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TECHNOLOGICAL CHANGE AND INPUT SUBSTITUTION POSSIBILITIES IN PAKISTAN'S AGRICULTURE

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This study examines how the use of new technologies has affected substitution among inputs and technological bias. The values of the pair-wise substitution elasticities and demand elasticities are determined by jointly estimating with IZEF, the parameters of the cost and share equations derived from a translog cost function. Time series regressions show that in the pre-Green Revolution period land and labour were strong substitutes for each other but they were weak substitutes for working capital. While the fixed capital was a weak substitute for land and working capital, it was a good substitute for labour. After the Green Revolution era, land and labour continued to be strong substitutes for each other but working capital and fixed capital turned strong complements and the former also became a good substitute for land and the latter a weak substitute for labour. Next, the pre-Green Revolution neutral technological bias with respect to fixed and working capital later led to land and labour savings. The results show that intensity of capital in domestic agriculture is on the increase and the dynamics of the new technological and not even the rising input prices have caused the technological bias observed in the analysis.

I. Introduction

Agricultural technologies have popularly been classified as mechanical technologies and biological technologies. Mechanical technologies relate generally to those technologies which are embodied in machines and appliances; such as tractors, tube-wells, threshers, diggers, combines, etc., used in performing different farm operations. By using power, these technologies reduce drudgery of human as well as animal labour work by facilitating substitution of power and machinery for it. Typically, mechanical technologies enable farmers to expedite farm operations and cultivate more land with some labour input and increase cropping intensity. Similarly, diffusion of these technologies results not only in higher cropping intensity but also in quick planting and harvesting of crops, and handling of output. Although,

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these technologies have a positive effect on cultivated area and cropping intensity but they do not necessarily increase crop yields.

Biochemical technologies, on the other hand, relate to new, more input responsive seed varieties, use of chemical fertilizer and controlled application of irrigation water. Application of these technologies, in general, induces substitution of labour and industrial inputs for land. Besides, these technologies increase crop yields.

Biological technologies have also been regarded as the cause and effect of the Green Revolution that occurred during the 1960s and 1970s in different countries of the world. In Pakistan, the Green Revolution started during the early 1960s, although some of the modern inputs were introduced in the late 1960s. The main ingredients (inputs) of the Green Revolution were identified as HYVs, fertilizers, pesticides, tractors and irrigation.

The issue of the adoption of mechanical technologies, particularly with respect to their impact on labour displacement, continues to be important. It has been argued that the adoption of capital-intensive techniques are ill-suited to the country's factor endowments as they not only create less job opportunities compared to labour-intensive technologies but also cause factor market distortions [Sharma (1991)]. Thus, there is a need to systematically analyze the possibilities of input substitution in Pakistans' domestic agriculture for relevant policy purposes. Theoretically, if the elasticity of substitution of inputs is large, a small reduction in the relative price of labour would lead to a rapid increase in employment. On the other hand, if it is low, the removal of distortions from the factor market will not have much effect on production techniques.

Thus, obviously in situations where labour is relatively scarce and fixed capital such as farm machinery is relatively abundant, increased use of mechanical technologies would be more profitable from society's perspective. Alternatively, in countries where land is relatively scarce and labour is abundant, increased application of biological technologies will be more profitable. Accordingly, in Pakistan, which is characterized by excess labour, biochemical technologies need to be given precedence over mechanical technologies, for promoting application of new technologies in agriculture.

Despite the obvious role of these technologies in production and employment, several questions about their real impact are yet to be answered. For example, biological technologies are labour-intensive but they also involve significant application of working capital in the form of fertilizer, pesticides, etc. As such, there is a need to have categorical answers to questions whether the biological technologies are labour-using or labour-saving and whether working capital is complementary to or a substitute for labour, for generating policy relevant information.

An analysis of input substitution possibilities through estimation of a production function may be undertaken before proceeding on to the application of new technologies. Production function techniques for analyzing farm production have undergone pronounced refinements over the years. Review of relevant literature shows that the earlier version of the Cobb-Douglas production function and its different versions like quadratic, transcendental, CES, multi-factor CES and VES and generalized production functions has been replaced from early 1970s onwards, by relatively more flexible production functions like translog production function for examining farmer production behavior. A number of research studies have estimated the elasticities of substitution, technological bias, returns to scale, etc., in agriculture in recent years by applying either a translog production function [Denny and Fuss (1977), Chan and Mountain (1983), Alderman (1984), Capalbo and Denny (1986)], or a translog cost function [Christensen, Jorgensen and Lau (1971), and (1973), Thrisk (1974), Binswanger (1974b); Moroney and Humphrey (1975), Nghiep (1979), Ray (1982), Sharma (1991), or a translog profit function [Humphrey and Moroney (1975), Sindhu and Baanante (1981), Antle (1984), Kumbhakar and Bhattacharyya (1992)].

In Pakistan, researchers have also examined the effect of new technologies on input substitution, technical efficiency, returns to scale, etc., by using different functional forms. For example, Aslam (1978) estimated technical efficiency and returns to scale by using Cobb-Douglas production function and Wizarat (1981) measured the contribution of technical change to the growth of agricultural value-added with growth accounting technique. Similarly, Khalji (1986) estimated input elasticities by analyzing an aggregate production function with the ordinary least squares method. A number of studies have also examined farm production by applying translog cost and profit function, [Parikh (1985), Ali and Parikh (1992), Chaudhary, Naqvi and Mufti (1997), Chaudhary, Khan and Naqvi (1998), and Chaudhary and Mufti (1999)]. Although, these studies make a contribution to the analysis of production behavior of Pakistani farmers, no study has yet analyzed the effect of modern technologies on input substitutions; to show whether or not the characteristics of farm technology and its biases have changed during the post-Green Revolution period.

II. Method of Analysis and Data Collection

We specified the following twice-differentiable aggregate production function for the agricultural sector of Pakistan:

$$Q = f(N, L, Fc, Wc. T)$$

Where,

Q = gross value of crop output,
N = land (total cultivated area),
Fc = fixed capital (tractors and tube-wells),
Wc = working capital (fertilizer, seeds and pesticides), and
T = Technological index (time variable, T, is used as a proxy for index).

The duality theory[1] states that cost and production functions are dual to each other under given regularity conditions and all the information underlying the technology is contained in both of them. Thus, the dual of the above mentioned production function is accordingly expressed below as a twice-differentiable cost function applied for this analysis.[2]

$$C = f(Q, PN, PL, PFc, PWc, T)$$

where,

Q = gross value of crop output,
PN = price of land,
PL = price of labour,
PFc = price of fixed capital,
PWc = working capital, and
T = technological index.

The analysis is based on the time-series data from 1947-48 to 1998-99. Data from different sources like Economic Survey, Agricultural Statistics, Statistical Year Books and 50 Years of Pakistan in Statistics were merged to create the required data set. Relevant data on gross value of crop output and cropped area were obtained from the Economic Survey of Pakistan. The total value of tractors was calculated by multiplying their number available from the Economic Survey and the Agricultural Statistics of Pakistan with their prices obtained from the Agricultural Development Bank of Pakistan. The total value of tube-wells was also computed similarly by multiplying their number given in the Agricultural Statistics of Pakistan by their prices reported in the Census of Agricultural Machinery. To ensure compatibility of the dependent and the independent variables, their base was converted to 1990-1991.

Wages of agricultural labour were obtained from Monthly Statistical Bulletins for the years 1963-64 to 1986-87 and from Chaudhry, Naqvi and Mufti (1997) for the remaining years of the study period. The total value of farm seeds, fertilizers and pesticides was derived for the study period by weighting the quantities of different varieties with relevant prices as reported in the Agricultural Statistics of Pakistan. The rental cost of irrigated and rain-fed areas of Punjab, as reported by Renkow (1993) was generalized for the whole of Pakistan and extrapolated for the years of the study after 1993.

[1] See, Diewert (1974), Baumal (1977), and Varian (1978).

[2] The Translog Cost Function is basically derived from Taylor's Theorem. The process of deriving a translog function is explained in detail in Christensen, Jorgenson and Lau (1971) and (1973), and Diewert (1974).

III. Estimation Procedure

The applied translog cost function may be written in its general form as follows:

$$LnC = \alpha_0 + \gamma_Q \ln Q + 0.5\gamma_{QQ}(\ln Q)^2 + \sum_i \alpha_i \ln(p_i) +$$

$$\sum_i \gamma_{iQ} \ln(Q)\ln(p_i) + 0.5\sum_i\sum_j \gamma_{ij} \ln(p_i)\ln(p_j) +$$

$$\alpha_t T + 0.5\alpha_{tt} T^2 + \sum_i \alpha_{it} \ln(p_i)T + \gamma_{Qt} ln(Q)T \quad (1)$$

i, j = N, L, Fc, Wc

where, $\gamma_{ij} = \gamma_{ji}$, which shows the symmetry constraint. Furthermore, a well-behaved production function must be homogenous of degree one in input price. This implies the following relationship among the parameters:

$$\sum_i \alpha_i = 1 \quad \sum_i \gamma_{iQ} = 0$$

$$\sum_i \gamma_{ij} = \sum_j \gamma_{ji} = \sum_i\sum_j \gamma_{ij} = 0 \quad (2)$$

The parameters of this function under restrictions of symmetry and homogeneity, are jointly used to estimate share equations, as follow:

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{\partial C}{\partial P_i} \bullet \frac{P_i}{C}$$

i = factor inputs.

By Shephard's Lemma, $(\partial C/\partial P_i) = X_i$. Substituting it in the above expression:

$$\frac{\partial \ln C}{\ln P_i} = \frac{P_i X_i}{C} = S_i$$

which is our share equation. Thus, from equation (1) the following implies:

$$\frac{\partial \ln C}{\partial \ln P_i} = S_i$$

$$S_i = \alpha_i + \sum_j \gamma_{ij} \ln p_j + \gamma_{iQ} \ln Q + \alpha_{iT} \ln T \quad (3)$$

i = factor inputs.

where $S_i = (iP_i/C)$ is the i[th] cost. Note that $\Sigma_i S_i = 1$.

Note that $\gamma_{ij} = (\partial S_i / \partial \ln P_j) \cdot \gamma_{ij})$, will be less than (greater than) zero if the $_i$th share decreases (increases) with the change of price of the jth factor. Thus, the $\gamma_{ij}s$ contain the same information as the familiar Allen partial elasticities of substitution, i.e., γ_{ij} is the change in the $_i$th factor share due to a change in the jth input price. Unlike the restrictions for linear homogeneity of the cost function, the monotonicity and curvature restrictions are not easily handled within the economic framework. This is because both involve inequality restrictions on the parameter set or share equations. As a result, the conventional approach has been to check the estimated model for these properties rather than imposing restrictions on estimation. Therefore, these properties must be checked locally.

A cost function is said to be monotonically increasing in price if:

$$C(Q, P_i) > C(Q, P_j)$$

where $P_i > P_j$.

It implies that $(\partial C/\partial P_j) > 0$. We can write this condition as:

$$\frac{\partial C}{\partial P_j} = \frac{\partial \ln C}{\partial \ln P_j} \cdot \frac{C}{P_j} > 0 \tag{4}$$

We know from above that $(\partial \ln C/\partial \ln P_j) = S_j$. Substituting this expression in equation (4) an equivalent expression is obtained as:

$$\frac{\partial C}{\partial P_j} = \frac{S_j C}{P_j} > 0 \tag{5}$$

It appears from equation (5) that monotonicity in price holds if and only if cost shares are positive. Since total cost (C) and factor price P_i are positive by definition, a necessary and sufficient condition for monotonicity in price is that the cost shares are greater than zero as shown below:

$$S_i = \frac{\partial \ln C}{\partial \ln Q} = \gamma_{QQ} \ln(Q) + \sum_i \gamma_{iQ} \ln(P_i) > 0 \tag{6}$$

The curvature condition for the cost function requires that the Hessian matrix, H, of the second order partial derivatives with respect to factor prices should be negative semi-definite. The symmetric Hessian matrix, H, has $\partial^2 C/\partial P^2_j$ as diagonal elements and $(\partial^2 C/\partial P_i \partial P_j)$ (i ≠ j) as off-diagonal elements.

It is to be further noted that:

$$\alpha iT = \partial S/\partial \ln T = \partial^2 \ln C/\partial \ln P_i \partial \ln T = \partial^2 \ln c/\partial \ln T \partial \ln P_i = \alpha T_i \tag{7}$$

The coefficient α_{iT} is the factor bias of technical change for the ith input. It gives the change in the rate of technical change, which corresponds to the change in the price of the ith input. The technological change is ith factor saving, neutral or according to equation (7), α_{iT} is strictly positive, zero or strictly negative, holding factor prices constant.

IV. Elasticity of Substitution

Allen partial elasticity of substitution, δ_{ij}, is the change in the ith factor share due to change in the jth input price [(as suggested by Binswanger (1974a)].

$$\sigma_{ij} = \frac{(\delta_{ij} + S_i S_j)}{S_i S_j} \tag{8a}$$

and

$$\sigma_{ii} = \frac{(\delta_{ii} + S^2{}_i - S_i)}{S^2{}_i} \tag{8b}$$

If $\sigma_{ij} > 0$ when $(i \neq j)$, then the input i and j are substitutes for each other. On the other hand, if $\sigma_{ij} < 0$, then i and j are complements.

The own elasticity of demand for input i with respect to its market price can be estimated as:

$$E_{ii} = \frac{S_i(S_i - 1) + \gamma_{ii}}{S_i} \tag{9}$$

The scale economies are defined as unity minus the elasticity of the total cost with respect to output as:

$$SE = \frac{(1 - \partial \ln C)}{\partial ln\, Q} \tag{10}$$

Scale economies are independent of factor prices if and only if the production function is homothetic. The production function can be restricted to be homothetic, only if the cost function can be written as a separable function in price and output. Following Christensen and Green (1976), the cost function equation (1) and share equation (3) is estimated jointly as a multivariate regression system by using the iterative Zellner Efficient (IZEF) method in the manner proposed by Bernt and Christensen (1973). This procedure is completed in two steps: First, it estimates the system with the least squares method and constructs a consistent estimate of a covariance matrix. Second, a new covariance matrix is constructed. This procedure continues to iterate from estimates of parameters till convergence is complete.

Since the cost shares satisfy the adding up restrictions, i.e., $Si = 1$, the error sums to zero. Because of this, the error covariance matrix of the system of share equations becomes singular. The SURE estimators require the inverse of the error covariance matrix for their determination. It will not exist for the sub-system of the share equations due to singularity. However, dropping one of the share equations resolves the problem of singularity. The dropped equation recovers its parameters with the help of adding up restrictions. Since the IZEF estimates converge to MLEs and the MLEs are unique, the IZEF estimates are invariant to which equation is dropped.

The translog cost function is estimated along with share equations for three time periods: 1947-48 to 1967-68 (pre-Green Revolution period), 1968-69 to 1998-99 (post- Green Revolution period) and the combined period from 1947-48 to 1998-99. A comparison of estimates of the function for the pre and post-Green Revolution periods enables us to know whether the characteristics of technological change and its biases have changed during the Green Revolution period.

V. Interpretation of Results

Regression coefficients of the translog cost function are presented along with corresponding t-values for the three periods in Tables 1 to 3. The results show that most of the estimated parameters for the entire study period and sub-periods are statistically significant at the 5 per cent level of significance. Before proceeding further, it must be realized that the validity of the coefficients depends on the satisfaction of the cost function to be a dual of the production function which depends on the fulfillment of the conditions of symmetry and linear homogeneity in prices, monotonicity and concavity. According to the results all these requirements are completely satisfied. Specifically, it has been found from the analysis that the factor shares evaluated at each observation were positive, which satisfies the condition of the monotonicity in prices. Next, as the elasticity of total cost with respect to output' at 0.1 was found to be positive, it led to the fulfillment of the condition of monotonicity in output. Further, since the principal minors of the Hessian matrix alternated in signs as stated in theory, the last condition of concavity of the production function was also satisfied.

As far as the homotheticity and homogeneity conditions of the cost function are concerned, according to Shepherd (1970) and, Denny and Fuss (1977), the cost function can be written as a separable function of factor prices and output. It is well known that all homogeneous functions are homothetic, while the converse is not true. The homotheticity condition of production function imposed on the cost function in the form of equation (3) is satisfied. The computed value of χ^2 was 19.56, which is greater than the critical value at 5 per cent level of significance. So we

TABLE 1

Estimated Coefficient of the Translog Cost Function
(Using Zellner's Seemingly Unrelated Procedure
with Symmetry and Cross Equation Restrictions)
Time Period I (1947-68)

Parameter	Estimates	t-statistics
α_{LT}	0.300	4.50*
α_{FT}	0.170	1.90**
α_{WT}	–0.190	–1.38
γ_{LQ}	–0.170	–3.40*
γ_{FQ}	0.080	3.30*
γ_{WQ}	0.060	2.70*
β_{LN}	–0.120	–35.30*
β_{FN}	–0.030	–6.10*
β_{WN}	–0.016	–3.70*
β_{LW}	0.210	0.18
β_{WF}	0.490	0.26
β_{LF}	0.010	–1.16
α_{L}	0.630	7.50*
α_{F}	–0.210	–1.85**
α_{W}	–0.230	–2.80*
α_{O}	18.100	1.70**
α_{T}	0.310	1.70**
α_{TT}	0.250	1.80**
γ_{Q}	–4.900	–1.10
γ_{QQ}	0.970	1.01
γ_{TQ}	–0.060	-1.60**
α_{N}	0.530	1.90*
β_{LL}	0.110	4.40*
β_{FF}	0.060	3.60*
β_{WW}	0.050	5.30*
β_{NN}	0.290	24.10*
γ_{NQ}	–0.050	–1.03
α_{NT}	–0.800	–3.40*
Log Likelihood Function	322.500	

*Significant at the 5 per cent level of significance. **Significant at the 10 per cent level of significance.
L = labour, N = land, FC = fixed capital, WC = working capital, T = technology, and, Q = output.
α, β, γ are parameters.
(subscripts) Indicate change in the former with respect to change in the latter.

TABLE 2

Estimated Coefficient of the Translog Cost Function
(Using Zellner's Seemingly Unrelated Procedure with Symmetry and Cross Equation Restrictions)
Time Period II (1969-99)

Parameter	Estimates	t-statistic
	ssss	
α_{LT}	–0.290	4.45*
α_{FT}	0.170	1.23
α_{WT}	0.260	–2.35*
γ_{LQ}	–0.050	–3.10*
γ_{FQ}	0.110	3.50*
γ_{WQ}	0.060	2.70*
β_{LN}	–0.120	–39.00*
β_{FN}	–0.060	–8.50*
β_{WN}	–0.015	-3.70*
β_{LW}	0.530	0.40
β_{WF}	0.140	0.67
β_{LF}	–0.900	–0.97
α_{L}	0.620	7.30*
α_{F}	–0.350	–1.90*
α_{W}	–0.230	–2.21*
α_{O}	19.200	3.40*
α_{T}	0.330	1.90*
α_{TT}	0.340	1.70
γ_{Q}	–5.700	–1.30
γ_{QQ}	1.200	1.30
γ_{TQ}	–0.060	–1.80**
α_{N}	0.070	3.30*
β_{LL}	0.170	2.80*
β_{FF}	0.590	0.67
β_{WW}	–0.540	1.90**
β_{NN}	–0.200	–2.60*
γ_{NQ}	–0.007	–0.80
α_{NT}	–0.700	4.27*
Log Likelihood Function	329.800	

*Significant at the 5 per cent level of significance. **Significant at the 10 per cent level of significance. (subscripts) Indicate change in the former with respect to change in the latter.

TABLE 3

Estimated Coefficient of the Translog Cost Function
(Using Zellner's Seemingly Unrelated Procedure with Symmetry and Cross Equation Restrictions)
Combined Time Period 1947-99

Parameter	Estimates	t-statistics
α_{LT}	–0.360	–1.80*
α_{FT}	0.790	0.40
α_{WT}	0.120	1.81**
γ_{LQ}	0.130	2.40*
γ_{FQ}	–0.150	–1.20
γ_{WQ}	–0.230	–15.00*
β_{LN}	–0.070	–11.00*
β_{FN}	–0.020	–4.00*
β_{WN}	–0.020	–4.10*
β_{LW}	–0.010	–4.30*
β_{WF}	0.030	1.10
β_{LF}	–0.130	–0.40
α_{L}	–0.190	–0.53
α_{F}	–0.310	–1.30
α_{W}	0.930	1.60**
α_{O}	33.900	1.70**
α_{T}	0.480	1.25
α_{TT}	0.330	1.10
γ_{Q}	–11.000	–1.20
γ_{QQ}	2.400	1.10
γ_{TQ}	–0.090	–1.10
α_{N}	0.900	3.30*
β_{LL}	0.180	2.40*
β_{FF}	0.090	0.93
β_{WW}	–0.710	1.80**
β_{NN}	–0.031	–2.80*
γ_{NQ}	–0.009	–3.90*
α_{NT}	–0.870	4.40*
Log Likelihood Function	394.750	

*Significant at the 5 per cent level of significance. **Significant at the 10 per cent level of significance. (subscripts) Indicate change in the former with respect to change in the latter.

reject the null hypothesis and conclude that the underling production is not homogenous. The rejection of homothetic assumption implies that there exists a bias in favour of certain inputs as the scale of production expands.

The coefficient of price output variable, σ_{iQ} can be used to study changes in input intensities as the level of output increases. It measures the change in cost share of input with respect to one per cent increase in output with prices of all other inputs increasing (decreasing) with the level of output. We found the intensity of fixed capital and working capital to be increasing while that of labour and land to be decreasing, with the level of output.

VI. Technological Change

The estimated translog cost function denoted by equation (1) allows the determination of technological bias. A technological change that shifts the cost function without changing the factor.shares is called a neutral technological change. If a technological change, on the other hand, shifts the cost function and also changes the factor shares under constant prices, it is called a biased technological change. To test whether the technological change has been neutral or biased, the log-likelihood ratio test is used. According to the results of this test the technological change has been neutral during the first time period, as shown by the computed value of test statistics of 8.1, which is less than its critical value of 9.45, at 5 per cent level of significance. However, technological bias did occur during the second and the third combined time period, as the computed value of the test statistics of 43.52 exceeded the critical value of 18.48 at the one per cent level of significance. These results are as expected because increase in the farm production during the first study period 1947-1968 came primarily from expansion in cultivated area in the country. New technologies had yet not been diffused at any appreciable scale, except for the last 5 to 6 years of this period. In this latter period the application of modern inputs took off and continued to increase in subsequent years causing a shift in the cost function.

A technological change can be factor-using or factor-saving, depending upon the sign of the estimated parameter (α_{iT}). The coefficient, α_{iT}, is the factor bias of technological change for a given input and gives the change in the rate of technological change due to a given change in the price of the i[th] input. More specifically, a technological change is factor-using, neutral, or factor-saving, when under constant prices the value of α_{iT} is positive, zero or negative, with factor prices held constant. On this basis, the technological change was neutral with respect to fixed capital in the first period but it was land-and-labour-saving in the second and neutral in the third period. However, it was working capital-using in both the second and third periods. The increase in productivity during the first period is largely attributable to new land brought under cultivation and personal management of farmers.

Technological change was neutral in the first period because the level of application of modern inputs was low in most years of this period and their contribution to productivity was felt only toward the end years of the first period when their application picked up. It may be realized that cultivation of HYVs of rice and wheat dominated domestic agriculture from 1969-70 onward. It corresponded to the strategy of increasing agricultural production by adopting yield-augmenting and land-saving technologies. More specifically, the cultivation of HYVs in those years was accompanied by increased application of chemical fertilizers and pesticides along with improvements in irrigation facilities. As such, increased use of these biological technologies turned out to be both land-and- labour-saving as well as labour-saving. This was due to the extensive use of biological technologies, which increased the productivity of land and also led it to be used more intensively; which, in turn, increased the productivity of labour, implying that biological technologies were also indirectly labor-saving. Since the productivity of land improved on increased application particularly of biological technologies and since fertilizers, pesticides and seed varieties (defined as constituting working capital), accounted for the dominant components of the package of those technologies; the technological change turned out as working capital-using during the post-Green Revolution period. The technological change in this period was neutral with respect to fixed capital because the increased use of farm technologies is known to have increased the cultivated area and not necessarily yield of crops. These results are consistent with results of earlier research. For example, Nghiep (1979) and Sharma (1991) reported technological change as labour-saving in Japanese and Korean agriculture, respectively. However, Zareef (1999) reported it to be land-saving in Pakistan.

What was the effect of input prices on technological bias in Pakistan's agriculture is interesting to know. While farm level prices of all input factors have increased constantly in Pakistan, prices of capital and chemical fertilizers have increased more rapidly. Specifically, prices of working capital and fixed capital have increased between 1950 and 1999 by 69 per cent and 7 per cent respectively, whereas average land and labour prices have increased only by 8 per cent and 10 per cent, respectively. How such increases in prices have created biases and substitution among inputs is discussed with the innovation hypothesis in view. According to Binswanger (1974b) this hypothesis emphasizes that "if innovation possibilities are neutral and factors prices are exogenous to the industry, then a factor saving bias should be associated with the rising factor price. On the other hand, if the innovation possibilities are not neutral, then it is possible that the factor rising bias is associated with a rise in the price of the corresponding factor."

It is argued that our results for the whole and the post-Green Revolution subperiod support the non-neutral innovation hypothesis. For example, it is found that technological innovations, not factor prices, accounted for most of the biases in domestic agriculture during the above mentioned periods. However, technological innovations were largely neutral during the pre-Green Revolution period in which input factor prices showed a modest rising trend. The situation of input factor prices changed markedly in the subsequent periods. The prices of both labour and working capital increased at an accelerated rate in the early seventies. Rising input factor prices could perhaps have made technological innovations capital-using during the post-Green Revolution period. Had innovation possibilities been neutral, labour would have been substituted for working capital in that period. Ordinarily, any price-induced bias is working capital-saving, not working capital-using. If the price induced biases are important, then the working capital using bias would have been even larger in the absence of a rise in working capital prices.

VII. Allen Elasticities of Substitution

The Allen elasticities of substitution and the direct price elasticities of factor inputs are derived from the coefficients of the jointly estimated translog cost function and share equations. Further, as suggested by Uzawa (1962) Allen partial and pair-wise elasticities of substitution are obtained by fitting, the coefficients of the Allen elasticities depicted in Tables 4 and 5 by equation (8a) and (8b). Theoretically, algebraic signs associated with the coefficients of partial elasticities indicate whether the given inputs are substitutes or complements of each other. For example, if $\sigma ij > 0$ when $(i \neq j)$, the given inputs are substitutes for each other; they are complements when it is less than zero. Further, inputs are defined as strong or weak substitutes or complements, depending on the statistical significance of the relevant coefficient of elasticity at the given, (say, 5 per cent) level of significance.

The pair-wise elasticities of substitution depicted in the above-mentioned tables, which are estimated at the sample mean level, show that land and labour were strong substitutes for each other, whereas working capital was a weak substitute for both land and labour in the pre-Green Revolution period. Relatively, low application level of working capital is the reason for its weak substitutability for land and labour. Fixed capital, while being a weak substitute for both land and working capital, was a good substitute for labour in this period. This is also consistent with farmers' response to conditions where labour is incapable of accomplishing the task. Farm machinery and other farming tools then serve as a natural substitute for labour.

In the second time period (1968 to 1999) considered for this analysis, land and labour were found to be strong substitutes while working capital and fixed capital were strong complements. During this period, working capital was a good substitute for land and labour, which is consistent with prior expectations. Furthermore, it was found that fixed capital was a weak substitute for land and labour during this post-Green Revolution period. For fixed capital to be a weak substitute for labour in an era of advanced technological innovations is difficult to defend. The only plausible reason for such an unexpected relationship of labour with fixed capital during the period of rapid diffusion of new technologies, is the dominance of large size farm machinery; which is not easy to substitute for labour, when majority of farms is small in a country. For the the post-Green Revolution period, the major finding compared to pre-Green Revolution period, is that working capital and fixed capital were strong complements of each other. This purports that both the biological and mechanical technologies witnessed simultaneous progress in their application during the post land reform period in the country.

For the whole sample period, all estimated values of $\sigma_{ij's}$ were associated with

TABLE 4

Allen's Elasticities of Substitution
Time Periods I, II and III

Elasticities	Estimates	t-statistics
	Time Period I: 1947-68	
σ_{NL}	1.14	4.60*
σ_{NF}	0.11	3.56*
σ_{NW}	0.38	5.71*
σ_{LF}	0.79	23.11*
σ_{LW}	0.46	–1.45
σ_{FW}	0.23	3.32*
	Time Period II: 1969-99	
σ_{NL}	1.10	12.48*
σ_{NF}	0.08	5.36*
σ_{NW}	0.74	4.37*
σ_{LF}	0.45	21.26*
σ_{LW}	0.76	–2.85*
σ_{FW}	–1.75	–1.89**
	Time Period II: 1947-99	
σ_{NL}	1.21	12.31*
σ_{NF}	0.06	4.12*
σ_{NW}	0.17	4.39*
σ_{LF}	0.32	20.83*
σ_{LW}	0.67	–2.81*
σ_{FW}	–1.18	–2.43*

*Significant at the 1 per cent level of significance,
**Significant at the 5 per cent level of significance.

theoretically valid signs and statistical significance at 5 per cent level of significance. In terms of their relationship to each other, land and labour were strong substitutes, whereas, working capital and fixed capital were strong complements. However, both fixed capital and working capital were weak substitutes for land throughout the entire period of this study. Also, working capital was a good substitute for fixed capital, it was a weak one for labour. As expected, the relationships between inputs observed for the whole period resemble more of those related to the post-Green Revolution period than the pre- Green Revolution period, because of the differences in the application of new technologies in the two periods.

TABLE 5

Own Price Elasticities of Demand
Time Period I, II and III

Elasticities	Estimates	t-statistics
	Time Period I: 1947-68	
E_{NN}	–0.57	–31.11*
E_{LL}	–0.62	–25.12*
E_{FF}	–0.09	–2.64*
E_{WW}	–0.24	–3.25*
	Time Period II: 1968-99	
E_{NN}	–0.58	–14.58*
E_{LL}	–0.62	–27.28*
E_{FF}	0.35	0.77
E_{WW}	–0.18	–1.71**
	Time Period III: 1947-99	
E_{NN}	–0.59	–17.93*
E_{LL}	–0.48	–16.51*
E_{FF}	0.24	3.15*
E_{WW}	–0.23	–0.88

*Significant at the 1 per cent level of significance,
**Significant at the 5 per cent level of significance.

VIII. Price Elasticities of Demand

The price elasticities of land, labour, working capital and fixed capital, as reported in Table 5, were found to be negative (less than one), and significant at 5 per cent level of significance for the first period. Except for the price elasticity of fixed capital, which is positive and significant at the 5 per cent level of significance, the price elasticities of the remaining three inputs were all negative (less than one), and significant at 5 per cent level of significance for the second as well as the combined period. In fact, all the estimated results of the own demand elasticities were consistent with the postulates of cost minimizing factor demand theory, except for fixed capital in the second and the combined period.

A comparison of input demand elasticities in Table 8 shows considerable variation in their values from country to country. As such, it is difficult to make any generalization about the values of elasticities of demand for input factors. The elasticities of the same inputs have been found to be low in some countries and high in others. The only generalization that can be made is that all studies included, show the demand for all inputs to be price inelastic.

One important aspect of the estimated elasticities is that own price elasticities of demand for all inputs, included in the analysis, are less than one. These results are in consonance with earlier results. However, own price elasticity of demand for labour is substantially lower than unity, which can be explained by the nature of its supply. Since most of the labour is provided by family members (for whom the opportunity cost is very low), there is typically little change in its use in response to changes in its usage rate.

All coefficients of own price elasticities are theoretically correct (negative), except for the fixed capital, which is positive. This inconsistency is not unique to this study. Earlier, Nghiep (1979) found positive price elasticities for labour and machinery (fixed capital) in Japan. Similarly Sharma (1991) also found the price elasticity of fixed capital in the agricultural sector of Korea, as positive. For Pakistan, Zareef (1999) and Mufti (1995) also found the price elasticities for land and tube-wells to be positive. It means that certain positive price elasticities for agricultural inputs are possible because the cost function may not be well behaved, and also, because the agricultural sector itself is treated as a production unit.

IX. Comparison with Earlier Studies

A comparison between the current study and the earlier studies, regarding the technological change, input substitution and input factor demand elasticities has been made in this section to highlight the relevance of the results. Since different studies have used different models and data sets, their results may not be directly comparable in quantitative terms. Nevertheless, comparing results of different studies in qualitative terms may still be useful. A reflection on the values of elasticities reported in Table 6 reveals that there is strong evidence of technological bias in favour of capital, chemicals and land and against labour in different countries of the world. Alternatively expressed, technological changes have tended to be labour-saving and capital-and-chemical-using in different countries of the world.

Similarly, comparison of elasticities in Table 7 show that fixed capital, fertilizer, and other purchased materials have generally been substituted for labour in varying degrees in different countries. Although, capital has been substituted for labour, relatively higher degree of substitution of fertilizer for labour has occurred in advanced countries of the world, especially USA. However, capital and land have been substituted for all other inputs in both USA and Canada. Based on the pair-wise elasticities of substitution, Lopez (1980) found considerable substitution of capital for labour in Japanese agriculture. Similarly, Sharma (1991) found a high degree of substitution between land and labour as well as a high degree of complementarily between working capital and fixed capital. The same holds for Pakistan's agriculture.

It may be stated that on the whole capital has tended to be substituted for labour and land for capital but chemicals have tended to be complements of both labour and capital in different countries. The results of the present analysis are consistent with earlier results, i.e., capital (mechanical technologies) and chemicals (biological technologies) were found to be complements of each other.

TABLE 6

Technological Change Biases for Selected Studies

	Biases			
Research studies	Labour[a]	Capital[b]	Fertilizer[c]	Land[d]
Present Study	Saving	Neutral	Using	Saving
Antle (1984)	Saving	Using	Using	Using
Binswanger (1974)	Saving	Using	Using	–
Brown and Christensen (1981)	Saving	Using	Saving	–
Sharma (1991)	Saving	Neutral	Using	Saving
Zareef (1999)	Saving	Using	Using	Saving

Note:
Blank spaces indicate that no estimated was reported.
[a]Defined as hired labour in Brown and Christensen.
[b]Defined as machinery in Antle and Binswanger
[c]Defined as materials in Brown and Christensen and as chemicals in Antle.
[d]Defined as fixed input in Brown and Christensen.

TABLE 7

Estimated Elasticities of Substitution from Various Function Models

Research Studies	Sample/ Model	Estimated Elasticities of Substitution					
		Labour[a]/ Capital[b]	Labour[a]/ Fertilizer[c]	Labour[a]/ Land[c]	Capital[b]/ Fertilizer[c]	Capital[b]/ Land[d]	Land[b] Fertilizer[c]
Present Study	Time Series: Pakistan:						
	(I) 1947-68	0.79	0.46	1.14	0.23	0.38	0.11
	(II) 1969-99	0.45	0.76	1.10	–1.75	0.08	0.74
	(III) 1947-99: Translog Cost Model.	0.32	0.67	1.21	–1.18	0.06	0.17
Binswanger (1974)	Pooled: annual, U. S., States, 1949, 1954, 1959, 1964; Translog Cost Model.	0.85	–1.62	0.20	–0.67	1.22	2.99
Brown and Christnsen (1981)	Time Series: annual, U. S., 1947-74; Restricted Translog Cost Model.	0.32	1.24	–	0.01	–	–
Lopez (1980)	Time Series: annual, Canada, 1946-77; Generalized Leomtief Cost Model.	1.78	0.88	0.11	1.56	0.23	0.99
Ray (1982)	Time series: annual, U. S., 1939-77; Translog Cost Model.	0.75	5.73	–	1.21	–	–
Sharma (1991)	Time Series: annual, Korean 1918-71; Translog Cost Model.	–0.28	–0.12	1.13	–1.25	0.01	0.14
Mufti (1995)	Survey Data; Translog Cost Model.	–0.19	0.35	–	0.98	–	–
Perveen (1994)	Time Series: Pakistan 1959-92, Nested CES Model.	–1.25	–1.0	–0.9	–1.29	–	–
Parikh	Survey Data Pakistan.	0.43	0.84	–	2.6	–	–

Note: Blank spaces indicate that no estimated was reported. [a]Defined as hired labour in Brown and Christensen and in Ray. [b]Defined as machinery in Binswanger as farm real estate and capital in Ray. [c]Defined as material in Lopez and in Brown and Christensen. [d]Defined as land and structures in Lopez. Treated as fixed input in Brown and Christensen.

TABLE 8

Summary of Own Price Elasticities of Demand

Research studies	Sample/model	Labour[a]	Capital[b]	Chemicals[c]	Land[d]
Present study	Time Series: annual, Pakistan				
	(I) 1947-68	–0.62	–0.09	–0.24	–0.57
	(II) 1969-99	–0.62	0.35	–0.18	–0.58
	(III) 1947-99	–0.48	0.24	–0.23	–0.59
Antle (1984)	Time Series: annual, U.S.,1910-46, 1947-78; Translog Profit Model, single output.	–0.01	–0.25	–0.25	–0.18
Binswanger (1974)	Pooled Time Series/cross-section: U.S. States, 1949, 1954, 1959, 1964; Translog Cost Model, single output.	–0.91	–1.09	–0.95	–0.34
Brown and Christensen[e] (1981)	Time Series: annual, U.S., 1947-74; Restricted Translog Cost Model, single output.	–0.66	–0.05	–0.20	–
Lopez (1980)	Time Series: annual, Canada, 1946-77; generalized Leontief Cost Model, single output.	–0.52	-0.35	–0.41	–0.42
Lopez (1984)	Cross-section: Canada, 1971; generalized Leontief Cost Model, multiple outputs.	–0.38	–1.48	–	–0.48
Ray (1982)	Time Series: annual, U. S., 1939-77; Translog Cost Model, multiple outputs.	–0.84	–0.43	0.40	–
Sharma (1991)	Time Series: annual, Korea. 1918-1971; Translog Cost Model.	–0.47	0.21	0.10	–0.40
Mufti (1995)	Survey Data Pakistan. Translog Cost Model.	–0.45	–0.96	–1.11	
Parikh	Survey[*] Data Pakistan. Translog Cost Model.				–

[a]Defined as hired labour in (1984), Brown and Christensen, and Ray, and hired and family labour in present study. [b]Defined as machinery in Antle and Binswanger as farm real estate and capital in Ray, and tubewells and tractors in present study. [c]Defined as fertilizer in Shumway, Lopez (1984), Binswanger, and Ray; defined as materials in Lopez (1980) and Brown and Christensen, and fertilizer and pesticides in present study. [d]Defined as land and structures in Lopez (1980, 1984). Treated as a fixed input in Brown and Christensen, Shumway, and Ray.

X. Conclusions

This study examines how input substitution proceeds with increased application of technological innovations along with technological bias and elasticities of input demand in Pakistan's agriculture, during the pre- and post-Green Revolution periods.

The process of technological change and the elasticities of substitution are examined by using the translog cost function for the three time periods: pre-Green Revolution period (1947–1968), post-Green Revolution period (1969-1999) and the aggregate period 1947–1999. As to the substitution possibilities between inputs during 1947 to 1968; land and labour were found as strong substitutes of each other, working capital as a weak substitute for land and labour, fixed capital as a weak substitute for both land and working capital, but a good substitute for labour. Similarly, land and labour were found to be strong substitute while working capital and fixed capital strong complements of each other during the post-Green Revolution period. During the same period, working capital was also found as a good substitute for land and labour and fixed capital as a weak substitute for land and labour. The major finding for the post-Green Revolution period as compared to the pre-Green Revolution period was that working capital and fixed capital were strong complements of each other, implying that both the biological and mechanical technologies progressed simultaneously in the country during the post-Green Revolution period.

This analysis shows that technological innovations in the first period of the analysis were neutral. However, in general, they were labour-saving and capital-using in the second and third periods. The study also shows that factor prices, despite their rapid overtime increase, did not account for any significant bias in the farm level application of technological innovations. Biases have occurred due to the technological innovations themselves. However, in Pakistan, despite a continuous rise in input prices, the technological changes over time have tended to be working capital-using.

During the combined period, land and labour have turned out to be strong substitutes for each other. In contrast, working capital and fixed capital were found as strong complements of each other but weak substitutes for land. However, working capital was a good substitute for labour but fixed capital was a weak one, for the study period.

The clearest conclusion of the analysis is that the increase in the use of fertilizer and pesticides was mainly due to innovation possibilities, their prices were only marginally influential in their increased application.

Except for the price elasticity of fixed capital, which is positive and significant at 5 per cent level of significance, elasticities of land, labour and working capital are negative; and significant at 5 per cent level of significance in all the time periods analyzed. As such, the demand for all these inputs has been price inelastic.

XI. Policy Implications

1. Since labour was found to be a substitute for all other inputs and since farm capital showed a decline in substitutability between labour and fixed capital, when substitution of labour for working capital increased, the rate of mechanization decreased while the intensity of the use of chemicals increased. This means that the expanded application of biological technologies encourages employment of farm labour.
2. The higher degree of substitution between labour and fertilizer, relative to the labour and capital was consistent with the observed decline in employment of labour force in agriculture. There is only limited scope for employment expansion in agriculture through increasing irrigation water supply, it leads to expansion in cropped area and higher cropping intensity.
3. Substitution possibilities among factor inputs are limited, therefore adjustment through factor prices will be difficult. Significant changes in the underlying technological structure will be required for increasing productivity and employment in the agricultural sector in Pakistan.

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