# The Allocation of Research Expenditures Among Competing Crops:

## The Application of An *Ex Ante* Model to Bangladesh

Mohammed Ahsan Habib,
David Butterfield
and
Stuart Mestelman*

### I. Introduction

Existing retrospective studies of investment in agricultural research and extension programmes, many of which are surveyed in Arndt and Ruttan (1977), Evenson, Waggoner and Ruttan (1979), and Norton and Davis (1981), indicate that such investment exhibits a high social rate of return. Nevertheless, vigorous programmes of agricultural research are not always popular among the developing countries. In a report describing the first five-year plan of Bangladesh, the IBRD (1974) indicated that not only was the level of expenditure on agricultural research exceptionally low, but that the allocation of these resources appeared to be inefficient. The IBRD recommended the "the relative priorities should be carefully reassessed, particularly in respect to the specific program of research work" which these resources should support. Furthermore, while Bangladesh was experiencing a substantial expansion in the enrollments in agricultural training institutes, these facilities had not been developed enough to ensure a system of well equipped and effective extension agents. It is within this framework that the need for a formal allocation model for research and

* Ahsan Habib is Assistant Professor of Economics at Adrian College, Adrian, Michigan, and David Butterfield and Stuart Mestelman are Associate Professors of Economics and QSEP Research Associates, McMaster University, Hamilton, Ontario, Canada. The authors wish to thank David Feeny and Atif Kubursi for valuable comments on a previous draft of this paper.

extension service expenditure is approached; the existing system, which does not utilize such a procedure, is not working well.

Existing *ex ante* allocation models have been discussed by Shumway (1981) and Norton and Davis (1981). The models developed by Binswanger (1978) and Evenson and Kislev (1975) are highly theoretical and are difficult to implement empirically. The empirical *ex ante* models are, on the other hand, incomplete in several respects. The model of Ramalho de Castro and Schuh (1977) is restricted to closed economies and also overlooks the cost of research. Araji, Sim and Gardner (1978) developed another such model which incorporates research costs but is not explicit as to the measurement of benefits from crops which are traded internationally. Another important omission is that none of these models recognize that attempts to obtain increasing gains in productivity will often be limited by short-run innovation possibilities.

This paper presents an *ex ante* model for the allocation of research expenditures among competing crops. It corrects the inadequacies of the models cited above by considering crops that are traded abroad, research costs, the measurement of benefits, and the inclusion of a ceiling to the level of technological change achievable for each crop, given a specific period of time over which a research programme will be conducted. This last characteristic is used in an attempt to capture the rapidly rising cost of innovation which appears at some point in the process of generating technical innovations over relatively short periods of time. While the model developed here is utilized to determine an efficient allocation of research funds among the major agricultural crops of Bangladesh, the necessarily subjective nature of many elements in the analysis, as pointed out by Shuway (1981), must be considered when evaluating the policy implications of the results.

## II. The Model

The allocation of research expenditures among competing crops is modeled by the development of a potential benefits from technical change function for each crop, as well as a research cost function for each crop. Both benefits and costs are expressed as a function of a supply shift parameter. The maximization of the net benefits from research and development requires the determination of the value of this shift parameter, and this exercise necessitates the development of a programming algorithm in the case where the available research and development funds are constrained. The benefit function, the cost function and the solution to the maximization problem are presented in this section.

### *1. The Benefit Functions*

Following Akino and Hayami (1975), Ramalho de Castro and Schuh (1977), and Araji, Sim and Gardner (1978), benefits are measured as the consumers' plus producers' surpluses generated by a shift in the supply curve, following the implementation of technical change.[1] The relevant demand and supply relationships are represented by equations (1) and (2), respectively.

$$(1) \qquad Q_{D_i} = H_i P_i^{-d_i}$$

$$(2) \qquad Q_{S_i} = G_i P_i^{s_i}$$

where $Q_{Di}$ and $Q_{Si}$ are the quantities demanded for and supplied of crop i, $H_i$ and $G_i$ are demand and supply function parameters, $d_i$ and $s_i$ are demand and supply own price elasticities, and $P_i$ is the price of crop i.[2]

Following a $100h_i$ percent increase in the supply of crop i, because of a technical innovation, the new supply function is represented as

1 This objective does not consider the distributional effect that technical change will have on agents in the developing economies. In particular, as pointed out by Lindner and Jarrett (1978) and Habib (1980), technical change may have positive net benefits but the distribution of benefits may be such as to discourage the adoption of the new technology. Producers may suffer net losses while consumers realize gains. We are primarily interested in production efficiency and leave distribution issues aside in this analysis.

2 This functional form is used because of the alternate functional forms considered it best fits the data of Bangladesh, to which this model was applied. The selection was based on conventional $R^2$ statistics. The terms $G_i$ and $H_i$ represent the effect on the demand and supply functions of variables other than the price of crop i. The specific composition of these terms is not relevant since they will not appear in the net benefit expression. Estimates of alternate functional forms can be found in Habib (1980).

(3)[3] $Q_{S_i} = (1+h_i)\, G_i P_i^{s_i}$

Assuming that markets are cleared, both before and after the technical change, the annual benefits from technological improvement in the production of crop i, $A_i$, can be expressed as

(4) $A_i = Q_i^0 P_i^0 \,[(1-d_i)^{-1} - (1+s_i)^{-1}]\, [1-(1+h_i)^{k_i}]$ when $d_i \neq 1$

and as $A_i = Q_i^0 P_i^0 (s_i + 1)^{-1} \ln (1+h_i)$ when $d_i = 1$

where $k_i = (d_i - 1)(s_i + d_i)^{-1}$, and $Q_i^0$ and $P_i^0$ are the equilibrium values prior to technical change. Equation (4) would apply to a situation where the product was neither imported nor exported and for which the world market was neglected (if any existed).

If the crop is traded in the world market and if the country's production is large enough to influence world prices, the expression for $A_i$ is modified to

(5) $A_i = Q^0_{Di}\, (\alpha P^0_{wi})\, (1-d_i)^{-1}\, [1-(1+b_i h_i)$

$-(1-d_i)\,(s_{wi}+d_{wi})^{-1}\,]\; - Q^0_{S_i}\, (\alpha P^0_{W_i})\, (1+s_i)^{-1}\, [1-(1+h_i)$

$(1+b_i\, h_i)^{-(1+S_i)\,(s_{wi}+d_{wi})^{-1}}\,]$ when $d_i \neq 1$ and to

3 The privotal supply shift is chosen, rather than a parallel supply shift, to represent technical change for the parallel shift suggests that at each price, the increase in output will be the same as at every other price. This is not a sensible proposal. While a new technique will allow producers to expand the output resulting from a given set of resources, this absolute output increase will not be independent of input utilization. Since input utilization is expected to expand as supply prices rise, it should be expected that the absolute increase in output due to technical innovation will be greater as this supply price rises.

$$A_i = Q^0_{Di}\ (\alpha P^0_{wi})\ (s_{wi}+d_{wi})^{-1}\ln(1+b_i h_i) - Q^0_{si}\ (\alpha P^0_{wi})$$

$$(1+s_i)^{-1}\ [1-(1+h_i)\ (1+b_i h_i)\ ^{-(1+s_i)\ (s_{wi}+d_{wi})^{-1}}]$$

when $d_i = 1$,

where $P^0_{wi}$ is the world price, $d_{wi}$ and $s_{wi}$ are the elasticity parameters of the world demand and supply function for crop i and $Q^0_{Di}$ and $Q^0_{si}$ are the equilibrium quantities demanded and supplied locally. The parameter $b_i$ represents the share of world market output accounted for by the country experiencing the technical change, and $\alpha$ is the ratio of local to world market prices.[4]

A third situation is that in which the country exports crop i in the world market, but its contribution is not large enough to influence world prices. The demand function facing domestic suppliers will exhibit an infinite elasticity in the relevant range and annual benefits can be measured by

$$(6)\qquad A_i = h_i\ (1+s_i)^{-1} Q^o_i\ \alpha P^o_{wi}$$

These three cases are represented in Figures 1, 2 and 3.

Before introducing the cost functions for technical change, the annual benefit expressions must be converted into a present value of benefits expression. This is done by assuming that a constant stream of benefits for q years will result from technical innovation, starting p years after the initiation of a research programme. Then, for a given discount rate, r, the conversion is accomplished by summing over the discounted future benefits. This is expressed as

$$(7)\qquad R_i = \sum_{t=p}^{p+q} A_i\ (1+r)^{-t}$$

4 Equation (5) was derived by stipulating a set of demand and supply functions for the world market similar to those represented by equations (1) and (2). For details see Habib (1980).

This implies that any technical innovations are instantaneously adopted by producers, and that benefits suddenly cease after a given period of time. Certainly any *ex ante* planning will be sensitive to assumptions of this sort, and alternate specifications of the benefit function should be incorporated whenever information pertaining to diffusion patterns, discount rates and lifetimes of both projects and innovations are obtained for the particular economy to which an *ex ante* model is applied.

*2. The Cost Functions*

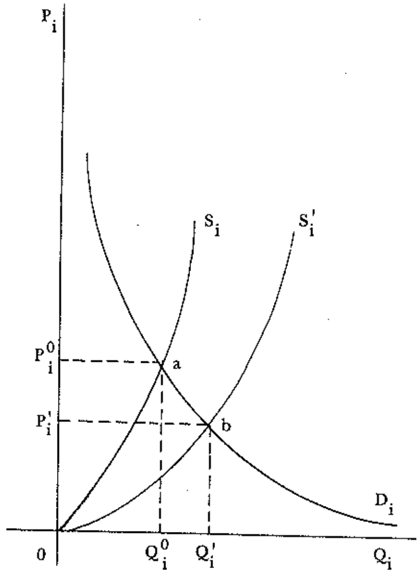
It is difficult to specify an accurate cost function for technical change and innovation in the absence of any knowledge of the actual activities leading to an innovation. Only aggregate data are available for the countries which report data on research programmes. These data were used for the specification of linear cost functions. This specification of the cost function can be viewed as an approximation to a more complex functional form. The approach used here can easily accommodate more complex cost functions. However, the available historical data does not provide enough information to specify more complex functions.[5] In general, the present value of the research expenditure on crop i, incurred over a period of time which may be more than one year, will be represented as

$$(8) \quad c_i = v_i h_i \text{ and } h_i \leqq h_i^u$$

where $v_i$ is the cost of a one hundred percent shift of the supply function of crop i, and $h_i^u$ is the maximum value that $h_i^u$ can

5 It might be expected that the cost of supply shifts may better be represented by a third degree polynomial which would indicate high marginal costs associated with initial innovative activity, but which would eventually exhibit lower marginal costs of supply shifts which may be falling or constant. Finally, rising marginal costs would be realized.

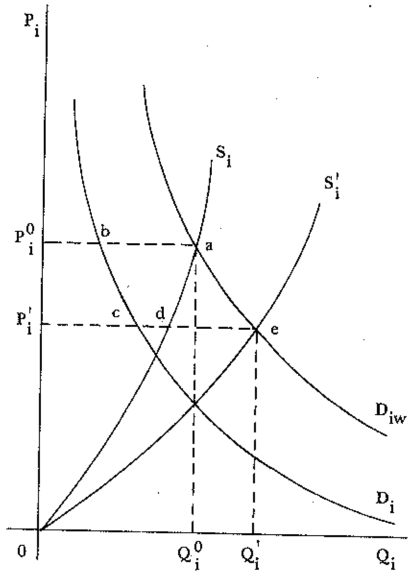
The assumption made in this paper suggests that the existing state of technical development is such that further advances can be made at constant marginal cost, but that a constraint on the extent to which the supply function may shift exists because of a time constraint which is placed on the research. Bangladesh may be able to borrow some new techniques from IRRI and/or India, which may support the constant marginal cost assumption. Because the cost parameters are based on historical data, they implicitly incorporate geoclimatic conditions and farmed area in the regions generating the data. What is not explicitly modeled is the effect of these variables' influence on the cost parameters. The necessary data for this was not available.




$A_i = \text{Oab}$

**Figure 1**

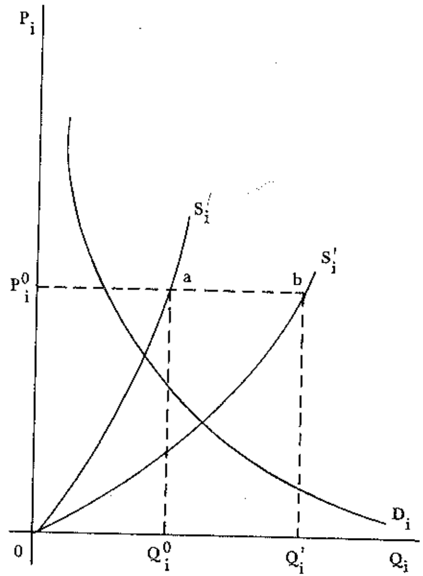
Annual Benefits ($A_i$) When Crop is Only Consumed and Produced Domestically




$A_i = \text{Ode} - \text{abcd}$

**Figure 2**

Annual Benefits ($A_i$) When Crop is Traded on World Market, and Domestic Country Can Affect the World Price




$A_i = \text{Oab}$

**Figure 3**

Annual Benefits ($A_i$) When Crop is Traded on World Market, and Domestic Country Has No Affect on Price feasibly attain. This maximum value is introduced to account for the anticipated rapidly rising marginal cost of invention and innovation which will result if technical change is expected to occur over a relatively short period of time. This is an extreme situation where the supply of new techniques becomes inelastic at some level of expenditure. The value of $h_i^u$ will depend upon the natural characteristics of the country for which the technology is being developed and upon the research facilities and personnel available for the process. Obviously countries with few qualified scientists will find a given level of research and development expenditures less productive than would a country with many well trained researchers. Over time it would be expected that $h_i^u$ will change as research, the borrowing of technology and production experience accumulate.

The annual cost of extension and maintenance research is assumed to be $100e_i$ percent of the present value of the total research cost leading to the technical change in the production of crop i. This specification also could have been more complex, explicitly reflecting the variables which may influence the value of $e_i$. The use of the invariant $e_i$ is an attempt to try to include some measure of extension costs and to permit testing the sensitivity of the allocation results to changes in possible aggregate extension cost parameters.[6] By combining these costs with research cost, an expression for total programme cost for crop i can be derived. This cost function is expressed as

6 The formulation of the extension cost function is more difficult to justify than the choice of a constant $v_i$. Certainly the number of farms to be serviced by extension workers should affect extension costs attributable to new research results, as should the size of the existing extension service. To the extent that expenditures on extension services are so much greater than expenditures on research in developing countries (as compared to developed countries), an argument may be made that large increases in extension service expenditures are not needed to disseminate new information (the delivery system is in place, waiting for something to deliver). On the other hand, the extension worker may be a non-productive member of a patronage dominated bureaucracy, and the dissemination of new technologies may require new, well trained personnel.

While the assumption of extension costs being a given proportion of the total amount of resources expended on research does not necessarily account for the variables which may affect this proportion, the use of sensitivity testing of the extension cost parameter is an attempt to counter any criticism which could arise from the use of one specific value (given the arbitrariness of the choice of functional form). Our results indicate that while the total allocation of resources to research, development and extension activities is affected by the magnitude of the extension cost parameter, the order in which the crops receive funds is not altered. The matter of varying this parameter across crops is addressed in the text of the paper.

(9) $C_i = \phi_i h_i$ and $h_i \leq h_i^u$

where $\phi_i = v_i + \sum_{t=p}^{p+q} e_i v_i (1+r)^{-t}$

### 3. *The Maximization of Net Benefits*

The maximization of net benefits from technical change and innovation will yield optimum values for the shift parameters. These unconstrained optima are identified as $h_i^*$. However, the constraints on the extent to which innovation and technical change can actually increase supply must be considered. Since this constraint does exist at any point in time, "effective" values of the shift parameter will be obtained, which will be at most as large as the optimum values. These effective shift parameteres are denoted as $h_i$ and are determined by the following rules.

(10a) if $0 \leqq h_i^* \leqq h_i^u$ then $h_i' = h_i^*$

(10b) if $h_i^* < 0$ then $h_i' = 0$

(10c) if $h_i^* > h_i^u$ then $h_i' = h_i^u$

Since expenditure, E, is constrained, the allocation of resources to alternative research programmes (for different crops) can be found by maximizing the sum of net benefits realized from the expansion of production of all crops subject to the constraint that the total expenditure on research and extension programmes is, at most, as large as the aggregate expenditure constraint.[7]

7 The use of constrained funds denies the existence of perfect capital markets and implies that the shadow discount rates may assume different values in different periods. In this study they have been approximated by a single rate of discount.

The fact that the effective shift parameter values do not necessarily equal the optimum shift parameter values and that some crops may have linear benefit functions complicates the derivation of the effective shift parameter values for the crops involved in the research programme. A search process comprised of several steps may be utilized to overcome these problems. The method of the search process is to find the crop or crops for which marginal benefits relative to marginal costs are the highest and then to allocate funds sequentially.[8] This search process can be summarized most concisely by the solution to the following non-linear programming problem:

$$\text{(11)} \qquad \underset{h_i}{\text{Maximize}} \sum_i B_i(h_i),$$

$$\text{subject to } E \geqq \sum_i \phi_i h_i,$$

$$\text{and} \quad 0 \leqq h_i \leqq h_i^u,$$

where $B_i(h_i) = R_i - \phi_i h_i$. Any saddle point of the Lagrangian expression

$$\text{(12)} \qquad L(h_i, y_1, x_i, z_i) = \sum_i B_i(h_i) + y_1 (E - \sum_i \phi_i h_i)$$

$$+ \sum_i x_i (h_i^u - h_i) + \sum_i z_i h_i$$

is a solution of this problem. The first-order (Kuhn-Tucker) conditions are

$$\text{(13a)} \qquad (\partial B_i / \partial h_i) - y_1 \phi_i - x_i + z_i = 0$$

8 A detailed elaboration of the search process for situations in which $\partial(\partial B_i/\partial h_i)/\partial h_i = 0$ can be found in Habib, Butterfield and Mestelman (1981).

(13b) $E \geqq \Sigma \phi_i h_i$

(13c) $0 \leqq h_i \leqq h_i^u$

(13d) $\sum_i z_i h_i = 0$

(13e) $\sum_i x_i (h_i^u - h_i) = 0$

(13f) $y_1 (E - \sum_i \phi_i h_i) = 0$

Thus if $h_i = 0$ then $x_i = 0$, $z_i \geqq 0$ and $(\partial B_i / \partial h_i) = y_1 \phi_i - z_i \leqq y_1 \phi_i$. If $h_i = h_i^u$ then $x_i \geqq 0$ and $z_i = 0$ and $(\partial B_i / \partial h_i) = y_1 \phi_i + x_i \geqq y_1 \phi_i$. Finally, if $0 < h_i < h_i^u$ then $x_i = 0$ and $z_i = 0$ and $(\partial B_i / \partial h_i) = y_1 \phi_i$.

The shadow price of the research budget constraint, $y^*_1$, is equal to the ratio $(\alpha B_i / \alpha j_i)/\phi_i$ for all crops whose supply shift parameters lie between zero and the upper limit. The ratio $(\alpha B_i / \alpha h_i)/\phi_i$ represents the marginal net benefit per additional dollar spent on research on crop i. Thus, at the optimal allocation, all crops whose shift parameters lie between zero and their upper limit have the same marginal benefit, $y_1^*$. All crops whose shift parameters are at their upper limit have a marginal net benefit which is greater than or equal to $y_1^*$; and all crops whose shift parameters are set at zero have a marginal net benefit less than or equal to $y_1^*$.

The non-linear programming formulation of the problem may appear to be difficult. However, the sequential search process which leads to the solution is straight forward and can be implemented using only a desk calculator. In addition, the sequence in which research funds are allocated provides an intuitive understanding of the relative merits of research in the different crops.

## III. An Application to Bangladesh

The allocation model described above is now used to determine that optimum allocation of resources to research activities which are directed towards developing new technologies in jute, rice, sugarcane and tea. These crops are all produced in Bangladesh, which is a predominantly agricultural country with little previous agricultural research activity. Bangladesh is a major supplier of jute to the world market and rice is the staple food crop.[9] The other two crops are traded internationally, but Bangladesh's share in this trade is small enough that Bangladesh producers can be treated as price takers.

The supply and demand elasticities needed to evaluate the annual benefits from technical improvement in the production of each of the four crops are presented in Table 1. Since no signifi-

**Table 1**

ELASTICITY PARAMETERS, COST COEFFICIENTS, MARKET PRICES AND QUANTITIES

| Crop (i) | $s_i$ | $d_i$ | $s_{wi}$ | $d_{wi}$ | $v_i^1$ | $P_i^2$ | $Q_i^3$ |
|---|---|---|---|---|---|---|---|
| Jute | 0.69 | 0.88 | 0.712 | 0.553 | 169.42 | 137.67 | 0.509 (0.977) |
| Rice | 0.18 | 0.28 | -- | -- | 185.29 | 283.95 | 12.764 |
| Sugarcane | 0.31 | ∞ | -- | -- | 25.49 | 18.95 | 6.590 |
| Tea | 0.32 | ∞ | -- | -- | 67.77 | 1240.32 | 0.036 |

*Source:* Habib (1980)
[1]This is in millions of 1978 U.S. dollars per unit of $h_i$.
[2]These are in 1978 U.S. dollars per ton.
[3]These are in millions of metric tons. The figure in parenthese represents total domestic supply, the others are total domestic demand.

9 In the exercise that follows, rice is treated as a crop which is neither imported nor exported, but whose domestic price is determined endogenously by the domestic market. The small amount of imported rice which is distributed by the government to selected urban consumers at subsidized prices is ignored. Also, if technical change reduces domestic prices relative to world prices, the implicit constraint on the export of rice would result in an underestimate of benefits following from the technical change.

cant indigenous research activity has been undertaken for these crops, estimates of the cost coefficients for research activity, $v_i$, are obtained by taking comparable cost figures from research done in other countries. While it is not likely that these historical cost coefficients will precisely reflect future costs and successes realized by agricultural research activities in Bangladesh, they may provide guidance for the allocation of a limited budget to research activities. This is particularly valuable in a situation such as that described in IBRD (1974), where there is research activity currently being carried out and where there are few experienced research managers.

Since our cost coefficients are based on historical data for both research costs and yield increases, they represent both successful and unsuccessful research projects and actual rates of adoption in the countries from which they are drawn. Any application of these cost coefficients of other countries should include a careful comparison of the research facilities, research personnel, extension networks and other institutional features which affect research success and adoption rates, and the coefficients should be modified accordingly.

Research expenditures incurred in Japan, and their resultant yields, as reported by Hayami and Akino (1977) are used to compute cost estimates for rice. The research cost figures for rice were further modified to account for the fact that nearly 23 percent of Bangladeshi rice is already produced through improved technology with little scope for immediate further improvement. For sugarcane, the results of Evenson (1969) for the Caribbean area are used. The research cost coefficients for jute and tea provide particular problems, for no information concerning successful technical innovation in the production of these crops could be found. For these crops the research cost coefficients applying to cotton and cocoa research in Brazil, as reported by Ayer and Schuh (1972) for cotton and Alvin (1976) for cocoa, were used. Although research on cotton has been directed towards the increase of fibre content, which would be the objective of jute research, the plants themselves are very different. Also, the substitution of cocoa research expenditure coefficients for tea is questionable, since the only similarity between the harvested parts of the plants is their use in a beverage. In defense of this selection it should be pointed out that both crops are perennial tropical tree crops and that innovation in each may well draw on the same pool of as yet poorly developed scientific knowledge.

The results following from the use of the cost coefficients introduced here can illustrate the value of a technique, but should not be interpreted as providing a definitive solution to the problem of resource allocation to research activities in agriculture in Bangladesh. The research cost coefficients all appear in Table 1.

The price and quantity values for the year 1978 were computed from various published statistics and are regarded as the pre-technical change equilibrium values. All monetary values are expressed in 1978 U.S. dollars. These prices and quantities appear in Table 1.

The value of the divergence between the world and local market prices of jute, $\alpha$, is set equal to 1. This assumes that for the purpose of computing the optimum allocation of resources to agricultural research domestic users of jute are required to recognize the full opportunity cost of their use of jute.

The length of time required to develop a new technology, $P_i$, is set equal to 5 years for all four crops and the length of time over which the benefits of the new technology are measured, $q_i$, is set equal to 15 years for all four crops. The five year time period for the development of the new technology has a basis in the work of Evenson (1971), in which data are presented which indicate a median time lag between research investment and impact on production of approximately five to eight years, and in Bredahl and Peterson (1976), in which the lag associated with cash grains is set at 5 years. In fact, the lag for the time for tea would most likely be longer than would the lag for the other crops while the lag time for rice may be less. The choice of fifteen years for the measurement of benefits is much more arbitrary.

In the absence of no further agricultural development, it may be expected that the benefits of the initial development programme could be realized indefinitely. However if the benefit stream is assumed to remain uniform over an infinite time horizon, the present value of benefits realized during the first fifteen years following the initial impact of the innovation would be approximately ninety percent of the present value of the benefits realized over the infinite period.

In addition to the truncated benefit period, the assumption of a uniform flow of benefits following the five year research period needs some justification. Since actual farming data is used to calculate the cost coefficients, the supply shift associated with any given expenditure of research resources overestimates the actual impact of the technical change during the initial years, but will underestimate benefits accruing after greater diffusion of the technology has occurred. The assumption of the uniform distribution of benefits was arbitrary. Probably a third degree polynomial would provide a better representation of the flow of benefits. This would first exhibit low but rapidly growing diffusion and later falling rates of diffusion as the technology spreads. Perhaps a natural decay factor should be introduced. We believe the uniform distribution of benefits is adequate for demonstrating the application of the allocation procedure. Using a different distribution pattern for benefits changes the proportional relationship between $A_i$ and $R_i$ (see equation 7) and thus changes marginal net benefits. The extent to which this *ex ante* model overstimates or underestimates the present value of net benefits will depend upon the number of years of observations used to calculate the cost coefficients, the rates of diffusion of technical change and the discount rate used.

The discount rate chosen for this particular application is 15 percent. This represented the rate of return to relatively riskless private investment in Bangladesh in 1978, and may serve as the conventional high value for the social discount rate.[10]

The parameter for extension and maintenance cost, $e_i$, was set at 6 percent of total research cost, $v_i h_i$. Since the total research cost represents expenditures over a five-year period, setting $e_i$ at 6 percent of these expenditures is equivalent to assuming that annual extension and maintenance costs will be approximately 30 percent of annual expenditure on research. In Araji, Sim and Gardner (1978), it is noted that maintenance cost alone may be expected to fall between 10 and 35 percent of research expenditures. This sug-

10 This rate may be somewhat high for the return to relatively riskless private investment, if all output is measured in real terms, since there is a component of the 15% market rate that accounts for expected price increases (inflationary trends). However, the use of lower discount rates will have the effect of increasing the present value of each potential research programme, but will not affect the relative prositions of the four crops with regard to their importance in the research plan.

gests that 30 percent may result in an understatement of costs and hence an overstatement of net benefits. In order to test the sensitivity of the results to the value of this parameter solutions were computed for $e_i$ equal to 3, 6, and 12 percent.[11]

Moreover, without specific *crop-wise* extension and maintenance cost data, differences in the $e_i$ coefficient across crops cannot be incorporated. Inclusion of such differences could affect the sequence in which research funds are allocated to crops.

The parameters remaining to be specified represent Bangladesh's share of the world's supply of jute, the total value of resources available for allocation to the four research programmes and the upper limits which the values $h_i$ can take (the maximum feasible shift of the supply function). The first, $b_{jute}$, is set equal to 35 percent of the world's supply. This was Bangladesh's 1978 share of the world jute supply.

The total present value of resources available for allocation to research, extension and maintenance activities for rice, jute, sugarcane and tea over a twenty year period is set at \$50, \$100, \$450 and \$500 million.

Assuming that the annual real expenditure on agricultural development is maintained at its 1978 level over the twenty year period, the present value of these expenditures is \$831.81 million. If two-thirds of this amount is devoted to research, maintenance and extension expenditures on the four crops considered here (which comprise nearly ninety percent of the total value of agricultural output in Bangladesh), the resulting amount is \$554.54 million. This is the basis of the high resource constraint introduced above.

Two sets of values are introduced as alternate estimates of the maximum feasible shift parameters, $h_i^u$. The first set represents modest targets while the second indicates more ambitious targets. The modest values were computed for all four crops by taking the

11 The ratio of extension services to research expenditure in 1965 was shown by Evenson and Kislev to be 1.29 in South and Southeast Asia, 1.12 for "all" developing counries, and 0.57 for all developed countries. The Araji, Sim and Gardner (1978) work seems to support the Evenson and Kislev (1975) data for developed countries. Evenson and Kislev (1975) suggest that developing countries may systematically underinvest in research relative to extension services. In particular, they show that the internal rate of return to research expenditures is more than twice that to extension services. Alternate values for $e_i$ consider extension expenditure from .15 to .60 of annual research expenditure.

current yield differences between Bangladesh and neighboring Asian countries with comparable climatic and resource conditions. The more ambitious targets were obtained for jute from two Bangladeshi experimental station reports cited in F.A.O. (1975) and for rice from adjusted actual differences in yields between traditional and improved varieties cultivated in Bangladesh. The targets for sugarcane and tea were based on differences between yields in Bangladesh and the United States of America and Sri Lanka.

The alternative values of $h_i^u$ are presented in Table 2 and the results of the optimum allocation of resources to each crop for each case are presented in Tables 3, 4 and 5. Table 6 contains the net benefits associated with the optimum allocation of resources to each crop given the alternate values of $h_i^u$ and E, with $e = 0.06$. The share of research resources and net benefits accruing to each crop appears in Table 7 for $e = 0.06$.

## Table 2

MAXIMUM FEASIBLE SUPPLY SHIFT PARAMETERS ($h_i^u$)

| Crop | Modest Targets | High Targets |
|---|---|---|
| Jute | 0.130 | 1.000 |
| Rice | 0.086 | 1.685 |
| Sugarcane | 0.120 | 0.820 |
| Tea | 0.400 | 1.180 |

*Source:* Habib (1980).

Table 3

OPTIMUM ALLOCATION OF RESEARCH RESOURCES WITH $e = 0.03$[1]
(in millions of U.S. dollars)

| Crop | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 |
|---|---|---|---|---|---|
| Jute | 0 | 24.27<br>(.130*) | 0 | 0 | 27.34<br>(.146) |
| Rice | 17.56<br>(.086)* | 17.56<br>(.086)* | 100<br>(.490) | 344.06<br>(1.685)* | 344.06<br>(1.685)* |
| Sugarcane | 3.37<br>(.120)* | 3.37<br>(.120)* | 0 | 23.03<br>(.820)* | 23.03<br>(.820)* |
| Tea | 29.07<br>(.389) | 29.87<br>(.400)* | 0 | 82.91<br>(1.110) | 88.12<br>(1.180)* |
| Total | 50** | 75.07 | 100** | 450** | 482.55 |

[1]The numbers in the parentheses are the respective values of the effective supply shift parameter, $h'$. Each * indicates that $h'$ is equal to $h_i^u$ (the upper bound). The double asterisks indicate that the expenditure constraint was binding. Cases 1 and 2 correspond to modest targets ($h_i^u$) while cases 3, 4 and 5 correspond to high targets. See Table 2 for these values.

## IV. Summary of the Results and Concluding Comments

Using the parameter values presented in section III, and the model presented in section II the optimum allocation of resources to research activities suggest the following points.

1. Within the context of Bangladesh, rice, sugarcane and tea exhibit positive net benefits from expenditures on research and the associated extension programmes for all values of e, while jute exhibits positive net benefits only for low values of e. The net benefits associated with rice are large relative to those associated with the other crops, especially when the high targets are assumed.

2. When resources are constrained it is possible to determine crop priorities on the basis of the marginal net benefits per dollar spent on research and associated activities. For $e = 0.06$ and $h_i = 0$ (prior to any technical change) these values are 0.03, 45.85, 9.57,

## Table 4

OPTIMUM ALLOCATION OF RESEARCH RESOURCES WITH $e = 0.06$[1]
(in millions of U.S. dollars)

| Crop | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 |
|---|---|---|---|---|---|
| Jute | 0 | 7.47<br>(.037) | 0 | 0 | 2.64<br>(.013) |
| Rice | 19.19<br>(.086)* | 19.19<br>(.086)* | 1000<br>(.448) | 375.91<br>(1.685)* | 375.91<br>(1.685)* |
| Sugarcane | 3.68<br>(.120)* | 3.68<br>(.120)* | 0 | 25.17<br>(.820)* | 25.17<br>(.820)* |
| Tea | 27.13<br>(.332) | 32.64<br>(.400)* | 0 | 48.93<br>(.600) | 96.29<br>(1.180)* |
| Total | 50** | 62.98 | 100** | 450** | 500** |

[1]The numbers in the parentheses are the respective values of the effective supply shift parameter, $h_i'$. Each * indicates that $h_i'$ is equal to $h_i^u$ (the upper bound). The double asterisks indicate that the expenditure constraint was binding. Cases 1 and 2 correspond to modest targets ($h_i^u$) while cases 3, 4 and 5 correspond to high targets. See Table 2 for these values.

0.41 for jute, rice, sugarcane and tea, respectively. For this example funds are allocated first to rice and then to sugarcane. After sugarcane has been expanded to the point where no further supply shift is possible, expenditure is again devoted to rice until the upper bound is reached. Funds are then allocated to tea until the corresponding physical limit is reached, and only then are resources devoted to jute. This sequence is the same for each value of e chosen, as indicated in Tables 3, 4 and 5.

3. Based on the yield differences between Bangladesh and neighboring Asian countries the set of modest feasible shift parameters could be realized with a relatively low level of expenditure (less than the maximum allocated for research, maintenance and extension expenditures).

4. Although the set of high shift parameter ceilings represent ambitious targets for which a relatively large research expenditure

## Table 5

OPTIMUM ALLOCATION OF RESEARCH RESOURCES WITH e = 0.12[1]
(in millions of U.S. dollars)

| Crop | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 |
|---|---|---|---|---|---|
| Jute | 0 | 0 | 0 | 0 | 0 |
| Rice | 22.44 (.086)* | 22.44 (.086)* | 100 (.383) | 420.57 (1.612) | 439.60 (1.685)* |
| Sugarcane | 4.31 (.120)* | 4.31 (.120)* | 0 | 29.43 (.820)* | 29.43 (.820)* |
| Tea | 23.26 (.244) | 38.17 (.400)* | 0 | 0 | 30.97 (.325) |
| Total | 50** | 64.91 | 100** | 450** | 500** |

[1]The numbers in the parentheses are the respective values of the effective supply shift parameter, $h_i'$, Each * indicates that $h_i'$ is equal to $h_i^u$ (the upper bound). The double asterisks indicate that the expenditure constraint was binding. Cases 1 and 2 correspond to modest targets ($h_i^u$) while cases 3, 4 and 5 correspond to high targets. See Table 2 for these values.

## Table 6

NET BENEFITS FROM THE OPTIMUM ALLOCATION OF RESEARCH RESOURCES WITH e = 0.06
(in millions of U.S. dollars)

| Crop | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 |
|---|---|---|---|---|---|
| Jute | 0 | 0.11 | 0 | 0 | 0.07 |
| Rice | 789.82 | 789.82 | 2837.97 | 4879.41 | 4879.41 |
| Sugarcane | 35.26 | 35.26 | 0 | 240.92 | 240.92 |
| Tea | 11.17 | 13.44 | 0 | 20.15 | 39.65 |
| Total | 836.25 | 838.63 | 2837.97 | 5140.48 | 5160.05 |

## Table 7

SHARE OF RESEARCH RESOURCES AND NET BENEFITS ACCRUING TO EACH CROP WITH $e = 0.06$[1]

| Crop | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 |
|---|---|---|---|---|---|
| Jute | 0/0 | .12/.00 | 0/0 | 0/0 | .01/.00 |
| Rice | .38/.95 | .30/.94 | 1.0/1.0 | .83/.95 | .75/.94 |
| Sugarcane | .07/.04 | .06/.04 | 0/0 | .06/.05 | .05/.05 |
| Tea | .55/.01 | .52/.02 | 0/0 | .11/.00 | .19/.01 |

[1]The numbers appearing on the right side of the diagonal represent the crops' share of total net benefits in each case. The numbers on the left side of the diagonal are the crops' share of research resources. Note that for jute in cases 2 and 5 and for tea in case 4 net benefits accruing to research expenditures on each of these crops is less than one percent.

is warranted, this expenditure is still within the means of Bangladesh. In particular, under the assumption of high shift parameter ceilings, rice and sugarcane research should receive the first priority.

5. The findings reported above also provide empirical support to the general remark made by Binswanger (1978) that, although crops with a greater share of farm output will dominate others, a reversal is possible when research costs are brought into consideration. From the empirical results it is found that the largest crop, rice, commands priority over all others. But although jute is next to rice in acreage and the value of production, sugarcane dominates jute by virtue of its low research cost.

6. The importance of world market effects is shown by the low ranking of jute. An expansion of jute supply reduces the world market price of jute. This reduction limits the marginal benefit so severely that for $e = 0.12$ the marginal *net* benefit at $h_1 = 0$ is negative. If the depressing effect of expansion of jute supply on the world market price had not been included in the analysis the benefits from research in jute would have been overstated.

Although the model presented in section II presents an improvement over the existing *ex ante* models for allocating research expenditures among competing crops, there are several areas in which further improvements must be made. The interdependencies between the supply and demand functions for the various competing crops are not included in this presentation. Most notably missing is the effect of changing rice and jute productivity on each other's supply. Since they compete for the same land, technical changes which result in decreases in rice prices may result in a reduction in land going to rice and in an increase in acreage in jute. However, the same sort of effects may occur when jute productivity rises. The interactive effects must be included in a complete *ex ante* model. A second effect of a similar nature that may be incorporated into the model is the income effect on demand following increases in productivity and the resulting changes in national income.

While the previously mentioned effects may be identified as supply and demand effects, there are also technical effects that need to be modelled and incorporated into the *ex ante* model. The precise process of how a technical change is translated into a shift in supply needs to be investigated as does the entire process of the adoption of any technical changes. Both are necessary to obtain accurate estimates of the benefits of technical change. However, the effects of the adoption rate on crop priorities will be minimal if such rates do not differ significantly among various crops. Finally, the analysis of the cost aspects of research and extension services can be improved. The cost figures of the present paper are obviously weak. As research proceeds, and more facts are accumulated, these figures can be modified and the conclusions reexamined.

Although the tenuous data assumptions and questionable proxy variables cast some doubt on the results of an *ex ante* resource allocation model, the exercise of refining existing models is not without merit. In many instances, and particularly in the developing countries, the expertise of the experienced research manager, who can make allocations as if he has carried out *ex ante* evaluation with the appropriate data, may not be available. In those situations the exercise of applying a formal model may help research managers formulate objectives and identify data needs. To the extent that formal models are incomplete the inexperienced research manager may not be led to consider many important aspects of the problems he is expected to examine.

The model presented in section II extends the work of Ramalho de Castro and Schuh (1977) and of Araji, Sim and Gardner (1978) by treating an open economy situation in which some products are traded competitively in international markets while the sale of other products may have a significant impact on world prices. A second extension is the introduction of possible technical limits to supply shifts resulting from investment in research and extension work. Each of these enrichments to the model may have a significant impact on research priorities.

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