Notes & Comments

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

by

HIROMITSU KANEDA and MOHAMMED GHAFFAR*

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[1]. According to the pioneering study by the Late Ghulam Mohammad, additional water made available by the tubewells enabled the farmers to: "*i*) increase the depth of irrigation for 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" [4, p. 44].

The data used in the present article have been taken from a survey of tubewell farmers (herein referred to as 1967 data) conducted in the winter of 1967 by Mohammed Ghaffar under the direction of Edwin H. Clark II, and the Late Ghulam Mohammad, about 125 tubewell farmers were interviewed in six districts of the former Punjab: Multan, Sahiwal (Montgomery), and Jhang, referred to as the "cotton area"; and Gujranwala, Sialkot, and Lahore, designated in this study as the "rice area", on account of their major *kharif* (summer) crops. These six agricultural districts rank highest in the number of private tubewells in existence, accounting altogether for more than 70 per cent of the total number of private tubewells in West Pakistan (Appendix Table A-1). Moreover, except for the Sialkot district in which agricultural output stagnated,

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*The authors are, respectively, a Research Adviser and a Research Assistant at the Pakistan Institute of Development Economics.

[1]There were 34,400 private tubewells in 1964/65; 9,100 were added in 1965/66 and 9,500 in 1967, thus, raising the number of private tubewells in West Pakistan to some 53,000 by 1967 [2].

all the five districts experienced remarkably high average rates of growth in gross value of production during the period 1960-65 (the second-plan period[2]). These six agricultural districts produced some 51 per cent of the gross value of agricultural output of the Punjab.

Essentially, though the present study is an extension of Ghulam Mohammad's pioneering study of tubewells in the Punjab [4], yet we have tried to attempt to improve the results obtained by Ghulam Mohammad in two important respects. The first distinguishing characteristic of the present study is that it uses the 1967 survey data more carefully selected from wider areas[3]: in contrast to Ghulam Mohammad's study, we have included data not only from relatively less developed districts but also from *tehsils* that are comparatively more representative of the whole district.

The second characteristic of our study is its emphasis on statistical analyses of the effects of tubewells on the productivity of inputs with the help of some regression models. Our objective has been to separate out the output growth after the introduction of tubewells between the effects of increased intensity of cultivation and the residual effects not accounted for by the increased inputs of cropped area and associated labour use. We shall be interested also in analysing the differential effects of tubewell water on farm production according to the size of the operating acreage and the area in which the farm is located.

It seems appropriate to warn the reader at the outset of two important limitations imposed on this study. They concern the timing and the nature of the survey, which was conducted in the winter of 1967, before the dawn of the "green revolution". The short-stemmed varieties of wheat and rice imported from abroad and the greatly increased use of fertilizers have dramatically increased the agricultural output of West Pakistan since 1967/68. There is no question that additional supplies of irrigation water, which preceded the recent breakthrough in foodgrain production, played the role of a catalyst in intro-

[2]During the period 1960-65, the annual percentage increase in gross value of agricultural production was 5.7 in Multan, 6.4 in Sahiwal, 5.1 in Jhang, 4.3 in Gujranwala, and 4.0 in Lahore [3].

[3]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 districts ranking high among those in the Punjab. The *tehsils* covered within the cotton area are Mailsi and Khanewal in Multan district, Sahiwal and Pakpatan in Sahiwal district, and Jhang in Jhang district. The *tehsils* in the rice area are Gujranwala and Wazirabad in Gujranwala district, Sialkot and Daska in Sialkot district, and Chunian and Kasur in 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 1967 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 the rice area, which are the best districts in the two areas included here. The 1967 Survey includes not only relatively less developed Jhang district in the cotton area, but also *tehsils* that are comparatively more representative of the whole. While all the areas selected by Ghulam Mohammad were situated on perennial canals, the present sample includes areas commanded by semi-perennial canals as well (*e.g.*, Pakpatan tehsil).

ducing (and rapidly diffusing) the yield-increasing innovations. By making it possible to grow more crops, more lucratively per acre of cultivated area (per year), tubewell water and new seeds as well as increased application of fertilizers have increased the aggregate output of the agriculture of West Pakistan. The data used in this study, however, relate to the period before these new developments took place. The empirical results of this study, therefore, are of limited applicability to interpretation of the recent developments, although it is hoped that the methodology adopted here may find future application in similar studies as more recent data become available for analysis.

It should be noted that the survey itself was designed and executed for purposes other than this particular analysis. As a consequence, some of the important variables in the context of this study were not covered in the survey. However, it is our conviction that the data generated by the survey are sufficiently varied and detailed to withstand a further analysis of this type. Since the survey included only those farmers who had private tubewells, in what follows "nontubewell farmers" and "tubewell farmers" refer to the situations "before" and "after" the introduction of tubewells in the operations of these farmers.

Effects of Tubewells on Cropping Patterns and Cropping Intensities

Table I presents cropping patterns and cropping intensities of tubewell and nontubewell 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 the cotton area and rice and sugarcane in the rice area. Noteworthy is the decrease in the acreage of cotton in the rice area. Owing to the yield disadvantage of cotton and to the government's 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 urgent attention to the nation's fibre supply problem.

The cropping intensity of the tubewell farmer is higher than that of the nontubewell farmer. In the cotton area, the former averaged 127 per cent and the latter 81 per cent. In the rice area the corresponding figures were 147 per cent and 108 per cent, 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 nontubewell 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 cropping

TABLE I

CROPPING PATTERNS AND CROPPING INTENSITIES[a] OF TUBEWELL AND NONTUBEWELL FARMERS, 1967[b]

Crop	Cotton area		Rice area		Both areas	
	Tubewell farmers	Non-tubewell farmers	Tubewell farmers	Non-tubewell farmers	Tubewell farmers	Non-tubewell farmers
	(.....	.....	*per*	*cent*	.....	.....)
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
Subtotal 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
Subtotal 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
Subtotal	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**

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

[b]1967 denotes *rabi* (winter) crop of 1966/67 and *kharif* (summer) crop of 1967.

Source: The 1967 Survey conducted by the PIDE.

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 nontubewell farmers by the size of operating acreage. Table II reveals, moreover, some additional information regarding the economic impact of tubewells by the size of operating acreage. First, for both tubewell and nontubewell farmers, the cropping intensity of the larger size farm is lower than that of the smaller size farm. This was also revealed by the 1960 Agricultural Census of Pakistan. Second, although the cropping intensity of a larger tubewell farm tends to remain lower than that of a smaller tubewell farm, the

TABLE II

CROPPING INTENSITIES OF TUBEWELL AND NONTUBEWELL FARMERS BY SIZES OF OPERATING ACREAGE, 1967

(Per Cent of Cultivated Area)

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 acres	78.9	73.9	152.8	40.9	63.8	104.7
25.1—50.0 acres	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 acres	57.6	47.5	105.1	39.2	38.6	77.8
25.1—50.0 acres	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 acres	67.6	62.9	130.5	39.9	50.4	90.3
25.1—50.0 acres	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 the PIDE.

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.

Effects of Tubewells on Crop Yields

According to Table III, the observed yields of major crops in the rice area tend to be lower than in the cotton area. This is in part due to the fact that soils in the rice area are adversely affected by waterlogging and salinity problems and, therefore, are, on average, less productive than in the 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 the cotton area than in the rice area are partly attributable to the

TABLE III

AVERAGE YIELD OF CROPS, TUBEWELL FARMERS, AND NONTUBEWELL FARMERS, 1967

Crop	Average yield		
	Rice area	Cotton area	Both areas
Tubewell Farmers	(......*maunds per acre*......)		
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
Nontubewell 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 the PIDE.

varieties of rice grown in respective areas. In most parts of the rice area, superior varieties of rice (*basmati*) are grown, while in the cotton area mainly the coarse varieties that respond strongly to additional supplies of water are grown.

Table IV presents the observed yields of major crops of tubewell and nontubewell 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.

Effects of Tubewells on Inputs

Cultivation Methods: Both tubewell armers and nontubewell farmers used the same methods of cultivation and similar types of implements. Some

TABLE IV

AVERAGE YIELDS OF MAJOR CROPS OF TUBEWELL AND NONTUBEWELL FARMERS, BY THE SIZE OF OPERATING ACREAGE, 1967

Crop	Size of operating acreage				
	Below 12.5 acres	12.6—25.0 acres	25.1—50.0 acres	Above 50.0 acres	Average
	(................. *maunds per acre*				.................)
Tubewell Farms					
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
Nontubewell Farms					
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 the PIDE.

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 ploughs and others, all of which are animal-drawn. Their adoption was usually initiated by tubewell farmers and later on followed by nontubewell 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 have placed severe limits 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 which were used by Ghulam Mohammad since 1967 Survey did not include fertilizer use. 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 per cent. This reflects the tendency for tubewell farmers to concentrate on a few valuable crops and apply fertilizers to all these crops, while nontubewell 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. However, it can be stated that the doses of fertilizers per acre in 1967 were higher for tubewell farmers than it was in 1964/65[4]. It is suspected, therefore, that there existed a greater disparity in the use of fertilizers between tubewell and nontubewell farmers during the survey of 1967.

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

[4]It may be noted that according to the 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 was, of course, partly due to the introduction of short-stemmed varieties of wheat and rice and hybrid maize that respond favourably to a higher dose of fertilizer than the local varieties; and partly to proper dissemination of knowledge and information by the government agencies and efforts of the extension services coupled with the favourable prices of fertilizers.

been able to discern any significant differences in the use of insecticides between tubewell and nontubewell 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 V indicates that the average farm size grew by 11 per cent 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 was rented in from the neighbouring nontubewell farmers or absentee landlords; and *c*) additional units of land were purchased from the increased income resulting from tubewells.

Labour: Table V shows that on the average the surveyed nontubewell farmers worked about 9 per cent more than 8 hours a day, while the tubewell farmers on the average spent 24 per cent more than the usual 8 hours a day. So far as physical labour input is concerned, hired labour input increased proportionately 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 the average about 57 per cent higher than that on nontubewell farms.

TABLE V

LAND AND LABOUR INPUTS, TUBEWELL AND NONTUBEWELL 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 hours	11.23 hours
Average	8.75 hours	10.84 hours
Labour per acre at average working hours		
Family labour	0.082 men	0.084 men
Hired labour	0.045 men	0.061 men
Total labour	0.127 men	0.145 men

Source: The 1967 Survey conducted by the PIDE.

Effects of Tubewells on the Productivity of Inputs

With the advent of tubewells, more land, more labour, and increased amount 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 for our attention.

It is one thing to assert that because of the additional supplies of water, the increased inputs of land, labour, and other factors are responsible for higher output; and quite another to ask whether such increase in quantities of inputs could have resulted in higher output, in the absence of changes which brought forth additional supplies of water.

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 innovation in the production function estimated 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 are 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 production-function approach

[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 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.

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

The Basic Model

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

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

where Y is gross output, X cropped area, and Z is labour input 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 labour input, respectively. The equation incorporates an unspecified variable 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 labour, and tubewell water are the major input categories and that additional supplies of water from tubewells augment the productivity of other inputs multiplicatively.

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

$$y = a+bx+cz+g(t)+u \qquad \text{.....................(1')}$$

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 nontubewell 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.

[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 important, the question of whether inputs of social capital and changes in the quality of inputs are being correctly incorporated into calculations.

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 the size classes the 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 in which there is only one size class in each agricultural area. (These assumptions are released in the subsequent models.) Rewrite (1′) with subscripts r and t, the former denoting agricultural area and the latter the availability of tubewell water:

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

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.

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

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

$$y_{rt}+a'_r+bx'_{rt}+cz'_{rt}+u_{rt}\,. \qquad \text{..............(4)}$$

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 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 nontubewell 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 ($s = 1, \ldots, S$), we obtain three regression models corresponding to the preceding three assumptions: (a), (b) and (c).

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[7]Obviously, there are more combinations of assumptions that can be formulated than these given here. The number of relevant combinations is, however, limited by the questions to be asked in the study and the statistical procedures followed.

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

$$y'_{rsti} = a'_{rsi} + bx'_{rsti} + cz'_{rsti} + u_{rsti}\,.$$

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

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

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

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 labour) 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 Mohammed Ghaffar. Gross output is the rupee value 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 effect of increases in the cropping intensities after the farmers had the tubewells installed, as contrasted to before the installation of tubewells. 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 are given in Appendix Table A-2.

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-per-cent 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 is not.

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

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. The 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.

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

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

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 labour is too large to permit us to say anything positively about its quantitative significance.

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 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

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

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 measure of the impacts of additional supplies of water from tubewells. The results of such computations are given in Table VI.

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 the rice area and the cotton area, farms with the operating acreage of between 12.5 and 25.0 acres and those having between 25.1 and 50.0 acres, and especially the latter, appear to benefit most from additional supplies of water made available from tubewells.

TABEL VI

RESIDUAL MEASURE OF THE INFLUENCES OF TUBEWELL WATER ON PRODUCTIVITY, BY SIZE AND AGRICULTURAL AREA

Size of Area	Measured g(t)		Tubewell farm as percentage of Nontubewell farms
	Nontubewell farms	Tubewell farms	
Rice Area			
Below 12.5 acres	2.418094	2.310497	95.6
12.5—25.0 acres	2.163277	2.246989	103.9
25.1—50.0 acres	2.128734	2.226399	104.6
Above 50.0 acres	2.139853	2.167278	101.3
Average	2.234423	2.251387	100.8
Cotton Area			
Below 12.5 acres	2.274129	2.275998	100.1
12.5—25.0 acres	2.242306	2.271806	101.3
25.1—50.0 acres	2.144836	2.216408	103.3
Above 50.0 acres	2.212030	2.234051	101.0
Average	2.213709	2.249201	101.6

Note: Computed on the basis of Model B.

The above finding is hardly surprising. It has been known that most of private tubewells were installed by cultivators possessing 12.5 acres or more. Smaller farmers either installed tubewells jointly or sold the surplus water in an attempt to utilize more fully the capacity of their tubewells. It is, nonetheless, interesting to observe that more than 60 per cent 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 VII. 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.

Concluding Remarks

In the absence of quantitative 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 nontubewell farms in this paper, the failure to explicitly account for the differences in input patterns other than the cropped area and labour may well have influenced our estimates of the impact of 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.

The most important conclusion that emerges from this study is that before the spread of new seeds and increased application of fertilizer the benefits of supplementary irrigation from tubewells were mainly in increasing the intensity of cropping. The yield effects of tubewell water were rather small and their residual effects, after taking account of increases in inputs of land (cropped acreage) and labour, turned our to be very small.

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 quantity of output, but also increase the efficiency in which these inputs are

TABLE VII

SHARE OF INCREASES IN PRIVATE TUBEWELL INSTALLATION, BY SIZE OF HOLDINGS, SELECTED DISTRICTS, 1960-62—1963-65*

District	Year	Size of Holdings of tubewell farmers				
		Below 12.5 acres	12.5-25.0 acres	25.1-50.0 acres	Above 50.0 acres	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

*Computed form Mohammed Ghaffar, *et al.*, [1].

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

[a]Total includes single-owner tubewell not classified by size of holdings.

[b]Per cent shares do not add up to 100 because of *a* above.

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 favouring on balance those with 25 to 50 acres in both the rice and cotton areas; 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 practices 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 neighbours.

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Appendix A

TABLE A-1

ESTIMATED NUMBER OF PRIVATE TUBEWELLS BY DISTRICTS, 1967 SIX SELECTED DISTRICTS IN THE FORMER PUNJAB

District	Estimated number of private tubewells in 1967	Per cent 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**

Source: [2, p. 11].

TABLE A-2

DISTRIBUTION OF OBSERVATIONS BY SIZE OF FARM, AREA, AND AVAILABILITY OF TUBEWELL WATER, 1967 SURVEY

Farm	Number of farms				
	Size of operating acreage				
	Below 12.5 acres	12.5—25.0 acres	25.1-50.0 acres	Above 50.0 acres	Total
Tubewell Farms					
Rice area	15	13	13	6	47
Cotton area	14	17	19	9	59
Nontubewell Farms					
Rice area	14	13	12	4	43
Cotton area	12	16	17	7	52

Note: The smaller number of observations included in nontubewell farms are due to deficiencies in survey response regarding the period before the installation of tubewells.

Source: Data collected by the 1967 Survey by the PIDE.