means that the availability of additional supplies of water from tubewells and the possibility of better control of their use enable the larger farmers to increase yield *per acre per year* proportionally more than the smaller farmers, even if the crop yields per acre stayed constant.

Table 2

Cropping Intensities of Tubewell and Non-Tubewell Farmers By Sizes of Operating Acreage, 1967

(Percent of Cultivated Area)

	Tubewell Farmers			Nontubewell Farmers		
	Kharif	Rabi	Total	Kharif	Rabi	Total
RICE AREA						
Below 12.5 acres	70.5	72.8	143.3	55.6	79.2	134.8
12.6 - 25.0	78.9	73.9	152.8	40.9	63.8	104.7
25.0 - 50.0	77.1	67.7	144.8	39.9	60.2	100.1
Above 50.0 acres	53.0	70.2	123.2	44.2	50.4	94.6
COTTON AREA						
Below 12.5 acres	70.6	59.1	129.7	51.0	48.4	99.4
12.6 - 25.0	57.6	47.5	105.1	39.2	38.6	77.8
25.1 - 50.0	63.5	61.5	125.0	38.1	42.2	80.3
Above 50.0 acres	64.4	47.1	111.5	37.9	30.7	68.6
BOTH AREAS						
Below 12.5 acres	70.5	66.2	136.7	53.9	64.9	118.3
12.6 - 25.0	67.6	62.9	130.5	39.9	50.4	90.3
25.1 - 50.0	69.0	64.0	133.0	38.8	49.6	88.4
Above 50.0 acres	59.4	57.2	116.6	40.1	37.8	77.8

Source: Computed from the data collected by the 1967 Survey by PIDE.

3. Effects of Tubewells on Crop Yields

According to Table 3 the observed yields of major crops in rice area tend to be lower than in cotton area. This is in part due to the fact that soils in rice area are adversely affected by waterlogging and salinity problems and, therefore, are on average less productive than in cotton area. The difference in the varieties of crops grown in respective areas also explains a part of the divergence in yield performances. The observed higher yields of rice in cotton area than in rice area are partly attributable to the varieties of rice grown in respective areas. In most parts of rice area superior varieties of rice (Basmati) are grown, while in cotton area mainly the coarse varieties that respond strongly to additional supplies of water are grown.

Table 4 presents the observed yields of major crops of tubewell and non-tubewell farms by the size of operating acreage averaged over both areas. In general, it is observed that the yield performance of the larger farm exceeds that of the smaller farm, regardless of the availability of additional supplies of water from tubewells. Nonetheless, with the sole exception of sugarcane, the data confirm the improved performance of crops with additional supplies of water in all size levels.

Table 3

Average Yield of Crops, Tubewell Farmers and Non-Tubewell Farmers, 1967

(Maunds per acre)

	Rice Area	Cotton Area	Both Areas
TUBEWELL FARMERS			
Cotton	5.6	10.6	10.4
Rice	22.8	28.7	23.6
Maize	15.4	15.3	15.3
Sugarcane	26.9	35.9	30.8
Wheat	13.1	16.9	15.3
NON-TUBEWELL FARMERS			
Cotton	7.9	8.8	8.7
Rice	22.2	20.2	22.7
Maize	12.3	12.4	12.4
Sugarcane	34.9	27.4	31.6
Wheat	12.4	15.0	13.6

Source: The 1967 Survey conducted by PIDE.

Table 4

Average Yields of Major Crops of Tubewells and Non-Tubewell Farmers, By the Size of Operating Acreage, 1967

(Maunds per Acre)

	Below 12.5	12.6-25.0	25.1-50.0	Above 50.0	Average
<u>TUBEWELL FARMS</u>					
Cotton	9.5	7.8	9.8	11.6	10.4
Rice	23.8	25.0	23.8	23.9	23.6
Maize	11.1	18.2	17.2	21.3	15.3
Sugarcane	11.3	29.2	41.0	37.3	30.8
Wheat	15.9	16.6	16.0	15.5	15.3
<u>NON-TUBEWELL FARMS</u>					
Cotton	7.5	8.6	8.2	8.8	8.7
Rice	23.2	22.8	23.2	25.0	22.7
Maize	11.4	14.3	12.9	15.0	12.4
Sugarcane	n.a.	24.6	29.8	48.8	31.6
Wheat	14.3	13.4	15.0	13.4	13.6

Source: Computed from the data collected by the 1967 Survey by PIDE.

4. Effects of Tubewells on Inputs

Both tubewell farmers and non-tubewell farmers used the same methods of cultivation and similar types of implements. Some visible improvements in the methods of cultivation with the installation of tubewells are exemplified by the introduction of drills for line sowing, the use of improved cultivators, the adoption of inter-culture implements, mouldboard plows and others, all of which are animal-drawn. Their adoption was usually initiated by tubewell farmers and later on was followed by non-tubewell farmers as well.

Fertilizers: The traditional agricultural practices, limited and uncertain canal water supplies, lack of funds and credits, and the prevailing illiteracy among the rural population of West Pakistan has placed severe limit on the use of fertilizers. Moreover, the inefficient methods of fertilizer distribution, inadequate transportation and storage facilities (especially on local levels) have affected the use of this input.

In studying the impact of additional water supplies on fertilizer use, we may summarize the results of the 1964/65 survey data used also by Ghulam Mohammad. The use of phosphorus fertilizers was almost negligible, thus making nitrogenous fertilizers the only ones used by the farmers of this region. The dose of fertilizer application per acre more than doubled after the installation of tubewells, if judged on the basis of the cropped acreage. However, since ~~the~~ proportion of fertilizer consuming crops increased after additional water became available, on the basis of acreage that was actually given fertilizer treatment, the dose increased only about 30 to 40 percent. This reflects the tendency for tubewell farmers to concentrate on a few valuable crops and apply fertilizers to all these crops, while non-tubewell farmers tend to grow a greater number of different crops (in order to avoid the risk of weather variability) and apply fertilizers to a limited number of crops. These observations relate to the 1964/65 survey, since no special survey was made on the fertilizer use in the winter of 1967. Nonetheless, it can stated that the doses of fertilizers per acre in the latter period were undoubtedly higher for tubewell farmers. It is suspected, therefore, that there existed a greater disparity in the use of fertilizers between tubewell and non-tubewell farmers during the survey of 1967.

According to estimates by the United States Agency for International Development, the fertilizer consumption in West Pakistan more than doubled during the period between 1964/65 and 1967/68. This is, of course, partly due to the introduction of short-stemmed varieties of wheat and rice and hybrid maize that respond favorably to a higher dose of fertilizers than the local varieties. Needless to say, [illegible] dissemination of knowledge and information by the government agencies and efforts of the extension services coupled with the favorable prices of fertilizers were also instrumental in increasing consumption.

Insecticides: The use of insecticides in West Pakistan is quite limited. They are usually limited to seedbed nurseries, fruit gardens and orchards and are rarely used for crop production. To some extent in sugarcane and maize production insecticides are applied from roots through irrigation water. If cotton areas are attacked by some insect pests, they are covered by the eradication campaigns sponsored by the government agencies. So far we have not been able to discern any significant differences in the use of insecticides between tubewell and non-tubewell farmers.

Land: The farming unit tends to increase with the installation of tubewells. The scattered land areas are consolidated for the purpose of better irrigation practices and the farm sizes tend to grow. Table 5 indicates that the average farm size grew by 11 percent after the installation of tubewells. This increase in the size of farm may be attributed to the following factors: (a) Unused areas were brought under cultivation due to increased supplies of water from tubewells; (b) Additional land were rented in from the neighboring non-tubewell farmers or absentee landlords; and (c) Additional units of land were purchased from the increased income resulting from tubewells.

Labour: Table 5 shows that on average the non-tubewell farmers surveyed worked about 9 percent more than 8 hours a day, while the tubewell farmers on average expended 24 percent more than the usual 8 hours a day. So far as physical labourinput is concerned, hired labour input increased proportionally more than family labour with the coming of tubewells. Because of the longer working hours per man per day and also of the increased number of workers (both family and hired hands), the input of labour on tubewell farms was on average about 57 percent higher than that on non-tubewell farms.

Table 5

Land and Labour Inputs, Tubewell and Non-Tubewell Farms

	Non-tubewell farms	Tubewell farms
Average farm size	30.25 acres	33.60 acres
Average working hours/per day:		
Family Labour	8.30 hours	10.44 hours
Hired Labour	9.20	11.23
Average	8.75	10.84
Labour per acre at average working hours		
Family Labour	0.082 men	0.084 men
Hired Labour	0.045	0.061
Total Labour	0.127	0.145

Source: The 1967 Survey conducted by PIDE.

5. Effects of Tubewells on the Productivity of Inputs

With the advent of tubewells, more land, more labour and increased amounts of other inputs are used to produce greater quantities of output per year. This is what Ghulam Mohammad observed a few years ago and our survey data amply confirm his observations. There is, however, another set of considerations which calls our attention.

It is one thing to say that thanks to additional supplies of water inputs of land, labour, and other factors are increased to produce a greater amount of output. It is quite another to ask whether such increases in the quantities of inputs could have produced, in the absence of changes which brought forth additional supplies of water, the increased amount of output, or how much of that increase could be attributable to tubewells alone, if, in comparing the two situations before and after, the existence of tubewells was the sole difference.

The traditional procedure has been to use a partial productivity index, (e.g.,average output per unit of labour, or of land) or a total productivity index (output per unit of total input, weighing each category of inputs by its earnings before the change) as a measure of the impact of technical improvement. Familiar among the partial approaches to this question has been to assume homogeneity of labour(or land) and measure productivity growth in terms of product per man-hour (or per acre).[5]

A more recent procedure is to use production functions. Comparisons are made between the level of output that would have been produced, using the level of inputs prevailing after the introduction of innovations, with the production function before the innovation, and the level of output obtained currently (after the innovations) with the same inputs. The increase in the current level of output over the level projected from the production function prevailing before the innovations is then attributed to the impact of those innovations.

The choice of analytical procedures, assumptions and kinds of data to be used is determined essentially by the question: to what use are the results to be put? It is inevitable that the purpose of analysis should affect its form. With due attention to the deficiencies of the

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[5] No doubt, labour (or land) is quantitatively the largest input (in marginal units of measure, i.e., as a share of income or value added), so that large changes in labour (or land) productivity are likely to reflect at least roughly the changes of a properly defined measure of productivity. But, of course, in general, labour (or land) productivity measure will grow, as other inputs have grown relative to labour (or land). Labour (or land) productivity will therefore be a better measure of total productivity, the more nearly proportional the increase of labour (or land) and other productive factors over time, and the smaller the relative weight of nonlabour (or nonland) resources in total input.

production function approach adopted here,[6] in what follows in this section we shall outline the analytical procedure adopted and the assumptions associated with them.

6. The Basic Model

Suppose that the influences of additional supplies of water can be incorporated in the basic production relationship characterized as follows:

$$(1) \qquad Y = AX^{b}Z^{c}G(t)$$

where Y is gross output, X cropped area, and Z is labourinput in man-hours. The unknown parameters in this equation are A, b and c, the latter two being the elasticities of output with respect to cropped area and labourinput, respectively. The equation incorporates an unspecified G (t) which accounts for the influences of additional supplies of water from tubewells. The form of the function reflects the hypothesis that cropped area, man-hours of labor, and tubewell water are the major input categories and that additional supplies of water from tubewells augment the productivity of other inputs multiplicatively.

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[6] Conceptual problems involved in measuring changes in productivity can be enumerated below. First, bias may be introduced if: (i) the farms are not operating at equilibrium both before and after the change; (ii) the prices of factors relative to each other and/or the prices of products relative to each other do not remain unchanged; and (iii) the impact of innovations is not "neutral".

Secondly, another set of problems is introduced into empirical research in determining what should go into the output and input measures. Some of these problems result from specification of a production function assumed, use of data available, and, more importantly, the question of whether inputs of social capital and changes in the quality of inputs are being correctly incorporated into calculations.

Let lower-case letters denote logarithms of the original variables. Introducing a stochastic term in the basic equation, we obtain a regression equation,

(1') $y = a + bx + cz + g(t) + u.$

All that is needed now for statistical estimation of the parameters is to specify the method by which the variable $g(t)$ can be dealt with.

Suppose that we want to study production relationships covering two distinct classes of farmers, tubewell farmers and non-tubewell farmers, in different areas cultivating different size holdings. Production relationships may differ not only because of the availability of additional supplies of water from tubewells but also because of different impacts of cropping patterns and the scales of operating acreage. In order to isolate and obtain meaningful inferences of the effects of tubewells on production relationships we may proceed as follows:

(a) Among different size classes and also among different agricultural areas the impacts of tubewells are different. The output elasticities (the parameters b and c) are likewise different among the different size classes and areas.

(b) Among different size classes and also among different agricultural areas the impacts of tubewells are different. The output elasticities (as defined here) are the same, however, regardless of the size, location and availability of tubewell water.

(c) In all agricultural areas and size classes the [illegible] influences of tubewells and the output elasticities are the same.

Corresponding to the three assumptions above[7/], three regression models can be constructed and $g(t)$'s, i.e., the influences of additional supplies of water from tubewells, can be estimated. It suffices to illustrate the procedure for a simple case. Take, for example, a hypothetical case where there is only one size class in each agricultural area. Rewrite (1') with subscripts r and t, the former denoting agricultural area and the latter the availability of tubewell water:

$$(2) \qquad y_{rt} = a_r + bx_{rt} + cz_{rt} + g(t) + u_{rt}$$

Let the average value of a variable over the R agricultural areas in t be denoted by a dot in place of the r subscript.

$$(3) \qquad y_{.t} = a_. + bx_{.t} + cz_{.t} + g(t)$$

Now if we subtract (3) from (2), we obtain a regression equation involving only the variables measured from their respective (logarithmic) means:

$$(4) \qquad y'_{rt} = a'_r + bx'_{rt} + cz'_{rt} + u_{rt}$$

Equation (4) contains only those parameters that can be estimated by the ordinary least-squares method. The variable $g(t)$ can be estimated from equation (3), after the parameters are ascertained, according to respective assumptions to be made about the nature of a_r.

For example, let it be assumed that $a_r = a_.$, that is, the "influences of tubewell water" are the only unspecified factors at work in the basic production relationship. This means that with the

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[7/] Obviously, there are more combinations of assumptions that can be same values of x_{rt} and z_{rt}, the values of y_{rt} are the same for all observations belonging to either tubewell farmers or non-tubewell farmers. Then g(t) can be computed numerically as a residual from equation (3).

Following essentially the same procedure as above, allowing, however, several size classes in each agricultural area to be subscripted with s (s = 1, ..., S), we obtain three regression models corresponding to the preceding three assumptions: (a), (b) and (c).

Model A

$$y_{rst.} = a_{rs.} + b_{rs}x_{rst.} + c_{rs}z_{rst.} + g(t)_{rs}$$

$$y'_{rsti} = a'_{rsi} + b_{rs}x'_{rsti} + c_{rs}z'_{rsti} + u_{rsti}.$$

The subscript i denotes individual observation in a size class within given r, s, and t. The additional assumption required here is that $a_{rs.} = a_{rsi}$.

Model B

$$y_{rst.} = a_{rs.} + bx_{rst.} + cz_{rst.} + g(t)_{rs}.$$

$$y'_{rsti} = a'_{rst} + bx'_{rsti} + cz'_{rsti} + u_{rsti}.$$

The additional assumption is once again $a_{rs.} = a_{rsi}$.

Model C

$$y_{..t.} = a_{...} + bx_{..t.} + cz_{..t.} + g\ (t)$$

$$y''_{rsti} = a''_{rsi} + bx''_{rsti} + c''_{rsti} + u_{rsti}$$

7/ Cont'd.

formulated than those given here. The number of relevant combinations is, however, limited by the questions to be asked in the study and the statistical procedures followed.

where " denotes the deviations of the variables from their respective overall means (covering all the areas and size classes within them). The assumption is that $a_{...} = a_{rsi}$ for all observations.

The statistical results of the three models can be subjected to variance-covariance analysis for testing empirical validity of the alternative assumptions contained in each of the models. First we estimate 16 Model A regressions (different influences of tubewells and different parameters for each size class in each area) and see whether or not the regressions are successful in explaining the data. If they explain the data at all, we proceed to Model B (different influences of tubewells for different size classes in different areas, but the same parameters for the entire sample) and compare it with Model A. Specifically, an F-test is carried out between the two residual mean squares. If the computed F turns out to be significant, it means that the coefficients b and c (the elasticities of output with respect to cropped area and labor) cannot be assumed the same for the entire sample. Hence Models B and C, which assume the same coefficients for different size classes and areas must be abandoned. If, on the other hand, the computed F-ratio is not significant, we may proceed with the assumption that the regression coefficients are the same for all the areas and size classes. In the same manner as above an F-test between Model B and Model C should be carried out next. If this turns out to be not significant, then we proceed to the simplest Model C, which assumes that in all agricultural areas and size classes the influences of tubewells and the output elasticities are the same.

The mathematical logic involved in the statistical procedure adopted here is the same as that of the classical least-squares method that includes the use of dummy variables. As dummy variables are used for the purpose of accounting for the effects of different factors at work, the data variables in this procedure are grouped according to the different factors that may influence their mean levels. The ordinary regression method is then applied to the deviations from the respective means rather than to the observations themselves. One advantage of the method used here is that the process of computations can be made simpler because of a fewer number of variables included in the regression and, therefore, expediting the processing of data in the absence of a high-speed computer.

The Results of the Regression Analyses

The data variables are derived from the 1967 tubewell survey conducted by Mohammad Ghaffar. Gross output is the evaluation (in rupees) of all the crops grown during Kharif and Rabi seasons at the prices prevailing on the farm level. Cropped area is the sum of the acreage under all crops and includes the effects of increases in the cropping intensities of tubewell farmers as contrasted to non-tubewell farmers. Labour input is derived from the number of workers on the farm, including both family members and hired hands, multiplied by the respective working hours per day. All the data variables refer to either before or after the installation of tubewells on the farm. The distribution of observations by the size of operating acreage, the areas, and the availability of tubewell water is given in Appendix Table II.

The sums of unexplained residuals, together with the degrees of freedom and the residual mean squares obtained from each of the three regression models are given below.

	SS	DF	MS
Deviations due to Model C	8.681285	197	.044067
Deviations due to Model B	4.725869	183	.025824
Deviations due to Model A	4.084733	153	.026698

The computed F statistics for the comparison of Model C with Model B and that of Model B and Model A are 1.706 and 1.034, respectively. The first test turns out to be significant at the 1 percent level of significance, whereas the second does not.[8/] These results imply that the differential treatment of the variable g(t) among the different size classes and agricultural areas is to be significant, but that the differential treatment of the output elasticities are not. In other words, all the farms, regardless of size, location and supplies of additional water from tubewells, can be treated equally so far as the output elasticities are concerned. Only difference among the farms is that the output augmenting effects of tubewells depend on the farm's size and location. In view of these results, we assume hereafter that all farms have the same elasticities of output and that they differ only with respect to the influences of tubewell water.

[8/] The tabular values of F at the appropriate degrees of freedom are approximately 1.4 for 1 percent and 1.3 for 5 percent level of significance.

The regression estimates of the output elasticities by Model B are as follows:

$$y'_{rsti} = \underset{(0.069)}{1.093}\, x'_{rsti} + \underset{(0.041)}{0.052} z'_{rsti},$$

where ' denotes the variables measured from their respective (logarithmic) means grouped separately by the size of operating acreage, the agricultural area, and the availability of tubewell water. The figures in parentheses under the regression coefficients are their standard errors.

The estimated elasticity of output with respect to cropped acreage is close to unity. The output elasticity with respect to labour input, however, is not significantly different from zero, although the estimate turns out to be positive. The results indicate that, in case the output augmenting effects of tubewells are independently accounted for, gross output tends to increase in the same proportion by which cropped area is increased. The variation in the effects of increased inputs of labor is too large to permit us to say positively about its quantitative significance.

8. The Independent Effects of Tubewells on Productivity

Model B selected in the previous section yields a set of residual measures of the output augmenting effects of tubewells. The residual measures are derived from the equations of the form,

$$y_{rst.} = bx_{rst.} + cz_{rst.} + g(t)_{rs}$$

for the [illegible] different classifications adopted for Model B.[9]

for the 16 different classifications adopted for Model B.[9] This means that the values of $g(t)_{rs}$ would differ, depending on the (class average) values of gross output, cropped acreage, and labour input, since the elasticities of output are assumed to be the same in all the size classes in all areas regardless of the availability of tubewell water. In other words, in any size class in a given area, if the values of gross output, cropped area, and labour input were the same before and after the installation of tubewells, the resulting $g(t)_{rs}$ would also be the same. If, therefore, we observe differences in the values of gross output after the installation of tubewells, a part of the variations would be attributed to changes in the amounts of cropped area and labour input and the rest to the residual measures of the impacts of additional supplies of water from tubewells. The results of such computations are given in Table 6.

Since the values of $g(t)$ are not independent of the units in which the original variables are measured, strict numerical comparison of the values is not recommended. It is interesting to note, however, that the residual measure of the impact of tubewell water on productivity increases more for the middle size classes than for the others. In both rice area and cotton area, farms with the operating acreage of between 12.5 and 25.0 acres and those with between 25.1 and 50.0 acres, and especially the latter, appear to benefit most from additional supplies of water made available from tubewells.

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[9] For each t, t = 1, 2 (i.e., non-tubewell and tubewell farms), r= 1, 2 (i.e., rice area and cotton area) and s = 1, ...,4(i.e., the four size classes).

Table 6

Residual Measure of the Influences of Tubewell Water on Productivity, by Size and Agricultural Area

	Measured $g(t)$		Tubewell Farms as % of Non-tubewell farms
	Nontubewell farms	Tubewell Farms	
RICE AREA			
Below 12.5 acres	2.418094	2.310497	95.6%
12.5 - 25.0	2.163277	2.246989	103.9
25.1 - 50.0	2.128734	2.226399	104.6
Above 50.0	2.139853	2.167278	101.3
Average	2.234423	2.251387	100.8
COTTON AREA			
Below 12.5	2.274129	2.275998	100.1
12.5 - 25.0	2.242306	2.271806	101.3
25.1 - 50.0	2.144836	2.216408	103.3
Above 50.0	2.212030	2.234051	101.0
Average	2.213709	2.249201	101.6

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*Computed on the basis of Model B.

The finding above is hardly surprising. It has been known that most of private tubewells were installed by cultivators with 12.5 acres or more. Smaller farmers installed tubewells jointly or sold surplus water in an attempt to utilize more fully the capacity of their tubewells. It is nonetheless interesting to observe that more than 60 percent of the increase in new installations of tubewells between 1960-62 and 1963-65 is shared by the middle size class farms. On the basis of the detailed survey figures available for only four of the six districts under study, the share of each size class in the increase of new tubewell installations was calculated. The results are presented in Table 7. It is quite clear that the size class holding between 12.5 and 25.0 acres and that holding between 25.1 and 50.0 acres figured most prominently in the increase of new tubewell installations. It can be understood that farmers in these classes, especially those in the class of 25.1 to 50.0 acres, were best motivated to take advantage of the increase in productivity of inputs resulting from additional supplies of water from tubewells.

9. Concluding Remarks

In the absence of quantitiative information pertaining to the inputs of capital assets and current inputs (fertilizers, insecticides, etc.) for the individual farms surveyed, the present study has much to be improved upon. Although we have made some tentative observations on the input patterns of tubewell farms and non-tubewell farms in this paper, the failure to explicitly account for the differences in input patterns other than cropped area and labour may well have influenced our estimates of the impact of

Table 7

Share of Increases in Private Tubewell Installation, By Size of Holdings, Selected Districts, 1960-62 to 1963-65

		Size of Holdings of Tubewell Farmers				
Districts	Years	Below 12.5	12.5-25.0	25.1-50.0	Above 50.0	Total a/
		-- Total Number of Tubewells Installed --				
RICE AREA						
Lahore	1960-62	74	105	128	125	434
	1963-65	129	250	288	262	932
Gujranwala	1960-62	177	370	604	386	1570
	1963-65	437	815	1195	626	3076
COTTON AREA						
Multan	1960-62	156	460	690	1224	2567
	1963-65	352	839	1110	1419	3776
Sahiwal	1960-62	214	529	627	818	2200
	1963-65	363	916	1039	1021	3354
		-- Increase in the Number of Installations and Its Share by Size of Holdings --				
RICE AREA						
Lahore	Increase	55	145	160	137	498
	% Share b/	11.0	29.1	32.1	27.5	100
Gujranwala	Increase	260	445	591	240	1506
	% Share b/	17.3	29.2	39.2	15.9	100
COTTON AREA						
Multan	Increase	196	379	420	195	1209
	% Share b/	16.2	31.3	34.7	16.1	100
Sahiwal	Increase	149	387	412	203	1154
	% Share b/	12.9	33.5	35.7	17.6	100

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*Computed from Mohammad Ghaffar, et. al., "Size of Holdings of Private Tubewell Owners," PIDE Research Report No. 69, various district tables.

a/ Total includes single-owner tubewells not classified by size of holdings.

b/ Percent shares do not add up to 100 because of a/ above.

Total number of tubewells installed refers to the total number of private tubewells (both individually owned and jointly owned) installed in the specified three years.

tubewell water. Some of the major causes of the "green revolution" now taking place in West Pakistan are (i) increased use of fertilizers; (ii) increased use of improved varieties of seeds; and (iii) improvements in cultural practices, including improved farm implements, as well as (iv) increased water supplies from tubewells. By accounting for the last factor only, and with the use of a residual method of estimation, we may have attributed too much for this particular factor. Nonetheless, presumption is strong that additional supplies of water from tubewells have played the role of catalyst in introducing the parallel changes in the use of other inputs. Further studies in greater detail have to wait until the relevant quantitative data become available and the impact of the "green revolution" becomes better known.

Within the limits of this study, however, the following conclusions emerge: (1) Additional supplies of water from tubewells not only increase the inputs of labour and cropped acreage and, thus, enable the farmer to produce a greater amount of output, but also increase the efficiency in which these inputs are transformed into output; (2) The output augmenting effect of tubewell water is most pronounced in the farms holding between 12.5 and 50.0 acres, particularly favoring on balance those with 25 to 50 acres in both rice and cotton areas; (4 (3) The pattern of increases in tubewell installations reveals that the farms in these size classes have responded most conspicuously to the expanded economic opportunities made available.

Tubewell farmers, regardless of their size holdings, are "progressive farmers". Generally speaking, the practice leading up to the "green revolution" in West Pakistan have been initiated and exploited by tubewell- farmers. The technological possibilities opened up by these farmers and the benefits clearly demonstrated by them will be expected to lead other farmers to emulate their progressive neighbors.

Appendix Table I

Estimated Number of Private Tubewells by Districts, 1967

Six Selected Districts in the Former Punjab*

Districts	Estimated Number of Private Tubewells in 1967	Percent of the Total in West Pakistan, 1967
Multan	9,950	18,8%
Sahiwal	9,580	18.1
Jhang	3,270	6.2
"Cotton Area"	22,800	43.0
Gujranwala	7,350	13.9
Sialkot	4,670	8.8
Lahore	3,580	6.8
"Rice Area"	15,600	29.4
Total West Pakistan	53,000	100.0

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*Source: Mohammad Ghaffar and Edwin H. Clark II, "Installation of Private Tubewells in West Pakistan, 1964-67," Research Report No. 71 (Karachi, Pakistan Institute of Development Economics, 1968), p. 11.

Appendix Table II

Distribution of Observations by Size of Farm, Area, and Availability of Tubewell Water, 1967 Survey

	Number of Farms				
	Size of Operating Acreage				
	Below 12.5	12.6-25.0	25.1-50.0	Above 50.0	Total
TUBEWELL FARMS					
Rice Area	15	13	13	6	47
Cotton Area	14	17	19	9	59
NON-TUBEWELL FARMS					
Rice Area	14	13	12	4	43
Cotton Area	12	16	17	7	52

Source: Data collected by the 1967 Survey in PIDE.

Note: The smaller number of observations included in Non-tubewell farms is due to deficiencies in survey response regarding the period before the installation of tubewells.