PN-AAQ-045
ISN=34666

Bulletin Number 83-3

September 1983

ECONOMIC DEVELOPMENT CENTER

ESTIMATING THE YIELD ADVANTAGE OF HIGH YIELDING WHEAT VARIETIES: THE USE OF ON-FARM YIELD CONSTRAINTS DATA

Joseph G. Nagy

ECONOMIC DEVELOPMENT CENTER
Department of Economics, Minneapolis
Department of Agricultural and Applied Economics, St. Paul

UNIVERSITY OF MINNESOTA

PNAAQ045
ISN 34688

62

September 1983

ESTIMATING THE YIELD ADVANTAGE OF HIGH YIELDING WHEAT VARIETIES: THE USE OF ON-FARM YIELD CONSTRAINTS DATA

by

Joseph G. Nagy*

Bulletin No. 83-3
September 1983

* Graduate Research Assistant, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, Minnesota.

Funding for this research was provided under a contract from the U.S. Agency for International Development - University of Minnesota Asia Agricultural Research Review Project (Contract No. AID/ASIA-C-1456).

The author gratefully acknowledges the invaluable advice and help of Dr. Vernon W. Ruttan and Dr. Carl E. Pray in preparing this paper.

TABLE OF CONTENTS

		Page
I.	Introduction	1
II.	Overview of the Index Number Approach	1
III.	Estimation of the Shift Parameter K	4
IV.	The Use of On-Farm Yield Constraints Data	7
V.	Summary and Conclusion	13

I. Introduction

The accurate measurement of the yield advantage of new crop varieties over old crop varieties is important in assessing the contribution made by crop development research. Unbiased estimates of the yield advantage of improved crops are difficult to obtain in particular for the High Yielding Varieties (HYV's) in Less Developed Countries (LDC's). This in turn has led to the questioning of robust rate of returns to crop development research from using the Index number approach. [8,10].[1/]

This paper briefly reviews the Index number approach of estimating the contribution made by crop development research and then discusses the problems of obtaining accurate yield advantage figures and the problems of estimating the supply shifter used in the Index Number Approach. The paper then discusses the use of On-Farm Yield Constraint Data as a source of data for estimating the yield advantage. Yield constraint data from Pakistan is used as an illustration.

II. Overview of the Index Number Approach

The Index Number Approach (consumer-producer surplus approach) estimates the benefits to agricultural research by measuring the change in consumer surplus (CS) and producer surplus (PS) from a rightward shift in the supply curve that has been brought about through technological change.

1/ See Ruttan [12, pp. 242-246] for a summary of rate of return studies.

The change in CS in Figure 1 is shown by areas A + B and is a positive change given a supply shift from Q_s' to Q_s and a demand curve that is not perfectly elastic. The gain occurs because consumers pay the lower price P_0 brought about by the technological change. The change in producers' welfare (PS) is Area C minus Area A. The change in PS is the difference between what is gained because of lower costs per unit of output (Area C) and the increased quantity marketed Q_1 to Q_0 minus the loss incurred from the drop in price from P_1 to P_0 (Area A). PS may be positive or negative depending on the elasticities of supply and demand. The gross annual research benefit (GARB) is then Area B + Area C.

Annual benefits may be calculated once the following data and information is made available: 1) supply and demand elasticities, 2) yearly price and quantity data, and 3) the annual leftward shift in the actual supply curve Q_s in order to establish the pre-innovation supply curve Q_s' (usually called the supply shifter K).[2/] An internal rate of return may then be calculated from the annual stream of benefits derived from the index number approach and the associated annual stream of research costs of the new technology.

The index number approach has gone through an evolution since the Griliches hybrid corn study in 1958[5]. This "first generation" model used a unitary elastic demand curve and estimated returns for both a perfectly elastic and inelastic supply curve with a crude guesstimate of the supply shifter K. Although the model was crude, Griliches [5], along

---

2/ K is traditionally known as the supply shifter as in the articles by Griliches, Peterson and Ayer and Schuh. However, Akino and Hayami interpret K as a production function shifter. See the appendices to Hayami and Akino, page 52.

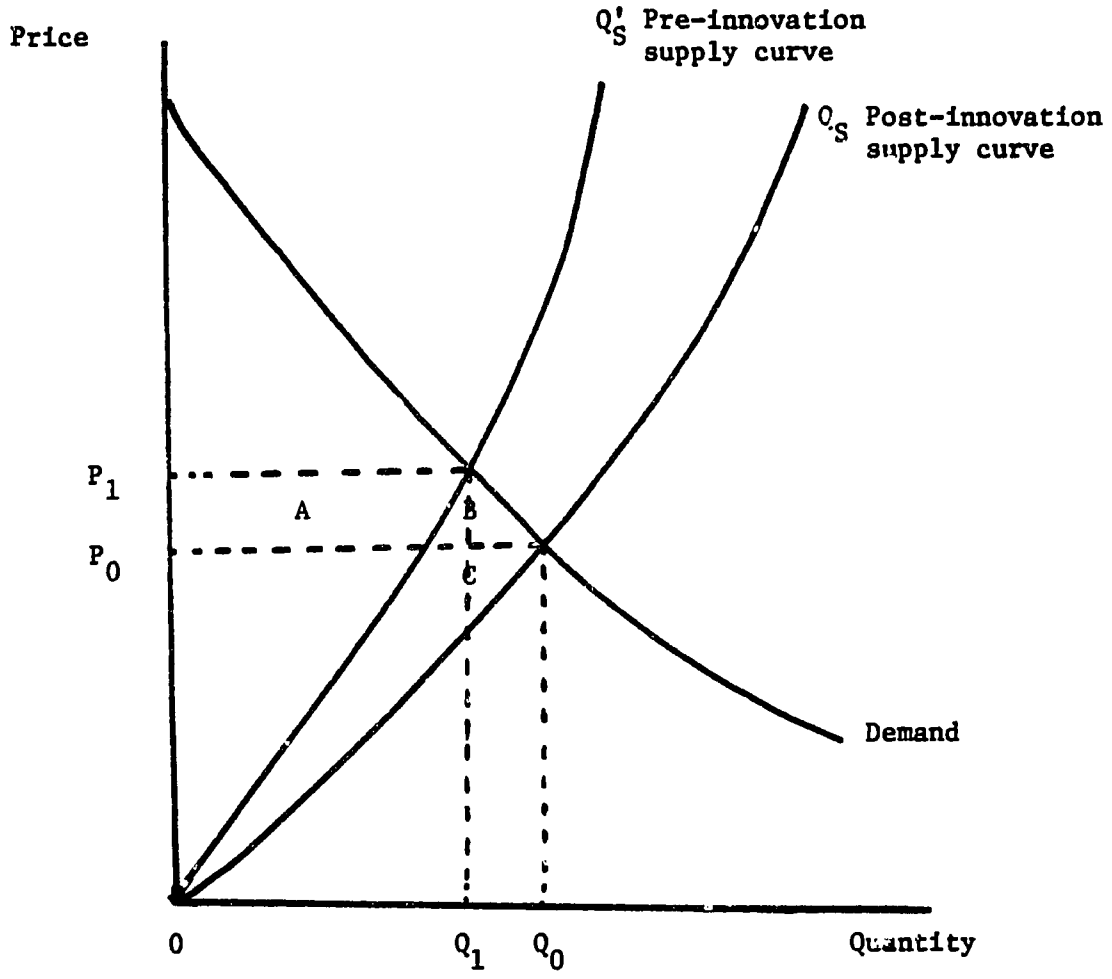

Figure 1. Model of Returns from Crop Varietal Improvement.

with the pioneering work by Schultz [14], started people thinking about the returns to research and led to "second generation" models that gave more attention to elasticities of suppy and demand, estimation of expenditures, the shift factor K and the change in the distribution of income from technological change. Among the early second generation models were Peterson's poultry study [11], Ayer and Schuh's Brazilian cotton study [2], Akino and Hayami's study on rice in Japan [1] and Schmitz and Seckler's tomato harvester study [13].

III. Estimation of the Shift Parameter K

The index number approach using the horizontal supply shift method requires knowledge of what the production of a certain commodity would have been given that producers did not have access to the innovation under study. The most popular way in specifying the shift from Q_s to Q_s' in Figure 1 follows that of the Ayer-Schuh and Akino-Hayami models as indicated below:

$$K_\tau = \sum_{i=1}^{n} \left[(1 - Y/Y_i) \cdot L_{i\tau} \right] \times 100 \qquad (1)$$

where:

K_τ = the percentage decrease in production that would have resulted if producers used the old unimproved varieties;

Y = the average yield of the unimproved varieties that would be grown in the absence of new improved varieties (the base yield);

Y_i = the yield of an improved variety i that is sown in year t;

$L_{i\tau}$ = the proportion of total land sown that is sown to variety i in year t;

n = the number of improved varieties sown in year t; and

Y/Y_i = the inverse of the yield advantage of improved variety i.

A problem arises in obtaining an accurate measure of the yield advantage Y_i/Y. In some studies, Y_i and Y are arrived at through the use of experimental station yield trial data since this is a readily available and most often the only reliable source. It is also the only source of data that can show the relative yields by variety over the history of the crop development research.

One of the arguments against using experimental yield trial data is that superior management practices and techniques are used and therefore the results may not reflect the on-farm situation. Another argument is summed up by Hertford, Ardila, Rocha and Trujillo [7, p. 87].

> " . . . estimates based only on comparisons of yields obtained on plots seeded to new varieties and others seeded to unimproved varieties would be biased upward because of the strong, positive interactions of the new varieties with such inputs as fertilizers and water."

The argument by Hertford et al is that the yield advantage estimate would be biased upward because the estimate may also include the contribution made by inputs such as fertilizers and water. To account for this problem, they estimated the yield advantages of new varieties in Columbia by estimating production functions of yield as a function of new varieties and other inputs. For example, using data from commercial rice trial plots, they estimated yield as a function of 20 variables which included size of plot, seeding rate, seven seed variety variables, two time variables and four variables to differentiate locations. In comparing K obtained using the formula as presented in equation (1) and the K obtained from the regression results for rice, the former was an average twice that of the latter.[3/]

3/ For an alternate procedure for estimating K, see K. M. Scobie and Rafael Posada T. [15].

The use of experimental yield trial data does not provide a good estimate of the shift parameter K in less developed countries (LDC's) because of the previous arguments. However, in the case of some crops in developed countries (DC's) experimental yield trial data does offer a good estimate of the yield advantage and shift parameter K. Take for example, the case of rapeseed breeding in Canada (Nagy and Furtan [9]). Rapeseed is a specialized crop grown by above average farmers who in general apply optimal amounts of fertilizers and other inputs. Furthermore the old base yield varieties are similar in response to inputs like fertilizer.

The rapeseed experimental yield data gives a close estimate of a change in yield solely due to varietal improvement because the experimental yield data for each new variety is averaged over several repetitions at many geographical locations within the crop growing area and over several years under profit maximizing input use (not output maximizing) and management. The base yield varieties were included in the yearly experiments, thus the yield of the base varieties Y are compared with the yields of new varieties Y_i under modern cultural practices. Also, due to the method of calculating K, the experimental yield varietal difference is transmitted as a percentage and not in absolute terms. For example, if experimental yield trial data indicates that a new variety exhibits a four bushel per acre increase over the base yield Y of 40 bushels per acre, then K = 9.09%. If the on-farm yield was 35 bushels per acre, then the pre-innovation yield would be (35 - (.0909 x 35)) = 31.82 bushels per acre and not (35 - 4) = 31 if the absolute value were used. It is also the opinion of the rapeseed breeders that the relative yield increases from experimental trials can be expected to be transmitted to on-farm yields under average farm conditions and where

farm management ability and practices are of good standards. Thus for crops grown in DC's such as rapeseed, experimental yield trial data may give good estimates of the yield advantage of new varieties.

IV. The Use of On-Farm Yield Constraints Data

The estimation of the yield advantage using the Hertford, et al, method does require substantial data which is not readily available in most LDC countries. A new source of data may exist for the estimation of the yield advantage due to varietal yield increasing research. The source of data is from the "On-Farm Yield Constraints Studies" that are now being conducted in several LDC's.

The main focus of the On-Farm Yield Constraint studies are to measure the on-farm yield gap between existing recommended practices and existing farm practices. The analysis shows the contribution to output of individual test factors that make up the gap between existing farm practices and recommended practices. Factors such as the level of fertilizer use, weeding, planting time period and planting depth have been analyzed. (DeDatta, et al [4]).

Several on-farm yield constraint trials have also included variety as one of the test factors. Furthermore, some of the trials have used pre HYV's vs. post HYV's as the test factors. The information gained from such trials can be used in determining the yield advantage of HYV's. Table 1 and Table 2 show the results of wheat yield constraint trials in Pakistan on Barani (rainfed) and irrigated land respectively. Three test factors are involved in the trials: 1) Farmers variety (tall variety) vs. recommended HYV variety; 2) Farmer fertilizer application rate vs.

Table 1. Wheat Yield Constraint Trial Data on Rainfed Land, Pakistan.

Treatments	Yield Index
1. V1F1W1	100.0
2. V1F5W1	128.2
3. V1F1W5	107.1
4. V1F5W5	136.5
5. V5F1W1	116.1
6. V5F5W1	148.0
7. V5F1W5	128.3
8. V5F5W5	155.7

Six locations, three replications.

V1 = Farmers Variety (C-591)

F1 = Farmers Fertilizer (50N and 26P lbs/acre)

W1 = Farmers Weeding (no practice)

V5 = Recommended Variety (Lyallpur - 73)

F5 = Recommended Fertilizer (101N and 75P lbs/acre)

W5 = Recommended Weeding Practice (two weedings)

Source: M. Manzoor Ali, On-Farm Yield Constraints Research In Pakistan; Pakistan Agricultural Research Council, Islamabad.

Table 2. Wheat Yield Constraint Trial Data on Irrigated Land, Pakistan.

Treatments	Yield Index
1. V1F1W1	100.0
2. V1F5W1	108.9
3. V1F1W5	110.7
4. V1F5W5	101.8
5. V5F1W1	155.3
6. V5F5W1	164.3
7. V5F1W5	150.0
8. V5F5W5	167.8

four replications

V1 = Farmers Variety (mainly C-591 and other tall varieties)

F1 = Farmers Fertilizer (50N and 20P lbs/acre)

W1 = Farmers Weeding (no practice)

V5 = Recommended Variety (ZA-77)

F5 = Recommended Fertilizer (120N and 60P lbs/acre)

W5 = Recommended Weeding Practice (one hand weeding)

Source: Natali, A. H., Annual Progress Report, 1980-81, Wheat Section, Agricultural Research Institute, Tandojam, Pakistan.

recommended rates and; 3) Farmers weeding practice vs. recommended. All other inputs are held constant at a level of good farm practices and input use. The trials were conducted on farmers fields.

The information contained in Tables 1 and 2 can be used in calculating the wheat yield advantage of HYV's in Pakistan. By rearranging the treatments as is done in Table 3, the contribution to yield from the use of HYV's under four different input levels can be established. For example, Category I in Table 3 holds constant the two test factors of fertilizer and weeding at the farmers input levels of F1 and W1 while allowing the variety test factor to change from the farmers variety V1 to the recommended HYV V5. The yield advantage of using the HYV holding the other test factors at F1W1 can then be calculated and is 16.1 percent or 1.161 and 55.3 percent or 1.553 for unirrigated and irrigated land respectively.

To estimate the shift parameter K using the information from Table 3, equation (1) will have to be respecified. First, information of the yield advantage by variety is not available and therefore the old tall variety C-591 and the two HYV's LYP-73 and ZA-77 will become the proxies for the base yield (Y) and all HYV's (Y_i) respectively. The C-591 variety was one of the most popular pre-semi-dwarf varieties grown in Pakistan and its average yield and characteristics are very similar to other tall varieties. The average yield and characteristics of LYP-73 and ZA-77 on average are also very similar to other semi-dwarf varieties grown in Pakistan. Secondly, instead of weighting each varieties yield advantage by the proportion of land it was sown to in year t, an overall yield advantage figure would be obtained by weighting the yield advantage of each of the four input categories in Table 3 by the proportion of land

Table 3. Wheat Yield Advantages from Varietal Improvement Research.

Input Category	Treatments	Unirrigated Yield Index	Unirrigated Percentage Increase	Irrigated Yield Index	Irrigated Percentage Increase
I	V1F1W1	100.0	16.1	100.0	55.3
	V5F1W1	116.1		155.3	
II	V1F5W1	128.2	15.4	108.9	50.9
	V5F5W1	148.0		164.3	
III	V1F1W5	107.1	19.8	110.7	35.6
	V5F1W5	128.3		150.0	
IV	V1F5W5	136.5	14.1	101.8 1/	64.8
	V5F5W5	155.7		167.8	

Source: Tables 1 and 2.

1/ Treatment V1F5W5 under irrigated conditions would appear to be lower than expected thus biasing the yield advantage of input category IV upward.

sown to HYV's in each category. The shifter K would then be found by using the following formula:

$$k_\tau = 1 - \left[\frac{1}{((1-YA) \times LHYV_\tau) + 1} \right]$$

where:

k_τ = The percentage decrease in production that would have resulted if producers used the old tall wheat varieties.

YA = The overall average yield advantage of HYV's.

$LHYV_\tau$ = The proportion of land sown to HYV's in year τ.

In the case of Pakistan, accurate figures of the land sown to each input category of table three are not available. When equally weighted, the yield advantage would be 1.164 and 1.517 for unirrigated and irrigated land respectively. However, in Pakistan, most of the total production from the area sown to HYV's of wheat would come from input categories I and III. Equal weighting of categories I and III would give a yield advantage estimate of 1.180 and 1.455 for unirrigated and irrigated land respectively.

The yield advantage for irrigated and unirrigated land can be weighted by the area of unirrigated land sown to HYV's and the area of irrigated land sown to HYV's to produce the overall yield advantage due to the varietal improvement of wheat. About 10 percent of all HYV's sown in Pakistan are sown on unirrigated land, thus, the overall yield advantage is 1.43. In comparison, Sidhu's production function analysis indicates yield advantage figures ranging from 1.23 to 1.45 for wheat in the Indian Punjab in 1967/68 and Columbian research analysis in 1971 suggested a 1.46 figure for semi-dwarf wheat varieties. (Dalrymple).

A comparison of the wheat yield advantage using the On-Farm Yield Constaints data can be made with the yield advantage calculated from experimental yield trial data from Pakistan. The average experimental research station yield in kg/acre of the dominant pre-HYV wheat varieties of C228, C217, C591, C518, C271 and C273 is 890.6. The average experimental research station yield in kg/acre of the dominant HYV's of MexiPak Ch-70, Blue Silver, SA-42, Y-ecora and Pari-73 is 1697.5.[4/] The simple calculation of the yield advantage using experimental research station data is 1.91 which is more than twice the yield advantage of the 1.43 calculated using On-Farm Yield Constraints data.

V. Summary and Conclusion

The index number approach estimates the benefits to agricultural research by measuring the change in consumer and producer surplus from a rightward shift in the supply curve brought about through technological change. The challenge is to accurately measure the shift in the supply curve that is solely due to the new technological advance under study. In the case of yield increasing crop development research, an estimate of the yield advantage of the new variety solely due to yield increasing research is required. Problems exist in obtaining accurate yield advantage estimates using readily available experimental yield trial data for those crops with strong positive interactions with inputs such as fertilizer and water. This problem has been overcome by estimating production functions of yield as a function of new varieties and other inputs.

4/ Experimental yield trial data from Dr. M. A. Bajwa, Director, Wheat Research Institute, Faisalabad, Pakistan.

The estimation of the yield advantage using the production function approach does however require a substantial amount of data. Another source of data to estimate the yield advantage is the On-Farm Yield Constraint studies that are now being done in many LDC's. The case of obtaining the wheat yield advantage of HYV's in Pakistan was illustrated and compared favorably with previous work.

Admittedly, the On-Farm Yield Contraints data used in the illustration does have faults. First, the trials are for one year only at limited locations. The accuracy of the yield advantage estimates would be enhanced had more years of data been available at more locations throughout Pakistan. Secondly, other yield constraint factors such as tillage, method of sowing and fertilizer applications at lower and at a zero rate should be included in the trials.

Although On-Farm Yield Constraint data could be designed better if the purpose in mind was to solely estimate the yield advantage of HYV's, the data gives a fair representation of the contribution of wheat HYV's to the increased overall yield that has taken place in Pakistan. With the knowledge that On-Farm Yield Constraint data can be used to compute yield advantage figures, agriculture economists in need of such data and who are involved in setting up On-Farm yield trials can specifically design the trials to also meet their requirements.

References

1. Akino, M. and Y. Hayami, "Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development," American Journal of Agricultural Economics, 57 (1975): 1-10.

2. Ayer, H.W. and G. Edward Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil," American Journal of Agricultural Economics 54 (1972): 557-69.

3. Dalrymple, D., "Impact of Research on Wheat and Rice Production," Resource Allocation and Productivity in National and International Agricultural Research, ed. T.M. Arndt, D.G. Dalrymple, and V.W. Ruttan, Minneapolis: University of Minnesota Press (1977).

4. DeDatta, Gomez, Herdt and Barker, Methodology for an Integrated Experiment-Survey on Rice Yield Constraints, International Rice Research Institute,

5. Griliches, Z., "Research Costs and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economics 66 (1958): 419-31.

6. Hayami, Y. and M. Akino, "Organization and Productivity of Agricultural Research Systems in Japan," Resource Allocation and Produtivity in National and International Agricultural Research, ed. T.M. Arndt, D.G. Dalrymple and V.W. Ruttan, Minneapolis: University of Minnesota Press (1977).

7. Hertford, R., J. Ardila, A. Rocha, and L. Trujillo, "Productivity of Agricultural Research in Colombia," Resource Allocation and Productivity in National and International Research, ed. T.M. Arndt, D.G. Dalrymple and V.W. Ruttan, Minneapolis: University of Minnesota Press (1977).

8. Jarrett, F.G., and Lindner, R.K., Research benefits revisited. Review of Marketing and Agricultural Economics 45 (December, 1977): 167-178.

9. Nagy, J.G. and W.H. Furtan, Economic Costs and Returns From Crop Development Research: The Case of Rapeseed Breeding in Canada," Canadian Journal of Agricultural Economics 26 (1978): 1-14.

10. Pasour and Johnson, "Bureaucratic Productivity: The Case of Agriculture Revisited," Public Choice 39 (1982): 301-317.

11. Peterson, W.L., "Returns to Poultry Research in the United States," Journal of Farm Economics 49 (1967): 656-69.

12. Ruttan, V.W. Agriculture Research Policy, University of Minnesota Press, Minneapolis, 1982.

13. Schmitz, A. and D. Seckler, "Mechanical Agriculture and Social Welfare: The Case of the Tomato Harvester," American Journal of Agricultural Economics 52 (1970): 569-78.

14. Schultz, T.W., The Economic Organization of Agriculture, McGraw-Hill, New York, 1953.

15. Scobie, G.M. and R.T. Posada, "The Impact of Technical Change of Income Distribution: The Case of Rice in Colombia," American Journal of Agricultural Economics 60 (1978): 85-91.

ASIAN AGRICULTURAL RESEARCH REVIEW PROJECT REPORTS

UM/EDC Bulletins

81-1	Vernon Cardwell, James C. Moomaw, Vernon W. Ruttan, "Agricultural Research in Indonesia" (March 1981)
81-2	Vernon W. Ruttan, "The Asia Bureau Agricultural Research Review" (March 1981)
81-3	Robert E. Evenson, Paul E. Waggoner, Paul R. Bloom, "The Agricultural Research System of The Philippines: A Reconnaissance Report" (May 1981)
82-1	Carl E. Pray, Vernon B. Cardwell, Bo G. Crabo, Paul S. Teng, "The Agricultural Research System of Pakistan: The Report of the Minnesota Reconnaissance Team" (Revised October 1982)
82-2	M. Prahladachar, "Income Distribution Effects of Green Revolution in India: A Review of Empirical Evidences" (April 1982)
83-1	David C. Salmon, "Congruence of Agricultural Research in Indonesia 1974-1978" (January 1983)
83-2	Vernon W. Ruttan, "Reforming the Global Agricultural Research Support System" (March 1983)
83-3	Joseph G. Nagy, "Estimating the Yield Advantage of High Yielding Wheat Varieties: The Use of On-Farm Yield Constraints Data" (September 1983)

UM/EDC Reprints

82-1	Carl E. Pray, "The Economics of Agricultural Research in Bangladesh" (December 1979)
82-2	Carl E. Pray, "The Green Revolution as a Case Study in Transfer of Technology" (November 1981)
82-3	V.W. Ruttan, "Bureaucratic Productivity: The Case of Agricultural Research" (1980) E.C. Pasour and M.A. Johnson, "The Case of Agricultural Research Revisited" (1982) V.W. Ruttan, "A Rejoinder" (1982)

Other Reports

UM/EDC REPORT, 1980/82	Carl E. Pray, "Private Agricultural Research in Asia," pp. 14-27.