DECOMPOSITION ANALYSIS OF OUTPUT CHANGE UNDER NEW PRODUCTION TECHNOLOGY* IN WHEAT FARMING: SOME IMPLICATIONS TO RETURNS ON RESEARCH INVESTMENT

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STATEMENT OF THE PROBLEM

Total change in production and change in productivity¹ are two important dimensions of agricultural growth. In the State of Punjab the index (1961-62 = 100) of agricultural production increased to 115.18 in 1965-66 and to 222.13 in 1972-73. For wheat, the corresponding figures were 116.57 and 326.62.² Productivity index (1961-62 = 100) for wheat increased to 128.11 in 1966-67 and to 189.02 in 1970-71.³ Further, in Ferozepur district of Punjab, during the production year 1967-68, per acre output on a Mexican wheat (MW) farm was 40 per cent higher than that on a local wheat (LW) farm.⁴ These statistics indicate in broad terms substantial growth in output and productivity of the Punjab agricultural economy. The two dimensions of agricultural growth have been much more evident in the wheat farming sector. The marked output and productivity growth in the wheat farming sector has given rise to many interesting issues relating to growth. How much of the growth in output is due to technical change⁵ and how much of it is due to increased quantity of inputs?⁶ How much is the value of inputs saved as a result of technical change? What is the extra value of output obtained from a given quantity of resources? What are the implications of technology component of output growth to investment in agricultural research? This paper is an attempt to evaluate some of these issues. The specific objectives of the paper are to (1) decompose the total change in per acre wheat output with the introduction of new production technology into the proportion due to technical change and the proportion due to the change in the input level; (2) estimate the value of inputs saved with new

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* In this paper, we define new production technology to include production practices associated with Mexican wheat variety and old production technology is defined to include production practices associated with local wheat variety.

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1. The concept of productivity as used in this context is partial productivity ratio, that is the ratio of output to area. We do recognize the limitations associated with the partial productivity ratio. However, an increase in this ratio is crucial for a region where land is a limiting factor.


5. Technical change in a production function context refers to a change in the parameters of the production function. It can be viewed as an upward shift in the production function.

technology; and (3) to bring out the implications to investment in agricultural research.

These objectives are evaluated with cross-section input-output data on 105 Mexican wheat farms and 131 local wheat farms for the year 1967-68 from Ferozepur district of Punjab. The agency which collected these data was the Directorate of Economics and Statistics, Ministry of Food and Agriculture, Government of India. 7

ECONOMIC AND EMPIRICAL MODELS

The convenient economic model for decomposing total change in output is the production function. For any production function, the total change in output is brought about by shifts in the parameters that define the function itself and by changes in the volume of inputs. Since the data base of the present study is the same as the one used by Sidhu, 8 in our choice of functional form one important result obtained by him is kept in view. Following Kmenta, 9 Sidhu estimated the CES production function and found that the Cobb-Douglas framework would represent the data adequately. Further, he also found that constant returns to scale would characterize the input-output relationships prevailing in the Punjab wheat farm economy. In addition to these two results, Bisaliah, using Chow test, 10 finds that the parameters of the production function generated by the new production technology are different from those generated by old production technology. This implies a structural break in wheat production relations. This result supports our rationale for decomposing the total change in output. The two results obtained by Sidhu suggest that the decomposition analysis could be undertaken with Cobb-Douglas per acre production function.

In logarithmic form, Cobb-Douglas production function for local wheat is:

\[ \log Y_1 = \log A_1 + a_1 \log N_1 + b_1 \log F_1 + C_1 \log K_1 + U_1 \ldots \ldots \ldots (1) \]

where

- \( Y_1 \) = wheat output in quintals per acre,
- \( N_1 \) = per acre labour input measured in hours,
- \( F_1 \) = value of fertilizer and farmyard manure measured in rupees per acre,
- \( K_1 \) = value of capital services measured in rupees per acre. 11

7. On details of methodology followed in collecting these data, see S.S. Sidhu: Economics of Technical Change in Wheat Production in Punjab (India), Ph.D. Dissertation, University of Minnesota, St. Paul, U.S.A., 1972, Chapter III and Bisaliah: op. cit., Chapter II.

8. Ibid.


11. Capital variable includes depreciation charges calculated by straight line method, interest expenses, operating expenses of physical capital, value of irrigation expenses, bullock labour charges and value of seed—all measured in rupees.
A_1 is the scale parameter, and a_1, b_1 and C_1 denote output elasticities of the respective inputs; U_1 is a random disturbance term independently distributed with zero mean and finite variance.

Per acre production function for Mexican wheat is:

\[ \log Y_2 = \log A_2 + a_2 \log N_2 + b_2 \log F_2 + C_2 \log K_2 + U_2 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2) \]

Definitions of variables and parameters in (2) are the same as in (1).

Taking differences between (2) and (1), and adding some terms and subtracting the same terms:

\[ \log Y_2 - \log Y_1 = (\log A_2 - \log A_1) + (a_2 \log N_2 - a_1 \log N_1) + (b_2 \log F_2 - b_1 \log F_1) + (c_2 \log K_2 - c_1 \log K_1) + (U_2 - U_1) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3) \]

Rearranging terms in (3):

\[ \log Y_2 - \log Y_1 = \log \left( \frac{A_2}{A_1} \right) + [(a_2 - a_1) \log N_1 + (b_2 - b_1) \log F_1 + (C_2 - C_1) \log K_1] + [a_2 (\log N_2 - \log N_1) + b_2 (\log F_2 - \log F_1) + C_2 (\log K_2 - \log K_1)] + [U_2 - U_1] \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4) \]

Equation (4) can also be re-written as:

\[ \log \left( \frac{Y_2}{Y_1} \right) = \log \left[ \frac{A_2}{A_1} \right] + [(a_2 - a_1) \log N_1 + (b_2 - b_1) \log F_1 + (C_2 - C_1) \log K_1] + [a_2 \log \left( \frac{N_2}{N_1} \right) + b_2 \log \left( \frac{F_2}{F_1} \right) + C_2 \log \left( \frac{K_2}{K_1} \right)] + [U_2 - U_1] \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (5) \]

The decomposition equation (5) involves decomposing the natural logarithm of the ratio of 'new' output to 'old.' It is approximately a measure of percentage change in output with the introduction of new technology.\(^{12}\) The first bracketed expression on the left hand side is a measure of percentage change in output due to shift in scale parameter (A) of the production function;

\[^{12}\] \[ \log \left( \frac{Y_2}{Y_1} \right) = \log (1+X) \cong X \text{ for } |x| < 1 \]

where x is a percentage change in output; it is approximately a percentage change because the higher order terms in a Taylor Expansion are discarded.
the second bracketed expression, the sum of the arithmetic changes in output elasticities each weighted by the logarithm of the volume of that input used, is a measure of change in output due to shifts in slope parameters (output elasticities) of the production function; the third bracketed expression is the sum of the logarithms of the ratio, for each input, of ‘new’ to ‘old’ input, each weighted by the output elasticity of that input; this expression is a measure of change in output due to changes in the per acre quantities of labour, fertilizer and capital used given the output elasticities of these inputs under new production technology.

EMPirical RESULTS

With decomposition equation (5), using the values of production parameters (Appendix Table 1) and the input levels (Appendix Table 2), we have decomposed the total change in per acre wheat output with the introduction of new technology. The results are presented in Table I. Per acre production of wheat with Mexican variety was about 40 per cent higher than that with local variety. How much of this increased output is due to technical change and how much of it is due to change in the input levels?

Table I—Decomposition Analysis of Total Change in Per Acre Wheat Output Between New and Old Production Technology

<table>
<thead>
<tr>
<th>Item</th>
<th>Percentage attributable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total change in measured output</td>
<td>40.20</td>
</tr>
<tr>
<td>Sources of change</td>
<td></td>
</tr>
<tr>
<td>1. Technical change</td>
<td>15.00</td>
</tr>
<tr>
<td>2. Change in inputs:</td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td>2.10</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>15.10</td>
</tr>
<tr>
<td>Capital</td>
<td>8.30</td>
</tr>
<tr>
<td>Total due to input change</td>
<td>25.50</td>
</tr>
<tr>
<td>Total due to all sources</td>
<td>40.50</td>
</tr>
</tbody>
</table>

* Parametric values for computing these percentages are drawn from Tables 1 and 2 in Appendix.

First, the contribution of technical change to total change in output is estimated to be 15 per cent. This value is obtained by adding the values of the first and second bracketed expressions on the right hand side of equation (5). Technical change affects the sources of output growth by shifting the values of scale and slope parameters of the production function. With the same level of per acre inputs of labour ($N_1$), fertilizer ($F_1$) and capital ($K_1$), 15 per cent more output could be obtained with Mexican wheat. In fact,
an essential ingredient of technical change is a shift in the production function such that a larger output is obtained from a given level of inputs.

Second, an increased use of labour, fertilizer and capital per acre under new production technology has contributed about 25.5 per cent of the increased output. To the estimated 25.5 per cent contribution, the contribution of fertilizer (15 per cent) is the highest, followed by capital (8 per cent) and labour (2 per cent). The contributions of fertilizer and capital have far-reaching implications for the growth promoting interactions between agriculture and industry.

**Some Implications to Returns on Research Investment**

The basic result which we have obtained with the decomposition analysis is that with the same level of per acre inputs of labour, fertilizer and capital, 15 per cent more output could be obtained with new production technology. This is obviously in conformity with the hypothesis that technical change is a major source of output growth in agriculture. However, as argued by Schultz, technical change is not a “manna from heaven.” Resources must be devoted for that and we ought to know the costs of and returns to producing new technology. Basically, there are three quantitative methods of evaluation of returns to investment in agricultural research: (1) Value of Inputs Saved Approach, (2) Consumer Surplus Approach, and (3) Marginal Product Approach.

Given the nature of data, we propose to work with the value of inputs saved approach. Before doing so, a brief reference to the other two methods is in order. In the consumer surplus approach, the extra value of output obtained from a given quantity of resource is estimated. Using cash-flow technique with annual research costs as outflows and annual value of consumer surplus as inflows, the rate of return to research investment is computed. With

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marginal product approach, one can compute directly the marginal product of research from the production function. But these marginal products cannot be interpreted as marginal rates of return unless the returns are forthcoming in the same year when the research investment is made. A substantial lag between research input and output is generally expected.

With the value of inputs saved approach, we estimate the resources required to produce the per acre new technology level of output by old technology. The difference between this figure and the resources actually used to produce the new technology level of output represents the value of input saved because of the higher level of efficiency due to new technology. To estimate the value of resources saved with the introduction of new technology, we formulate the following expression:

Let:

\[ Y_{NT} = \text{per acre output with new technology}, \]
\[ Y_{OT} = \text{per acre output with old technology}, \]
\[ R_{NT} = \text{value of labour, fertilizer and capital inputs used in producing } Y_{NT}, \]
\[ R_{OT} = \text{value of labour, fertilizer and capital inputs required to produce } Y_{NT} \text{ with old technology}, \]
\[ r = \text{percentage increase in output per acre under new technology with the old technology volume of labour, fertilizer and capital inputs per acre}, \]
\[ S_{R} = \text{value of per acre labour, fertilizer and capital inputs saved to produce } Y_{NT} \text{ with new technology}. \]

Therefore:

\[ R_{OT} = \left(1 + \frac{r}{100}\right) R_{NT} \] ................. (6)
\[ S_{R} = \left(\frac{r}{100}\right) R_{NT} \] ................. (7)

The results on the value of inputs saved are shown in Table II. As shown in the table, the value of additional resources required to produce the new technology level of output \( Y_{NT} \) by old technology comes to Rs. 67. In the absence of new technology, a farm-firm in Ferozepur district would have required additional resources valued at Rs. 67 per acre to produce the new technology level of output during the year 1967-68. This magnitude of resource saving has been due to an upward shift in the production function or a downward shift in the unit cost function with the introduction of new technology.19

19. Cost function and the underlying Cobb-Douglas production function are related to each other by the duality theorem. In fact, Sidhu: op. cit., has estimated that the unit cost function has shifted downwards in the order of 15.54 per cent.
### Table II—Value of Inputs Saved due to New Technology of Wheat Production during 1967-68

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RNT</td>
<td>Rs. 446.50</td>
</tr>
<tr>
<td>ROT</td>
<td>Rs. 513.50</td>
</tr>
<tr>
<td>r</td>
<td>Rs. 67.00</td>
</tr>
</tbody>
</table>

**Value of inputs saved (Sr) per acre in Ferozepur district**

**Total value of inputs saved**

\[
\left( \sum_{i=1}^{n} S_R \right) \text{ in Punjab State}^2 \quad \text{Rs. 10.60 crores}
\]

**Total value of inputs saved**

\[
\left( \sum_{i=1}^{m} S_R \right) \text{ in India}^3 \quad \text{Rs. 48.70 crores}
\]

**Notes:**
1. The value of RNT is obtained by adding per acre expenses on labour, fertilizer and capital inputs. Labour bill is obtained by multiplying total man-hours given in Appendix Table 2 by the sample mean hourly wage rate of Rs. 0.69; value of r is drawn from Table 1; ROT is computed by using the expression (6).
2. Value of \( \sum_{i=1}^{n} S_R \) is obtained with Sr Rs. 67.00 and \( n = 15,78,330 \) acres under Mexican wheat in Punjab during 1967-68.
3. Value of \( \sum_{i=1}^{m} S_R \) is obtained with Sr Rs. 67.00 and \( m = 72,69,210 \) acres under Mexican wheat in India during 1967-68.

For the entire State of Punjab, the total value of resources saved is estimated to be about Rs. 10.6 crores. For all-India, this value comes to Rs. 48.7 crores for the year 1967-68. Our estimates of the value of resources saved for Punjab State as well as for India need to be qualified. Since the production function parameters, the input levels, and the input prices cannot be assumed to be the same either throughout the State of Punjab or throughout India, the bias in our estimates is quite obvious.

An alternative way of evaluation of the returns to research investment is to estimate the quantity of extra output obtained with new technology using the old technology volume of inputs. We formulate the following expression for this purpose:

Let: \( \triangle Y = Y_{NT} - Y_{OT} = \text{change in output per acre in quintals} \)

\[ r = \text{the same as defined earlier} \]

\( (\triangle Y)(r) = \text{quantity of extra output due to technical change alone} \)
The results obtained with this approach are presented in Table III.

**Table III—Quantity of Extra Output Per Acre under New Technology with Old Technology Level of Inputs during 1967-68**

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>YNT</td>
<td>12.32 (quintals)</td>
</tr>
<tr>
<td>YOT</td>
<td>8.24 (quintals)</td>
</tr>
<tr>
<td>ΔY</td>
<td>4.08 (quintals)</td>
</tr>
<tr>
<td>r</td>
<td>0.15</td>
</tr>
<tr>
<td>(ΔY) (r)</td>
<td>0.61 (quintals)</td>
</tr>
</tbody>
</table>

Quantity of extra output for the State of Punjab 96,278 (tonnes)

Quantity of extra output for all-India 4,43,422 (tonnes)

During the year 1967-68, the quantity of extra wheat output accrued to a farm-firm in Ferozepur district with no additional cost to the firm on resources comes to 61 kg. per acre. The total quantity of extra output with no cost comes to 96,278 tonnes for Punjab and to 4,43,422 tonnes for India as a whole during the same year.

We have estimated the value of resources saved and the quantity of extra output produced for the year 1967-68, when only 35.4 per cent of the total wheat area in Punjab and 20.1 per cent of the total wheat area in India was under new technology. By 1973-74 the entire wheat area of about 24 lakh hectares in Punjab and about 109 lakh hectares (57.2 per cent of the total wheat area) in India were under new technology. To estimate the value of resources saved and the quantity of extra output produced for each year, changes in the production function parameters, input-output levels and input prices need to be taken into account.

We recall that the estimated value of inputs saved per acre with new technology comes to Rs. 67. If we compare this annual value of inputs saved and the annual expenditure on wheat research, that is a measure of return to investment in research. Since we don’t have the data on annual expenditure on wheat research, what we have estimated is only a gross return to research investment. However, to give sole credit for inputs saved to research ignoring extension and investment in education, both general and vocational, is to impute a higher return to research than is legitimate.

20. Note that this is the quantity of extra output produced under new technology with old technology level of inputs.
Table 1—Per Acre Production Function Estimates for Mexican and Local Wheat

<table>
<thead>
<tr>
<th>Sample</th>
<th>Number of observations</th>
<th>Variables</th>
<th>Elasticity of output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967-68 (Mexican wheat)</td>
<td>105</td>
<td>$A_2$ (constant)</td>
<td>1.320</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L_2$</td>
<td>0.568</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$N_2$</td>
<td>0.065</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_2$</td>
<td>0.092</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$K_2$</td>
<td>0.275</td>
</tr>
<tr>
<td>1967-68 (Local wheat)</td>
<td>131</td>
<td>$A_1$ (constant)</td>
<td>1.530</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L_1$</td>
<td>0.626</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$N_1$</td>
<td>0.216</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_1$</td>
<td>0.091</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$K_1$</td>
<td>0.067</td>
</tr>
</tbody>
</table>

$R^2 = 0.16$ for Mexican wheat, $R^2 = 0.27$ for Local wheat

Notes: 1. Regressions linear in natural logarithms are estimated by least squares, restriction of estimates to constant returns to scale. Elasticity of output for land is obtained by the homogeneity of degree one constraint as follows:

$$\frac{Y}{L} = A \left( \frac{N}{L} \right)^a \left( \frac{F}{L} \right)^b \left( \frac{K}{L} \right)^c$$

$$Y = A \ L^{1-a-b-c} \ N^a \ F^b \ K^c$$

Output elasticity for land is: $(1-a-b-c)$.

2. For 1967-68 (Mexican wheat), t-value for the output elasticity of fertilizer is significant at $\alpha = 0.005$, for capital at $\alpha = 0.01$; for labour, t-value is not significant at any reasonable level.

3. For 1967-68 (Local wheat), t-values for labour and fertilizer are significant at $\alpha = 0.005$; but for capital it is not significant at any reasonable level.

Table 2—Sample Geometric Mean Levels of Per Acre Output and Inputs

<table>
<thead>
<tr>
<th>Item</th>
<th>Sample</th>
<th>1967-68 (Mexican wheat)</th>
<th>1967-68 (Local wheat)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td></td>
<td>12.32</td>
<td>8.24</td>
</tr>
<tr>
<td>Labour</td>
<td></td>
<td>222.00</td>
<td>161.00</td>
</tr>
<tr>
<td>Fertilizer</td>
<td></td>
<td>69.50</td>
<td>13.50</td>
</tr>
<tr>
<td>Capital</td>
<td></td>
<td>224.00</td>
<td>166.00</td>
</tr>
</tbody>
</table>