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ECONOMICS OF TECHNICAL CHANGE IN WHEAT PRODUCTION IN PUNJAB (INDIA)

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Economics of Technical Change in Wheat Production in Punjab (India)*

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There seems to be a consensus in the literature on the 'green revolution' that the spread since 1965 of high-yielding cereal varieties has ushered in an era of agricultural transformation in many parts of Asia. Fear of the Malthusian spectre[1] has been somewhat allayed and new hope for these countries generated. The realizable potential for greater agricultural output improves the prospects for sustained growth of these economies. The challenge facing policymakers and planners of these and other less developed countries is to convert the potential into a sustained basis for economic development and growth.

While the technological breakthrough in cereal production has obviously generated increased agricultural output and farm incomes, the distribution of gains seems not to be even. Larger land owners appear to be benefiting from the new technology much more than small farmers and laborers. This constitutes another challenge to the policymakers of these countries to design programs which will distribute the gains from the new agricultural technology more evenly.

The answers to these challenges are by no means easy to intuit. At the very least it requires an understanding of the nature and impact of the transformation that has already occurred or is under way. What we need is not a simple impressionistic assessment of this change but quantitative measures which can be usefully

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employed in applications of economic theory to develop effective policies.

Northwestern India and Pakistan have achieved significant increases in yields and output of wheat.[2] In this paper an attempt is made to determine empirically the parameters of this change in the Indian Punjab.[3] Also, we seek to explain the process of absorption of new wheat technology over the four year period 1967/68-1970/71, that is, the process of technical change. Specifically, we try to provide answers to the following set of questions: What is the nature of the production technology of the "New Wheat" compared to the "Old Wheat?"; i.e., is technical change neutral or non-neutral? What are the differences in the long-run cost functions of new and old wheats? What changes have occurred in the factor demand functions, particularly the labor demand function? And what is the magnitude of gains from adaptation of high-yielding wheat varieties? How did the new wheat production function and the long-run cost function behave over the four year period 1967/68 to 1970/71?

The pursuit of these objectives will also provide information on the existence of economies of scale in wheat production and enable us to explore its implications with respect to farm size adjustments.

I. Theoretical and Operational Framework

Two inter-related models were developed: a simple model based on the standard neoclassical production function, and a cost function model developed largely by Nerlove [30]. Neither model alone accomplishes all our objectives; each has shortcomings but their combined use enables us to accomplish what we want.

Let the production function for wheat be represented by:

$$Y = F(N,L,K) \tag{1}$$

where Y is physical rate of output and N, L and K are input rates of labor, land and capital services respectively, during a given period of production.

If we assume that the form of the production function is of the Cobb-Douglas type, (1) may be written:

(2) $$Y = A N^{\alpha_1} L^{\alpha_2} K^{\alpha_3} \exp(\delta_j + u)$$

where δ_j denotes the coefficient of the jth dummy variable designed to capture appropriate 'effects' and u is the random disturbance term independently distributed with zero mean and finite variance. The usual error term is broken up into two components, a measure δ of the neutral variations in efficiency[4] among farms and the residual term u. This enables us to identify neutral productivity differences among old and new varieties of wheat, maintaining the assumption that there are no non-neutral differences in the respective technologies. Because our objective is to discover the nature of differences among these technologies, the hypothesis that technical change is of the neutral type is empirically tested. This formulation also enables us to compare the production relation for new wheat for the four individual years. The model can be extended to more than three input variables and we do include fertilizer as a separate variable.

There are two questions on the choice of the Cobb-Douglas form. Firstly, does such a function represent the conditions of wheat production, reasonably well? Put differently the point is associated with substitution possibilities between different inputs: the Cobb-Douglas function implies a unitary elasticity of substitution between any pair of inputs and the question is whether it should be tested rather than assumed beforehand. Hayami [14], Hayami-Ruttan [15, pp. 102-107] and Yotopoulos, Lau and Somel [39] in their researches found the elasticity of substitution not to be significantly different from one. Following Kmenta [25] we estimated a CES production function using our data for the four year period (1967/68 to 1970/71) for new wheat. The results [37, Appendix II] indicate that we cannot reject the hypothesis that Cobb-Douglas form represents the data adequately.

Another property of the Cobb-Douglas function is both an advantage and a defect. The degree of returns to scale[5] is invariant with the level of output. This is valuable in itself. But it is not possible to ascertain if there are additional economies

of scale within the output range studied or to determine the sources of the economies of scale.

On the use of ordinary least-squares regression techniques for estimation of production models, there are numerous warnings in the literature. The problem is that in a production system the production function is not an isolated relation.[6] Data observations are generated by profit-maximizing (or cost-minimizing) considerations of the firm and thus output and input levels are simultaneously determined. The production function is only one of a system of simultaneous equations, and single equation estimates are in general biased and inconsistent.[7]

The production environment in the present study does not seem to be different from the specification requirements of the studies referred to in footnote 7. Our production function is thus well specified and we assume no problem of identification. We also develop a Cost Function Model, as an alternative approach, and include input prices which are exogeneously determined among the independent variables.

Another difficulty in production function studies is that some variables (management, for example) cannot be included in the analysis. Griliches [10] showed that in a Cobb-Douglas framework this imparts biases to the coefficients of included variables. We will discuss this point again in relation to the cost function estimates, where left out variables seem to be a serious problem.

To obtain estimates of long-run cost functions and to make direct comparisons of four-year shifts in the cost functions of old and new wheats, we use a cost function model first used by Nerlove [30, Chapter 6] with slight modifications. Let

(3) $C = wN + tL + iK$ be the total cost of production where

C = total production costs in rupees

w = hourly wage rate of labor

t = per acre rent of land for wheat

i = price of capital

N = labor input in hours

L = acres of land, and

K = capital input.

Minimization of costs (3) subject to the Cobb-Douglas production function (2) yields the following marginal productivity conditions:

(4) $$\frac{wN}{\alpha_1} = \frac{tL}{\alpha_2} = \frac{iK}{\alpha_3}$$

The derived input demand functions for N, L and K can be obtained by simultaneously solving the marginal productivity conditions (4) and the production function (2):

(5) $$N = \beta_1 \gamma^{\frac{1}{\gamma}} \frac{w^{\frac{\alpha_1}{\gamma}} t^{\frac{\alpha_2}{\gamma}} i^{\frac{\alpha_3}{\gamma}} e^{-(\frac{\delta+u}{\gamma})}}{w}$$

(6) $$L = \beta_2 \gamma^{\frac{1}{\gamma}} \frac{w^{\frac{\alpha_1}{\gamma}} t^{\frac{\alpha_2}{\gamma}} i^{\frac{\alpha_3}{\gamma}} e^{-(\frac{\delta+u}{\gamma})}}{t}$$

(7) $$K = \beta_3 \gamma^{\frac{1}{\gamma}} \frac{w^{\frac{\alpha_1}{\gamma}} t^{\frac{\alpha_2}{\gamma}} i^{\frac{\alpha_3}{\gamma}} e^{-(\frac{\delta+u}{\gamma})}}{i}$$

where $$\beta_j = \alpha_j (A\, \alpha_1^{\alpha_1} \alpha_2^{\alpha_2} \alpha_3^{\alpha_3})^{-\frac{1}{\gamma}} \qquad j = 1, 2, 3$$

and $$\gamma = \alpha_1 + \alpha_2 + \alpha_3.$$

The total cost function can now be obtained[8] by substituting (5), (6) and (7) for N, L and K respectively in the cost equation (3):

(8) $$C = \beta \gamma^{\frac{1}{\gamma}} w^{\frac{\alpha_1}{\gamma}} t^{\frac{\alpha_2}{\gamma}} i^{\frac{\alpha_3}{\gamma}} e^{-(\frac{\delta+u}{\gamma})}$$

where

$$\beta = \beta_1 + \beta_2 + \beta_3 = \gamma (A\, \alpha_1^{\alpha_1} \alpha_2^{\alpha_2} \alpha_3^{\alpha_3})^{-\frac{1}{\gamma}}$$

Let the cost function (8) be written in logarithms of the variables:

$$\ln C = \ln \beta + \frac{1}{\gamma} \ln Y + \frac{\alpha_1}{\gamma} \ln w + \frac{\alpha_2}{\gamma} \ln t + \frac{\alpha_3}{\gamma} \ln i - \frac{\delta}{\gamma} - \frac{u}{\gamma} \tag{9}$$

which forms the basic estimating equation for the cost model.

There are several points to be made about this model. The parameter γ provides a direct single estimate of returns to scale as a reciprocal of the coefficient of logarithm of Y, which is independent of the level of output and input prices. This is a considerable advantage. The invariance of γ with respect to output level does not allow us to ascertain whether the degree of returns to scale varies over different ranges of output.[9] This difficulty can, however, be oevercome by dividing the total observations into several groups and fitting separate functions, or by introducing $(\ln Y)^2$ as an additional term in model (9), and we use both techniques.

Secondly, the inclusion of input prices directly in the cost function helps us to obviate some usual problems with statistical estimation of long-run cost functions. We don't need to deflate cost figures cross-sectionally or over the four-year period studied. Unique correspondence between the empirically estimated cost function and the underlying production function is assured,[10] so that the parameters of the production function can easily be evaluated. Because all our independent variables in model (9) are exogenous its coefficients can appropriately be estimated by least squares, and we have no problem of identification.[11]

In (9) $(\frac{\delta}{\gamma})$ can be interpreted as coefficient(s) of the dummy variable(s) which can be introduced to compare neutral differences in cost functions of old and new wheats and over the four years studied.

For purposes of empirical estimation, model (9) has to be further amended. This is necessary because data on capital price i is not available for individual farms. We can write (9) as:

$$\ln C = \beta^* + \frac{1}{\gamma} \ln Y + \frac{\alpha_1}{\gamma} \ln w + \frac{\alpha_2}{\gamma} \ln t - \frac{\delta}{\gamma} - \frac{u}{\gamma} \tag{10}$$

where $$\beta^* = \ln \beta + \frac{\alpha_3}{\gamma} i.$$

Since $\gamma = \alpha_1 + \alpha_2 + \alpha_3$, α_3, the output elasticity with respect to capital input can be evaluated from this restriction and the estimates of γ, α_1 and α_2 from (10). The elimination of capital price i from the model, however, raises a specification problem [Griliches 10] and biases the coefficients of the remaining variables. Considering the likely imperfections[12] in the capital market, it can be argued a priori that output Y and capital price i are negatively correlated. This biases downward $(\frac{1}{\gamma})$ the estimated coefficient for logarithm of output, and biases upward γ the measure of returns to scale. This is a weakness in that the estimated output elasticities with respect to various inputs and the measure of returns to scale are not reliable estimates. The model does provide direct estimates of the percentage shifts in the cost functions of old and new wheats and of the yearly percentage shifts in the cost function of the new wheat.

2. Data Sources and the Variables

Farm level cross-sectional data for the four years 1967/68 to 1970/71 form the empirical basis of this study. The three different samples which form the data base have slightly different geographic coverage and differ somewhat in sample size and stratification purposes.

Ferozepur sample has a coverage of 150 farms, spread over 15 villages for the years 1967/68 and 1968/69 in the district of Ferozepur, which forms the southwestern part of Indian Punjab. This district has approximately 20 percent of the total area as well as 20 percent of the total cropped area of the state [7, pp. 10, 65]. Ferozepur wheat production in 1967/68 was 21.38 percent of the total wheat production in Punjab [24, p. 8]. This constitutes a fairly representative sample for the state.

The Directorate of Economics and Statistics (Ministry of Food and Agriculture, Government of India) collected data on these 150 farms for all farm enterprises for

the crop years 1967/68 to 1969/70, for "Studies in Economics of Farm Management in Ferozepur District of Punjab." Wheat data were only a part of these data and was copied from their records.[13] For another 304 farms, 1969/70 data were made available by the Economic Adviser to the Government of Punjab. These farms are spread over Punjab in 19 villages with 16 farms in each village. This sample is larger than Ferozepur Sample, both in terms of number of farms and in geographic coverage with a wider range in terms of land area and output per farm. As in the Ferozepur Sample, wheat data were only a part of the data collected for all engerprises. The basic purpose of this study was to study effects of tractor cultivation in Punjab farming. For future reference the sample will be called Tractor Cultivation Sample.

As suggested in [37, Appendix I] the state of Punjab is divided into five agro-climatic regions based on climate and soils, with three regions [(ii), (iii) and (iv)] more important for wheat production. A regionally stratified sample was designed to account for regional differences in wheat production.[14] A total of 128 farms were studied during the crop year 1970/71--46 in zone (ii), 31 in zone (iii) and 51 in zone (iv), with the number of farms in each zone roughly proportional to the wheat area. At each site, farm lists were prepared, so that randomly selected 10 percent of the farms would give the desired number.

The author was responsible for the design and supervision of data collection work for this sample. Whereas the data sheets and approach were similar to 'Cost Accounting Method,' used for the first two samples, the farm visits were not as intensive. Each farmer was contacted periodically--not daily--to record his wheat-related activities. This sample will be referred to as 'Regionally Stratified Sample.'

A brief summary of the coverage and data used is provided in Table I.

Table 1

Brief Summary of the Samples and Data

Sample	Geographic Coverage	No. of Villages Included	No. of Farms	Crop Year	Wheat Type	Observations Available
Ferozepur	District-Ferozepur	15	150	1967-68	New	105
				1967-68	Old	132
				1968-69	New	144
Tractor Cultivation	Punjab	19	304	1969-70	New	287
Regionally Stratified	Punjab	7	128	1970-71	New	128

The Variables

The variables used in this study are defined as follows:

Y = physical output of wheat measured in quintals per farm (including by-products.[15] By-products were converted into quintals of wheat by dividing the total value of by-products by wheat price.)

N = the labor input per farm used for wheat production measured in hours, and includes both family and hired labor. (Child and female labor was converted into man equivalents by treating 2 children (or women) equal to one man.)

L = the land input measured as acres of wheat grown per farm.

F = the current value in rupees of fertilizer and farm-produced manures per farm.

K = a measure of the flow of capital services going into wheat production per farm. (An hourly flow of services is derived for each durable input including capital in the form of livestock that the farm uses in wheat production. It includes depreciation charges, interest charges and operating expenses. Depreciation schedules are based on the specific life of each input, but interest costs are estimated at a uniform interest rate of 10 percent of annum.[16] The actual number of hours of use times the hourly flow of services of each durable input gives its total service flow.[17] Aggregation of these asset-specific service flows plus the seed costs yields a measure of the capital services.[18])

K_1 = the flow of total capital services less F i.e., $K_1 = K - F$, including animal power but not fertilizer.

w = the hourly wage rate of labor, obtained by dividing the total wage bill by total labor input N. (Total wage bill for labor includes payments to labor hired on daily wage basis, labor hired on annual contract basis and the imputed value of services of family labor.)

t = the average rental price of land per acre per farm, obtained by dividing the total rental value of land per farm by the wheat land per farm (L). (Total rental value of land services for wheat production per farm includes the actual rent paid for rented-in land in cash or share of the produce and the imputed rental value of owned land. For lands producing two crops during the year half of the annual rent is treated as the share of the wheat crop.

I = "price" of capital input.

P_f = price of fertilizer.

C = the total cost of wheat produced per farm in rupees. It is the sum of wage bill, total land rent, capital costs K_1 and fertilizer bill F.

3. Empirical Results and Their Interpretation: Old *Versus* New Wheats

The main objective is to evaluate the nature and magnitude of change in technology of wheat production from old to new wheats. For this purpose the production function in equation 2, and the cost function in equation 10 are used employing 1967/68 data from the Ferozepur Sample. Old wheat continued to be grown during the subsequent two years 1968/69 and 1969/70. Because the number of farms growing this wheat and the area planted to it had been substantially reduced, no meaningful comparative analysis was possible for these years.

Production Function Model

The results from the least-squares regressions linear in natural logarithms for equation 2 are presented in Table 2. The output elasticities with respect to all inputs have the right signs and have reasonable values. Three important conclusions come out of these results. First we compare the separate regressions I and II with the pooled regression IV, and separate regressions V and VI with the pooled regression VIII. Analysis of covariance gave F-ratios[19] of 0.27 with 3 and 228 degrees of freedom and 1.39 with 4 and 226 degrees of freedom, which are not significant at 90 percent level. Therefore we cannot reject the hypothesis that output elasticities with respect to various inputs are the same in separate regressions for old and new wheats, if we allow the constant terms in the two regressions to differ.

ESTIMATES OF PRODUCTION FUNCTION FOR WHEAT, 1967-68, PUNJAB, INDIA

Regression Number	Type of Wheat	Number of Observations	Constant	Coefficient of D^0	N	L	K or K_1	F	R^2	SEE[a/]	Returns to Scale	F-ratio[b/]
I	Old	131	-0.254 (0.585)		0.098 (0.082)	0.500 (0.086)	0.429 (0.093)		0.835	0.352	1.027	0.42
II	New	105	-0.330 (0.680)		0.086 (0.093)	0.503 (0.092)	0.482 (0.128)		0.943	0.395	1.071	6.38**
III	Pooled	236	-0.906 (0.419)		0.089 (0.062)	0.406 (0.056)	0.552 (0.073)		0.914	0.381	1.048	4.60*
IV	Pooled	236	-0.195 (0.446)	-0.219 (0.056)	0.099 (0.060)	0.511 (0.061)	0.449 (0.076)		0.919	0.370	1.059	7.00**
V	Old	131	1.096 (0.549)		0.209 (0.080)	0.623 (0.081)	0.060 (0.094)	0.092 (0.016)	0.849	0.337	0.984	0.19
VI	New	105	0.175 (0.625)		0.091 (0.091)	0.528 (0.091)	0.328 (0.110)	0.116 (0.045)	0.943	0.395	1.062	4.75*
VII	Pooled	236	0.350 (0.409)		0.173 (0.060)	0.531 (0.058)	0.213 (0.073)	0.108 (0.015)	0.918	0.373	1.025	1.20
VIII	Pooled	236	0.698 (0.415)	-0.186 (0.056)	0.163 (0.059)	0.593 (0.060)	0.195 (0.071)	0.088 (0.016)	0.921	0.365	1.039	3.20

Notes:
Regressions linear in logarithms are estimated by least squares.
Dependent variable is output of wheat Y, in physical units.
D^0 is a dummy variable with a value of one for 'old wheat' and zero otherwise.
N, L, K or K_1 and F are labor, land capital costs and fertilizer costs per farm, $K=K_1+F$. In regressions I to IV, K includes F.
Standard errors of coefficients are in parentheses.
*Significant at 95 percent level. **Significant at 99 percent level.
a/Standard errors of estimate are in natural logarithms of output of wheat measured in quintals.
b/F-ratio is calculated to test the hypothesis of constant returns to scale.
R^2 is the coefficient of determination adjusted for degrees of freedom.

Second, from regressions VIII and IV, it can be observed that intercept terms for old wheat are lower by 18.60 percent and 21.90 percent respectively, or the intercepts for new wheat are higher by 22.85 percent and 28.04 percent. This can be interpreted as a neutral upward shift in the wheat production function resulting from the introduction of the new wheat.

Third, when the model does not include fertilizer as a separate variable, mildly increasing returns to scale are indicated for new wheat, in regressions II and III as well as the pooled regression IV; for pooled regressions VII and VIII constant returns to scale are indicated. It may also be noted that the last mentioned two regressions indicate improvement relative to regressions III and IV, both in terms of the standard errors as well as the plausibility of the elasticity estimates. Including fertilizer as a separate input of production and use of an intercept-shifting dummy to capture the effects due to change in wheat type makes a slightly better specification. The finding of a neutral upward shift of the order of 22.85 to 28.04 percent from the introduction of new wheat is of greater importance. The magnitude of the shift is almost unprecedented[20] in the history of agricultural research effort. It is very valuable in terms of resource savings per unit of wheat and increased supplies of wheat. Later we evaluate the impact in terms of the downward shift in the long-run unit cost function.[21]

The findings that the shift in the production function is neutral and that constant returns to scale prevail, simplify quantification of the resulting shifts in the factor demand functions and their consequences. Next we take up input demand functions and later compare the marginal value products of various inputs for old and new wheat.

Input Demand Functions

The derived input demand functions were obtained by solving simultaneously the production function and the marginal productivity conditions. For the Cobb-Douglas case equations (5) to (7) were obtained as demand functions for N, L and K respectively, and the demand function for fertilizer can be obtained in the same way. For the case of constant returns to scale (γ the measure of returns to scale is equal to one), these demand functions should be written without γ. These functions can be evaluated on a per acre basis by using the per acre sample mean levels of output Y for old and new wheats and comparing their shifts.

For this purpose we ran a least-squares regression restricting the estimates to constant returns to scale. These results are presented in (11):

$$\text{(11)} \quad \ln (Y/L) = \underset{(.383)}{1.001} - \underset{(.055)}{.164D^0} + \underset{(.057)}{.139}\ln(N/L) + \underset{(.071)}{.173}\ln(K_1/L) + \underset{(.016)}{.088}\ln(F/L),^{22}$$

$$SEE^{23} = .367, \; R^2 = .370$$

where D^0 is a dummy variable with a value of one for old wheat and zero for new wheat. A 17.30 percent neutral upward shift of the production function for new wheat is indicated.

From (11) the production function estimates for new and old wheats can be written as:[24]

$$\text{(12)} \qquad Y = 2.718\, N^{.139}\, L^{.600}\, K_1^{.173}\, F^{.088}$$

$$\text{(13)} \qquad Y = 2.316\, N^{.139}\, L^{.600}\, K_1^{.173}\, F^{.088}$$

Equations (12) and (13) are the estimates obtained by requiring constant returns to scale in (all) the inputs of labor, land, capital (K_1) and fertilizer and the input elasticities in (12) and (13) differ slightly from the unrestricted estimates of regression VIII in Table 2. By substituting the production coefficients from (12) in demand functions (5) to (7) and a similar function for fertilizer, the input demand functions for N, L, K_1 and F by farms producing new wheat for the constant returns

to scale case are given by:

(14)
$$N = .152\ Y\ w^{-.861}\ t^{.600}\ i^{.173}\ p_f^{.088}$$
$$L = .656\ Y\ w^{.139}\ t^{-.400}\ i^{.173}\ p_f^{.088}$$
$$K_1 = .189\ Y\ w^{.139}\ t^{.600}\ i^{-.827}\ p_f^{.088}$$
$$F = .096\ Y\ w^{.139}\ t^{.600}\ i^{.173}\ p_f^{-.912}$$

By a similar substitution of production coefficients from (13) in demand functions (5) to (7) and a similar function for fertilizer, demand functions for N, L, K_1 and F by farms producing old wheat are given by

(15)
$$N = .178\ Y\ w^{-.861}\ t^{.600}\ i^{.173}\ p_f^{.088}$$
$$L = .770\ Y\ w^{.139}\ t^{-.400}\ i^{.173}\ p_f^{.088}$$
$$K_1 = .220\ Y\ w^{.139}\ t^{.600}\ i^{-.827}\ p_f^{.088}$$
$$F = .112\ Y\ w^{.139}\ t^{.600}\ i^{.173}\ p_f^{-.912}$$

If we divide both sides of the demand functions for N, K_1 and F in (14) and (15) by L, we get per acre demand functions. By substituting the sample mean output per acre in the righthand side and multiplying it by the respective sample mean prices[25] we find that these per acre demand functions for new wheat are higher by 25 percent than old wheat. This shift in the factor demand functions in wheat industry has important implications for factor markets and the labor absorptive capacity of 'green revolution'. By way of illustration we work out an example. The wheat area planted to new wheat in Punjab was 3.6 percent, 35.4 percent, 48.5 percent and 65.5 percent during the years 1966/67, 1967/68, 1968/69 and 1969/70 respectively [37, Appendix I]. If we assume a perfectly elastic labor supply, a 25 percent shift to the right of the labor demand function implies that labor absorption in wheat production in Punjab during these years increased by 0.9 percent (1966/67), 8.85 percent (1967/68), 12.13 percent (1968/69) and 16.38 percent (1969/70). It should be emphasized that these estimates pertain only to the expansion of labor

absorption in wheat production. Estimates of the extent to which employment opportunities increased in farming by increased multiple cropping (made possible by the shorter growing period of new wheats) and in other agriculture-related sectors of the economy do not seem to be feasible at this time. Some observers [Shaw, 35, page 52] feel that such indirect effects on expansion of employment perhaps exceed the direct effects. Thus, there seems to be substantial labor-absorptive capacity in the 'green revolution'.

As a matter of government policy, chemical fertilizer was supplied at a given price all over the state, and we can assume a perfectly elastic supply of chemical fertilizer. The shift of the per acre fertilizer demand function resulting from new wheats was the same as for labor. Increases in the use of other forms of capital would be expected, with their magnitude depending upon the supply elasticities of various forms of capital. The case of land is different. Due to the relatively inelastic supply of land, the increased land productivity that resulted from the introduction of new wheats became a windfall gain to the owners of farm land--a gain in the form of increased land values at almost no cost to the owners.[26] These gains were in addition to gains in net incomes that resulted from the new wheats. Gains from increased land values and the net income from the new wheats increase linearly with the amount of land owned and have increased existing inequalities of income distribution in rural Punjab in favor of larger land owners.

Two broad comments seem to follow from Table 3. First, the estimated marginal value product of land is considerably larger for new wheat and much above the sample's geometric mean value of land rent per acre. This increase in land productivity resulting from the introduction of high-yielding varieties of wheat was reflected in subsequent years in rising land values as pointed out above. Second, a seemingly unreasonable magnitude for the marginal product of fertilizer in the production of

Table 3

Average and Marginal Value Products for Different Inputs in the Production of Old and New Wheat, 1967/68, Punjab, India
(Calculated at geometric means)

Input	Geometric Means		Average Value Products		Marginal Value Products Using Output Elasticities From: Regression VIII (Table 2)		Regression IV (Table 2)		Geometric Mean Price Mean the Sample
	Old Wheat	New Wheat	Old Wheat	New Wheat	Old Wheat	New Wheat	Old Wheat	New Wheat	
	rupees per unit of input								
Labor (hrs)	1064.30	590.11	4.09	4.21	0.65	0.67	0.41	0.42	0.69[a]
Land (acres)	6.62	2.67	658.66	931.59	388.61	549.60	335.92	475.11	139.15[b]
Capital, K (Rs)	1313.40	820.72	3.31	3.03			1.49	1.36	
Capital, K_f (Rs)	1107.60	590.50	3.93	4.21	0.79	0.84			
Fertilizer (Rs)	100.48	184.93	43.39	13.45	3.91	1.18			
Output (quintals)	54.60	32.57							
Output price* (Rs/quintal)	79.86	76.37							

[a]Sample geometric mean wage rate per hour.
[b]Sample geometric mean land rent per acre.
*Sample arithmatic means.

old wheat--about three and a half times larger than new wheat--suggests the hypothesis of 'yield ceiling' for old wheats:[27] old Indian varieties of wheat which have tall-growing tender straw are susceptible to lodging under heavy fertilization and this characteristic works as a limiting factor for yields beyond a 'yield ceiling.' The observed high value for the marginal product of fertilizer in the production of old wheat is thus explained by the probable existence of a discontinuity in the marginal product curve for fertilizer. It should denote no irrationality on the part of producers in the use of fertilizer or for the possibility of increasing output of old wheat by increased fertilization.

Cost Function Model

In this section we make quantitative assessment of the nature and magnitude of shift in the long-run cost function of wheat. Because the cost function and the underlying Cobb-Douglas production function are related to each other by the duality theorem, we can also obtain input elasticities from the estimated cost function. Also we can examine the question of returns to scale. Least squares regression results separately for old and new wheats and for the pooled data for equation 10 are given in Table 4; the indirectly derived parameters of the production function are given in Table 5.

Estimates in Table 4 indicate that intercepts of old and new wheat cost functions differ by 18.40 percent. An analysis of covariance test comparing the separate regressions for old and new wheats (I and II) with the over-all regression IV yields an F-ratio of 0.79 with 3 and 228 degrees of freedom. This means that the two cost functions differ only in the intercepts and not in slopes: the introduction of high-yielding wheats has shifted the long-run unit cost function neutrally downward by 15.54 percent. During the year 1970/71 India produced about 21 million tons of wheat worth about 16 billion rupees nearly all of which was new wheat; this amount

TABLE 4.

ESTIMATES OF COST FUNCTION FOR WHEAT BASED ON EQUATION 2.10, 1967/68, PUNJAB, INDIA

Regression Number	Type of Wheat	Number of Observations	Constant	Coefficient of D^0	Coefficient of Y	Coefficient of w	Coefficient of t	R^2	SEE[a/]	Returns to Scale
I	Old	131	3.871 (0.361)		0.821 (0.031)	0.059 (0.090)	0.155 (0.057)	0.845	0.307	1.128*
II	New	105	3.907 (0.516)		0.868 (0.023)	0.118 (0.119)	0.089 (0.085)	0.943	0.358	1.152*
III	Pooled	236	3.764 (0.306)		0.872 (0.018)	0.077 (0.075)	0.126 (0.050)	0.918	0.342	1.146*
IV	Pooled	236	3.695 (0.296)	0.184 (0.044)	0.857 (0.017)	0.089 (0.072)	0.130 (0.048)	0.923	0.330	1.166*

Notes:
Regressions linear in logarithms are estimated by least squares. Dependent variable is total cost C of wheat in rupees per farm, D^0 is a dummy variable with a value of one for 'old wheat' and zero otherwise. Y, w and t are the output of wheat per farm in physical units, wage rate per hour and the rent of wheat land per acre respectively. The standard errors of coefficients are in parentheses.
a/ Standard errors of estimate are in natural logarithms of total cost of producing wheat per farm in rupees.
*Indicates that returns to scale are different from one at 95 percent level of significance.

Table 5

INPUT ELASTICITIES AND RETURNS TO SCALE DERIVED FROM ESTIMATES OF THE COST FUNCTION PRESENTED IN TABLE 4

Regression Number	Input Elasticities of Labor	Land	Capital (K)	Returns to Scale
I	0.072	0.189	0.957	1.128*
II	0.136	0.103	0.913	1.152*
III	0.088	0.144	0.914	1.146*
IV	0.105	0.152	0.909	1.166*

*Indicates that returns to scale are different from one at 99 percent level of significance.

of old wheat could have been produced only with 18.40 percent more resources.

The estimated coefficient $(\frac{\hat{\delta}}{\gamma})$ for the dummy variable D^0 is 0.184 for regression IV and the estimate for γ is 1.166. Thus $\hat{\delta}$ = 21.45 percent, which is a measure of the neutral upward shift in the production function.

Both for the separate and pooled regressions increasing returns to scale are indicated. But $(\frac{\hat{1}}{\gamma})$, the coefficient for log Y, could be biased downward since the model does not include the 'capital price'; on a priori considerations[28] this price may be negatively correlated with output, and returns to scale may be over-estimated.

The estimates of output elasticities with respect to land (Table 5) are implausibly low (and vice versa for capital) compared to the direct production function estimates. Again the left-out variable effect is probably the reason. The per acre land rent t and output per farm Y are positively correlated[29] and this implies a negative correlation between t and the left-out variable 'capital price.'

The estimated coefficients for log t in Table 4 and the derived output elasticities with respect to land (Table 5) are thus biased downward.

4. Empirical Results and their Interpretation: Production and Cost Relationships for New Wheat, 1967/68-1970/71

In this section we attempt to analyze the nature of the change in the new wheat production function and in the long-run cost function over the four year period 1967/68-1970/71, and to provide estimates of the new wheat production function. The basic tools for these analyses are (1) the production function in equation 2 and (2) the cost function in equation 10.

Production Function Model

Results of the least-squares estimates from equation 2 are summarized in Table 6. Regressions in Table 6 treat fertilizer as a separate factor of production in the specification of the production function. At a 95 percent level of significance mildly increasing returns to scale are indicated for the years 1967/68 and 1970/71. For these years a relatively large number of observations had output below the respective sample means, and these probably account for the mildly increasing returns.

In order to test the hypothesis of the equality between sets of production coefficients in the production functions for the years 1967/68, 1968/69, 1969/70, 1970/71, we compare the separate regressions I, II, III and IV with over-all regression V in Table 6. The calculated F-ratio is 5.30 with 15 and 636 degrees of freedom which is significant at the 99 percent level. Thus, the hypothesis of equality between the sets of coefficients in the four yearly regressions is rejected, indicating that the production function for the new wheat has been unstable over the four year period. It is, however, necessary to go a step further. In over-all regression VI each of the coefficients for all the three 'year dummy variables' has

TABLE 6

ESTIMATES OF PRODUCTION FUNCTION FOR NEW WHEAT, 1967/68 - 1970/71, PUNJAB, INDIA

Year	1967/68	1968/69	1969/70	1970/71	Over-all		
Regression Number	I	II	III	IV	V	VI	VII[a]
No. of Observations	105	136	287	128	656	656	656
Constant	0.175	0.678	1.064	-1.733	0.333	0.304	-2.549
	(0.625)	(0.898)	(0.305)	(0.564)	(0.230)	(0.253)	(0.092)
D_1						-0.298	-0.477
						(0.047)	(0.049)
D_2						-0.282	-0.462
						(0.044)	(0.046)
D_3						-0.171	-0.411
						(0.048)	(0.049)
Labor	0.091	0.198	0.113	0.473	0.209	0.190	0.194
	(0.091)	(0.146)	(.052)	(0.094)	(0.040)	(0.040)	(0.032)
Land	0.528	0.577	0.723	0.305	0.604	0.613	0.500
	(0.091)	(0.135)	(0.062)	(0.099)	(0.039)	(0.043)	(0.032)
Capital, K_1	0.328	0.108	0.127	0.173	0.099	0.161	0.244
	(0.110)	(0.127)	(0.051)	(0.072)	(0.015)	(0.039)	(0.035)
Fertilizer	0.116	0.110	0.031	0.110	0.082	0.066	0.068
	(0.044)	(0.033)	(0.018)	(0.032)	(0.016)	(0.014)	(0.014)
R^2	0.943	0.875	0.877	0.922	0.908	0.915	0.916
SEE[b]	0.395	0.405	0.324	0.255	0.359	0.347	0.343
Returns to scale	1.062	0.993	0.993	1.061	0.994	1.030	1.006
F-ratio[c]	4.75*	0.04	0.09	4.51*	0.23	2.50	0.15

Notes: Equations linear in logarithms are estimated by least squares.

Dependent variable is output of wheat in physical units.

D_i ($i = 1,2,3$) are the year dummies taking the value of one for 1968/69, 1969/70 and 1970/71 respectively and zero otherwise.

Standard errors of coefficients are in parentheses.

[a] The inputs for this regression are measured in value terms.

[b] Standard errors of estimate are in natural logarithms of wheat output measured in quintals.

[c] The calculated F-ratio is for testing the hypothesis of constant returns to scale.

*Indicates the F-ratio is significant at 95 percent level.

$\bar{R}^2$ is the coefficient of determination adjusted for degrees of freedom.

a negative sign and is significant at 99 percent level; the analysis of covariance comparing the separate yearly regressions with over-all regression VI (Table 6) gave F-ratio of 2.27 with 12 and 636 degrees of freedom which is significant at 95 percent level (but not 99 percent). That is, the hypothesis of equality between slope coefficients allowing the intercepts in yearly regressions to vary, is rejected less strongly. Thus, while we reject on statistical grounds the hypothesis of neutral variations in favor of non-neutral variations in the production function over the four year period, the evidence is not very stong. Unusually small standard errors for the coefficients of the 'year dummy variables' support the view that exogenous factors like weather and change (some deterioration)[30] in seed quality may account for the downward shift[31] in the years subsequent to 1967/68. Another explanation could be that during the year 1967/68 the new wheats were planted on the best available wheat lands and marginally inferior lands were added during the next two years. It seems reasonable that all three factors--adverse weather, deterioration of seed and addition of marginally inferior lands in production--may have contributed to a downward shift in the production function after 1967/68, but an assessment of their relative influences seems impossible.

We observe that the absolute size of the coefficient for the year 1970/71 is much smaller than the coefficients for 1968/69 and 1969/70, which means that the downward shift of the production function was to come extent reversed. The question is whether the downward movement was a temporary phenomenon or is a long-run technological regression in the production of new wheats. The problem seems to be worth investigation by wheat breeders and agronomists.

The introduction of year dummies into the model in regression VI improved the estimates slightly both in terms of the fit of the equations as well as the standard errors of the input elasticities which seem to be quite reasonable. For regression VII all inputs are measured in value terms. This resulted in lower standard errors

of all the coefficients and slightly better fit for the equation. One possible explanation for this could be that part of the quality adjustments for the inputs (in particular land) is taken care of by the value measures.

As pointed out earlier, statistical evidence points out (although not very strongly) that there have been some yearly changes in the output elasticities as well as in the efficiency parameters. It seems possible to argue that the 'year dummy variables' only partially captured the effects of seed quality, weather and land quality and that their remaining influence caused yearly changes in the output elasticities. It is not difficult to imagine that weather differences could cause differential increases in the rate of application of various inputs. The observed yearly differences in the behavior of output elasticities thus seem to be a reasonable or expected phenomenon. Subsequent evidence from the cost function model, (with exogenous independent variables) shows clearly that the yearly changes in the new wheat production function are neutral displacements of the efficiency parameter. We, therefore, maintain that the yearly differences in the new wheat production function were neutral in character, that is, the efficiency parameter in the production function changed but not the output elasticities.

There is an additional reason for maintaining this hypothesis. In agriculture weather is responsible for considerable variability in annual production. Application of least squares to individual farm observations for estimating the parameters of a Cobb-Douglas production function is an averaging process. The estimates obtained from this averaging process, using four years' data, should have better predictive value than those obtained from a single cross-section. For this reason estimates obtained from the four years' pooled data, particularly those employing value measures of inputs--regression VII in Table 6--are considered relatively better estimates. The consequences of the year-to-year movements in the production function on the cost function are traced in the next section where we use the cost function model.

Cost Function Model

The cost function Model 10 has several advantages over the production function model. It yields direct estimates of the long-run cost function, a single estimate of returns to scale, and the use of year dummies enables us to study yearly differences in the cost function. From this model, it is also possible to study whether the degree of returns to scale varies with the level of output. Since this model affords a single independent estimate of γ which is equal to the sum $\alpha_1 + \alpha_2 + \alpha_3$, the output elasticities for labor and land can be derived from the coefficients of logarithms of w and t respectively; and the coefficient for capital K can be obtained from this restriction. However, there is a serious weakness in this model. Omission of capital price biases the coefficients of the other variables, and the individual parameters are not accurately measured. In this section we explore these points by estimating this model. The results of least-squares regressions from equation 10 are summarized in Tables 7 and 8. The indirectly derived parameters of the production function from regression V (Table 7) and regression I (Table 8) are given in Table 9.

From Tables 7 and 8 we note that in all cases increasing returns to scale are indicated. The derived estimate of the output elasticity (Table 9) with respect to labor is quite comparable in magnitude to the direct production function estimates of regressions V, VI and VIII, Table 6. However, the elasticities with respect to land and capital have implausible magnitudes being too small for land and too large for capital. Our earlier reasoning (while discussing the results of the cost function model in the case of old and new wheats) is a logical explanation for these results. The omission of the price of capital from the cost function model biases the coefficient of logarithm of output $\frac{1}{\gamma}$ downward[32] and γ the measure of returns to scale upward. This also biases the coefficient of land price (as well as output elasticity with respect to land) downward.

TABLE 7

ESTIMATES OF THE COST FUNCTION FOR NEW WHEAT, 1967/68-1970/71, PUNJAB, INDIA

Regression Number	Year	No. of Observations	Inter-cept	Coefficients of Y	Coefficients of w	Coefficients of t	R^2	SEE[a]	Returns to Scale
I	1967/63	105	3.907 (0.516)	0.868 (0.023)	0.118 (0.119)	0.089 (0.085)	0.943	0.358	1.152*
II	1968/69	136	3.616 (0.635)	0.858 (0.029)	0.437 (0.127)	0.226 (0.104)	0.884	0.371	1.166*
III	1969/70	287	4.103 (0.305)	0.856 (0.019)	0.127 (0.079)	0.111 (0.051)	0.874	0.301	1.168*
IV	1970/71	128	4.800 (0.319)	0.910 (0.025)	0.244 (0.118)	0.046 (0.069)	0.937	0.219	1.099*
V	pooled	656	3.445 (0.188)	0.894 (0.011)	0.236 (0.051)	0.243 (0.035)	0.913	0.339	1.119*

Note: Regressions of logarithms of total cost (C) on logarithms of output (Y), wage rate (w) and per acre land rent (t) are estimated by least squares.

Standard errors of coefficients are in parentheses.

*Means that increasing returns to scale are indicated at 99 percent level of significance using F-ratio test.

a/ The standard errors of estimate are shown in natural logarithms of total costs measured in rupees.

TABLE 8

ESTIMATES OF THE COST FUNCTION FOR NEW WHEAT, 1967/68-1970/71, PUNJAB, INDIA

Regression Number	Inter-cept	Coefficients of D_1	D_2	D_3	ln Y	$(\ln Y)^2$	ln w	ln t	R^2	SEE[a]	Returns to Scale
I	3.879	0.402	0.416	0.327	0.865		0.211	0.121	0.926	0.313	1.156*
	(0.178)	(0.043)	(0.040)	(0.046)	(0.011)		(0.049)	(0.035)			
II A					0.852						1.175*
					(0.026)						
II B					0.860						1.162*
					(0.019)						
II	3.911	0.406	0.417	0.330			0.211	0.119	0.926	0.313	
	(0.190)	(0.044)	(0.040)	(0.046)			(0.050)	(0.035)			
II C					0.866						1.154*
					(0.016)						
II D					0.858						1.165*
					(0.014)						
III	3.815	0.396	0.410	0.321	0.899	-0.005	0.206	0.124	0.926	0.313	1.112*
	(0.196)	(0.044)	(0.040)	(0.046)	(0.044)	(0.006)	(0.050)	(0.035)			

Notes: Dependent variable was logarithm of total cost per farm.

Standard errors of coefficients are in parentheses.

*Means that increasing returns to scale are indicated at 99 percent level.

a/ Standard errors of estimate are shown in natural logarithms of total costs, measured in rupees.

TABLE 9

PARAMETERS OF THE COBB-DOUBLAS PRODUCTION FUNCTION DERIVED FROM COST FUNCTION ESTIMATES, 1967/68-1970/71, PUNJAB, INDIA

Parameter	Regression V Table 5.5	Regression I Table 5.6
δ_1		-0.465
δ_2		-0.481
δ_3		-0.378
α_1	0.264	0.244
α_2	0.272	0.140
α_3	0.583	0.772
Returns to Scale	1.119	1.156

Notes: δ_i (i = 1, 2, 3) are the implicit coefficients for the year dummy variables in the production function and are derived from $-\frac{\delta_i}{\gamma}$, the estimated coefficients for the year dummy variables for 1968/69, 1969/70 and 1970/71 respectively, and $\frac{1}{\gamma}$, the estimated coefficient for logarithm of output in the cost function, regression I, (Table 5.6). They indicate percentage change in the efficiency parameter of the production function relative to the year 1967/68.

α_i (i = 1, 2, 3) are the implicit elasticities of output with respect to labor, land and capital λ. They are derived from $\frac{1}{\gamma}$, $\frac{\alpha_1}{\gamma}$ and $\frac{\alpha_2}{\gamma}$, the estimated coefficients of logarithms of Y, w and t respectively in the cost function and the restriction

$$\gamma = \sum_{i=1}^{3} \alpha_i .$$

An analysis of covariance comparing separate regressions I, II, III and IV with the pooled regression V (Table 7) gives an F-ratio of 10.51 with 12 and 640 degrees of freedom which is significant at 99 percent level implying that there are significant differences in the four years' cost functions. But comparing separate regressions I, II, III, and IV (Table 7) with the pooled regression I (Table 8) which has the intercept-shifting year dummies in it, gives an F-ratio of 1.12 with 9 and 640 degrees of freedom, which is not significant at 90 percent level. On the basis of these tests, we conclude that the annual variations in the new-wheat cost function and in the underlying production function have been neutral in character, that is, the intercept terms of the logarithmic functions changed significantly from year to year but not the regression coefficients. Thus, the estimated coefficients of the dummy variables D_i ($i = 1, 2, 3$) for regressions I, II and III (Table 8) can be interpreted to represent percentage upward shifts in the yearly total cost functions relative to the year 1967/68 (at existing factor prices). These shifts are the combined result of decline in the efficiency parameter of the production function and a rise in the average level of input prices relative to 1967/68. The rupees per quintal costs calculated at the geometric means from each years' sample were 50.91 for 1967/68, 72.97 for 1968/69, 70.81 for 1969/70 and 63.41 for 1970/71. The derived estimates of δ_i ($i = 1, 2, 3$) from $-\frac{\delta_i}{\gamma}$ for regression I (Table 8) shown in Table 9 have negative signs and represent magnitudes in percentage terms by which the production function for years 1968/69, 1969/70 and 1970/71 was lower relative to 1967/68. These estimates correspond quite closely to those obtained from the Cobb-Douglas production function (Table 6).

In order to determine whether the degree of returns to scale varies with the level of output, two variants of the cost function in equation 10 were tried. In the first case, we divided the 656 observations into four equal groups of 164 observations each, based on the ascending order of output per farm. Then by using slope dummies for each

group, we allowed the coefficients of logarithms of output to vary across groups, while keeping the coefficients for logarithms of w and t and D_i (i = 1, 2, 3) equal in all groups. These estimates and the values of γ for the four groups (A, B, C, D) are presented in Table 8, where regression II is represented by groups IIA, IIB, IIC and IID. In this regression coefficients for logarithm of output (the reciprocals of these coefficients represent returns to scale) pertain to the output range represented by each individual group but the coefficients for the three dummy variables, for log w and log t are common to all four groups (IIA, IIB, IIC and IID). In order to test whether the coefficient for logarithm of output and hence γ (the measure of returns to scale) varied among the four groups, we compared regression II represented by groups IIA, IIB, IIC and IID with the over-all regression I (Table 8). Analysis of covariance test gives an F-ratio of 0.68 with 3 and 646 degrees of freedom which is not significant at 90 percent level. These results, therefore, support the hypothesis that the degree of returns to scale does not vary with the level of output in the range of output observed.

In the second variant of the cost function, the degree of returns to scale is treated as a continuous function of output instead of breaking the sample into groups, assuming that variations in returns to scale are only of the neutral type. If we let γ (Y) be of the form,

$$\gamma\ (Y) = \frac{1}{a_0 + a_1 \ln Y},$$

the cost function equation 10 can be written as:

$$(16) \qquad \ln C = b^* + a_0 \ln Y + a_1 (\ln Y)^2 + \frac{\alpha_1}{\gamma} \ln w + \frac{\alpha_2}{\gamma} \ln t - \frac{\delta}{\gamma} D_i - \frac{u}{\gamma}$$

In equation 16 the degree of returns to scale is increasing, invariant or decreasing with the level of output if $a_1 \lesseqgtr 0$. Results of applying least-squares to equation 16 are presented as regression III in Table 8. The coefficient a_1 in our estimates is not different from zero at 90 percent level of significance using two-tailed t test. Supported by our first test we conclude that the degree of returns

to scale does not vary with the level of output in the range of output observed. That is to say, there are no additional scale economies available from enlarging the size of wheat-producing farms in our sample. As to the size of these economies it has already been pointed out that the cost function model imparts an upward bias and that the estimates from the production function model indicate constant returns to scale.

5. Summary and Conclusions

We have attempted to give empirical content to the change in production technology of wheat resulting from the introduction of Mexican wheat varieties in Indian Punjab. The models are simple and represent applications of the standard neoclassical theory of cost and production. Empirical evidence is based on farm-level primary data--for the years 1967/68 to 1970/71--the scope of which covers almost the entire state of Punjab and which have been generated by careful record keeping.

The results indicate that the technical change has been approximately neutral--it has not been strongly biased in either a labor-saving or a capital-saving direction. It has been cost saving. Technical efficiency has increased by almost one-fourth and unit costs of production have declined by about 16 percent. The demand per acre for labor, fertilizer and capital inputs have increased by about 25 percent.

The results also indicate that the unit costs of production of new varieties started to rise after the growing season 1967/68. This was the result of a rise in the average level of input prices and some decline in the efficiency parameter of the production function. This decline may have been due to adverse weather, defective seed quality, addition of marginally inferior lands to new wheat production after 1967/68, or a continuous technological regression (genetic degeneration of seed) in the production of new wheat. The upward shifts in the long-run cost function relative to 1967/68 have been of the order of about 40 percent for 1968/69, 41 percent for

1969/70 and 32 percent for 1970/71.

The new wheat technology also appears to be neutral with respect to farm size. From the data used in this study there seems to be no strong evidence against the phenomenon of constant returns to scale in the production using new wheat varieties. We cannot argue against small farms on the grounds of economies of scale or that small farms did not benefit from the new wheat.

Footnotes

[1]For example Myrdal [29] considers India and some other densely populated areas of Asia as evidence of the Malthusian thesis. Also see Paddock and Paddock [31] for a dramatized view of famine possibilities and Cochrane [6] for an optimistic view.

[2]The Punjab farms are multi-enterprise farms. This study deals only with wheat, not all farm enterprises.

[3]See Sidhu [37, Chap. III and App. I] for a brief discussion of the Punjab Region of India and some of the problems which have a bearing on motivation for this research.

[4]Neutral variation in efficiency in this case means that only the constant A varies from farm to farm and not the output elasticities with respect to various inputs. An increase in the efficiency parameter A represents a neutral technological gain. See also Zellner et. al. [40] for a discussion of the neutral disembodied productivity differential.

[5]The degree of returns to scale for the Cobb-Douglas production function is equal to the sum of output elasticities with respect to all inputs.

[6]For this and other related problems see Walters [38] for a survey article on "Production and Cost Functions."

[7]Griliches [12], Mundlak and Hoch [28] and Zellner, Kmenta and Dreze [40], however, argue that because inputs in agriculture are largely predetermined because of a considerable lag in production and because error is largely weather determined, simultaneous equation bias will be small for well specified production functions.

[8]The procedure followed for this derivation is essentially that of Nerlove [30, Chapter 6]. Also see Heady and Dillon [17, pp. 59-64], Henderson and Quandt [18, Chapter 3] and Johnston [21, Chapter 2] for variants of this procedure.

[9]See Heady [16, pp. 364-91] for long-run cost possibilities in agriculture. He argues that agriculture is perhaps characterized by first falling, then constant over some range of output, but ultimately increasing, long-run average costs. For an

excellent discussion which explains the existence and observed wide range of firm sizes under increasing returns to scale see Lydall [27]. In his argument the existence of a falling long-run cost curve, instead of telling what is available to all potential firms, tells what may be available at each point along the curve to a firm which is already nearly at that point. In other words expansion to the next size requires learning and experience. His point is developed primarily for the nonagricultural sector where he assumes economies of scale to be pervasive. It should be equally applicable to the agricultural sector if in fact economies of scale exist in some output range.

[10]See Shephard [36] for the 'fundamental duality' between the cost and production functions. See also Samuelson [34, Chapter IV].

[11]Much, however, depends upon the reliability of input price data. To the extent interfarm price variations reflect input qualities rather than true price variations due to location and time, our estimates may be defective. This could be a more serious problem with land rent which may include a land quality component.

[12]The capital market does exhibit imperfections: long-period loans are not easily available to smaller and poorer farmers; transactions costs are independent of the loan amounts, and certain types of capital costs are indirectly subsidized for larger producers. Supply of electricity for irrigation purposes is a case in point. Electricity charges are at a fixed rate of approximately Rs 8.50 per month per horse power of the motor used and are thus independent of the electricity used. See G. S. Brar and H. S. Sandhu [4] for details of rate structure for different sizes of electric motors. Also see C. H. Hanumantha Rao [32] for the argument that farm machinery has been made artificially cheap through liberal import policy and through the extension of institutional credit for the purchase of tractors on unduly liberal terms.

[13]Data for 1969/70 from this sample were not available for this study.

[14]The agriclimatic zoning was done when Punjab and Haryana were one state and the three zones under consideration actually cover both the present States of Punjab and Haryana--extending from northwest to southeast. It is suggested that the sites selected for the Punjab investigation are reasonably representative of the counterpart zonal areas lying in Haryana State as well.

[15]The major by-product is wheat straw, which in chaffed form is fed to cattle. Sometimes sarson (an oilseed crop) is also grown mixed with wheat.

[16]A. S. Kanlon, S. S. Miglani and S. K. Mehta [24, p. 70] report that 68 percent of the amount borrowed in case of Ferozepur Sample for the year 1968/69 was at an interest rate of 9-10 percent per annum. The range of interest charges varied from 6.5 to 20 percent.

[17]For the Regionally Stratified Sample (1970/71), this procedure was used by the author himself. For Ferozepur Sample and Tractor Cultivation Sample, essentially the same procedure was employed.

[18]Unless the estimating models have the value of fertilizer F as a separate variable K also includes F.

[19]See Johnston [22, pp. 136, 137] and Chow [5] for an explanation of this test.

[20]Results reported in [37] from the profit function formulation, indicate this shift may be still larger.

[21]It would be possible to use these results--and subsequent results from the cost funtion--to compute a rate of return to the applied research effort incurred in India on adapting the high-yielding varieties of wheat. But we have not been able to obtain for this purpose the relevant data on the expenditures incurred.

[22]Figures in parentheses are the standard errors.

[23]Standard error of estimate is measured in natural logarithms of per acre output of wheat measured in quintals.

[24]The coefficient for land L is derived implicitly from estimates of (11). Per acre production function with four inputs can be written:

$$\frac{Y}{L} = A \left(\frac{N}{L}\right)^{\alpha_1} \left(\frac{K_1}{L}\right)^{\alpha_3} \left(\frac{F}{L}\right)^{\alpha_4} . \quad \text{Thus}$$

$Y = A N^{1} L^{(1-\alpha_1-\alpha_3-\alpha_4)} K_1^{\alpha_3} F^{\alpha_4}$ that is, coefficient for land $\alpha_2 = (1-\alpha_1-\alpha_3-\alpha_4)$.

[25]These sample means for the year 1967/68 are:

	New Wheat	Old Wheat
Output per acre (quintals):	13.00	8.50
Price per quintal (Rupees):	76.37	79.86

[26]See Robert W. Herdt and Willard W. Cochrane [19] for a perspective on capitalization of the gains of technological advance in the form of increased land values.

[27]See [37, Appendix Table 1.2].

[28]Note our earlier discussion on this point in footnote 12.

[29]The simple correlation coefficient is 0.395.

[30]During farm visits in 1970 and 1971 Punjab farmers generally complained of defective seed quality after 1967/68, that is, that seed did not perform as well during later years. I think mixing of lower quality seed with better seeds occurred at more than one level of seed distribution channel. During 1968/69, 1969/70 and 1970/71 crop years, weather was somewhat adverse relative to 1967/68.

[31]Because the observed shifts are downward, we seem to be involved in a terminological problem. Normally, the production function shifts due to neutral or non-neutral technical change would be expected to be upward. As used here, the word shift is intended to relate only to the stability of the new wheat production relationship during the four year period studied.

[32]Since, as has already been argued, the price of capital and the output of wheat may be negatively correlated.

References

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