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RESEARCH NOTES

PRODUCTION RESPONSE OF HIGH-YIELDING VARIETY OF RICE IN SOME LESS DEVELOPED COUNTRIES—ESTIMATION AND COMPARISON*

High-yielding varieties (HYVs) of rice were introduced commercially in most of the Asian rice producing countries in the year 1964-1965. The shorter maturity period of these HYVs also allows multiple cropping. These new improved varieties of rice (also of wheat) greatly increased yields in some of the less developed countries. However, the yield potential of the HYVs as determined on experimental plots is generally much higher than obtained by farmers. Also, a number of studies show that many farmers do not use appropriate amounts of complementary inputs with the new varieties. This behaviour may be based on either financial reasons or a continuation of traditional practices followed in the past. Fertilizer is one of the most important complementary inputs to be used with new varieties if yield potentials are to be attained. However, in comparing the increased production due to the HYVs under experimental and in commercial conditions it is difficult to determine the relative importance of the factors responsible for the difference in the potential and realized production.

In the present note we estimate the production and fertilizer response of the HYVs of rice from national data for a number of Asian countries. We also show how the estimates can be used in agricultural planning at the macro level.

THE MODEL AND THE DATA SITUATION

We assume the following linear relationship:

\[ P_i = \alpha_i + \beta_i A_{Ni} + \gamma_i H_{Hi} \quad \cdots \cdots \cdots \ (1) \]

\[ F_i = \pi_i + \delta_i A_{Ni} + \tau_i H_{Hi} \quad \cdots \cdots \cdots \ (2) \]

where \( P_i \) = production of rice in the \( i \)th country in thousand metric tons;
\( F_i \) = total nitrogenous fertilizer used in the country in thousand metric tons;
\( A_{Ni} \) = harvested area in native variety of rice in thousand hectares;
\( H_{Hi} \) = harvested area in HYV of rice in thousand hectares;
\( \alpha_i, \beta_i, \gamma_i, \pi_i, \delta_i \) and \( \tau_i \) are parameters to be estimated.

As indicated before, we analyse national level data for estimating the parameters of equation 1 or 2. Countrywide time-series data of rice production are available for a fairly long period. Time-series data pertaining to

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total (sum of native and high-yielding) harvested land area devoted to rice production are also accessible. The data for land allocated only to HYVs are not clearly specified with respect to planted acreage or harvested acreage. In our analysis we assume that the data of land area in HYVs represent harvested acreage in all the countries. By this assumption we may incorporate a bias (possible random) in the data for those countries for which the reported data actually refer to the planted acreage and include some which is not harvested. In most cases the HYVs are planted in irrigated land areas. Normally, the improved varieties have better care than the traditional varieties. Hence, there may be a relatively small difference between the area planted and the area harvested for HYVs of rice.

Referring to equation 2, the correct specification of the dependent variable should be for fertilizer used in rice production, and not for the total fertilizer used. But countrywise data for fertilizer used on specific crops are not available. Previous studies show that even crude figures of total fertilizer use can explain production increases of a particular crop quite satisfactorily. Thus in our model total fertilizer use may serve adequately as a proxy for fertilizer specifically used in rice cultivation. The time-series data of fertilizer consumption are readily available. The period covered in our analysis is 1966 to 1975 inclusive. For most of the countries, a fairly high partial correlation exists between the acreage allocated to the two varieties of rice. For countries such as India, Pakistan, Indonesia, Sri Lanka and Nepal the partial correlation between the acreages allotted to the two varieties is negative indicating that the bulk of the increase in acreage of the HYVs comes from transfer of land area from native varieties.

Equations 1 and 2 have been estimated for all the major rice producing countries of Asia. We report the estimated coefficients in those cases where the coefficients had the expected signs. Correction for autocorrelation was made for significant first order autocorrelation. The results are given in Tables I and III.

RESULTS

Referring to Table I, we find that all the coefficients associated with the acreages of the two varieties are highly significant. The coefficient \( \Gamma_i \) associated with the acreage of HYV is greater in magnitude than the coefficient \( \beta_i \) associated with the native variety. The coefficients \( \beta_i \) and \( \Gamma_i \) are the marginal products of native and HYV varieties respectively. Symbolically, the marginal product per hectare of HYV in country \( i \) is

\[
MP_{Hi} = \frac{\delta P_i}{\delta A_{Hi}} = \Gamma_i
\]

## Table I—Estimation of Production Response

<table>
<thead>
<tr>
<th>Country</th>
<th>Estimated value of $\kappa_i$</th>
<th>Estimated value of $\beta_i$</th>
<th>Estimated value of $\gamma_i$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>$-65729.4430$</td>
<td>$3.3332$</td>
<td>$3.7248$</td>
<td>$0.86$</td>
</tr>
<tr>
<td>Burma</td>
<td>$-206.5829$</td>
<td>$2.1234$</td>
<td>$3.8354$</td>
<td>$0.88$</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>$-512.5168$</td>
<td>$3.0778$</td>
<td>$3.2182$</td>
<td>$0.84$</td>
</tr>
<tr>
<td>Pakistan</td>
<td>$-592.2089$</td>
<td>$1.8596$</td>
<td>$3.6369$</td>
<td>$0.91$</td>
</tr>
<tr>
<td>Nepal</td>
<td>$262.7468$</td>
<td>$1.6981$</td>
<td>$1.8220$</td>
<td>$0.79$</td>
</tr>
<tr>
<td>Indonesia</td>
<td>$10085.7095$</td>
<td>$3.1700$</td>
<td>$4.8836$</td>
<td>$0.95$</td>
</tr>
</tbody>
</table>

Estimated equation: $P_i = \kappa_i + (\beta_i A_{Ni} + \gamma_i A_{Hi})$
where $P_i =$ production of rice (000 metric tons) in the ith country,
$A_{Ni} =$ harvested acreage in native variety of rice (000 hectares) in the country,
$A_{Hi} =$ harvested acreage in high-yielding variety of rice (000 hectares) in the ith country.

* Computed $t$ value.

per hectare marginal product of native variety in country $i$ is $(MP_{Ni}) = \frac{\delta P_i}{\delta A_{Ni}} = \beta_i$. Assuming that in country $i$, total production $P_i$, can be separated into production due to native varieties $(P_{Ni})$ and production due to HYVs $(P_{Hi})$, we have the following:

$$P_i = P_{Hi} + P_{Ni} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

thus $MP_{Hi} = \frac{\delta P_{Hi}}{\delta A_{Hi}}$

and $MP_{Ni} = \frac{\delta P_{Ni}}{\delta A_{Ni}}$.

We derive the expression for the ratio of marginal products (yields) as follows:

$$\frac{MP_{Hi}}{MP_{Ni}} = \frac{Y_i}{\beta_i} = \frac{\delta P_{Hi}}{\delta P_{Ni}} \cdot \frac{\delta A_{Ni}}{\delta A_{Hi}} \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

The ratio of average products (average yields) of the two varieties can be simplified as follows:

$$\frac{Y_{Hi}}{Y_{Ni}} = \frac{P_{Hi}}{P_{Ni}} \cdot \frac{A_{Ni}}{A_{Hi}} \quad \ldots \quad \ldots \quad \ldots \quad (5)$$
where $Y_{HI}$, $Y_{N_i}$ are average yields of the two varieties in country i. Assuming constant output elasticities of the two varieties, we can write the ratio of marginal yield (product) as:

$$\frac{Y'_i}{\beta_i} = (k) \frac{Y_{HI}}{Y_{N_i}}$$

where k is a constant which is the ratio of the assumed constant output elasticities of the two varieties and k should be greater than 1 in this case. It is of interest to compare the ratio of marginal yields (product) for different countries. The ratios $\left(\frac{Y'_i}{\beta_i}\right)$ computed for five countries are given in Table II.

**Table II—Computed Ratios of Marginal Yield**

<table>
<thead>
<tr>
<th>Country</th>
<th>Ratio ($\frac{MP_{HI}}{MP_{N_i}}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>1.11</td>
</tr>
<tr>
<td>Burma</td>
<td>1.80</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>1.04</td>
</tr>
<tr>
<td>Pakistan</td>
<td>1.95</td>
</tr>
<tr>
<td>Nepal</td>
<td>1.08</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1.53</td>
</tr>
</tbody>
</table>

The data from several countries suggest that the ratios of average yield of HYV to the average yield of native variety of rice ranges from 1.10 to 2.58. Thus our results (Table II) are within the relevant limit.

The estimates of the fertilizer use equation (2) are reported in Table III. Significant coefficients ($\delta_i$ and $\eta_i$) are observed for even a smaller number of countries compared to the production equation (1). The coefficients ($\delta_i$ and $\eta_i$) are used for prediction. We assume that any trend of fertilizer use by other crops in the historical time-series data will be implicit in our prediction of total fertilizer use.

**Table III—Estimation of Fertilizer Response**

<table>
<thead>
<tr>
<th>Country</th>
<th>Estimated value of $\pi_i$</th>
<th>Estimated value of $\delta_i$</th>
<th>Estimated value of $\eta_i$</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>$-2683.5471$</td>
<td>0.087403 (2.9)*</td>
<td>0.200233 (9.3)</td>
<td>.95</td>
</tr>
<tr>
<td>Burma</td>
<td>$-17.3292$</td>
<td>0.004647 (2.2)</td>
<td>0.096743 (19.0)</td>
<td>.96</td>
</tr>
<tr>
<td>Indonesia</td>
<td>$-178.8302$</td>
<td>0.032865 (1.4)</td>
<td>0.104327 (8.0)</td>
<td>.84</td>
</tr>
</tbody>
</table>

Estimated equation: $F_i = \pi_i + \delta_i\Delta_{N_i} + \eta_i\Delta_{HI}$

where $\Delta_{N_i}$ = total quantity of nitrogenous fertilizer consumed (000 metric tons) in the country, $\Delta_{HI}$ = harvested acreage in native variety (000 hectares) rice in the ith country, $\Delta_{HI}$ = harvested acreage in high-yielding variety of rice (000 hectares) in the ith country.

* Computed t value.

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Inter-relationship between Fertilizer and Production of Rice

The yields of both native and HYVs increase with fertilizer. For HYVs, it is important that sufficient quantities of fertilizer are used. For native varieties, land can more nearly be substituted for fertilizer. For HYV, fertilizer becomes an endogenous control variable. Though we have two separate equations (equations 1 and 2) for estimating rice production and fertilizer use, we can specify a simple model to evaluate the production response of fertilizer. Rewriting equations 1 and 2 in vector matrix form, we have the following:

\[
\begin{bmatrix}
P_i \\
F_i
\end{bmatrix} = \begin{bmatrix}
\kappa_i \\
\pi_i
\end{bmatrix} + \begin{bmatrix}
\beta_i & \Gamma_i \\
\delta_i & \eta_i
\end{bmatrix} \begin{bmatrix}
A_{Ni} \\
A_{Hi}
\end{bmatrix}
\quad \ldots \quad (6)
\]

or

\[
\begin{bmatrix}
A_{Ni} \\
A_{Hi}
\end{bmatrix} = \begin{bmatrix}
\beta_i & \Gamma_i \\
\delta_i & \eta_i
\end{bmatrix}^{-1} \begin{bmatrix}
P_i - \kappa_i \\
F_i - \pi_i
\end{bmatrix} = A \begin{bmatrix}
P_i^1 \\
F_i^1
\end{bmatrix}
\quad \ldots \quad (7)
\]

where A is the inverse matrix \[
\begin{bmatrix}
\beta_i & \Gamma_i \\
\delta_i & \eta_i
\end{bmatrix}^{-1}
\]
and \[P_i^1 = P_i - \kappa_i \quad \text{and} \quad F_i^1 = F_i - \pi_i\]

Equation 7 can be used directly in agricultural planning. The equation gives the area harvested of both varieties as a function of total production and fertilizer. The area harvested can then be suitably transformed to planted acreage and the planted acreage can be used for allocation of land area between the two varieties of rice. However, it is to be remembered that the analysis is based on historical performance of the variables on a national basis. The elements of the computed inverse is given in Table IV.

**Table IV—Elements of the Inverse (A) of the Coefficient Matrix**

<table>
<thead>
<tr>
<th>Country</th>
<th>(\kappa_{11}^{a})</th>
<th>(\kappa_{21})</th>
<th>(\kappa_{12})</th>
<th>(\kappa_{22})</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>0.58579</td>
<td>-0.25574</td>
<td>-10.89890</td>
<td>9.75730</td>
</tr>
<tr>
<td>Burma</td>
<td>0.51515</td>
<td>-0.24740</td>
<td>-20.42409</td>
<td>11.31808</td>
</tr>
<tr>
<td>Indonesia</td>
<td>0.59421</td>
<td>-0.19234</td>
<td>-28.64079</td>
<td>18.59166</td>
</tr>
</tbody>
</table>

\(a\kappa_{ij}\): Coefficient representing its row and jth column of matrix A.

The reduced form matrix A is generally very sensitive for prediction purposes. Hence, we have computed the inverse matrix only for those coun-

8. Sarkar and Heady, *op. cit.*
tries where the estimated coefficients are highly significant. To test the predictive capability of matrix A we compare the observed values of $A_{HH}$ and $A_{Ni}$ with the values computed by equation 7. Table V summarises the observed and computed values of the areas $A_{HH}$ and $A_{Ni}$ for the years 1966 and 1975. Referring to Table V, we find that, in general, the computed and the observed values of the land areas are much closer for 1975 than for 1966. Hence, it seems reasonable to use the inverse matrix A for short range prediction purposes. If the target production and fertilizer availability are given, we can predict the land areas needed.

<table>
<thead>
<tr>
<th>Table V—Comparison between Actual and Computed Land Areas Allotted to the High-Yielding and the Native Variety of Rice in 1966 and 1975</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>India</td>
</tr>
<tr>
<td>Burma</td>
</tr>
<tr>
<td>Indonesia</td>
</tr>
</tbody>
</table>

$A_{Hi}$: Area allotted to high-yielding variety of rice.
$A_{Ni}$: Area allotted to native variety of rice.

Now we turn to another interesting aspect of the inverse matrix A. The second column of the matrix consisting of elements $\kappa_{12}$ and $\kappa_{22}$ gives the fertilizer response of the land areas of the two varieties. Since fertilizer is one of the complementary inputs for HYVs, this response is very important. The response can be further interpreted in the following way: If available fertilizer changes by one unit, the acreage of the native variety changes by $\kappa_{12}$ unit and the acreage of HYV changes by $\kappa_{22}$ unit. In Table IV the sign of $\kappa_{12}$ is positive whereas $\kappa_{22}$ is negative. We find that if we increase fertilizer by one unit, we can support an added $\kappa_{22}$ amount of HYV acreage. Simultaneously, we can reduce the land area of the native variety by $\kappa_{12}$ and still fulfil the target production level. Thus we can decrease the total land area in rice cultivation by $\kappa_{12} - \kappa_{22}$ amount for each added unit of fertilizer. The surplus land then can be reallocated for production of other crops. Table VI shows the gain in land area for different countries.

<table>
<thead>
<tr>
<th>Table VI—Gain in Total Land Area for an Added Unit of Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>India</td>
</tr>
<tr>
<td>Burma</td>
</tr>
<tr>
<td>Indonesia</td>
</tr>
</tbody>
</table>

The difference in the gain in total land area between India and the two other countries is due to the difference in the magnitudes of the estimated coefficients ($\eta_i$, $\eta_i$, $\delta_i$, and $\eta_i$). Referring to Table I we find that in both Burma and Indonesia the ratio of the marginal yield of the two varieties (1.8
for Burma and 1.5 to Indonesia) is greater than the ratio for India (1.1). Also from Table II the fertilizer requirement coefficients are smaller in Burma (.0046 for the native variety and .0976 for the new variety) and Indonesia (.0328 and .1043 respectively) than in India (.0874 and .2002 respectively). The joint effect of the above two phenomena is mainly responsible for the difference in the potential area gain. Fertilizer in India is used not only in rice but on many crops. The green revolution has been very successful in India in wheat and a significant portion of total fertilizer available is used on wheat. Less fertilizer is used on other crops in Indonesia where rice is the main cereal crop. Thus in Burma and Indonesia, if an extra unit of fertilizer is made available, most of that extra unit is used for rice cultivation. In India, only a part of that extra unit goes into rice cultivation, the rest is used to cultivate other competing crops. In this way, the effect of increase in one unit of total fertilizer availability has a greater effect in rice production in Burma and Indonesia than in India. This is the physical reason for the difference in gain between India and the two other countries considered in this paper.

Implicitly, an increase in fertilizer use results in an increase in production (yield). Potential yield is always larger for the HYV than for traditional varieties. According to our model, the rule of thumb of fertilizer use is simple: If a unit of added fertilizer is made available, it should be used to increase the acreage under cultivation of HYV, thereby allowing the production target to be fulfilled by using less of the scarce land supply.

CONCLUSION

In an earlier work by the authors, isoquants denoting substitution between fertilizer and land area were generated for rice production in India. The present paper is an extension of the earlier work. In the present context, the land area is divided into areas pertaining to HYV and traditional varieties respectively and the differential effect of fertilizer used on two land classes has been considered. Instead of deriving isoquants in this paper, we generate coefficients indicating the substitutability of fertilizer and land used for both HYV and traditional varieties of rice. The extent of the substitutability has been compared for three Asian countries, viz., India, Burma and Indonesia. The method developed in the present note can also be used for simple agricultural planning at the macro level. Given a target production level and fertilizer availability, we can determine the allocation of land area between the two varieties of rice. The present study does not include another important input in rice cultivation, viz., irrigation. Efforts are being made to develop a generalised model consisting of all the important factors used in rice cultivation.

Hiren Sarkar and Earl O. Heady*