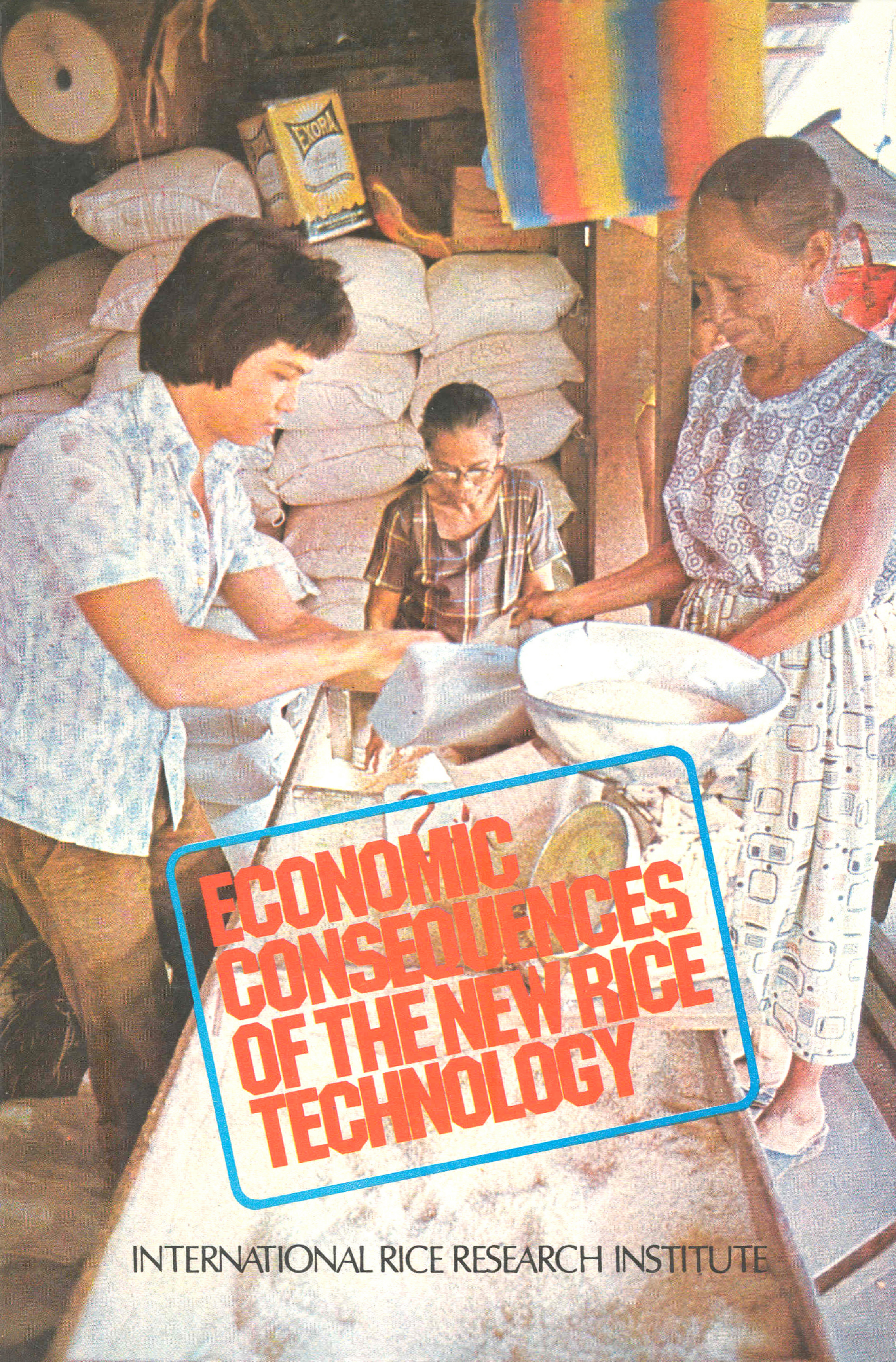


ECONOMIC CONSEQUENCES OF THE NEW RICE TECHNOLOGY

INTERNATIONAL RICE RESEARCH INSTITUTE

ECONOMIC CONSEQUENCES OF THE NEW RICE TECHNOLOGY

1978
THE INTERNATIONAL RICE RESEARCH INSTITUTE
LOS BAÑOS, LAGUNA, PHILIPPINES, P.O. BOX 933, MANILA, PHILIPPINES

Correct citation: International Rice Research Institute. 1978. Economic consequences of the new rice technology. Los Baños, Philippines.

The International Rice Research Institute currently receives support from a number of donors including The Ford Foundation, The Rockefeller Foundation, the United Nations Development Programme, the United Nations Environment Programme, the Asian Development Bank, the International Development Research Centre, the World Bank, and the international aid agencies of the following governments: USA, Canada, Japan, the United Kingdom, the Netherlands, Australia, the Federal Republic of Germany, Iran, Saudi Arabia, and New Zealand.

Contents

Foreword
Preface

OUTPUT AND SUPPLY

Exploring the gap between potential and actual rice yields: the Philippine case 3
R.W. Herdt and *T.H. Wickham*
Comments on "Exploring the gap between potential and actual rice yields: the Philippine case" 25
A.A.M. Ekramul Ahsan
Structural changes in rice supply relations: Philippines and Thailand 31
J.F. Sison, Somsak Prakongtanapan, and *Y. Hayami*
Comments on "Structural changes in rice supply relations: Philippines and Thailand" 49
J.G. Ryan

FARM INCOME STRUCTURE

Costs and returns for rice production 63
R.W. Herdt
Comments on "Costs and returns for rice production" 81
P.H. Calkins
Shares of farm earnings from rice production 87
C.G. Ranade and *R.W. Herdt*
Comments on "Shares of farm earnings from rice production" 105
R.S. Sinaga and *B.M. Sinaga*

LABOR AND MECHANIZATION

Labor utilization in rice production 113
R. Barker and *V.G. Cordova*
Comments on "Labor utilization in rice production" 137
K. Griffin
Mechanization and use of modern rice varieties 145
B. Duff

Comments on “Mechanization and use of modern rice varieties” 165
R.A. Morris and *Affendi Anwar*

FERTILIZER AND WATER

Modern rice varieties and fertilizer consumption 175
C.C. David and *R. Barker*
Comments on “Modern rice varieties and fertilizer consumption” 213
G. Desai
Complementarities among irrigation, fertilizer, and modern rice varieties 221
T.H. Wickham, R. Barker, and *M.V. Rosegrant*
Comments on “Complementarities among irrigation, fertilizer, and modern rice varieties” 233
L. Small

SOCIAL BENEFITS

Social returns to rice research 243
R.E. Evenson and *P.M. Flores*
Comments on “Social returns to rice research” 267
G.M. Scobie
Market price effects of new rice technology on income distribution 283
Y. Hayami and *R.W. Herdt*
Comments on “Market price effects of new rice technology on income distribution” 303
P. Pinstrup-Andersen

POLICY

New rice technology and national irrigation development policy 315
M. Kikuchi and *Y. Hayami*
Comments on “New rice technology and national irrigation development policy” 333
A. Siamwalla
New rice technology and policy alternatives for food self-sufficiency 337
R. Barker, E. Bennagen, and *Y. Hayami*

Comments on "New rice technology and policy alternatives for food self-sufficiency" 363
D.D. Hedley
New rice technology and agricultural development policy 367
V.W. Ruttan
Comments on "New rice technology and agricultural development policy" 383
A. Valdes
General comments 387
C.H. Hanumantha Rao
General comments 395
G. Ranis
Participants 402

Foreword

SCIENTISTS AT the International Rice Research Institute (IRRI) are keenly aware that new technology, although an essential element of agricultural development, can have harmful as well as beneficial effects. Research to identify socioeconomic consequences of the introduction of the new rice technology provides important information for the strategy and design of biological science and engineering research. IRRI's modest efforts in examining the consequences of the new technology have paid high dividends as the contents of this volume will attest.

The conference on the "Economic Consequences of the New Rice Technology" held at IRRI 13–16 December 1976 brought together a number of eminent social scientists 1) to exchange views on research procedures and findings, 2) to appraise the past efforts in *consequences* research at IRRI, and 3) to help set the goals and priorities for future work. Drs. R. Barker and Y. Hayami acted as convenors of the conference and assumed most of the responsibility for technical editing of the papers presented.

These published proceedings reflect the high degree of complementarity between research efforts in the biological and the social sciences.

N.C. Brady
Director General

Preface

THE DEVELOPMENT AND DIFFUSION of modern rice varieties since the mid-1960's have had a profound impact on the economies in tropical and subtropical Asia. Discussions of the socioeconomic consequences of the new rice varieties generated a large mass of literature, both scientific and popular. In many cases, however, the discussions have been impressionistic, not based on solid empirical evidence, as reflected in the sudden shift in the public mood from the initial enthusiasm on the *green revolution* to the current worry about a *world food crisis.*

Since the establishment of the International Rice Research Institute, its economists have engaged primarily in production-oriented micro research to maximize interactions with their colleagues in the biological sciences and in engineering. The objective was to achieve IRRI's primary mission to develop technology for the increase of rice production on farms in developing countries.

That the technology developed must improve the welfare of rural people engaged in rice production has always been kept in mind, however. Likewise, national policies on prices, trade, and provision of infrastructure such as irrigation were clearly recognized as the basic factors either constraining or promoting the realization of the potential of new rice technology. Thus, efforts were made to analyze broader social and economic problems, such as the impact of new rice technology on employment and income distribution, and the interactions between policy and technology.

Until recently, such research was ad hoc, primarily a by-product of direct production-oriented research. The analysis was limited mostly to problems in the backyard of IRRI, namely the Philippines. The trend toward wider use of the modern rice technology has, however, increased the need to assess its broad impact on the various aspects of economy and society in all of rice-growing Asia. In consideration of that need, IRRI organized in 1975 the major program area of *Economic Consequences of New Rice Technology.*

Because the problems to be examined by the *consequences* program are broad and versatile, analyzing them comprehensively is clearly beyond the capacity of IRRI or any other single agency. The need for collaborative research among national and international agencies thus became obvious. For that reason, IRRI organized this conference on the present state of knowledge and the future research need inherent in the socioeconomic consequences of new rice technology.

As bases for the discussion, resource papers based on accumulated empirical research findings during the past 10 years were prepared by IRRI economists. Discussants selected from among the specialists studying the socioeconomic impact of new rice technology in various parts of the world developed positive arguments to either support or refute the conclusions in the resource papers. The conference thus served as an overall critical review of IRRI's *consequences* research. At the same time, it identified the present state of knowledge through the discussions on whether — and how much — the findings at IRRI with respect to the Philippine case have anything in common with those in other countries.

The resource papers and the discussion papers presented at the conference are compiled in this volume. Although the problems covered are far from comprehensive, the materials add significantly to solid empirical evidence and can serve as the basis for future research to resolve controversial issues concerning the development and diffusion of new rice technology in Asia.

Randolph Barker and Yujiro Hayami

OUTPUT AND SUPPLY

Exploring the gap between potential and actual rice yields: the Philippine case[1]

R.W. HERDT AND T.H. WICKHAM

IN THE INITIAL FLUSH of enthusiasm that followed the release of the first tropical, semidwarf rice varieties that are highly responsive to fertilizers, predictions of imminent self-sufficiency for many of the developing countries were common. The Philippines was mentioned prominently among those expected to achieve self-sufficiency. But after a brief period in 1970 without rice imports, demand in the Philippines regularly exceeded production between 1971 and 1975, with self-sufficiency again proclaimed in 1976. Apparently some problems or constraining factors were not appreciated when the seed-fertilizer revolution started. We now explore some of the possible constraints to Philippine rice production to understand better why rice yields, and therefore rice production, have not increased more rapidly.

In this paper, constraints to rice production include the main factors that keep rice yields low. We briefly review constraints to the adoption of yield-increasing technology and explore in detail the constraints to increasing yields on existing rice land. We are primarily concerned with production constraints that affect farmers and that can be modified, not with those that presently appear to be outside the scope of man's influence.

The objective is to understand why on-farm yields are, on the average, so much lower than those under experimental conditions. The approach is to focus on farm-level constraints with the use of Philippine data.

The first section of the paper briefly discusses some issues relevant to the spread of new technology, the second section examines the possible constraints responsible for the gap between potential and actual yields, and the third section examines the results from a number of multifactor experiments to determine the possible effect of economic forces.

Agricultural economist, Department of Agricultural Economics, and agricultural engineer, Imgation and Water Management Department, International Rice Research Institute, Los Baños, Philippines.

---

[1] An earlier version of this paper was published in Food Research Institute Studies, Vol. 14, No. 2 (1975).

CONSTRAINTS TO THE SPREAD OF IMPROVED TECHNOLOGY

The flow of new rice technology from experiment stations must overcome physical, economic, and social constraints before that improved technology is adopted by farmers.

- To be adopted, the new technology must result in greater production per unit of inputs used than that from the previously existing technology.
- Given the costs, prices, tenure, and possible market discrimination that exist for particular individuals or locations, the technology must result in higher returns to family-owned resources than existing technology produces.
- The inputs, credit, markets, and the "social technology"[2] consisting of education, information, and decision-makers willing to take risks must be available for adoption to take place. Variability in yields and net returns must not be greater than that with the old technology.
- The social and personal changes as well as the output increases that result from accepting the new technology must be positively valued by both society and the individual.

There is no particular hierarchy in these requirements, but if any one is not fulfilled for a particular innovation or component of improved technology, then that innovation will not be adopted.

It appears that these conditions have been largely fulfilled for the modern varieties (MV) of rice in the Philippines. The varieties were first released in 1965. In 1966–67, they were planted in 2.7% of the rice area, and by 1969–70 they covered 44% of the area (Dalrymple, 1976). The proportion increased to 56% in 1971–72 and to 62% in 1974–75. Despite rapid adoption of new varieties, however, increases in Philippine rice production were disappointing.

PHYSICAL AND BIOLOGICAL CONSTRAINTS TO YIELDS

The data on actual yields of the MV on farms in the Philippines show why total rice production increases have been disappointing. On the average, MV grown with irrigation yielded 0.3 t/ha, or about 16% more than traditional varieties (TV); in rainfed fields they gave 0.1, or about 8% more than TV (Table 1). The yields are consistent with crop-cut yields in pilot studies. Such studies conducted in 1969–70 on 300 irrigated farms in Central Luzon and Laguna, revealed a 14% yield difference between TV and MV (Wickham, 1973). Absolute yield levels of the irrigated MV averaged 2.1 t/ha, far below the 6, 8, or 10 t/ha that was expected during the early days of IR8 (IRRI, 1967).

REASONS FOR THE YIELD GAP

Why is there such a difference between the expected and the actual? We hypothesize five possible reasons:

---

[2] We are indebted to Dr. Gelia T. Castillo of the University of the Philippines at Los Baños for this concept.

Table 1. Area and yield of modern[a] and traditional rice varieties under irrigated and rainfed conditions. Philippines, 1968–76 (Bureau of Agricultural Economics, Department of Agriculture and Natural Resources).

Year	Area (thousand ha)		Yield (t/ha)[b]	
	Modern	Traditional	Modern	Traditional
		Irrigated		
1968	447	862	2.0	1.6
1969	913	570	1.8	1.6
1970	827	519	2.2	1.9
1971	985	486	2.0	1.9
1972	977	355	2.1	1.7
1973	873	368	2.0	1.7
1974	1,194	299	2.1	1.9
1975	1,109	303	2.2	1.9
1976	1,207	287	2.3	2.0
Av.	948	450	2.1	1.8
		Rainfed[c]		
1968	254	1,260	1.3	1.2
1969	439	968	1.1	1.1
1970	527	828	1.5	1.5
1971	580	697	1.6	1.6
1972	850	698	1.4	1.4
1973	807	629	1.3	1.1
1974	982	552	1.5	1.2
1975	1,066	608	1.4	1.2
1976	1,092	602	1.5	1.3
Av.	733	760	1.4	1.3

[a] Includes IR-, BPI, and C-series. [b] Yield data converted from sacks of 44 kg. [c] Only lowland rainfed rice.

1. The reporting of yields by farmers is biased.

2. Expectations for the MV were unrealistically high; the *true potential yield* is considerably lower.

3. Potential yields of the MV are not fully expressed under conditions of poor environment.

4. Farmers strive for economic optimum, not maximum yields.

5. The supply of certain production inputs is less than is needed to achieve the economically optimum yield.

Bias in reporting yields. Three factors may bias reported yields:

1. Farmers count only what they actually recover after threshing, and may report their yields after deducting shares paid for harvesting (although care is taken to eliminate this source of error).

2. Errors arise because farmers tend to report the area of their farms to the nearest hectare or half hectare. Because yield is computed by dividing area into production, yields are miscalculated. A consistent direction of bias is serious, but there is no evidence on this point.

3. There is an obvious temptation to underreport for farmers who pay their land rentals as a percentage of harvest. The official data are therefore likely to understate actual yields and even careful survey techniques are likely to have the same problem (IRRI, 1974).

Each of these errors should bias reports of yields from TV and MV in the same way so that relative yields of the two types would be little affected. But even if bias led to underestimation of yields, it is not obvious that this alone would be enough to account for the difference between potential and actual yields of the MV.

High yield expectations. Undoubtedly, the original yield expectations for MV are high. Typical of the enthusiastic optimism was this comment by M. Yudelman (1972):"Where the new varieties of wheat, rice, and corn have been used with appropriate complementary inputs, the yields per acre have risen by as much as 100% . . ."

Those associated with the technological developments were only slightly more cautious. They reported yields 100 to 150% higher than prevailing averages, implying if not explicitly stating the widespread possibility of such yields. Others were somewhat more circumspect. In his 1969 discussion of prospects, Abel (1969) indicated that it was likely that the Philippines "could maintain physical self-sufficiency or have an exportable net surplus in rice for a number of years." Clearly, these expectations were too optimistic, but the question of the actual potential of the MV still remains.

Yields of 8 to 10 t/ha, repeatedly observed at IRRI, have been frequently mentioned and so provide a beginning, although admittedly arbitrary, estimate of the yield potential. The difference between 8 t/ha and the present Philippine national yield of about 1.8 t/ha is assumed as the gap between potential yield and actual yields.

Poor environment. Examining the environmental conditions where yields of 8 t /ha or more have been obtained, one soon wonders if that yield is typical of maximum yields even under those conditions. Is it only possible in dry seasons with exceptional weather even with the ideal water control that exists at IRRI?

To determine the maximum yields possible, considering year-to-year variability, we assembled data from the nitrogen response experiments on IR20, conducted cooperatively by IRRI and the Philippine Bureau of Plant Industry (BPI), during three to six dry seasons at four sites. The experiments were in four different regions of the country, and cannot represent the entire range of diversity in a country with as much climatic and soil variability as the Philippines.

Maximum dry season yields of IR20 averaged 6.4 t/ha for all sites and years with 120 kg N/ha (Table 2). Average yields of IR8 were higher, but IR8 is not presently grown by farmers and no longer appears to be a practical component of improved rice technology. Newer varieties, such as IR26, have a yield potential close to that of IR8.

The data indicated that with present technology, the average maximum potential yield is 6.4 t/ha. That, however, is only true for the dry season, when the high solar radiation clearly has a favorable influence on rice yields (De Datta and Zarate, 1970). In the Philippines, most of the rice is grown during

Table 2. Average yields of IR20 by season and amount of nitrogen applied at four Philippine sites, 1968-75 (Agronomy Department, IRRI).

Nitrogen (kg/ha)	Average yields (t/ha)				
	IRRI	Maligaya, Nueva Ecija	Pili, Camarines Sur	La Granja. Negros	Av.[a]
		Dry season			
	1969–75	*1970–75*	*1970–75*	*1970–73*	
0	4.5	3.6	3.9	4.1	4.0
60	6.1	4.9	5.6	5.7	5.6
90	6.6	5.2	6.0	6.1	6.0
120	6.9	5.5	6.2	6.9	6.4
150	7.0	5.6	6.1	6.6	6.3
180	6.8	5.5	5.8	5.9	6.0
Seasons (no.)	7	6	6	4	
		Wet season			
	1969–75	*1963–75*	*1968–75*	*1968–73*	
0	3.8	3.4	3.1	3.8	3.5
30	4.2	4.2	3.8	4.7	4.2
60	4.4	4.6	4.2	5.5	4.6
90	4.4	4.8	4.4	6.1	4.9
120	4.0	4.6	4.2	5.8	4.6
150	3.4	4.2	3.7	5.4	4.1
Seasons (no.)	7	8	8	6	

[a] Weighted by the number of seasons.

the wet season, when water is more readily available. About two-thirds is harvested between July and December, after maturing during periods of low solar intensity. One-third matures during the dry season and is harvested between January and June. Many parts of the country do not have a true dry season — there is considerable rain between January and June. But for our purposes the approximation of one-third in the dry and two-thirds in the wet season will be used.

Maximum wet-season yields at IRRI and the three BPI locations were generally obtained from 90 kg N/ha on IR20; the average at that level (four to six seasons and four locations) was 4.9 t/ha (Table 2). Calculating a weighted average of wet- and dry-season maximum yields results in an average maximum potential yield of 5.6 t/ha (a gap of 3.8 t/ha between actual and potential yields).

These data reflect average maximum yields with irrigation, but less than half of the rice area in the Philippines is irrigated. About 45% is rainfed lowland and 13% is upland. To determine the maximum potential yields for rainfed rice, yield data from several experiments by the IRRI Agronomy Department and the Rice Production Training and Research Department between 1972 and 1975 were examined. All the experiments were rainfed lowland with IR20, IR22, or the experimental line IR1529-280-3. Most of the trials were grown at sites in Central Luzon. In all, inputs — except the specified variables being

Table 3. Reported rainfed yields for IRRI varieties in various trials, 1972–1975 (IRRI annual reports, 1972–75).

Location	Year of trial	Main treatments in trial	Levels (no./treatment)	Av. yield (t/ha) of treatments with	
				Maximum yield	Minimum yield
IRRI	1972	Land preparation	3	4.8	3.2
	1973	Planting method	2		
		Water availability	2		
	1973	Nitrogen	5	4.7	3.5
		Variety	16		
	1973	Nitrogen	3	5.8	3.5
		Water availability	2		
		Variety	2		
		Time of application	2		
	1974	Nitrogen	5	3.1	2.4
		Variety	16		
Central Luzon	1972	Variety	2	5.0	2.0
		Location	2		
		Elevation	13		
	1972	Soil type	5	3.9	3.4
		Nitrogen	4		
		Phosphorus	3		
		Potash	3		
	1972	Package of fertilizer insecticide, herbicide	5	5.5	3.6
	1973	Nitrogen	3	3.7	1.9
		Insecticide & herbicide	2		
		Soil type	4		
	1973	Nitrogen	4	4.7	4.0
		Soil type	5		
	1973	Insecticide	8	4.1	3.5
		Location	9		
	1974	Soil type	3	5.3	1.8
		Location	2		
		Direct-seeding method	2		
Nueva Ecija	1973	Source of nitrogen	3	4.5	2.6
		Variety	2		
		Time of application	2		
	1974	Management package	5	4.6	2.2
	1975	Management package	5	3.6	2.2
		Av.		4.6	2.8

tested — were supplied to obtain maximum yield levels. The treatment giving the maximum yield at most sites was selected, and yields were averaged over all sites. The average maximums ranged from 3.1 to 6.9 t/ha (Table 3). The average over years and trials of the entries in the table gave an estimated potential maximum yield of 4.6 t/ha for rainfed lowland rice.

There are few data on maximum yields with MV as an upland crop, but some show the fertilizer response of upland IR5 (Table 4). Data from three sites, two seasons, and a number of planting dates show that maximum yields generally occurred with 120 kg N/ha, and that such yields ranged from 0.8 to 6.4 t/ha, with an average of 2.8 t/ha.

Having recognized the influence of irrigated, rainfed, and upland water

Table 4. Response to nitrogen of IR5 as an upland crop at three experiment stations in the Philippines. 1970–74 (IRRI Agronomy Department).

Site	Year	Grain yield (t/ha)[a] at kg N/ha		
		0	60	120
IRRI	1970	2.1	2.7	3.5
	1972	2.1	3.0	3.5
	1973	2.4	3.3	3.4
	1974	2.4	2.6	2.0
Maligaya, Nueva Ecija	1970	4.6	6.0	6.4
	1971	2.2	3.5	4.2
	1972	1.5	4.1	4.4
	1973	2.0	2.6	2.0
	1974	1.3	1.6	1.2
La Granja, Negros	1971	0.6	1.2	1.7
	1972	1.5	1.9	2.4
	1973	0.5	0.9	0.7
	1974	0.2	0.5	0.8

[a] Yields are averages over several seeding dates for each year.

regimes on maximum yields, we ask how realistic it is to expect farmers to obtain these maximum yields. Farmers may not find such yields within their reach, because they frequently have neither the control over water that an experiment station does nor the favorable rainfall and moisture conditions represented by the rainfed and upland maximum yield trials.

In recent years, much of the work of IRRI's Agricultural Economics Department has been on the adequacy or inadequacy of irrigation and its implications.

The data shown in Table 5 document some results for a 5,000-ha area within the Peñaranda River Irrigation System in Central Luzon. The area was classified into quarters, and the mean water availability for each quarter was determined as of a certain date during the dry season. Crop-cut yields were taken at the end of the season. All measures were most favorable for the first quarter, and decreased with distance along the canal.

In a 1969–70 study, 11 irrigated sites in Luzon were classified as to location along the first, second, or last third of the distribution canal (IRRI, 1974). Yield losses in the dry season, calculated on the basis of moisture-stress days, were 7% in the first third of the canal, 20% in the second third, and 25% in the last third. The average loss was 17%. Since the 11-site study is more broadly representative than the Peñaranda study, we assume that the average dry-season yields will be 17% lower than the maximum attainable under good water conditions. This conservative estimate of yield reduction due to moisture stress gives an average maximum attainable dry-season yield of 5.3 t/ha.

Yield reduction due to moisture stress in the wet season was considerably less than that in the dry season. At the 11 sites, the reduction was 4% in the first third of the canal system, 4% in the second third, and 8% in the last third, for an

Table 5. Adequately irrigated area and mean grain yields in a typical Central Luzon irrigation system.[a] 1973–74 dry seasons.

Section[b]	Command area Total (ha)	Command area Planted (%)	Planted area With water (%)	Planted area Yield (t/ha)
		1973		
1[c]	1,559	91	91	2.5
2[c]	1,171	82	67	2.2
3	873	59	35	1.5
4	1,907	22	0	0.4
Total	5,510	60	61	2.0
		1974		
1	1,220	97	97	2.6
2	1,134	90	93	2.4
3	1,988	62	63	2.2
4	1,422	28	28	2.1
Total	5,764	67	70	2.3

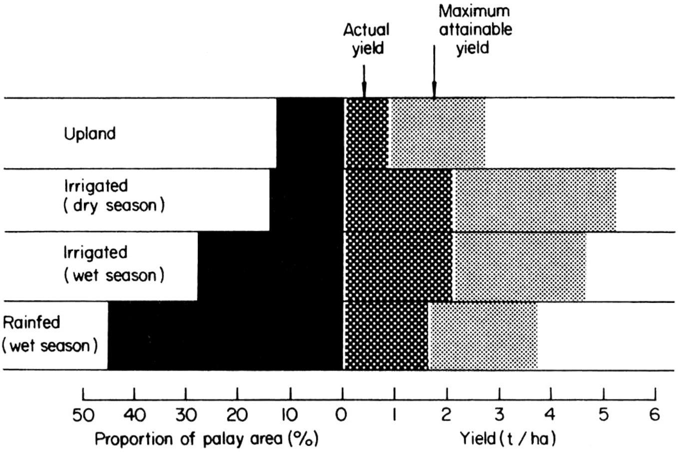
[a] Data are for consecutive sections served by Lateral C, Peñaranda River Irrigation System, Gapan, Nueva Ecija. [b] Section 1 is at the beginning of the lateral, Section 4 at the end. [c] Includes 274 hectares in Section 1 and 168 hectares in Section 2, which are outside the command area of those sections but were fully irrigated by pumps drawing water from the lateral (Tabbal, 1975).

average reduction of about 5%. That pulls the average maximum attainable wet-season yield down from 5 t/ha to 4.7 t/ha.

Similar estimates of the attainable maximum yields under representative rainfed conditions should be made because the previously quoted data were collected from selected rainfed plots. Research information on this aspect of rice production is extremely scarce. One available study relates to growing conditions prevailing in the sharply sloping areas adjacent to drainage creeks. In that study, plots were located at varying elevations in two well-defined small watersheds in Central Luzon. The yield of IR20 was reduced by 0.8 t/ha in one area and 0.9 t/ha in the other for each 1-m increase in elevation above the drainage outlet. This relationship may exaggerate the prevailing conditions in rainfed areas because the slopes in the study areas were much higher than the average for all rainfed areas. However, it seems reasonable to assume that moisture stress in unfavorably located rainfed areas reduced yields by about 20% below the levels observed experimentally. This would result in a 3.7 t/ha maximum attainable yield for a rainfed lowland rice crop.

The data on yields and area in different water regimes are summarized in Figure 1. Given these approximations, average actual yield is about 1.8 t/ha and maximum attainable average yield is about 4.1 t/ha for the country. The maximum attainable is, under present conditions, more than double the actual yields, but it is not quadruple the actual yields as might be implied by the 8 t/ha potential.

Our estimate of the maximum attainable national average yield (4.1 t/ha) takes into account year-to-year fluctuations in sunlight, rainfall, diseases, insect pests, and planting dates; seasonal variation and the fact that most of the rice is



1. Estimates of current actual yields, maximum attainable yields, and share of rice area for four types of rice culture, Philippines, 1969–72.

produced during the wet season when solar radiation is low; existing levels of water control in the irrigation systems of the country; the present proportion of rice grown under irrigated, rainfed, or upland culture; and the biological yield potential with today's technology.

It is well known that farmers' use of inputs is far below the level necessary for maximum yields. This behavior appears to result from farmers' ignorance of the effects of certain inputs on yield, especially insect and weed control; from the unavailability of inputs or cash with which to purchase them when they are needed; and from the economic calculations involved in using inputs.

Experimental data provide some insight into the effect of chemical control of insects and weeds. In IRRI insecticide experiments in 1971 and 1972, which used IR20 or a more recently released variety, yields were 36% higher when an insecticide was applied. The relative difference between treated and untreated plots was the same in the wet and dry seasons.

Experimental data intended to measure the effect of weed control were inconclusive for the purpose at hand. Yields of unweeded plots were usually low because weed growth was stimulated by the substantial fertilizer application used in the experiments. Typically, farmers who apply fertilizer also attempt to control weeds to some degree so a comparison of weeded and unweeded plots in experiments overstates the additional benefits of weed control. Hence, there is some question as to whether available data from weed-control experiments accurately reflect the effect of weed control in farmers' fields.

The yield contribution of individual inputs cannot be measured by simply considering the difference in yield with and without each input. A determination of the joint effects of various inputs is required; that, in turn, requires a carefully controlled multifactor experiment.

Economic constraints to yields. Farmers are influenced to aim for less than maximum yields by profit considerations and risk avoidance. Elementary production theory shows that because of diminishing returns, profits are always lower at maximum yield than at some lower level of input use. It may be, however, that farmers hesitate to use even the profit-maximizing levels of inputs because the greater cost of inputs might leave them badly in debt if the crop failed.

Although it seems certain that risk and diminishing returns both lead to reduced input use and, therefore, to lower yields, no one is sure exactly how farmers make their decisions, and what the precise impact of those decisions is.

Knowledge about how profit, risk, labor requirements, and other factors affect the decisions a farmer makes about the inputs he uses is extremely deficient. While most economists are convinced that farmers do not try to maximize yields, we are less sure of what they do maximize. Some may attempt to maximize profits or net returns over cash costs; others may seek a given rate of return or a given benefit:cost ratio for cash investments. In the following analysis the results that might occur if farmers followed a conservative cash-use rule, a profit-maximizing rule, or a maximum-yield rule are considered.

Expected net returns was used as the measure of profit. Because farmers make input decisions without knowing the price at which the crop will sell, they must depend on experience with price movements and on prices at planting time to judge what future prices will be. In most of the Philippines, prices have historically fallen an average of 20% from the time the wet-season crop is planted until it is harvested in November. Hence, expected net returns were calculated using the prices of inputs at planting time, and a rice price 20% lower than the price at planting.

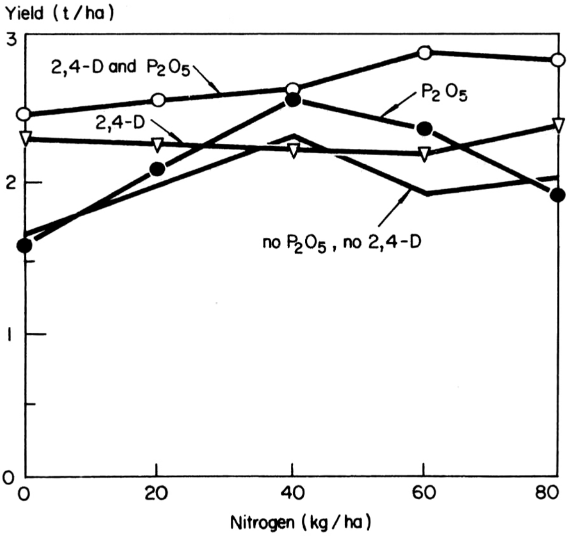
Other factors considered in measuring profitability were share rental agreements and the cost of harvesting, which increases as yields increase. As Alfred Marshall pointed out long ago, share-tenants will cultivate much less intensively than owner-operators or cash tenants if they pay the full cost of purchased inputs, but share with their landlords the increased revenues that result from them. This is becoming less a matter of concern in the Philippines as more and more farmers switch to fixed rents under land reform. Nevertheless, rent, seasonal price movements, the cost of harvesting, and interest on purchased inputs must be included in calculations of profitability.

Further difficulty arises because the level and combination of inputs that should be applied are not known regardless of what the farmers' objective function is. To determine them, data that relate the response of production to varying amounts of each input are needed. Many single factor experiments relate one input to output, but usually other factors are held constant at levels needed for maximum yield. For example, in experiments designed to test response to nitrogen, a high level of phosphorus, potash, weed control, and insect control is usually maintained to insure that these factors are not limiting. But to maximize profits, or to follow any decision rule other than yield maximization, farmers need to know the optimal combination of inputs. Such knowledge can be derived from analysis of varying combinations of input.

Two sources of data are available to examine these issues. The first is a rather diverse set of trials conducted during 1972 and 1973 in farmers' fields in Central Luzon. A second more homogeneous set of trials was conducted by IRRI's Agronomy Department in 1974, 1975, and 1976 in farmers' fields in Central Luzon.

The first experiment tested 36 different combinations of water control, weed control, and nitrogen and phosphorus applications in three irrigated and three rainfed locations during the 1973 wet season. In keeping with the objective of examining farmers's levels of inputs, the highest level of inputs was still modest. According to the results, location was of overwhelming importance. Application of 60 kg P_2O_5/ha (either basal or topdressed) was significantly better than no P_2O_5, and no significant yield improvement resulted when 2,4-D herbicide was supplemented with one hand weeding. Figure 2 shows the four resulting nitrogen response curves. Basal and topdressed P_2O_5 treatments were pooled because their cost and effect were about the same, but the 2,4-D plus hand-weeding treatments were eliminated because they did not increase yield but cost more than 2,4-D alone.

Yields without P_2O_5 or 2,4-D were lowest and those with both were highest. Nitrogen levels above 40 kg/ha generally gave lower yields unless both P_2O_5



2. Yield response to N in multifactor experiments under farmers' conditions. Three irrigated locations in Nueva Ecija, Philippines, 1973 wet season.

Table 6. Inputs, yields, and net returns of experiments in irrigated fields of three farms in Nueva Ecija, Philippines, 1973.

	Inputs					Increase over control		
Treatment no.	N (kg/ha)	P_2O_5 (kg/ha)	2,4-D	cost (US$/ha)	Total yield (t/ha)	Yield	Net return (US$/ha)	Net return per US$ cost
1	0	0	No	0	1.6	–	–	–
2	40	0	No	8	2.3	0.7[b]	b	4.5
3	60	0	No	12	1.9[a]	0.3	a	–
4	80	0	No	16	2.2[a]	0.6	a	–
5	0	60	No	14	1.6	0	b	–
6	40	60	No	22	2.5	0.9[b]	b	1.6
7	60	60	No	26	2.3[a]	0.7	a	–
8	80	60	No	30	2.0[a]	0.4	a	–
9	0	0	Yes	3	2.3	0.7	42	15.5
10	40	0	Yes	11	2.3[a]	0.7	a	–
11	60	0	Yes	15	2.2[a]	0.6	a	–
12	80	0	Yes	19	2.4	0.8[b]	b	1.7
13	0	60	Yes	17	2.5	0.9	41	2.5
14	40	60	Yes	25	2.7	1.1	46	1.8
15	60	60	Yes	29	2.7[a]	1.1	a	–
16	80	60	Yes	33	2.9	1.3	51	1.5

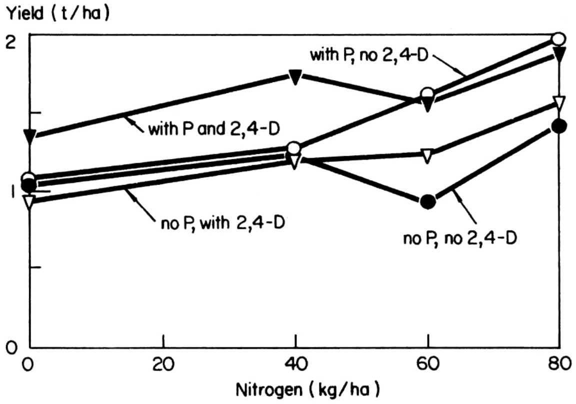
[a] Treatment with more input and the same or lower yield than anothertreatment. [b] Treatment with higher cost and the same or lower yield than another treatment.

and 2,4-D were used, illustrating clearly the production complementarity among the inputs.

Economic analysis is not required to eliminate all nitrogen treatments beyond the point of maximum output for a given P_2O_5 and weed control levels (treatments 3, 4, 7, 8, 10, 11, 15 in Table 6). Of the 9 treatments left, 4 (treatments 2, 5, 6, 12) are obviously uneconomic because they cost more than another treatment giving the same or higher yield. (Note that changes in the prices of inputs or of rice would require new consideration of which treatments are uneconomic in this sense.) Yields from the remaining 5 treatments (1, 9, 13, 14, 16) ranged from 1.6 t/ha for zero inputs to 2.9 t/ha with the highest level of inputs.

Calculations of costs and returns for these five treatments show that the highest yielding treatment is also the most profitable. Treatment 16 gave $51/ha increase in net returns over the control, but treatment 9 gave $42/ha and was much cheaper. There is relatively little difference in profitability between treatments 9 and 16, although the latter increased the yield almost twice as much. The cash cost of treatment 16, which is a reflection of the possible loss faced by the farmer, was 10 times greater than the cash cost of treatment 9. The return per unit of cash cost in treatment 9 was 10 times greater than that in treatment 16. With these alternatives, a farmer might quite rationally choose treatment 9 instead of 16.

The same experiment carried out on rainfed fields gave similar results (Fig. 3). Some of the high-input treatments again gave less output than lower input



3. Yield response to N under farmers' conditions. Three rainfed locations, Nueva Ecija, Philippines, 1973.

levels, leaving 11 treatments for analysis. Seven of the 11 were uneconomic because they gave either a lower yield at a higher cost or the same yield at a higher cost. The most profitable level of input use, which again gave the highest yield, was 60 kg N/ha, and 60 kg P_2O_5/ha, with chemical weed control (Table 7). The rate of return, however, was highest at a lower input level (treatment 9).

Table 7. Inputs, yields, and net returns of experiments in rainfed fields of three farms in Nueva Ecija, Philippines, 1973.

	Inputs					Increase over control		
Treatment no.	N (kg/ha)	P_2O_5 (kg/ha)	2.4-D	Cost (US$/ha)	Total yield (t/ha)	Yield	Net return (US$/ha)	Net return per US$ cost
1	0	0	No	0	1.0	–	–	–
2	40	0	No	8	1.2	0.2 [b]	b	–
3	60	0	No	12	0.9 [a]	–0.1	a	–
4	80	0	No	16	1.4	0.4 [b]	b	–
5	0	60	No	14	1.1	0.1 [b]	b	–
6	40	60	No	22	1.3	0.3 [b]	b	–
7	60	60	No	26	1.6	0.6 [b]	b	–
8	80	60	No	30	2.0	1.0	34	1.1
9	0	0	Yes	3	1.4	0.4	23	8.5
10	40	0	Yes	11	1.8	0.8	40	3.7
11	60	0	Yes	15	1.6 [a]	0.6	a	–
12	80	0	Yes	19	1.8 [a]	0.0	a	–
13	0	60	Yes	17	1.4	0.4 [b]	b	–
14	40	60	Yes	25	1.7	0.7 [b]	b	–
15	60	60	Yes	29	2.1	1.1	42	1.4
16	80	60	Yes	33	2.1 [a]	1.1	a	(–)

[a] Treatment with higher input and the same or lower yield than some other treatment. [b] Treatment with higher cost and the same or lower yield than another treatment.

Table 8. Economics of a multifactor experiment in irrigated fields, Gapan, Nueva Ecija, Philippines, 1972 dry season.

Treatment no.	Increases over farmers' treatments			Expected net returns per US$ cash cost
	Cash costs (US$/ha)	Expected net returns (US$/ha)	Yield (t/ha)	
1 (farmers')	–	–	3.9	–
2	7	44	0.5	6.5
3	15	42	0.6	2.9
4	21	64	1.2	3.0

Table 9. Economics of a management-package trial in irrigated fields, Gapan, Nueva Ecija, Philippines, 1972 wet season.

Treatment no.	Increase over the farmers' treatments			Expected net returns per US$ cash cost
	Cash costs (US$/ha)	Expected net returns (US$/ha)	Yield (t/ha)	
1 (farmers')	–	–	3.2	–
2	7	61	0.7	9.0
3	23	83	1.3	3.6

A related dry-season experiment had combinations of N, P_2O_5, and weed control (Table 8). There was no zero cash input level because farmers' treatments using N and weeding were taken as the standard for comparison. The best treatment yielded 1.2 t/ha more than the lowest yielding treatment. The highest yielding treatment gave the best returns, but it was not much more profitable than the somewhat lower input treatments. Treatment 2 gave net returns of $6.5/$ cash cost; treatment 4 gave $3/$.

In a simple 1972 trial comparing two improved management packages with farmers' treatments, the highest yielding package consisted of additional fertilizer and 2,4-D weed control that cost $23 more than the farmers' treatment (Table 9). It increased net returns by $83/ha. The lower cost input package was two-thirds as profitable, but it cost only one-third as much as the high cost package and gave a rate of return nearly three times greater.

All the preceding experiments depended exclusively on farmers' pest control techniques. Inefficient pest control was one reason for the relatively low yields.

Two trials with high levels of insect control as treatments, in addition to fertilizer and weed control, were also examined. In a 1972 rainfed trial of five management packages, yield increases over the lowest input package ranged from 0.6 to 1.2 t/ha (Table 10). The maximum yield treatment cost $57/ha more than the control and gave net returns of $14/ha more. Maximum profit, however, was recorded with treatment 2, which cost $14/ha more than the control and had $19/ha greater net returns than the control. It had the highest rate of return as well.

Table 10. Economics of a management-package trial in rainfed fields, Gapan, Nueva Ecija, Philippines, 1972.

Treatment no.	Increase over the control: Cash costs (US$/ha)	Increase over the control: Expected net returns (US$/ha)	Increase over the control: Yield (t/ha)	Expected net returns per US$ cash cost
1 (control)	–	–	2.1	–
2	14	19	0.6	1.3
3	28	19	0.8	0.7
4	40	14	0.9	0.3
5	57	14	1.2	0.2

In 1973, the trial was modified to test three levels of insect and weed control and three levels of nitrogen. Yields were substantially higher than in the other rainfed trials, partly because high levels of P and K were used, and because the plots were located where moisture stress would not be a problem. A few input treatments that resulted in uneconomic yields were eliminated, leaving four treatment combinations for which costs and returns were computed (Table 11). The maximum profit occurred with treatment 2, with a yield increase of 1.3 t/ha over the control. The maximum yield treatment (4) was less profitable than the low-input one because the latter cost much less — only $l0/ha compared with $49/ha. The rate of return on the low-input treatment was also considerably higher.

Beginning in the 1974 wet season, IRRI established a set of experiments in farmers' fields in Nueva Ecija to determine the yield response to alternative combinations or "packages" of inputs. Between 3 and 11 experiments were conducted each season; instead of summarizing them individually, we present data showing the average results for each season.

In the first three seasons, all factors in the experiment were increased from the low to the high treatment. In the last two seasons, first one factor and then others were increased. To illustrate we show the cost of each input included in the treatments.

Table 11. Economics of a management-package trial in rainfed fields, Gapan, Nueva Ecija, Philippines, 1973.

Treatment no.	Increase over the control: Cash costs (US$/ha)	Increase over the control: Expected net returns (US$/ha)	Increase over the control: Yield (t/ha)	Expected net returns per US$ cash cost
1 (control)	–	–	1.9	–
2	10	84	1.9	8.9
3	45	71	1.3	1.6
4	49	82	1.6	1.6

Table. 12. Economics of management-package experiments in seven farmers' fields in Nueva Ecija, Philippines, 1974 wet season.

Treatment no.	Increase over the farmers' treatment						Sites (no.) with	
	Cash cost (US$/ha)			Net benefits (US$/ha)	Yield (t/ha)	US$ return per US$ cost	Increased net benefits	Decreased net benefits
	Fertilizer	Weed control	Insect control					
1 (farmers')	–	–	–	–	1.7	–	–	–
2	13	12	30	11	0.2		3	4
3	41	9	76	–18	0.4	0.7	3	4
4	73	15	137	–32	0.7	0.7	2	5
5	98	27	227	–165	0.5	0.2	0	7

Table 13. Economics of management-package experiments in three farmers' fields in Nueva Ecija, Philippines, 1975 dry season.

Treatment no.	Increase over the farmers' treatment						Sites (no.) with	
	Cash cost (US$/ha)			Net benefits (US$/ha)	Yield (t/ha)	US$ return per US$ cost	Increased net benefits	Decreased net benefits
	Fertilizer	Weed control	Insect control					
1 (farmers')	–	–	–	–	4.5	–	–	–
2	25	12	30	–66	–0.9	negative	0	3
3	53	9	79	–71	0.3	negative	1	2
4	80	15	110	38	1.0	1.4	2	3
5	107	27	205	49	2.2	1.2	2	3

Table 12 shows the average results for experiments run during the 1974 wet season. The four packages raised yields modestly, but except for treatment 2, the net benefits from the alternative treatments were lower than those from the farmers'. The reason was partly the high cost of insecticides and partly the frequent typhoons during that season.

In the dry season of 1975, similar experiments were conducted in three farmers' fields (Table 13). Yield increases from treatments 4 and 5 were considerably higher than those during the previous wet season, but net benefits and the rate of return on investment was low because input costs were high. In the following wet season, input levels were somewhat lower than the previous year's, but the same pattern was observed (Table 14). High inputs resulted in yield increases of up to 1.2 t/ha with treatment 5, but treatment 2, which cost almost exactly the same as the farmers' treatment gave the highest profit. This suggests that farmers could have used their modest levels of inputs somewhat more efficiently, and that much higher levels would not have been profitable that season.

In 1976, the treatments tested were again modified to include a lower cost level of insect control, which was uniform for the high treatments. That, along with good weather, resulted in a set of treatments more profitable than the previous year's. Increases in dry-season yield and profits were impressive (Table 15). Yields in the wet season were increased by as much as 1.6 t/ha (Table 16), compared with 1.2 t/ha and 0.6 t/ha in the previous two years. Both treatments 3 and 4 were substantially more profitable than the farmers'.

The series of experiments in farmers' fields beginning with the 1974 wet season (Tables 12–16) have shown a steady improvement in the economic performance of the high packages. The improvement is due partly to better yields and partly to lower cost levels of insect control. It reflects a growing awareness of the relative costs and returns of various input components as well as increasing skill in applying those inputs. It is likely that farmers as well as researchers

Table 14. Economics of management-package experiments in 11 farmers' fields in Nueva Ecija, Philippines. 1975 wet season

Treatment no.	Increase over the farmers' treatments						Sites (no.) with	
	Cash cost (US$/ha)			Net benefits (US$/ha)	Yield (t/ha)	US$ return per US$ cost	Increased net benefits	Decreased net benefits
	Fertilizer	Weed control	Insect control					
1 (farmers')		–	–	–	3.2	–	–	–
2	19	12	25	20	0.2		7	4
3	40	8	49	20	0.5	1.5	7	4
4	61	14	86	–24	0.6	0.8	4	7
5	03	26	135	–35	1.2	0.8	3	8

Table 15. Economics of management-package experiments in nine farmers' fields in Nueva Ecija, Philippines, 1976 dry season.

Treatment no.	Increase over the farmers' treatment						Sites (no.) with	
	Cash cost (US$/ha)			Net benefits (US$/ha)	Yield (t/ha)	US$ return per US$ cost	Increased net benefits	Decreased net benefits
	Fertilizer	Weed control	Insect control					
1 (farmers')		–		–	4.2	–	–	–
2	41	20	24	112	0.4		6	3
3	75	20	101	238	2.1	3.6	7	2
4	109	20	101	254	2.3	3.0	6	3

Table 16. Economics of management-package experiments in nine farmers' fields in Nueva Ecija, Philippines, 1976 wet season.

Treatment no.	Increase over the farmers' treatment						Sites (no.) with	
	Cash cost (US$/ha)			Net benefits (US$/ha)	Yield (t/ha)	US$ return per US$ cost	Increased net benefits	Decreased net benefits
	Fertilizer	Weed control	Insect control					
1 (farmers')		–		–	2.8	–	–	–
2	36	20	28	108	0.9	7.0	7	2
3	60	20	73	124	1.4	2.4	8	1
4	84	20	73	126	1.6	2.1	8	1

go through a learning process upon the introduction of new technology. The process may also account for some of the observed yield gap.

The economic analysis of all experiments is summarized in Table 17. In three of the eight cases, the maximum yield treatment was also the maximum profit treatment. In the others, a lower yielding treatment gave higher profits. The maximum yield plots averaged 1.6 t/ha more yields than the control plots; the maximum profit plots averaged 1.2 t/ha more than the control. The plots with the maximum returns per dollar cash cost averaged 0.7 t/ha more yield than the control plots. Moreover, the plots with high rates of return were 75% as profitable as the maximum profit plots, while the latter required almost twice the cash input. The maximum yield plots gave the lowest rate of return, $1.5/$ invested, while the maximum profit plots averaged $1.8 and the high-return-per-dollar cash plots gave $2.1.

The pattern that emerges from these experiments can be summarized as follows:

1. In an experiment designed to obtain maximum possible yield, the treatment giving that yield will generally not give the maximum net return.

Table 17. Average increases in costs, returns, and yields of treatment levels based on three criteria and compared with those in famers' treatments in experiments in farmers' fields in Central Luzon, Philippines, 1972–76.

		Increases compared to farmers' levels of treatment with								
		Maximum yield			Maximum returns			Maximum return per US$ cost		
Years	Experiments (no.)	Net returns (US$/ha)	Cash costs (US$/ha)	Yield (t/ha)	Net returns (US$/ha)	Cash costs (US$/ha)	Yield (t/ha)	Net returns (US$/ha)	Cash cost (US$/ha)	Yield (t/ha)
					Dry season					
1972	1	64	21	1.2	44	7	0.5	44	7	0.5
1975	3	49	332	2.2	49	339	2.2	38	205	1.0
1976	9	254	230	2.3	254	230	2.3	238	84	2.1
					Wet season					
1972	2	48	40	1.3	52	19	1.0	40	11	0.7
1973	7	51	33	1.3	52	28	1.2	40	4	0.7
1974	7	–32	212	0.7	11	55	0.2	11	55	0.2
1975	11	–35	244	1.2	28	56	0.2	28	56	0.2
1976	9	254	177	2.3	254	177	2.3	112	84	0.4
All	49	94	187	1.7	114	121	1.4	82	65	0.8

2. The most profitable treatment will often be achieved at modest input levels and a yield somewhat lower — say 25 to 30% — than the maximum.

3. A low level of input use will, under most circumstances, be nearly as profitable as the maximum profit treatment and may give a higher rate of return. It will usually require considerably less cash investment, but may increase yields over the low input level only half as much as would the maximum yield treatment.

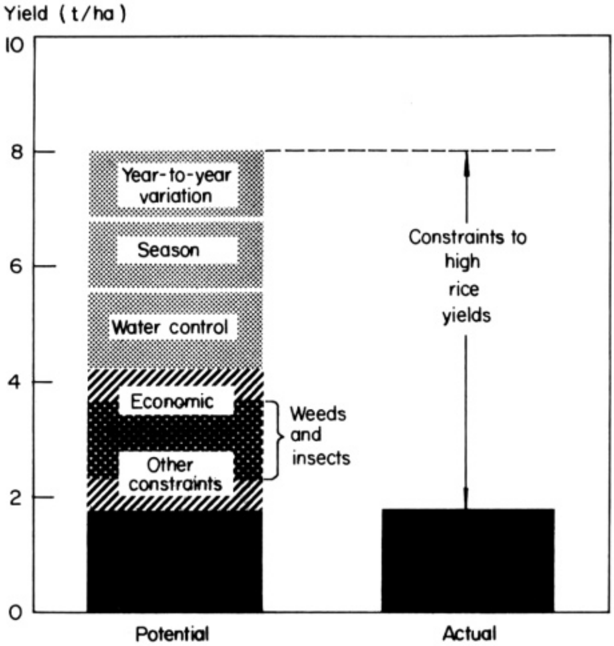
Given this general pattern, we guess that there are economic reasons why farmers' yields are 25% less than the previously defined attainable maximum of 4.1 t/ha. If that assumption is accepted, the economically attainable average yield from MV — with existing water control, seasonal distribution of production, and normal weather variation — is about 3.1 t/ha, leaving an unexplained gap of 1.3 t/ha between actual and attainable yield.

Other constraints. The final difference between the economically attainable national average yield and the reported actual yield in the Philippines can be attributed to yield losses due to pests and diseases that could be economically prevented, response bias, poorer soils than represented in the experiments, unavailability of inputs, economically irrational unwillingness to use available inputs, and the fact that 40% or so of the rice area is still planted to lower yielding TV. Lack of insect and weed control probably represents the major portion of the final difference. In experiments, insect control can contribute 1.5 t/ha additional yield, and weed control equally as much. Part of the reason for this noncontrol is, of course, economic. It is likely that present levels of control are far below the economic optimum, but the levels used in experiments probably exceed the economic optimum. Perhaps, a 1.5 t/ha higher yield could be economically obtained from both practices in the Philippines. It is impossible to vigorously defend the breakdown among factors, but it is a beginning toward identifying the factors that keep yields low.

SUMMARY AND CONCLUSIONS

The major factors that appear to be keeping Philippine national rice yields more than 6 t/ha below demonstrated levels are summarized in Figure 4.

Lack of control over water is the single biggest constraint. If all rice was fully irrigated, maximum yields could average 5.6 t/ha. Because much rice is rainfed or upland, and because much of the irrigated area suffers moisture stress during part of the growing season, lack of water control reduces the attainable yield by 1.4 t/ha. Water control is responsible for 23% of the difference between maximum possible and actual yields. Available solar radiation and other factors associated with season account for another 1.2 t/ha or 19% of the difference. Lack of irrigation is also indirectly responsible for a portion of this season-effect, because with more irrigation capacity, a greater proportion of the crop would be grown in the dry season. Economic factors including risk account for about 1 t/ha or 17% of the difference. Other constraints accounting for the dif-



4. A preliminary allocation among factors that constraint rice yields in the Philippines.

ference between maximum possible and actual yields are combinations of factors, including year-to-year variability in weather and damage by pests and diseases (1.2 t/ha or 19%), and a residual including the nonavailability of inputs and nonadoption of new technology (22%). Part of these constraints could be overcome through the use of inputs that are economical, but to which farmers may not have access.

Many of these constraints can be reduced by appropriate investment, research, or policy actions. Investments in the construction of irrigation and drainage systems, and modification of their management can alleviate the constraints imposed by poor water control. Policy measures to insure favorable prices and to make credit available may ease the economic constraints. Research to develop varieties with a higher degree of resistance to unfavorable environments will result in less year-to-year variability. Properly focused research may develop some rice genotypes resistant to drought, some that produce high yields under deep water, some that give higher yields under the low-radiation monsoon season, and even some that, with the aid of microbes, produce a greater proportion of the nitrogen they require for high yields.

Extension of activities aimed at teaching farmers about available technology and steps to improve the distribution of inputs would make more inputs usable on farms.

The ability to manipulate most of the constraints exists, provided that those responsible for policy, research, and extension seize the opportunity to use it.

REFERENCES CITED

ABEL, M. A. 1969. Prospects for rice and corn production and trade in the 1970's. *In* Agricultural revolution in Southeast Asia, Rept. SEADAG [S.E. Asia Dev. Adv. Group], Rural Dev. Seminar, Honolulu, June 19–21, 1969.

ATKINSON, L.J., and D. E. KUNKEL. HYV in the Philippines, progress of the seed-fertilizer revolution (U.S. Department of Agriculture, ERS, preliminary draft, December 11, 1973, processed).

CASTILLO, G. T. 1972. The new rice technology and patterns of rural life in the Philippines. Pages 105–114 *in* International Rice Research Institute. Rice, science, and man. Los Baños, Philippines.

DALRYMPLE, D. 1976. Development and spread of high-yielding varieties of wheat and rice in the less developed nations. U.S. Department of Agriculture.

DE DATTA, S.K., and P.M. ZARATE. 1970. Biometeorological problems in developing countries. Biometeorology 4(1):187.

INTERNATIONAL RICE RESEARCH INSTITUTE. 1967. Annual report 1966. Los Baños, Philippines. 302 p.

INTERNATIONAL RICE RESEARCH INSTITUTE. 1970. Annual report 1969. Los Baños, Philippines. 266 p.

INTERNATIONAL RICE RESEARCH INSTITUTE. 1974. Annual report for 1973. Los Baños, Philippines. 266 p.

TABBAL, D. F. 1975. The distribution of water supply and water adequacy within a gravity irrigation system. MS. thesis, University of the Philippines at Los Baños, Laguna, Philippines. (unpubl.)

WICKHAM, T. H. 1973. Predicting yield benefits in lowland rice through a water-balance model. Pages 155–181 *in* International Rice Research Institute. Water management in Philippine irrigation systems: research & operations. Los Baños, Philippines.

YUDELMAN, M. 1972. The green revolution. Pages 281–294 *in* Comparative experiences of agricultural developing countries. Indian Society of Agricultural Economics, Bombay.

COMMENTS ON EXPLORING THE GAP BETWEEN POTENTIAL AND ACTUAL RICE YIELDS : THE PHILIPPINE CASE

A. A. M. EKRAMUL AHSAN

THE HERDT AND WICKHAM PAPER explores some possible constraints to Philippine rice production by examining studies on adoption of yield-increasing technology on existing rice farms and from which they determine the production potential. The determination was primarily based on microlevel analysis and deduction from sporadic experimental results. The objective was to understand why rice yields at the farm level were much lower than those at the experiment station level.

CONCEPT AND DETERMINATION OF POTENTIAL YIELD AND YIELD GAP

The International Rice Agro-Economic Network group of agronomists, statisticians, and agricultural economists have arrived at a reasonably clear concept of potential rice yield and yield gap and have developed a practical and realistic methodology. The conceptual model of potential yield and yield gap is in Figure 1. The relative magnitude of yield levels assumes experiment station yield levels as the maximum. Accordingly, three types of yield gaps are shown.

1. Gap between maximum yield at experiment stations and potential yield on rice farms (Gap I).
2. Gap between potential yield at rice farm and actual farm yield (Gap II).
3. Total gap (Gap I + II).

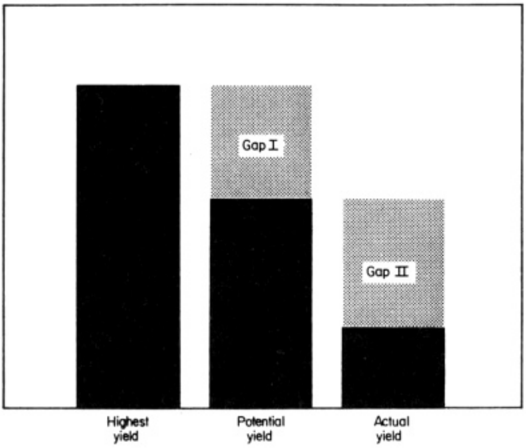
Gap I is useful primarily to the rice scientists and research administrators who determine research strategies. Gap II should be explored for its immediate usefulness to rice farmers, as well as to short- and medium-run national planning for increasing rice productivity.

Although Herdt and Wickham did not specify which yield gap was referred to, it appears that they referred to total gap (Gap I + II). The potential yield on the farm can be derived, however, by stepwise elimination of factors associated with the gap.

Methodology. The authors stated that the measurements of yield potential and the magnitude of the gap in the Philippines are not representative of all

---

Agricultural economist and head, Division of Agricultural Economics and Statistics, Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh.



1. Conceptual model of potential yield and yield gap.

situations within a country. In this regard, I point out that a single value, i.e. one specific level of potential yield and magnitude of yield gap, is not relevant to many agroclimatic and soil conditions in the country. I suggest, therefore, that the level of potential yield and the yield gap be situation specific, and that the situation be classified by regions in terms of seasonal variation, soil variability, and water regimes.

The Herdt-Wickham paper attempted an examination of the different water regimes by season — upland, irrigated dry and wet season, and rainfed — but the analysis that averaged all the situations to arrive at a single national potential yield level and its corresponding gap does not satisfy the requirements of research scientists, research administrators, policy makers, or rice farmers.

The method of measuring gap with respect to biological and economic factors is not specific. Also, there exists a conflict between physical maximum (national production) and economic optimum (profit considerations and rate of return for individual farmers) in terms of production level.

Bangladesh experience. In both absolute and relative terms, the modern rice varieties have spread less rapidly in Bangladesh than in the Philippines. Over a 10-year period the modern varieties spread to 15% of the total rice area of Bangladesh (Table 1). No dramatic yield increase has been experienced, however, although overall rice production recently increased.

Investigation of rice production to determine the yield potential of the improved technology and to quantify the magnitude of the yield gap revealed partial adoption of the improved technology. The potential yield levels of the

Table 1. Area (thousand ha) and production (thousand t) of modern varieties in Bangladesh, 1969–70 to 1975–76.

Years	Aus (March–August)		T. aman (June–December)		Boro (November–May)		Total	
	Area	Production	Area	Production	Area	Production	Area	Production
1969–70	17.42	85.51	11.75	56.50	234.90	1311.69	264.08	1453.70
% of season	0.51	1.89	0.20	0.53	26.57	45.14	–	–
% of total rice	0.17	0.47	0.11	0.31	2.28	7.27	2.56	8.06
1970–71	32.40	161.86	40.50	323.72	347.09	1812.55	419.99	2298.13
% of season	1.01	3.70	0.71	3.59	35.34	54.15	–	–
% of total rice	0.33	0.97	0.41	1.93	3.50	10.82	4.23	13.73
1971–72	49.01	196.98	253.53	1062.79	321.98	1475.08	624.51	2734.86
% of season	1.63	5.51	4.68	12.22	31.38	55.58	–	–
% of total rice	0.53	1.32	2.72	7.12	3.46	9.88	6.71	18.33
1972–73	66.42	255.01	558.50	1496.46	440.64	2046.18	1065.56	3797.65
% of season	2.26	7.35	9.76	17.54	44.70	64.73	–	–
% of total rice	0.69	2.00	5.80	9.87	4.57	13.49	11.06	25.04
1973–74	133.25	581.79	827.42	2988.34	588.87	2460.00	1549.53	6030.12
% of season	4.28	13.60	14.46	29.21	56.01	72.57	–	–
% of total rice	1.35	3.25	8.37	16.69	5.96	13.74	15.67	39.07
1974–75	283.10	1061.27	501.80	1635.42	660.15	2485.96	1445.04	5182.64
% of season	8.90	24.31	9.20	17.85	56.77	72.35	–	–
% of total rice	2.89	6.26	5.12	9.64	6.74	14.65	14.75	30.55
1975–76	353.16	1310.17	557.28	1844.62	729.00	2718.06	1639.44	5872.84
% of season	10.32	26.56	9.67	17.15	60.00	75.00	–	–
% of total rice	3.39	6.78	5.36	9.55	7.01	14.07	15.76	30.41

Table 2. Seasonwise production potential and yield gap on rice farms, Bangladesh. 1975–76.

	Paddy (t/ha)		
	Aus upland (semidry season)	Aman rainfed (wet season)	Boro irrigated (dry season)
1. Maximum yield at Experiment Station	5.4	5.5	6.3
2. Maximum yield at farmer's plot (crop-cut survey)	5.4	4.7	7.3
3. Potential yield at farmer's plot (agronomic field trials)	5.8	4.7	6.2
4. Yield gap I			
I_1 = (difference between no. 1 & 2)	0	0.8	1.0
I_2 = (difference between no.1 & 3)	–0.4	0.8	0.1
5. Average farmer's yield	2.2	2.8	3.7
6. Yield gap II			
II_1 = (difference between no. 2 & 5)	3.2	1.9	3.6
II_2 = (difference between no. 3 & 5)	3.6	1.9	2.5

technology in the farmers' field for different seasons were determined in the pilot project area of the Bangladesh Rice Research Institute. The average yield of rice farms and the corresponding yield gap in each season were measured (Table 2).

The potential yield was highest in boro with irrigation. The potential yield level was determined on the basis of trials in farmers' fields. Maximum yield in farmers' plots was determined by crop-cut. It was assumed that the high yield level attainable by a certain farmer could be considered as the potential yield level for that area. That level was consistent with the potential yield determined by the agronomic field trials in farmers' fields, except in boro when farmers' yield was much higher than the yield at the experiment station.

The higher productivity of rice farms was associated with the extent and effective adoption of modem rice varieties and associated technology. In aus, early drought and weed infestation limited the cultivation of the modern rice varieties. Water depth, and photoperiod sensitivity in case of late planting are problems in the successful cultivation of the modern rice varieties in the transplanted aman season. The modem rice varieties are generally suitable for growing in boro except that they are susceptible to low temperature.

The socioeconomic investigation of technology adoption and the productivity analysis in the pilot project area revealed a higher yield potential of the modern varieties, but the unavailability of essential inputs limited their spread.

The farmer's inability to adopt the improved technology resulted from a low resource base and a lack of capital.

Given the above limitations, modern rice production technology with the available modern varieties does not guarantee a dramatic production increase on rice farms.

CONCLUSION

Successful introduction of the new rice varieties and the improved technology requires acquisition and application of new skills of husbandry and management and a massive infusion of capital for good water control and management. Follow-up studies are required to adequately assess the problems of wide-scale adoption of the modern rice varieties and to determine their changing production potential.

The extent to which the new rice varieties and the improved technology can increase rice productivity is determined by the quality and quantity of various resources, including human, and the extent to which these can be upgraded and reorganized by improving the distribution system for the required inputs and the application of other inputs. Studies on the resources base (environmental, human, and economic) are recommended to determine the extent to which economical rice production expansion can be achieved.

I share with Herdt and Wickham the belief that rice scientists now face the tougher challenge of developing appropriate technologies, including new varieties to fit into the local conditions and into unfavorable environmental conditions.

Structural changes in rice supply relations: Philippines and Thailand

J.F. SISON, SOMSAK PRAKONGTANAPAN, AND Y. HAYAMI

THIS PAPER[1] ATTEMPTS to estimate the structural changes in rice supply relations that occurred when modern rice varieties were introduced into Southeast Asia. It includes case studies in the Philippines and Thailand.

HYPOTHESIS AND METHOD

One of the major controversies in past development economics was whether small peasant producers in developing countries respond rationally to economic incentives. A Philippine study was made by Mangahas et al. (1965) for rice and maize, and a Thailand study was made by Behrman (1967) for rice, maize, cassava, and kenaf. The studies showed that almost without exception, the peasant producers do, in fact, respond rationally to price incentives.

Since the controversy was settled empirically, the initial enthusiasm for the analysis of farm supply response faded. Rice supply study has been no exception. As summarized in Table 1, most of the rice supply studies for developing countries, including those of Mangahas et al. and Behrman, based their analyses on data gathered before 1965.

Since then, however, a number of factors that might have resulted in major changes in the rice supply relations have developed.

First, new rice technology represented by modern semidwarf varieties was developed and diffused rapidly in the Philippines. Diffusion of the same technology lagged in Thailand, partly because of difficulty there with water control

Former IRRI research scholar, Institute of Agricultural Development and Administration, University of the Philippines at Los Baños, Laguna, Philippines; former IRRI scholar now in Bangkok; and visiting agricultural economist, International Rice Research Institute, Los Baños, Philippines, now in Tokyo, Japan.

---

[1] Based on M.S. dissertations completed at IRRI Agricultural Economics Department by Jerome F. Sison (1976) and Somsak Prakongtanapan (1976).

Table 1. Estimates of the price elasticities of area response to rice supply in selected periods for various countries and regions in Asia.

Country or region	Period	Elasticity[a] Short-run	Elasticity[a] Long-run	Source
Punjab (India-Pakistan)	1914–45	0.31	0.59	Krishna, 1963
India (Tamil Nadu)	1947–65	0.03	0.04	Madhavan, 1972
Pakistan				
(Summer and winter)	1948–63	0.05		Hussain, 1964
(Summer only)	1948–63	0.12		
Bangladesh	1949–68	0.13	0.19	Cummings, 1974
Indonesia				
(Java and Madura)	1951–62	0.03		Mubyarto, 1965
Philippines	1947–63	neg	neg	Mangahas et al., 1965
Ilocos	1954–64	0.22	0.51	
Central Luzon	1954–64	0.13	0.62	
Southern Tagalog	1954–64	0.24	0.42	
Eastern Visayas	1954–64	0.13	0.15	
Cagayan	1954–64	neg	neg	
Thailand	1940–63	0.18	0.31	Behrman, 1967
Northeast	1940–63	0–0.57	0–1.04	
Central	1940–63	0–0.62	0–3.12	
Thailand	1951–71	0.07		Olarn, 1975
Korea	1960–71	0.06	0.24	Korea Agric. Econ. Res. Inst., 1973
Japan	1915–35	0.01	0.65	Hayami and Ruttan, 1971

[a] Neg = negative estimates of price elasticity.

and partly because of a strong Thai preference for a higher quality rice. However, locally adapted semidwarf Thai varieties selected recently have been propagated rapidly, although limited primarily to dry-season irrigated fields.

The modern varieties (MV) are characterized by a high-yield response to fertilizer input, especially in irrigated fields. Their development and diffusion, together with investments in irrigation systems, should make rice supply more responsive to changes in the price of rice relative to the price of fertilizer and other current inputs. The studies conducted during the pre-MV period failed to estimate the positive response of yield to price. It might be possible to find the effect of price on rice yield if we used the time-series data of a more recent 10-year span.

Second, opening new land for cultivation has become more difficult and costly. The rate of expansion of the cultivated area in the Philippines declined significantly from the 1950's to the 1960's. In Thailand, even though expansion has not decelerated as much, the expansion of the cultivation frontier to a point of environmental deterioration is a problem of increasing concern. Rice area expansion can be achieved either by shifting areas from other crops to rice, or by opening new land for rice production. A "closing cultivation frontier," or a growing difficulty in expanding the area for cultivation in the Philippines and Thailand should reduce the price elasticity of area response for more recent years, as compared with the periods covered by Mangahas et al. and Behrman.

To test the two hypotheses, the first on the impact of MV irrigation developments on the yield response, and the second on the impact of a closing cultivation frontier on the area response, we estimated the simple regression models of farmers' responses for both pre- and post-MV periods in the Philippines and Thailand.

The basic models of the area and yield response functions are, respectively,

$A = F\ (P, Pa, I, T, Ta, W)$

and $Y = g\ (P, Pf, I, T, W)$

where: A = area planted to rice,

Y = rice yield per hectare,

P = price of rice,

Pa = price of alternative crops,

Pf = price of fertilizer,

I = condition of irrigation,

T = rice production technology,

Ta = production technology of altrenative crops, and

W = weather condition.

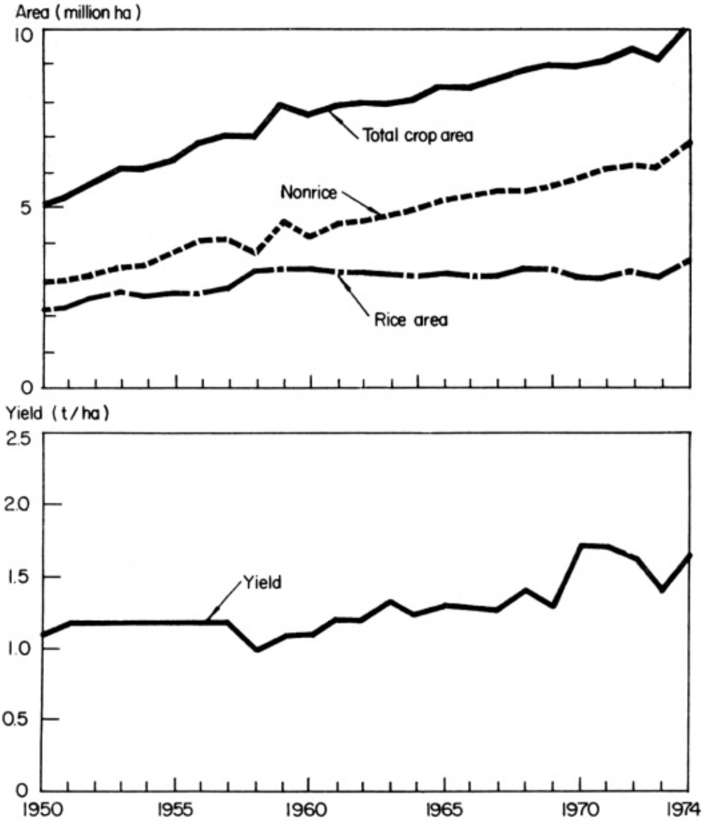
A large number of regression equations can be specified for different sets of data specifications, as explained in the next section. Both the simple model and a distributed-lag model of the Koyck-Nerlove variety are tried for the area response function, because an area change requires a longer adjustment period, especially when it involves the shifting of cultivation frontiers. Only the simple model is used for the yield response function, because the yield response is essentially a short-run phenomenon involving adjustments in current inputs, such as fertilizers, during a single production period.

The regression equations were estimated using the national aggregate time-series data. Although we conducted analyses for both whole nations, and separate regions within the nations, we limit this report to the results of national aggregate analysis.

Because farmers' decisions on the allocations of land and other inputs to rice production are made either before or during the production period, it is safe to treat the prices affecting farmers' production decisions as predetermined. Therefore, we tried only the single-equation approach and applied the ordinary least-sqaure method for estimation. Primarily for ease of computation and interpretation, the log-linear form was used exclusively for our functional specification.

DATA SPECIFICATIONS

Philippines. Aggregate time-series data used for the analysis of rice supply relations in the Philippines cover the period from 1949–50 crop year to the

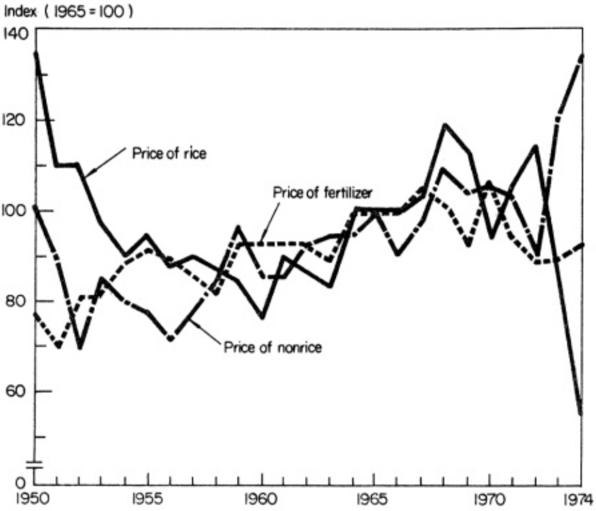


1. Trends in the areas planted to rice and nonrice crops, and in rice yield per hectare in the Philippines, 1950–74.

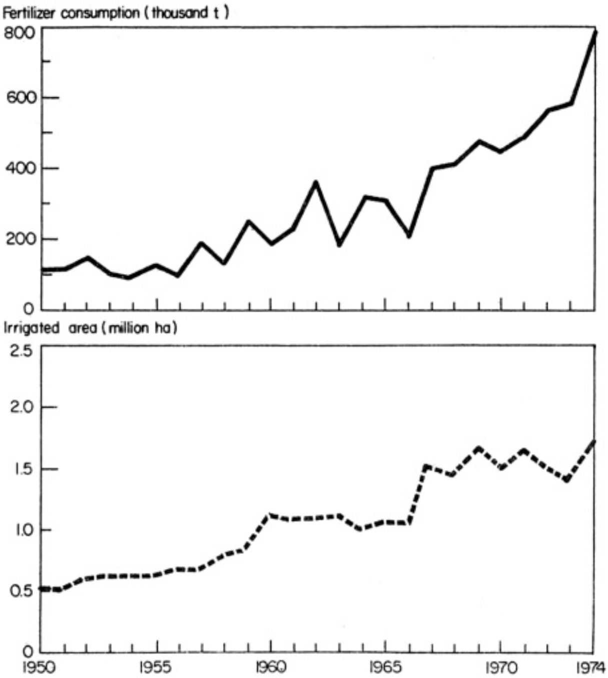
1973–74 crop year, the years for which data necessary for our analysis are available.

Data on rice and nonrice crop areas and on rice yield per hectare are plotted in Figure 1. (The areas are in gross terms, counted twice in case of double-cropping.) From the 1950's to the 1960's, the rate of expansion in total crop area declined, reflecting the tendency toward closing cultivation frontiers. The rice area became especially stagnant during the latter period. A slower increase in rice area than in nonrice crop area corresponded to the relative decline in the price of rice relative to the price of nonrice crops (Fig. 2). Despite an increase in the price of fertilizer in relation to the price of rice, the consumption of fertilizer continued to increase (Fig. 3). Rice yield per hectare was virtually stagnant, during the 1950's, but it began to show a rising trend in the 1960's (Fig. 1).

With those observations, we divided the whole period into two subperiods, 1950–60 and 1961–74, for which regression analyses were conducted sepa-



2. Trends in the prices of rice, nonrice crops, and fertilizer (deflated by the wholesale price index) in the Philippines, 1950–74.



3. Trends in irrigated area and fertilizer consumption in the Philippines, 1950–74.

rately. During the first period area expansion was the major factor that accounted for rice output growth; during the second period, the increase in yield per hectare became a major factor.

Most data used in this study were collected by the Bureau of Agricultural Economics (BAEcon) of the Department of Agriculture. Rice crop area (A) was in terms of area harvested for both the wet and the dry season. Rice yield per hectare (Y) was obtained by dividing total rice output (as paddy rice) by rice crop in a crop year.

Three series for the price of rice (P) were used:

- The average unit value obtained by dividing total output value by output quantity for a crop year,
- The average monthly price received by farmers for *palay ordinario,*
- The average monthly price received by farmers for *palay fancy.*

The latter two series were available only after 1954. Therefore, we extended them back to 1950 by multiplying the first series with the 5-year (1957–61) average ratios of the second and the third series with the first.

Two specifications for the price variable used for the area response function were:

- The average unit value of a previous crop year,
- The average prices received by farmers for 6 months before the planting period for the wet season (February–July) of both *palay ordinario* and *palay fancy.*

The three series were deflated by the wholesale price index, the price index of maize as a major alternative crop, and the price index of nonrice crops. Each of the variables of different specifications was, tried for the estimation of the area function.

The price series used for the estimation of the yield response function were those of the average prices of *palay ordinario* and *palay fancy* during the wet-season planting period (May–September). The prices were deflated by the price index of fertilizers. The average prices during the preplanting period (February–July) were also tried with similar results.

For the price of alternative crops (Pa) we used the price of maize, and the price index of nonrice crops (1965 = 100). The latter was constructed according to the Laspeyres formula covering maize, coconut, sugar, tobacco, and abaca. The price of alternative crops was included in the area response function either as a deflator of the price of rice.

The price of fertilizer (Pf) was represented by the price of ammonium sulfate, which was included in the yield response function as a deflator of the price of rice. Monthly wholesale prices of ammonium sulfate in Manila (collected by the Bureau of Commerce) were averaged for the same periods used for averaging rice prices for the yield response function.

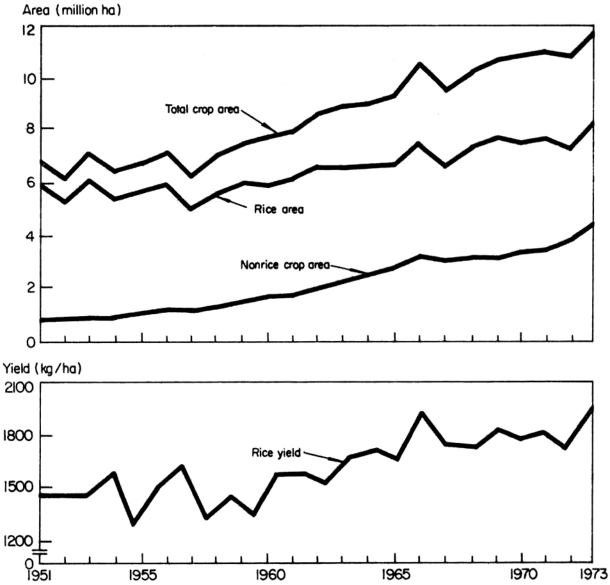
The irrigation variable (I) for the area response function was the ratio of irrigated area to total cultivated area. For the yield function, it was the ratio of irrigated rice area to total rice crop area.

For the technology variable in the area function, we used the average ratio of rice yield to maize yield per hectare for the past 5 years ($\bar{Y}_1$), which is supposed to represent the relative level of rice technology (T) to the technology of a major alternative crop (Ta). Another technology variable that was used in the area function was the ratio of rice yield to the average yield of five alternative crops ($\bar{Y}_2$), including maize, coconut, sugar, tobacco, and abaca. As a technology variable in the analysis of yield function, we tried the ratio of area planted with MV to total rice crop area (M). M is supposed to represent a level of rice production technology per se. In the yield function, only M was included in the regression analysis.

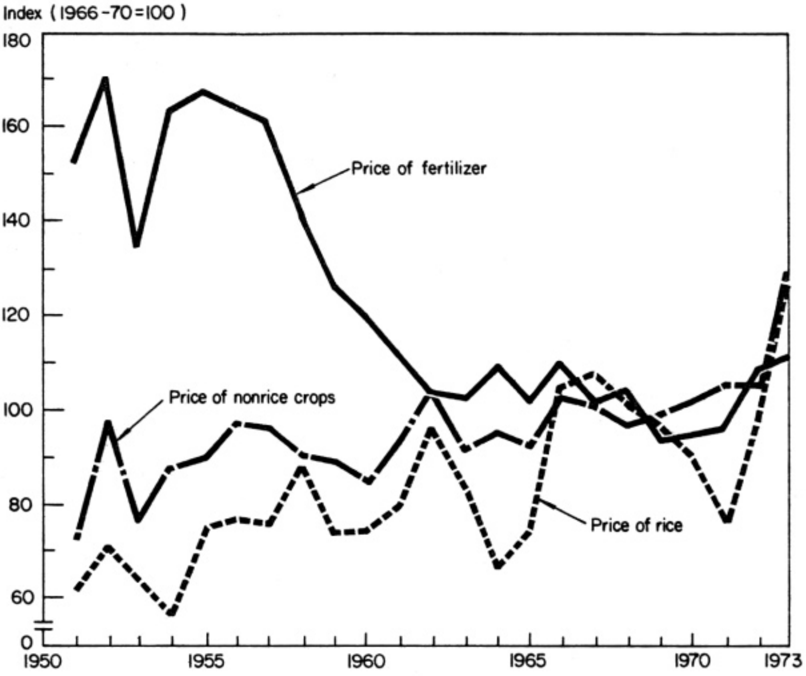
A major deficiency in our supply analysis for the Philippines was that we failed to specify any appropriate variable to represent weather (W). In the case of Thailand, the average rainfall is usually the decisive factor in determining both area planted to rice and yield. However, in the Philippines, typhoons, usually accompanied by heavy rainfall, are the major cause of crop damage. Therefore, it is difficult to select a single factor to represent weather conditions for rice production. For future improvement of rice supply analysis in the Philippines, the construction of an appropriate weather index will be a critical step.

Thailand. Aggregate time-series data used for the analysis of rice supply relations in Thailand cover the period from the 1951–52 crop year to the 1973–74 crop year.

Data on rice and nonrice crop areas, and of rice yield per hectare are plotted in Figure 4 (the areas are in gross terms, counted twice in case of double-



4. Trends in areas planted to rice and nonrice crops, and rice yield per hectare, in Thailand, 1951–73.



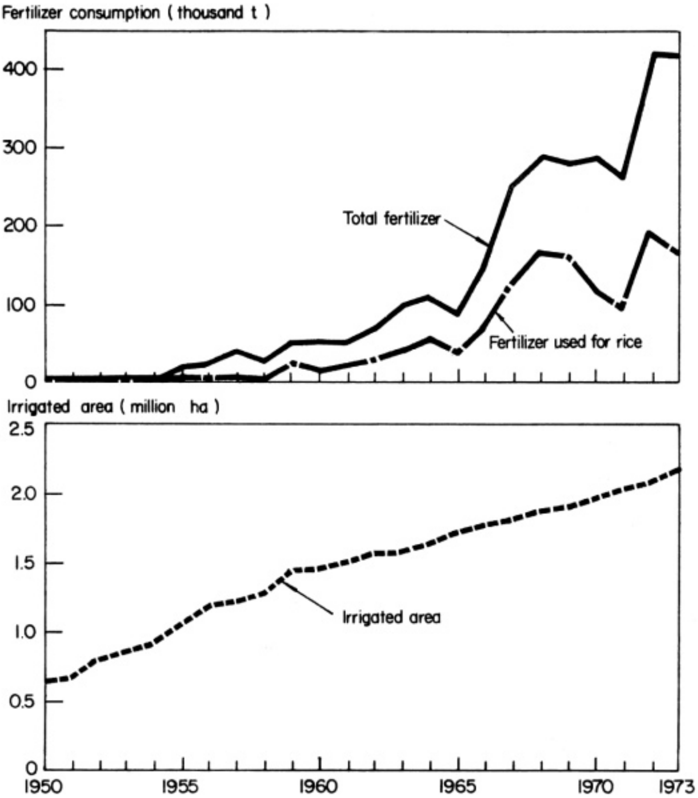
5. Trends in the price of rice, nonrice crops, and fertilizer (deflated by the wholesale price index) in Thailand, 1951–73.

cropping). Increases of rice area have been slow relative to those of the nonrice crop area, despite increases in the price of rice relative to the price of nonrice crops (Fig. 5). From the late 1950's to the mid-1960's, the price of fertilizer declined sharply. As if to follow this price decline, the consumption of fertilizer in Thailand increased sharply after 1964 (Fig. 6). Correspondingly, the level of rice yield per hectare also increased (Fig. 4).

With those observations, we divided the whole period into two subperiods, 1951–64 and 1965–73, for which rice supply function were estimated separately.

Rice crop area (A) was in terms of total area planted for both wet and dry seasons. Rice yield per hectare ($\bar{Y}$) was obtained by dividing total rice output (as paddy rice) by total rice crop area in a year. Both area and yield data were from the Rice Department, Ministry of Agriculture and Cooperatives.

The price of rice (P) was the average of monthly wholesale prices of grade 2 paddy in the Bangkok market. Two sources of the price data were the Division of Agricultural Economics (DAE), Ministry of Agriculture and Cooperatives for 1957–73, and the Department of Internal Trade (DIT) Ministry of Commerce for 1950–56. The two series for the overlapping years show very close agreement. The DAE series was extrapolated backward by multiplying the DIT series by the ratio between the two price series for 1957–61.



6. Trends in irrigated area and fertilizer consumption in Thailand, 1950–73.

Two specifications for the price variable were used for the area response function.

- The average price during the previous marketing period, December of previous year to April of current year, and
- The average price for the previous calendar year.

The two series were deflated either by the price index of nonrice crops or by the wholesale price index. Each of the four variations of the price variable thus obtained was tried in estimating the area response function.

The rice price variable used in the yield response function was the average price during the previous marketing period, December of previous year to April of current year, deflated by the fertilizer price index. The average price during the planting period, May to July of current year, was also tried but the results were inferior and are not reported here.

The price of alternative crops (*Pa*) was included in the area response function in the form of the price index of nonrice crops (1966–70 = 100). The index was constructed according to the Laspeyres formula involving cassava, kenaf, sugarcane, maize, and mung bean. This index was included in the estimation of the area response function either as a separate variable or as a deflator of the price of rice. Sources of original price data for index construction were the same as those for rice prices.

The fertilizer price variable (Pf) was the price index of fertilizers (1966–70 = 100) prepared by the Bank of Thailand. The index was included in the yield response function as a deflator of the price of rice.

The irrigation variable (I) for the area response functions was the irrigated area reported by the Royal Irrigation Department. We used the absolute area instead of the ratio of irrigated area to cultivated land area, because the data for the latter were not available. In the yield response function, I was the ratio of irrigated area to rice crop area.

For the technology variable (T), two specifications were used: ($\bar{Y}$) the average of rice yield for the past five years, and (M) the percentage of total rice crop area planted to MV. The two specifications were used alternately in the area function. But in the yield function, only M was used. $\bar{Y}$ was based on the data of the Rice Department, and M on the Dalrymple (1974) estimates.

The weather variable (W) was represented by the average annual rainfall based on the monthly rainfall data reported by the Department of Meteorological and Agricultural Statistics of Thailand for Changwat province.

FINDINGS

As explained in the previous section, we tried several alternative specifications for different variables. In combination they produced a large number of regression equations, especially for the area response model. Because it is difficult to choose *a priori* any single equation as superior to others, we discuss the findings of regression analysis of area response in terms of the distribution of estimated parameters rather than of the estimates of individual equations. This procedure implies a sensitivity test for a range of data specifications.

Philippines. The result of estimation of the area response function for the Philippines, using the simple and the distributed lag models, are summarized in Tables 2 and 3.

For the whole period (1950–74) as well as the two subperiods (1950–60 and 1961–74), the estimates of the price elasticity of area response are not statistically significant even at the 20% level. However, the price elasticity of area response declined from the first to the second period. Estimates of the short-run elasticity during the first period clustered around 0.1 to 0.2; those of the long-run elasticity, around 0.3. For the second period, estimates of the short-run and long-run elasticities both declined to less than 0.1.

The results seem to support the hypothesis that the price response of area planted in rice declined as the result of a “closing cultivation frontier,” which made the shifts of land to and from rice crop more difficult. However, it must be

Table 2. Results of estimation of area response function for the Philippines, using the simple model.[a]

	1950–74	1950–60	1961–74
Price elasticity	(16)	(10)	(10)
Range[b]	0.3 to .12	.06 to .35	.01 to .12
Mean[b]	.07	.15	.05
Mode	.06	.11	.05
Significance level[c]			
Irrigation elasticity	(16)	(10)	(10)
Range	.40 to .74	.85 to 1.23	.19 to 1.96
Mean	.57	1.01	.78
Mode	.54	.93	.19
Significance level	****	****	*
Technology elasticity ($\bar{Y}_1$)	(10)	(6)	(6)
Range	.27 to .73	.11 to .31	.07 to .41
Mean	.54	.21	.25
Mode	.71	.12	.29
Significance level	****		
Technology elasticity ($\bar{Y}_2$)	(6)	(4)	(4)
Range	neg [d]	neg	neg
Mean	neg	neg	neg
Mode	neg	neg	neg
Significance level			
Coefficient of determination (R^2)	(16)	(10)	(10)
Range	.870 to .931	.877 to .958	–.008 to .701
Mean	.897	.917	.315
Mode	.902	.955	.661

[a] Figures in parentheses are the number of regression equations estimated. [b] Ranges and means are calculated, excluding the largest and the smallest estimate. [c] Significance level for the majority of estimates (****, ***, **, * = significant at 1%, 5%, 10%. and 20%. respectively). [d] Neg = negative regression coefficients.

remembered that the estimated changes in price elasticities provide rather weak evidence, because the changes are not statistically significant at conventional levels according to the F-statistics derived from the covariance analysis.

Estimates of the price elasticity of area with respect to irrigation show that irrigation was the highly significant factor contributing to increases in rice crop area. From the first to the second period, the mode and mean of estimates of the short-run elasticity declined, but the range was expanded to include larger estimates for the latter period. Moreover, the mode and mean for the long-run elasticity are larger for the second period. Altogether, there is no evidence for the change in irrigation elasticity.

Coefficients of the relative level of rice production technology to the technology of alternative crops, as represented by the ratio of past 5-year average of rice yields to that of maize yields ($\bar{Y}_1$), are significant. In contrast, the ratio of the average rice yield to the average of five alternative crops ($\bar{Y}_2$) proved an inadequate variable in the area response function, with negative and nonsignificant coefficients. These results seem to reflect the fact that maize is the crop that competes with rice to a significant extent.

Although statistical evidence is weak, there is an indication that the elasticity of rice crop area with respect to technology ($\bar{Y}_1$) increased over time.

Table 3. Results of estimation of area response function for the Philippines, using the distributed lag model.[a]

	1950–74		1950–60		1961–74	
	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Price elasticity	(16)		(9)		(9)	
Range[b]	.01 to .07	.02 to .11	.01 to .23	.02 to .29	.01 to .06	.01 to .08
Mean[b]	.03	.06	.12	.17	.03	.05
Mode	.01	.06	.10	.28	.01	.07
Significance level[c]						
Irrigation elasticity	(16)		(9)		(9)	
Range	.26 to .64	.38 to .69	.47 to 1.26	.82 to 1.16	.19 to 1.72	1.40 to 2.14
Mean	.40	.53	.84	.94	.84	1.80
Mode	.31	.50	.47	.95	.19	2.20
Significance level	****	****	**	**	*	*
Technology elasticity ($\bar{Y}_1$)	(10)		(5)		(5)	
Range	.24 to .44	.31 to .76	06 to .19	.09 to .33	.06 to .46	$(\gamma < 0)$
Mean	.37	.51	.12	21	.20	$(\gamma < 0)$
Mode	.43	.75	.06	.09	.06	$(\gamma < 0)$
Significance level	**	**				
Technology elasticity ($\bar{Y}_2$)	(6)		(4)		(4)	
Range	neg[d]	neg	neg	neg $(\gamma < 0)$[e]	neg	neg
Mean	neg	neg	neg	neg $(\gamma < 0)$	neg	neg
Mode	neg	neg	neg	neg $(\gamma < 0)$	neg	neg
Coefficient of determination (R^2)	(16)		(10)		(10)	
Range	.714 to .928		.872 to .952		−.006 to .670	
Mean	.897		.917		.279	
Mode	.909		.950		.600	

[a] Figures in parentheses are the number of regression equation estimated. [b] Ranges and means are calculated, excluding the largest and the smallest estimate. [c] Significance level for the majority of estimates is ****, ***, **, I = significant at 1%, 5%, 10%, and 20%. respectively. [d] Neg. = negative regressions coefficients. [e] Coefficient of lagged dependent variable is negative.

The results of estimation of the yield response function are summarized in Table 4. The fits of the yield response function to the data of 1950–60 were very poor with the negative coefficients of determination adjusted for the degree of freedom. Such poor results were produced by the almost constant rice yield during the 1950's as shown in Figure 1. We cannot expect a decent fit of regression equations in the absence of variation in the dependent variable.

Estimates for the whole period show that the price of rice relative to the price of fertilizer was not a statistically significant factor in explaining yield variations in the Philippines, but irrigation and technology were highly significant.

Estimates of price elasticity are larger for 1961–74 than for 1950–60, but the differences are not statistically significant at conventional levels. Such results, are not inconsistent with the hypothesis that the yield response to price increased as a result of the introduction of MV and the development of irrigation systems, which made the marginal product curve of fertilizer steeper. However, such an inference should be taken with strong reservations because of the very poor fit of regression equations for the first period.

Table 4. Results of estimation of rice yield response function for the Philippines.

Time period	Elasticity[a]					R^2	D.W.
	Price[b]			Irrigation	Technology		
	P_1	P_2	P_3				
1950–74	0.02 (0.70)			0.20*** (2.79)	0.40*** (3.64)	0.787	1.6
		0.30 (0.38)		0.20*** (2.38)	0.40**** (3.29)	0.784	1.8
			0.04 (0.66)	0.22*** (2.51)	0.39**** (3.32)	0.786	1.8
1950–60	0.02 (0.78)			–0.06 (–0.35)		–0.117	1.3
		0.02 (0.23)		–0.07 (–0.32)		–0.195	1.7
			0.02 (0.21)	–0.07 (0.31)		–0.196	1.6
1961–74	0.15 (0.91)			0.21 (1.17)	0.41*** (2.62)	0.725	1.8
		0.18 (0.95)		0.22 (1.26)	0.42*** (2.64)	0.73	1.7
			0.10 (0.48)	0.23 (1.26)	0.38*** (2.43)	0.709	2.0

[a] ****, *** = significant at 1% and 5%. respectively. [b] The figures in parentheses are *t*-values. P_1 = average price received by farmers for *palay ordinario* during planting period (May–September) deflated by the average wholesale price of ammonium sulfate for the same period. P_2 = average price received by farmers for *palay fancy* during planting period (May-September) deflated by the average wholesale price of ammonium sulfate for the same period. P_3 = average price received by farmers for palay fancy during preplanting period (February-July) deflated by the average wholesale price of ammonium sulfate for the same period.

Thailand. The results of estimation of the area response function for rice in Thailand are summarized in Tables 5 and 6.

For the whole period (1951–73) as well as for the subperiods (1951–64 and 1965–73), estimates of the area elasticity with respect to price are significant at the 20% level. As with the Philippine case, estimates for 1965–73 are higher than estimates for 1951–64, supporting the hypothesis that the flexibility in the area response to price declined as the result of the closing cultivation frontier.

Both irrigation and technology proved to be highly significant variables in the area response function. The area elasticity with respect to irrigation seems to have increased, which may reflect the increasing role of irrigation in rice production in Thailand due to the rapid development of irrigation infrastructure. The coefficients of two technology variables, $\bar{Y}$ and M, are statistically significant.

Estimates of the area response function also show that the weather conditions represented by the annual average rainfall were the important determinant of area planted to rice in Thailand.

Table 5. Results of estimation of area response function for Thailand, using the simple model. [a]

	1951-73	1951-64	1965-73
Price elasticity	(20)	(17)	(17)
Range [b]	.09 to .45	.07 to .32	03. to .16
Mean [b]	.20	.20	.09
Mode	.12	.10	.03
Significance level [c]	*	*	*
Irrigation elasticity	(20)	(16)	(16)
Range	.16 to .31	.15 to .19	.81 to .92
Mean	.24	.17	.85
Mode	.31	.19	.85
Significance level	****	***	****
Technology elasticity ($\bar{Y}$)	(8)	–	–
Range	.81 to 1.29	–	–
Mean	1.05	–	–
Mode	.84	–	–
Significance level	****	–	–
Technology elasticity (M)	(8)		
Range	.07 to .23	–	–
Mean	.15	–	–
Mode	-	–	–
Significance level	****	–	–
Weather elasticity	(43)	(4)	(4)
Range	.41 to .77	.53 to .62	.40 to .51
Mean	.53	.59	.45
Mode	.48	–	–
Significance level	****	***	***
Coefficient of determination ($\bar{R}^2$)			
Range	.402 to .873	.456 to .493	.547 to .729
Mean	.776	.475	.628
Mode	.796	–	–

[a] Figures in parentheses are the number of regression equations estimated. [b] Ranges and means are calculated, excluding the largest and the smallest estimates. [c] Significance level for the majority of estimates (****, ***, **, * = significant at 1%, 5%. 10%. and 20%, respectively).

Table 6. Results of estimation of area response function for Thailand, using the distributed lag model.[a]

	1951–73		1951–64		1965–73	
	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Price elasticity	(24)		(16)		(16)	
Range[b]	.10 to .27	.36 to 1.00	.10 to .33	.15 to .58	.05 to .18	07 to .19
Mean[b]	.17	.71	.20	.31	.10	.13
Mode	.17	.87	.16	–	.07	–
Significance level[c]	**	–	**	–	–	–
Irrigation elasticity	(24)		(16)		(16)	
Range	.14 to .18	.24 to .32	.11 to .16	.16 to .22	.67 to .85	18 to 1.33
Mean	.16	.28	.15	.19	.79	.95
Mode	.16	.32	.14	.17	.82	.88
Significance level	***	–	***	–	***	–
Technology elasticity($\overline{Y}$)	(8)					
Range	.74 to .95	.81 to 1.25	–	–	–	–
Mean	.84	1.13	–	–	–	–
Mode	.81	–	–	–	–	–
Significance level	***	–	–	–	–	–
Technology elasticity (M)	(8)					
Range	.04 to .09	.08 to 25	–	–	–	–
Mean	.07	.16	–	–	–	–
Mode	.08	.08	–	–	–	–
Significance level	**	–	–	–	–	–
Weather elasticity	(49)		(4)		(4)	
Range	.37 to. 67	.57 to 1.82	.57 to .66	.79 to .93	.40 to .51	.67 to .69
Mean	.52	.82	.64	.86	.45	.68
Mode	.51	.70	.66	–	–	–
Significance level	****	–	****	–	****	–
Coefficient of determination ($\bar{R}^2$)						
Range	.705 to .867		.421 to .569		.434 to .606	
Mean	.818		.490		.540	
Mode	.815		.569			

[a] Figures in parentheses are the numbers of regression equations estimated. [b] Ranges and means are calculated, excluding the largest and the smallest estimates. [c] Significance level for the majority of estimates (****, ***, **, I = significant at 1%, 5%, 10%. and 20% level, respectively.

Table 7. Results of estimation of rice yield response function in Thailand. [a]

Time period	Elasticity[b]				R^2	D.W.
	Price	Irrigation	Technology (*M*)	Weather		
1952–73	0.17** (2.1)	0.10 (0.7)	0.07* (1.6)	0.59**** (2.8)	0.636	2.0
	0.18*** (2.2)	0.12 (0.8)		0.53*** (2.5)	0.602	1.8
		0.34**** (3.5)	0.08** (1.7)	0.70*** (3.2)	0.570	1.7
		0.39**** (4.2)		0.64**** (2.8)	0.524	1.5
1952–64	0.12 (0.9)	0.09 (0.4)		0.76** (1.9)	0.263	2.0
		0.23* (1.8)		0.86*** (2.2)	0.283	1.8
1965–73	0.07 (1.2)	1.05** (2.0)		0.31** (2.4)	0.509	3.4
		1.18** (2.3)		0.32*** (2.5)	0.498	2.9

[a] The figures in parentheses are *t*-values. [b] ****, ***, **, * = significant at 1%, 5%, 10%, and 20% level, respectively.

The results of estimation of the yield response function in Thailand are shown in Table 7. Estimates for the 19.52–73 period show that the response of rice yield to price was positive and significant, at the 5 or 10% levels. However, it should be noted that the price and the irrigation variables are highly correlated ($r = 0.9$). As a result, the irrigation coefficients are not statistically significant if the equations include both the price and the irrigation variables, but they become highly significant if the price variable is deleted. It seems reasonable to assume that the highly significant price coefficients in the yield response function resulted because the price variable seized a part of the effect of irrigation on rice yield through the process of least-square estimation.

The coefficients of the weather variable (rainfall) are all highly significant, suggesting the dominant influence of weather on rice yields in Thailand.

In comparing the 1952–64 estimates with the 1965–73 estimates, we see no indication that the response of rice yield to price increased over time. This may be because of statistical problems such as multi-collinearity, but probably more important is the fact that the introduction of MV in Thailand began much more recently than in the Philippines and the observations do not cover a period adequate to show the possible change in the price elasticity due to new rice technology. However, the coefficients of technology (*M*) estimated in the regressions for the whole period show that the diffusion of MV has had some significant impact on the levels of rice yield, even though it may not yet have had appreciable effect on the yield response to price.

The most interesting finding from the comparison of the 1952–64 and 1965-73 estimates is that the coefficient of irrigation increased while the coefficient of weather decreased significantly. That seems to suggest the hypothesis that rice yield in Thailand became less dependent on the natural water supply from rainfall as irrigation systems were developed.

CONCLUSIONS

The aggregate time-series analysis of rice supply in terms of both area and yield functions for the Philippines and Thailand produced results largely consistent with our two hypotheses on the structural changes in rice supply relations that have occurred in Southeast Asia along with the development and diffusion of MV.

- The response of rice area to price declined as cultivation frontiers were pushed into marginal areas and opening new land became progressively more difficult,
- The response of rice yield to price increased as the result of both the introduction of new rice technology and the development of irrigation systems, which made the application of fertilizer and related inputs more responsive to changes in the price of rice relative to the price of those inputs.

However, we have to admit that, although the results of the regression analysis are consistent, or at least not contradictory, they represent rather weak evidence in support of the hypotheses. Statistical significance levels are low for most of the estimated parameters, and parameter ranges are wide.

Relatively poor results of our regression analysis seem to be due partly from the poor data specifications. For example, the irrigation variable was constructed by simply adding areas under irrigation, and no adjustment was made for quality differences among the irrigated areas. Likewise, areas planted to MV were simply totaled to produce the technology variable, without consideration for the different effects of different varieties under different environmental conditions. In the Philippine study, the lack of an adequate weather variable represented a serious limitation.

Probably the basic constraint was that the data do not cover a time long enough to permit an estimate of possible structural changes. New rice technology is still in an early stage of development. Its impact may not have been large enough yet to show up in the aggregate time-series data, To obtain more conclusive evidence of the effect of new rice technology on the aggregate rice supply relations this analysis must be repeated after the time series have expanded.

REFERENCES CITED

BEHRMAN, J.R. 1967. Supply response in underdeveloped agriculture: a case study of four major annual crops in Thailand, 1937–63. Amsterdam: North-Holland, 1968.

CUMMINGS, J.T. 1974. The supply responsiveness of Bangalee rice and cash crop cultivator. Bangladesh Dev. Stud. 2:857–866.

DALRYMPLE, D.G. 1974. Development and spread of high-yielding varieties of wheat and rice in the less developed nations. US Dep. Agric. ERS Foreign Agricultural Economics Report No. 95.

HAYAMI, Y., and V. W. RUTTAN. 1971. Agricultural development: an international perspective. Johns Hopkins Press, Baltimore and London.

HUSSAIN, S.M. 1964. A note on farmer response to price in East Pakistan. Pak. Dev. Rev. 4:93–106.

KOREA AGRICULTURAL ECONOMICS RESEARCH INSTITUTE. 1973. An analysis of supply and demand structures for rice in Korea. Res. Rep. Ser. No. 53. Seoul, Korea.

KRISHNA, R. 1963. Farm supply responses in India-Pakistan: a case study of the Punjab region. Econ. J. 73:477–487.

MADHAVAN, M.C. 1972. Acreage response of Indian farmers: a case study of Tamil Nadu. Indian J. Agric. Econ. 27:67–86.

MANGAHAS, M., A.E. RECTO, and V.W. RUTTAN. 1965. Production and market relationships for rice and corn in the Philippines. Int. Rice Res. Inst. Tech. Bull. 9. Los Baños, Philippines. 284 p.

MUBYARTO. 1965. The elasticity of the marketable surplus of rice in Indonesia: a case study in Java-Madura. Ph. D. thesis, Ames, Iowa State University, Iowa.

OLARN, C. 1975. Aggregate production structure of paddy cultivation in Thailand: a time series analysis, 1951–73. Pages 191–205 *in* P. Sondyusuvan, ed. Finance, trade, and economic development in Thailand, essays in honour of Khunying Suparb Yossundara. Sinpong Press, Bangkok.

PRAKONGTANAPAN, S. 1976. Changes in the supply response of aggregate rice output in Thailand. M.S. thesis, University of the Philippines School of Economics, Quezon City, Philippines.

SISON, J.F. 1976. Structural changes in farm supply response of rice in the Philippines. M.S. thesis, University of the Philippines at Los Baños, Philippines.

COMMENTS ON STRUCTURAL CHANCES IN RICE SUPPLY RELATIONS : PHILIPPINES AND THAILAND

J.G. RYAN

THE TOPIC ADDRESSED by the authors is an important one as many policy questions can be answered if there is knowledge of the changes in rice supply relationships that structural changes cause.

Two main hypotheses are tested in the paper. The first is that the development of modern varieties (MV) of rice and new irrigation systems in the Philippines and Thailand has made rice supply more responsive to changes in the price of rice relative to prices of alternative crops, fertilizers, and other inputs. The second is that a "closing cultivation frontier" in those countries has reduced the price elasticity of area response for more recent years.

SOME COMMENT ON METHODOLOGTY

When one looks at the data provided by the authors it does not seem apparent that the *cultivation frontier* has been a constraint on the area of rice grown recently, particularly in Thailand. All the data I cite are taken from Sison et al., Figures 1–6. I recognize that total cropped area may represent the gross cropped area rather than the net cropped area, but the authors do not specify which of the two they refer to. If there is a large amount of double cropping the two measures of crop area will differ.

From 1951 to 1964 total crop area rose in Thailand by 14 million ha (33%), while from 1964 to 1973 it rose by 20 million ha (36%). In addition, the area of rice in Thailand has fallen from 88% of the total crop area in 1951, to 64% in 1973. Hence for Thailand it appears the upper ceiling on rice area in recent times may have been less constraining rather than more.

In the Philippines total crop area rose by 2.5 million ha (49%) between 1950 and 1960. From 1960 to 1974 it rose by 2.4 million ha (25%). In spite of this decline in the rate of growth of total crop area, the proportion of rice grown in the Philippines fell from 42% of the total crop area in 1950, to 35% in 1974. Although it is obvious the physical *land frontier* in these countries is being approached, the above figures do not indicate that it has, as yet, impinged on the areas sown to rice.

Economist, International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India.

To test the frontier hypothesis, Sison et al. subdivided the data into two periods (1950–60 and 1960–74 for the Philippines, and 1951–64 and 1964–73 for Thailand) and compared the elasticity parameters for the two periods. It seems arbitrary to choose these discrete periods for such a test, when the frontier presumably was approached in a continuous asymptotic fashion. A more direct test could be the incorporation in the models of a variable that explicitly measures "closeness to frontier." Kikuchi and Hayami constructed such an index for the Philippines in their paper (this volume), which examines the effects of new rice technology on public investment in irrigation systems. This type of variable could be utilized in the form of interactions with the price variables in the various models. There would then be no necessity to subdivide the data arbitrarily to perform the frontier test.

Subdividing the data in the way the authors did also tends to cloud the likely effect of the approaching frontier on supply response for another reason. It is well known that economic theory indicates that the elasticity of *output* supply falls when the elasticity of input supply does so, other things being equal. At the same time, as frontier land in Asia becomes less elastic, the elasticity of supply of other inputs like labor, fertilizers, and implements probably becomes greater. With the necessary changes having been made, the likely net effect on area supply response of the closing frontier, when data are subdivided into two time periods, is difficult to hypothesize. By using gross rice area as the dependent variable, the authors may have further weakened the likelihood that the aforementioned relationship would apply, as when frontier land becomes constraining, resulting in increasing use of changes in cropping intensity as the mechanism for area changes. This is reflected in changes in gross crop area.

If net rice area had been used as a dependent variable the hypothesized relationship between closeness of the frontier and net rice-area price response may be expected to exist, but the Value of empirically establishing such a result for policy purposes is not clear. In fact, the theoretical positive relationship between elasticities of input supply and product supply refers to the situation when the latter is measured in units of output. Gross area of rice land is really an intermediate input in this context rather than a final output and theory is not clear on how gross area sown should respond to a less elastic net land area.

To test the effect of MV rice technology on elasticities, the authors created variables consisting of past relative yields of rice and alternative crops, and the percentage of rice crops in. MV. However, these variables never interact with price variables so that their direct effect on elasticities cannot be inferred from the models employed. Discovering such effect was one of the primary aims of the study. Indeed by splitting the data the way they did and by not using any interaction variables the authors confounded the effects on price elasticities of the MV and the frontier constraint.

The yield models contain a probable bias in the estimates of the price elasticities because the variable — proportion of irrigation land in rice (I) — is likely to be positively dependent on price of rice (P). When both variables are used together as independent variables in single-equation models without explicitly considering their structural relationships, the price elasticities so derived are likely to be underestimated. The chances of multicollinearity problems arising also increase, as the authors recognize, and that can additionally cause overestimation of irrigation elasticities.

In view of the large number of different variable specifications tried by the authors, this "classical" statistician would have wanted to see those regression equations with the "best" statistical significance presented. The technique chosen of averaging regression coefficients across the different models and presenting them plus their modes and ranges has appeal, but it does not allow comparison of coefficients in the two periods in situations where the same specification for the variables is used.

SOME ALTERNATIVE FORMULATIONS

It would be useful to specify three alternative models to test the effects of MV rice technology on supply-response parameters, and then use analyses of covariance. The first would be an area supply function, the second an output supply function, and the third an aggregate production function. The output supply function allows incorporation of both area and yield responses to changes in input and output prices and technology variables.

I believe that deriving output supply relations is also more meaningful for addressing the policy issues mentioned earlier in this discussion. It allows comparison with the estimates of shifts in rice supply functions from MV using shifts in production functions presented by Evenson and Flores at this conference.

Area supply response. I took the liberty of fitting such models to the data for the Philippines, which were given in graphical form by Sison et al. in their paper. I supplemented the data with those from the Food and Agriculture Organization of the United Nations (1972, 1974). The results for area supply response are shown in Table 1. In all models the MV technology variable is set up in dummy form, taking the value zero in years prior to 1966–67 and the value one in subsequent years. According to Dalrymple (1976), 1966–67 was the first year when MV were grown in the Philippines. All other variables in the Table are self-explanatory.[1] Absolute price supply models were also tried, but they suffered from serial correlation, so the relative price models shown in Table 1 were preferred. In the area supply models the Nerlovian distributed-lag expectation model had much less serial correlation than the non-Nerlovian form and was chosen, whereas for the output supply models the reverse was true.

---

[1] It was not clear whether the fertilizer consumption and irrigated area data given in Sison et al. referred only to rice or to all crops in the Philippines. As logarithmic forms were used in my empirical analysis the coefficients on these variables will not be affected, if the latter is the case, as long as the percentage changes in the rice portions were the same as in the total. Anyhow, the analysis is primarily intended to be illustrative only. In the time available I was unable to obtain data to allow construction and inclusion in the models of a variable to measure "closeness to the land frontier." That is a needed refinement and should be included in future research in this area.

Equation I constrains slope and intercepts of area supply response to be equal in the pre- and post-MV rice period. Equation H constrains slopes but not intercepts, and equation III allows different slopes and intercepts in the two periods. As can be seen from the F-statistics in Table 1 (calculated using the procedures in Johnston (1972), I fail to reject the hypothesis that the advent of the MV in the Philippines has had no effect on the area supply intercept or on the area supply responses to changes in relative rice prices and irrigated area. I also fail to reject the hypothesis that there is no difference in the whole area supply relationship (intercept and slopes) after the advent of the MV.

In the constrained model in equation I, the short-run area elasticity with respect to relative rice prices is calculated as +0.02, while the long-run elasticity is +0.06. Statistically, however, the short-run elasticity and, possibly, also the long-run elasticity are not significantly different from zero. The suggestion is that the elasticity of area supply to changes in irrigated area became negative after introduction of the MV in 1966–67. However, to properly test that requires rerunning equation III with all technology variables dropped except the technology interaction with irrigated area, and conducting an F-test with equation I as the constrained model.

Some additional studies on rice-area supply response for India, which I have come across and which Sison et al. did not include, are summarized in Table 2.[2] Unfortunately virtually all cover the period before the availability of the MV so I cannot make inferences about the effects of MV on price response from these studies. The tables show, however, that rice area responses in general in most states of India are higher than those for the Philippines and Thailand calculated by Sison et al. and in Table 1. If one takes only the significant positive elasticities in Table 2 they average 0.31 for the short-run and 0.50 for the long-run. They compare with means of 0.12 and 0.17 for the Philippines for 1950–60, and 0.20 and 0.31 for Thailand for 1951–64, respectively, using the distributed lag estimates of Sison et al.

If the hypothesis about the effect of the approaching land frontier on rice area price response is correct, one might expect to see lower elasticities in India than in the Philippines and Thailand. India's population pressure presumably has forced it much closer to its land frontier than has that in either of the two other countries. It would be illuminating to add the post-MV data and include technology and closeness-to-frontier variables to Indian supply response models to also see if the relationships can be detected in a more land-scarce country like India.

Output supply response. I now turn to the output supply models. In equations IV, V and VI of Table 1 I show that the hypothesis that intercepts were the

---

[2] Numerous other studies have been conducted in India to explain marketable and marketed surpluses of paddy on farms by changes in farm size, rice area, rice production, family size, etc. Generally they show that rice production or rice area is positively related to these surpluses, so that positive area or production supply response to prices will also imply positive marketable and marketed supply responses. Some examples of such studies are those of Mandal and Ghosh (1968). Parthasarathy and Suba Rao (1964), Vyas and Maharaja (1966), George and Choukidar (1972). and a recent review by Raju (1976).

Table 1. Area and output supply response for rice in the Philippines. [a]

			Explanatory variable [b]											
Equation	Dependent variable	Intercept	Log (Rice price /non-rice price[c])	Log (Irrigated area)	Log (Area of rice lagged)l	Technology dummy	Technology dummy x [Log (Rice price [c] / non-rice price)]	Technology dummy x [Log (irrigated area)]	Technology dummy x [Log (area rice lagged)]	Log (Fertilizer price[c])	Technology dummy x [Log (Fertilizer price[c])]	R^2	D.W.	Constrained vs unconstrained F-statistics [d]
I	Log (Area of rice harvested)	0.0956	0.0155 (0.21)	0.0385 (0.85)	0.7372** (0.67)	–	–	–	–	–	–	0.88	0.49 [e]	0.08
II	Log (Area of rice harvested)	0.1023	0.0056 (0.07)	0.0111 (0.10)	0.7745 (3.72)**	0.0059 (0.29)	–	–	–	–	–	0.88	1.76 [e]	1.70
III	Log (Area of rice harvested)	0.0581	0.0895 (0.72)	0.0711 (0.62)	0.7511** (3.24)	0.9884 (2.19)	–0.3410 (–1.82)	–0.852 (–2.16)	–0.0589 (–0.12)	–	–	0.91	1.85 [f,g]	1.36
IV	Log (Production of rice)	3.5560	0.1790 (1.73)	0.6379** (11.50)	–	–	–	–	–	–0.2906 (–1.57)	–	0.92	1.35 [g]	1.85
V	Log (Production of rice)	3.5044	0.0759 (0.60)	0.5115** (4.75)	–	0.0348 (1.36)	–	–	–	–0.2077 (-1.09)	–	0.93	1.57 [g]	3.4*
VI	Log (Production of rice)	2.6817	0.0707 (0.42)	0.3782** (3.05)	–	1.4932 (1.89)	0.0436 (0.17)	0.5085 (0.97)	–	0.2744 (1.21)	–1.0166** (–3.11)	0.96	2.52 [g]	3.19*

[a] * and ** denote significance at the 5 and 1 % levels, respectively, using a two-tailed test. Logarithmic transformations are to base 10. [b] Figures in parentheses are *t*-values. [c] Prices were all lagged one year. [d] First *F*-value tests if technology dummy intercept coefficient is significant, the second if slope coefficients differ, and the third if both slopes and intercepts differ before and after MV. [e] Hypothesis of no serial correlation is not rejected. [f] *Not* possible to calculate a *h* statistic in these cases as there are two lagged dependent variables on the RHS. Figure is the ordinary D-W statistic and test is not possible. [g] Hypothesis of no serial correlation is neither accepted nor rejected.

Table 2. Some further selected estimates of area supply response for rice in India.

State	Period	Methodology	Elasticity[a] Short-run	Elasticity[a] Long-run	Source
West Bengal and Assam	1951–64	Simple are elasticity calculations	0.11		Jakhade and Majumdar, 1964
Andhra Pradesh	1952–65	Nerlovian linear models; absolute wholesale prices, yield and irrigated area, rainfall variables included.	0.32**	0.40**	National Council of Applied Economic Research, 1969.
Assam	"		0.01	0.05	
Bihar	"		0.12	0.14	"
Madhya Pradesh	"		0.01	0.02	"
Maharashtra	"		0.01	0.12	"
Uttar Pradesh	"		0.06	0.19	"
Madras State	"		0.24**	0.47**	"
West Bengal	"		0.22	0.40	"
Mysore State	"		0.10	0.17	"
Madras State	n.a.[b]	n.a.	0.11		Rajagopalan, 1967, as reported in Cummings, 1975.
Punjab	Post-WW II	n.a.	0.24		Kaul, 1967, as reported in Cummings, 1975.
Punjab	1961–70	Nerlovian linear models using relative price.	0.05	0.05	Sidhu and Kaul, 1971.
		With variable for price variance added	0.19	0.63	"
Punjab	1949–66	Nerlovian log models with variables for price variance, yield and time trend – using relative prices	0.18-0.33	0.39	Maji et al., 1971.
		– using absolute prices	0.11–0.15	3.56-0.67	
Andhra Pradesh	1950–67	Nerlovian linear models, prices deflated by cost of living indices; rainfall and time trend included.	0.48**	0.62**	Cummings. 1975
Assam	1955–67		0.07	0.07	"
Gujarat	1954–67		–0.07	–0.07	"
Himachal Pradesh	1949–66	"	–0.07	–0.06	"
Kerala	1951–66	"	–0.14**[c]	–0.12**[c]	"
Maharashtra	1955–67	"	–0.12**[c]	–014**[c]	"
Manipur	1955–67	"	0.20**	–1.25**	"
Mysore	1951–67	"	0.06	0.07	"
Pondicherry	1958–68	"	0.39	0.85	"
Punjab	1950–66	"	0.03	0.05	"
Tamil Nadu	1946–67	"	0.08	0.08	"
Tripura	1949–67	"	0.01	0.01	"
West Bengal — autumn	1949–66		0.37	0.38	"
winter	1949–66	"	0.09	0.08	"

[a] ** = significant at 5%. [b] Not available. [c] Rice deficit state with substantial trade barriers, which may explain the negative sign.

same before and after the new MV were introduced is not rejected. However, the hypothesis that the responses of rice output to changes in irrigated area, relative price of rice to nonrice crops, and fertilizer prices were the same after MV were introduced is rejected. The elasticities with respect to changes are:

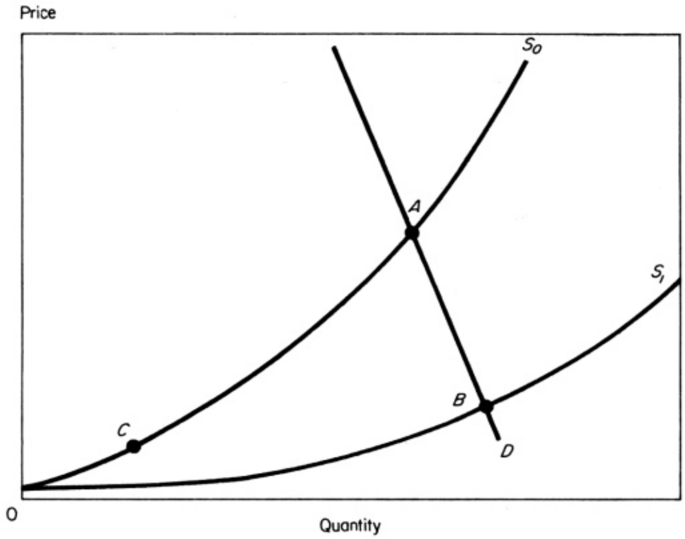
	Before MV	*After MV*
Price rice/price nonrice crops	+0.07	+0.11
Price of fertilizer	+0.27	–0.74
Irrigated area	+0.38	+0.89

It appears the output supply price elasticity increased by more than 50% after introduction of MV. The direction is as expected if the production functions of the MV with respect to inputs like fertilizers are steeper than those of the traditional varieties, as is the case. The output supply elasticity with respect to the price of fertilizer falls substantially in algebraic terms after introduction of MV; that is also expected for the same reason. The effect of changes in irrigation hectarage on rice supply after introduction of MV was much greater, probably because of its enhanced productivity as a result of the MV replacing traditional varieties.

If we insert the average 1972–74 values of the continuous variables into equation VI in Table 1 and calculate the production of rice with the technology dummy set at zero (pre-MV) and then one (post-MV), we find that the MV increased rice supply in 1972–74 by 26.5% in the Philippines. Without the MV, the supply would have been around 4.583 million t. As a result of MV it was about 5.8 million t. The figure of 26.5% agrees almost exactly with the "high" estimate of Evenson and Flores (this volume) for the Philippines for the same period using their general model. It is, however, much above the 13% quoted by Hayami and Herdt (this volume).

It appears from Figure 1 that costs of production after introduction of MV of rice have fallen more on marginal units (near A and B) than on inframarginal units (near Q_o). This suggests that marginal farms may have benefited more from new rice technology than have farms with lower cost structures. However, as Duncan and Tisdall (1971) point out, and as found by Evenson and Flores (this volume) under circumstances of very inelastic demand curves, research that reduces costs more on marginal farms may be at the expense of a reduction in the whole industry's producers' surplus.

From the producers' angle the desirable shift in the supply curve is one where cost reduction at the margin is less than that at the inframargin. Research that makes the demand more elastic and shifts it upwards at the same time also generates greater producers' surplus, but at the expense of consumers. This raises the point that in fitting single equation supply functions, both Sison et al. and I have ignored the possibility that as a direct result of introduction of the MV, the demand curve shifts and produces changes in elasticity also. Hayami and Herdt



1. Supply shift showing cost reductions of marginal producers exceeding those of inframarginal producers.

(this volume) partially account for this in their model of technological change in a semisubsistence rice market by allowing home consumption demand to shift after MV introduction. However, they do not estimate supply and demand functions simultaneously, but use shifts in fertilizer production functions as their index of supply shifts. There is evidence from the Indian studies, such as that of George and Choukidar (1972) in the West Godavari region of Andhra Pradesh, that a much higher proportion of the MV of rice than of the traditional varieties is marketed. Almost always when MV are grown in India, the farmers that grow them also grow an area of local varieties exclusively for home consumption. These locals generally command a price premium ranging from 10 to 15% over the MV in the market. There could thus be a somewhat differentiated product when MV are introduced and this may require a simultaneous equations approach to supply analysis, particularly when MV adoption rates are relatively high.

Aggregate production functions. Table 3 contains an aggregate production function for rice in the Philippines. This model uses total production as the dependent variable, not the yield per hectare of the Sison et al. model. Price variables are not included in order to avoid the type of bias that is possible in their formulation. Using the constrained versus the unconstrained F-tests, I reject the hypothesis that slope or intercept coefficients (separately or combined) were significantly different after the advent of the new MV. I suspect I do not detect a difference in fertilizer production elasticities, for example, because some variables are missing in the model — e.g. weather and labor input. Microlevel production functions are probably preferable in these circumstances.

Table 3. Aggregate production function for rice in the Philippines.[a]

			Explanatory variables[b]									
Equation	Dependent variable	Intercept	Log (Area of rice harvested)	Log (Fertilizer consumption)	Log (Irrigated area)	Technology	Tech. dummy x [Log (Rice area)]	Tech. dummy × [Log (Fertilizer consumption)]	Tech. dummy × [Log (Irrigated area)]	R^2	D.W.	F test[c]
VII	Log (Production of rice)	2.9140	0.0829 (0.40)	0.1376* (2.77)	0.03298** (3.24)	–	–	–	–	0.93	1.24[d]	1.34
VIII	Log (Production of rice)	2.9702	0.2628 (1.02)	0.0986 (1.65)	0.2660* (2.31)	0.0330 (1.16)	–	–	–	0.93	1.38[d]	1.48
IX	Log (Production or rice)	3.0158	0.3259 (1.16)	0.0600 (0.95)	0.2785* (2.13)	0.3323 (0.52)	–1.8509 (–1.65)	0.4881 (2.06)	–0.5808 (–1.05)	0.95	1.63[d]	1.47

[a] * and ** = significance at 5 and 1% levels, respectively, using a two-tailed test. Logarithmic transformations are to base 10. [b] Figures in parentheses are *t*-values. [c] See footnote d, Table 1. [d] Hypothesis of no serial correlation is neither accepted nor rejected.

CONCLUSION

In a reformulated model of rice area supply response in the Philippines, no significant difference was found in the price elasticity or the irrigation elasticity of area response for the periods before and after advent of the MV.

Economic theory does not guide us on what direction the rice area supply price elasticity will move if the cultivable land frontier is being approached, as rice land is an intermediate input and not the final output. Furthermore, the methodology chosen by Sison et al. to test the hypothesis that rice area supply price elasticity becomes more inelastic under such circumstances was shown in this paper to be patently inappropriate. If one were interested in testing a frontier hypothesis the model must specifically include a variable that measures closeness to the land frontier. Subdivision of the data as used by Sison et al. will not allow such a test.

Economic theory predicts that rice output supply price elasticity may decrease if land supply becomes more inelastic as the frontier is approached. However, this will be unequivocally true only if the elasticity of supply of all inputs other than land remains unchanged. For inputs such as labor and fertilizers, this was probably not the case during the period under examination. Hence, even if a variable for closeness to the land frontier were used as a proxy for the elasticity of land supply in output supply response models (its use in area supply models is not required theoretically), the assumption for other input supplies probably would be violated, thus vitiating the test.

A rice output supply model fitted to the same Philippine data used by Sison et al. showed that a statistically significant increase occurred in the rice price and irrigation elasticities of output supply after the MV were introduced. The elasticity of rice output supply with respect to price of fertilizers became significantly negative after the advent of MV; before MV it was positive, but not significantly different from zero. All these elasticity changes agreed with *a priori* theoretical expectations.

From the above it seems the results Sison et al. derive in their paper must be seriously questioned, both on theoretical and methodological grounds. Empirical results from reformulated models for the Philippines showed that conclusions quite different from those of Sison et al. can be derived from the same data. That may also be true for Thailand, but the reformulations were not tried on that data set.

It may be that the type of models used here and in Sison et al. simply ask too much of the data. This may be especially true for Thailand, where the MV's were introduced in 1969–70 and represented only 5.5% of the total rice area in 1974–75 (Dalrymple, 1976).

REFERENCES CITED

ALLEN, R.G.D. 1938. Mathematical analysis for economists. Macmillan and Co., London, 548 p.

CUMMINGS, J.T. 1975. The supply responsiveness of Indian farmers in the post-independence period: major cereal and cash crops. Indian J. Agric. Econ. 30(1):25–40.

DALRYMPLE, D.G. 1976. Development and spread of high-yielding varieties of wheat and rice in the less developed nations. USDA ERS USAID (Co-operating) For. Agric. Econ. Rep. 95.

DUNCAN, R., and C. TISDALL. 1971. Research and technical progress: the returns to producers. Econ. Rec. 47:124–129.

EVENSON. R.E., and P.M. FLORES, 1978. Social returns to rice research. Pages 243–265 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

GEORGE, P.S., and V.V. CHOUDKIDAR. 1972. Production and marketing pattern of paddy. Centre Manag. Agric., Indian Inst. Manag., Ahmedabad. Gujarat.

HAYAMI. Y., and R.W. HERDT. 1978. Market price effects of new rice technology on income distribution. Pages 283–302 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños. Philippines.

HOUCK, J.P.. and P.W. GALLAGHER. 1976. The price responsiveness of U.S. corn yields. Am. J. Agric. Econ. 58(4):731–734.

JACKHADE, V.M., and N.A. MAJUMDAR. 1964. Responses of agricultural producers to prices—the case of jute and rice in India. Indian J. Agric. Econ. 19(3&4):204–209.

JOHNSTON, J. 1972. Econometric methods. 2nd ed. McGraw-Hill Book Co., Tokyo. 437 p.

KIKUCHI, M., and Y. HAYAMI. 1978. New rice technology and national irrigation development policy. Pages 315–332 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños. Philippines.

MAJI. C.C., D. JHA. and L.S. VENKATARAMANAN 1971. Dynamic Supply and demand models for better estimations and projections: and econometric study for major foodgrains in the Punjab region. Indian J. Agric. Econ. 26(1):21–27.

MANDAL, G.C., and M.G. GHOSH. 1968. A study of marketed surplus of paddy at the farm level in four East Indian villages. Indian J. Agric. Econ. 23(3):21–29.

NATIONAL COUNCIL OF APPLIED ECONOMIC RESEARCH. 1969. Structure and behaviour of prices of foodgrains. New Delhi, India, 299 p.

PARTHASARATHY, G., and B.V. SUBA RAO. 1964. Production and marketed surplus of rice in the deltas of the south. Agric. Situation India 19(8):721–725.

RAJAGOPALAN, V. 1967. Supply response for irrigated crops in Madras state. Ph.D. dissertation, University of Tennessee. (unpubl.)

RAJU. V.T. 1976. Market surplus of farm products in India (literature review). Econ. Dep., International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India. (mimeo.)

SIDHU, D.S., and J.L. KAUL. 1971. Acreage response to prices for major crops in Punjab — an econometric study. Indian J. Agric. Econ. 26(4):427–434.

SISON, J.F., SOMSAK PRAKONGTANAPAN, and Y. HAYAMI. 1978. Structural changes in rice supply relations: Philippines and Thailand. Pages 31–48 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

UNITED NATIONS, FAO. 1972, 1974. Production yearbook. Rome.

VYAS, V.S., and M.H. MAHARAJA. 1966. Factors affecting marketable surplus and marketed supplies — a study in two regions of Gujarat and Rajasthan. Artha-Vikas 2(1):52–78.

FARM INCOME STRUCTURE

Costs and returns for rice production

R.W. HERDT

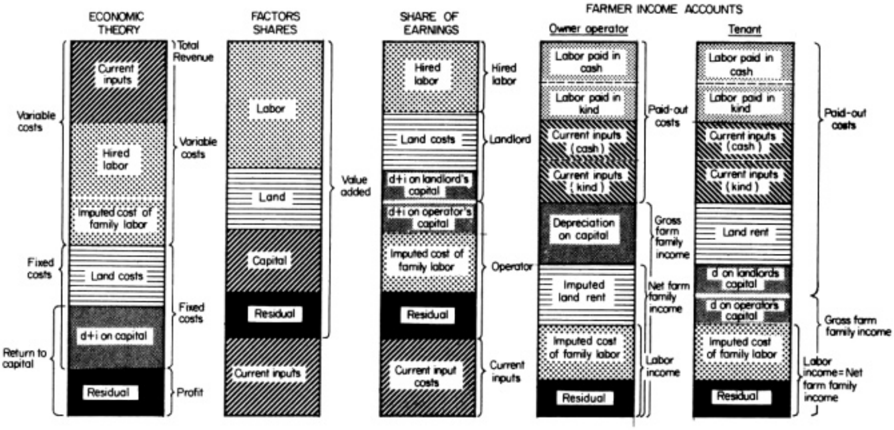
TECHNOLOGICAL AND INSTITUTIONAL changes in Philippine agriculture have been rapid since 1965. The switch from traditional rice varieties (TV) to semidwarf, fertilizer-responsive, modern varieties (MV) was rapid after the latter's introduction in 1966. Land reform was decreed in 1968, and enforcement accelerated after the implementation of martial law in 1972. Those changes were accompanied by many others — increasing use of chemical fertilizer, more effective implementation of government support and ceiling prices for rice, improvement of the road transportation network, provision of noncollateral loans, and various other programs designed to increase rice production. Especially in Luzon, where the influence of Manila is strong, the changes diffused through the rural areas with considerable force and speed.

Because there have been so many changes, and because rice production in a particular year is dependent on weather conditions, it is difficult to compare points in time and conclude that the differences between them were caused by certain innovations. Thus, this paper aims to determine the changes that have occurred in costs and returns of rice production since 1966 and to speculate on possible causes of those changes. The possible effects of adoption of MV, tenure changes, and mechanization are examined in particular.

METHODOLOGY

Costs and returns analysis is a common tool of agricultural economists, but the definitions used in such analyses are not standardized. To avoid ambiguity in the meaning of the concepts used, this section compares alternative accounting concepts and defines the concepts used later in the paper.

Agricultural economist, Department of Agricultural Economics, International Rice Research Institute, Los Baños, Philippines.



1. Alternative accounting systems for measuring farm costs and returns. d = depreciation; d + i = depreciation and interest.

Figure 1 illustrates different ways of measuring income and costs. Standard economic theory divides costs into fixed and variable categories. All resources used in production are evaluated at their market rate, and if long-run perfect competition does not prevail, the resulting residual is considered as pure profit. Alternatively, one may focus on the factors of production, dividing the total value of output into the payments made to each factor of production. Again, if long-run perfect competition does not prevail there may be a residual.

A modification of the factor-share approach in this volume (Ranade and Herdt) divides total output into the shares going to various classes of individuals involved in production. In this approach, the operator is credited with labor earnings of his family's contribution, the landlord and the operator divide the earnings of capital (depreciation and interest on capital), and the residual goes to the operator.

The farm income accounting used in this paper is illustrated in the last two parts of the figure. The focus in this method of accounting is on the earnings of family resources used in farming. This gives a measure of the incentives for production as well as a reflection of welfare as measured by farm family income.

Farm family income. Gross farm family income (GFFI) is defined as income received by the farm operator and is calculated as the residual after making actual payments for all expenditures incurred for production inputs, excluding any unpaid return to family-owned resources (land, labor, or capital). In other words, GFFI equals total return minus paid-out costs. The net farm family income (NFFI) is calculated by subtracting depreciation from GFFI. It is a measure of the income remaining with the farm family as a return to all the resources they own, adjusted to account for differences in capital endowments.

A comparison of the last two columns in Figure 1 shows the income differences between owners and tenants. For the tenants, land rent is a paid-out cost and reduces GFFI. In some cases, the landlord provides some capital as well as the land, in which case payment for that capital is included in the "rent." Clearly, the GFFI and NFFI of tenants will be lower than those of owner-operators. If imputed land rent is subtracted from the NFFI of owner-operators, the remaining labor income can be compared with the corresponding figure for tenants as a measure of productivity and welfare.

Price effects. Price changes make comparisons of income data over time questionable. Two alternative approaches are used here to deflate incomes for price changes. The first converts income data into *paddy equivalent* by dividing income by the price of paddy in the study years. This measure has the advantage of being comparable not only over time for one site, but even between countries having different monetary units. However, the paddy equivalent is not a good measure of the purchasing power of farm income if the price of paddy relative to other goods consumed by farm families changes over the period being considered. Therefore, a second deflation procedure divides monetary income measures by the consumer price index for regions outside Manila (1965 = 100) to get the "real" income measures.

Comparison of the structure of costs over time is also complicated by price changes. The usual method is to deflate total costs in current terms by an index of prices paid by farmers. Each price in the index is generally weighted by the quantity of each input. This procedure presents a problem when a large proportion of costs is land rent, for which the quantity is constant (per hectare). Because land rent is often paid in kind, it seems most appropriate to deflate land rents by paddy rice. It would also be misleading to deflate paid-out costs of owners by an index of prices paid including land rent.

For these reasons, instead of deflating by one price index, each component of costs for each group is deflated by an appropriate input-price index to convert all costs to 1966 real terms. Table 1 shows the prices and price indices used for the deflation procedures described here. The price of urea is the basis of the index of input prices. Average wage rates paid by the farmers in the survey were used to calculate the index of wages.

Because the primary objective of this paper is to explore the changes that have occurred over time, it is important to use concepts that are comparable over time. It is, however, also important to use a measure that has some validity for judging welfare. Income per hectare, income per farm, and income per unit of family labor used are all possible for that purpose. All three have appeal because of the interaction of farm size and labor practices with the resulting

Table 1. Prices and price indices related to rice production, July-December (wet season) of respective years, Philippines (Bureau of Agricultural Economics, Central Bank of the Philippines, and surveys).

Price index	1966	1970	1974	1975
Price of urea ($/kg of N)	.17	.20	.44	.58
Index of input prices	100	117	265	346
Agricultural wages, Laguna ($/day)	.53	.79	n.a.[a]	1.54
Index of wages, Laguna	100	148	n.a.	290
Agricultural wages, CL/L[b]/($/day)	.57	.73	1.15	n.a.
Index of wages, CL/L	100	128	202	n.a.
Consumer price index[c]	100	137	290	297
Palay price ($/kg)	.06	.06	.14	.15
Palay price index	100	112	250	267

[a] Not applicable. [b] Central Luzon/Laguna. [c] All items index for areas outside Manila.

measure. All three are shown but more detailed information is provided on income per farm and per unit of family labor contributed.

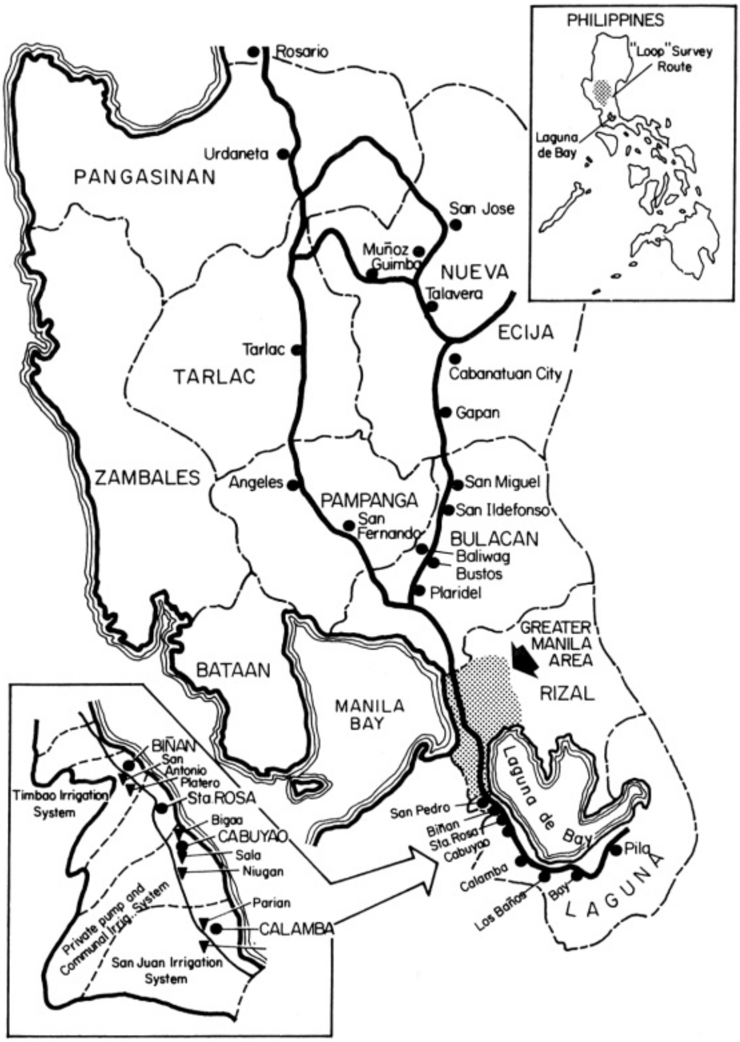
THE STUDY DATA

Data are examined for two samples of rice farms in Luzon for three years. A Laguna sample was chosen from among barrios in the towns of Biñan, Cabuyao, and Calamba in Laguna province and a Central Luzon—Laguna sample from along the route indicated in Figure 2. Table 2 gives some information about the two samples. For the Laguna sample, data were obtained for both wet and dry seasons between 1966 and 1971, and for 1975. Only the data for the 1966, 1970, and 1974 wet seasons were available for the Central Luzon and Laguna (CL/L) sample.

Examination of the map shows the two samples are quite different. The Laguna sample covered three municipalities within 30 km of each other. The CL/L sample was spread over 400 km and was much more heterogeneous than the Laguna sample, although it slightly overlaps with the Laguna sample region.

Tenure. The sample farms were classified by tenure of the land operated. The 1966 and 1970 Laguna samples had the same farmers, but in 1975 it was impossible to interview some of them, and so replacements from adjacent barrios were added. Some of the CL/L farmers included in the 1966 survey had stopped farming by 1970, and more had stopped or died by 1974; hence, the samples for various years are similar but not identical. The average farm size for both samples was about 2.3 ha. In Laguna, share-tenants predominated, and they had slightly larger farms than owners and leaseholders, but there is evidence that farmers do not accurately report their farm sizes (Guino et al., 1975; Roxas, 1976).

The number of owner-operators in Laguna was so small that the data for that class may be somewhat misleading. Leaseholders had slightly smaller farms than share-tenants in Laguna. In the CL/L sample, farm size among tenure



2. Location of the municipalities of Biñan, Cabuyao, and Calamba at Laguna, and the loop survey route for the Central Luzon/Laguna survey, Philippines.

classes did not differ. A modest shift in tenure occurred between 1966 and 1970 in both samples, but the major change occurred after 1970. The number of owners slightly increased but the major shift was from share-tenancy to leaseholding.

Technological change. Table 3 shows the use of MV and the average rice yields (all varieties) for the two samples. Adoption of the MV was almost complete between 1966 and 1970 in Laguna: in CL/L, two-thirds of the farmers adopted the new varieties between 1966 and 1970, and little increase in adoption occurred thereafter.

Table 2. Number of farms and average size, by tenure, in two groups of sample rice farms. Philippines, 1966–75.

Year	Season	Owner-operators		Share-tenants[a]		Leaseholders		All	
		Number	Size (ha)	Number	Size (ha)	Number	Size (ha)	Number	Size (ha)
				Laguna					
1966	Wet	2	1.00	104	2.40	8	1.75	114	2.33
1967	Dry	1	1.50	73	2.06	7	1.57	81	2.01
1970	Wet	4	1.77	96	2.33	13	1.96	113	2.28
1971	Dry	2	2.65	64	2.11	13	1.85	79	2.13
1975	Dry	6	1.63	66	2.30	70	2.06	142	2.34
1975	Wet	7	1.09	80	2.30	69	2.15	156	2.16
				Central Luzon and Laguna					
1966	Wet	9	2.79	50	2.40	11	2.35	70	2.44
1970	Wet	8	2.27	44	2.40	36	2.05	88	2.25
1974	Wet	11	2.86	19	2.18	36	2.49	66	2.46

[a] This category includes a few mixed-tenure farms with some share-tenanted land.

The CL/L sample represents a wide range of environments, some of which are apparently unsuitable for MV during the wet season. The Laguna sample is representative of the best of the range of environments. Yields in Laguna increased by 0.6 to 1.0 t/ha between 1966 and 1970 (except on the few owner farms) and continued to increase in 1975, especially in the dry season. In CL/L, yields increased 0.3 t/ha between 1966 and 1970, but fell slightly in 1974 when severe typhoons hit the survey area. In the light of the level of input used by farmers, and their expressed opinion, yields in the CL/L area were much below

Table 3. Use of modern varieties (MV) and average rice yields[a] of two groups of sample farms. Philippines, 1966–75.

Year	Season	Owner-operators		Share-tenants		Leaseholders		All	
		MV use (%)	Yield (kg/ha)	MV use (%)	Yield (kg/ha)	MV use (%)	Yield (kg/ha)	MV use (%)	Yield (kg/ha)
				Laguna					
1966	Wet	0	3531	0	2334	0	2598	0	2374
1967	Dry	0	3320	0	2630	0	2756	0	2650
1970	Wet	100	2886	97	3403	100	3245	98	3349
1971	Dry	100	1716	99	3360	100	3258	99	3286
1975	Dry	100	6417	98	4333	96	4600	99	4586
1975	Wet	100	3999	99	3495	94	3591	99	3568
				Central Luzon and Laguna					
1966	Wet	0	2806	6	2179	0	2134	4	2251
1970	Wet	n.a.	3263	61	2366	n.a.	2711	65	2589
1974	Wet	66	2855	65	2330	76.	2379	72	2444

[a] Converted from cavans per hectare. Because of a change in marketing practices, 1 cavan = 44 kg up to 1973 in Central Luzon; in 1974, 1 cavan = 50 kg. In Laguna 1 cavan = 44 kg up to 1974; in 1975, 1 cavan = 46 kg.

expectations and give a somewhat depressed income picture for that sample.

The data in Tables 2 and 3 suggest that changes in variety occurred mainly between 1966 and 1970, and changes in tenure occurred mainly after 1970. Tenure changes helped isolate the cause of the differences between the two periods. Grouping the sample farms into three tenure categories also helped isolate the effect of tenure changes.

FARM INCOME CHANGES

Table 4 shows some data used in calculating GFFI. Table 5 shows real income data. Comparison of the two income series shows the same trends and relationships whether income is deflated by the price index or by paddy prices alone. Paddy equivalent of GFFI per farm was somewhat higher in the CL/L sample than in the Laguna sample. This is a reflection partly of larger farms in CL/L and partly of somewhat lower paid-out costs there. Despite the increased yield, the paddy equivalent of GFFI in CL/L fell somewhat between 1966 and 1970 because of the increase in paid-out costs; it increased slightly between 1970 and 1974 because of changing prices.

The main impression one gets from careful examination of the income data for CL/L is one of relatively little change over the period. The only contradiction is the decrease in paddy equivalent of GFFI per man-day of family labor, which fell by nearly one-third between 1966 and 1970.

In the Laguna sample, the data for consecutive wet and dry seasons are nearly identical, except for the paddy price in the 1970 wet season and the 1971 dry season. Those price differences are matched fairly well by cost differences so that the paddy equivalent of GFFI for consecutive seasons are similar.

Table 4. Income data for the average of all farms in each sample, two groups of rice farms. Philippines 1966-75.

Year	Season	Yield (kg/ha)	Price ($/kg)	Gross revenue ($/ha per season)	Paid-out costs ($/ha per season)	GFFI[a] ($/ha per season)	Paddy equivalent of GFFI[b] (kg/season)		
							Per farm	Per ha	Per man-day family labor
				Laguna					
1966	Wet	2374	.0577	137	102	35	1413	606	13.1
1967	Dry	2650	.0556	147	111	36	1313	653	13.9
1970	Wet	3349	.0638	214	169	44	1606	703	25.3
1971	Dry	3286	.0882	290	221	68	1651	775	30.2
1975	Wet	3568	.153	546	343	203	2866	1327	51.2
				Central Luzon and Laguna					
1966	Wet	2251	.0612	138	87	51	2039	836	38.9
1970	Wet	2589	.068	176	121	55	1813	806	29.8
1974	Wet	2444	.1432	350	228	122	2091	850	27.8

[a] Gross farm family income. [b] Calculated by "deflating" gross farm family income by palay price in fourth column.

Table 5. Real income data for the average of all farms in each sample, two groups of rice farms, Philippines, 1966–75.

Year	Season	Real[a] gross farm family income (1966 US$ prices)		
		Per farm	Per ha	Per man-day family labor
		Laguna		
1966	Wet	78	33	0.72
1967	Dry	69	35	0.73
1970	Wet	71	31	1.12
1971	Dry	90	42	1.63
1975	Wet	131	65	2.34
		Central Luzon and Laguna		
1966	Wet	118	19	2.26
1970	Wet	86	38	1.41
1974	Wet	98	40	1.30

[a] Index of all-item consumer prices outside Manila used as deflator.

Between 1966 and 1970, incomes increased by about 15% in the Laguna sample, despite a 65% increase in costs. Increased yields along with a higher paddy price were responsible for the higher incomes. The paddy equivalent of GFFI per man-day of family labor increased by about 88% in Laguna between 1966 and 1970. The increase reflects the increase in GFFI per hectare as well as the reduction in family labor input. Between 1970 and 1975 incomes in Laguna continued to increase, nearly doubling for the average of all farms in the sample. That reflects a sharp reduction in real land rent during that period.

Table 6. Paddy-equivalent income[a] trends for farmers of three tenure classes in two samples of Philippine rice farms.

Year	Season	Paddy equivalent of gross farm family income (kg of palay/season)							
		Owner-operators		Share-tenants		Leaseholders		All	
		Per farm	Per man-day of family labor	Per farm	Per man-day of family labor	Per farm	Per man-day of family labor	Per farm	Per man-day of family labor
				Laguna					
1966	Wet	2306	29.0	1236	11.3	2422	30.5	1413	13.1
1967	Dry	2770	95.7	1126	11.4	2474	34.7	1313	13.9
1970	Wet	2151	65.3	1277	18.8	3419	76.4	1606	25.3
1971	Dry	2260	74.8	1293	22.2	2851	71.6	1651	30.2
1975	Wet	2611	95.5	2932	45.8	2752	54.47	2866	51.2
				Central Luzon and Laguna					
1966	Wet	5996	370.7	2481	106.9	1984	111.5	2038	38.9
1970	Wet	5805	380.6	1033	36.3	1807	64.8	1811	29.8
1974	Wet	4445	218.2	696	21.2	2257	69.5	2090	27.8

[a] Monetary value converted to kilograms of palay at the average price received for palay by the sample in each season.

Table 6 shows the paddy equivalent of income per farm and per man-day of family labor for the three tenure groups. In Laguna, income per farm was constant for share-tenants between the first two periods, but income per man-day of family labor nearly doubled because family labor input was reduced. About the same pattern was true for leaseholders in Laguna. Between 1966 and 1975, paddy-equivalent income increased for owners and share-tenants but decreased for leaseholders. As many farmers who were share-tenants in 1970 became leaseholders in 1975, the average rent increased from 460 kg to 649 kg of paddy equivalent. In addition, the real value of input use for this class doubled. These factors resulted in the reduction of GFFI for leaseholders.

Share-tenants in CL/L suffered sharp declines in their income both per farm and per man-day between 1966 and 1974. Leaseholders experienced a similar decline between 1966 and 1970, but their incomes improved somewhat between 1970 and 1974. Although there were few owner-operators, their income were much higher than those of other classes, especially in CL/L, because they had larger farms and used less family labor input.

PRODUCTION-COST CHANGES

One result of the introduction of modern rice varieties has been an increase in the use of purchased inputs. During the 10 years examined that increase has had a substantial impact on the structure of farm costs. Table 7 shows the proportion of total paid-out costs that were contributed by the major components of expenses. By far the largest proportion — exceeding 50% before 1970 – was for land rent. Labor for harvesting was the second largest component.

Table 7. Cost structure of two samples of Philippine rice farms, current prices, 1966-75.

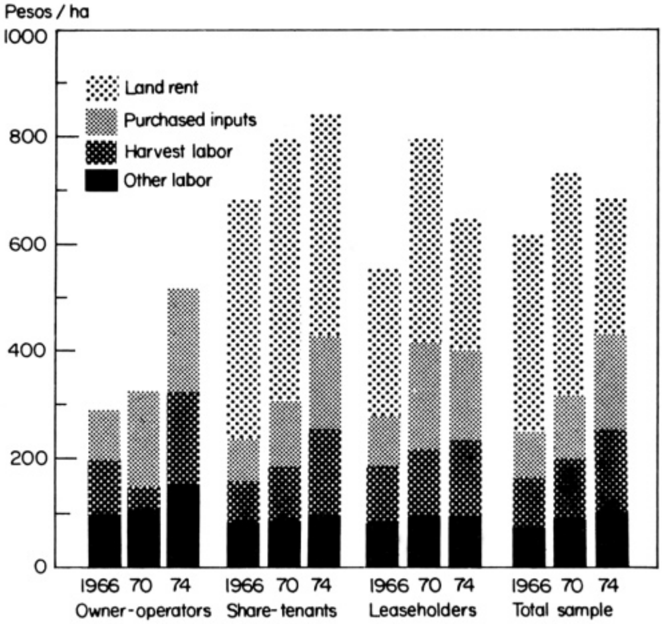
			Proportion of paid-out costs of production (%)									
Year	Season	Farm (no.)	Land rent	Fertilizer	Herbicides	Insecticides	Machinery[a]	Irrigation	Hired labor			
									Land	Seedlings [b]	Crop care [c]	Harvest, etc.
						Laguna						
1966	Wet	114	63	4	[d]	[d]	2	1	3	5	1	20
1967	Dry	81	63	4	1	1	2	1	3	4	1	20
1970	Wet	114	57	6	1	1	4	2	2	5	3	19
1971	Dry	81	58	6	1	1	3	2	3	4	3	19
1975	Wet	156	33	14	[d]	3	7	3	4	6	9	21
						Central Luzon and Laguna						
1966	Wet	70	58	5	[d]	[d]	7	2	4	7	1	16
1970	Wet	88	53	7	[d]	1	8	2	3	9	2	15
1974	Wet	66	39	15	1	3	8	2	3	8	2	18

[a] For land preparation and threshing. [b] Seedbed preparation, seedling care, pulling, transplanting. [c] Hand weeding, spreading or spraying fertilizer and chemicals. This underestimates the amount of labor input for weeding because of the practice of contracting weeding and harvesting to the same person and paying at the time of harvest. For the same reason, it overestimates the harvest labor input. [d] Less than 5%.

Between 1966 and 1970, when the MV were being adopted, the proportion spent on fertilizers, insecticides, herbicides, and machinery increased from 6% to 12% in Laguna and from 12% to 16% in CL/L. Between 1970 and 1974, the changes in tenure reduced costs substantially, pushing up the proportion of total costs contributed by purchased inputs to nearly 30%. The similarity between wet- and dry-season data in Laguna is striking: the major income differences arise from yields. Therefore, in the remaining part of the paper, only wet-season Laguna data are examined.

For a more concrete picture of the changes that have occurred in real costs, Figures 3 and 4 show the four major components of costs in deflated terms. In Laguna, between 1966 and 1970, the real rents of share-tenants increased substantially while those of leaseholds fell. Real expenditures on inputs increased by nearly 300%. Real expenditures for hired labor increased only modestly. Between 1970 and 1975, rents of share-tenants went down, while real expenditures on inputs increased. Total labor costs increased substantially mainly because of an increase in other labor costs, a phenomenon noted in all tenure classes.

In CL/L, real rents also increased between 1966 and 1970, but by 1974 they had decreased to a level lower than the initial. Also between 1966 and 1970, real expenditures on inputs more than doubled, with all tenure categories



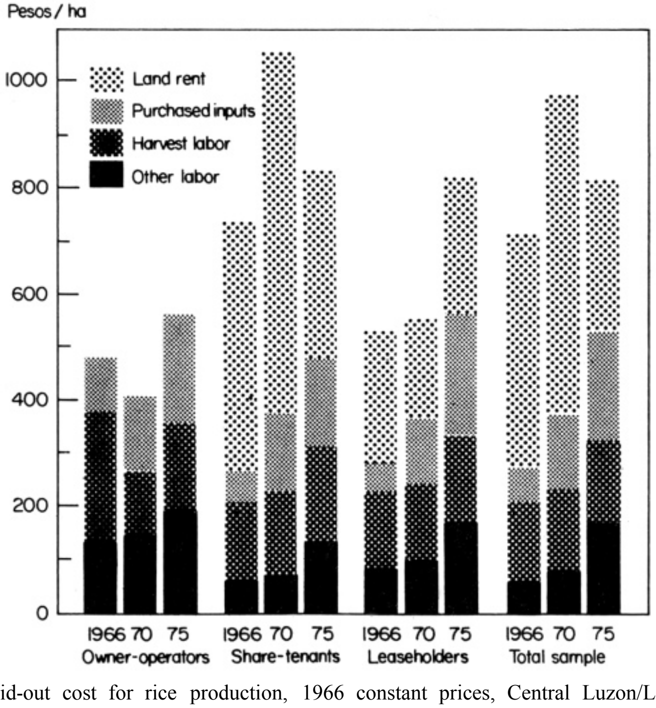
3. Total paid-out cost for rice production, 1966 constant prices, Laguna, Philippines.

showing an increase. Real expenditures on hired labor also increased. In 1974, both harvest labor payments and other labor payments were 50% higher than in 1966 in real terms.

Tables 8 through 10 show the average paid-out costs for all farms and for share-tenants and leaseholders in the two samples. Because of the relatively few owners, owners' costs are not shown separately but are included in Table 8.

The average expenditures for herbicides and insecticides are low; those for machinery and fertilizer expenses are somewhat higher. Comparison of Table 8 and 10 indicates little difference in costs among tenure groups. The data suggest that prior to 1974, price fluctuations of purchased inputs would have had relatively small impact on the total paid-out costs and incomes of most farmers. By 1974, however, expenditures on fertilizer and machinery had reached the point where those two inputs made up nearly one fourth of paid-out costs. The situation is traceable partly to the large price increases for those inputs after the oil price increase in 1973–74, and partly to a substantial increase in the use of the purchased inputs. The only major difference in costs between the two areas is for crop care in 1975 for which 10 times more was spent in Laguna than in CL/L.

Labor inputs. Table 11 supports the observation on the reduction of family labor and its impact on increasing returns per man-day of family labor. All



4. Total paid-out cost for rice production, 1966 constant prices, Central Luzon/Laguna, Philippines.

Table 8. Cost of rice production for all farmers in two samples of Philippine rice farms, current prices, 1966–75 wet seasons.

		Paid-out cost of production ($/ha)									
								Hired labor			
Year	Farm (no.)	Land rent	Fertilizer	Herbicides	Insecticides	Machinery[a]	Irrigation	Land preparation	Seedlings[b]	Crop care[c]	Harvest, etc.
					Laguna						
1966	114	61	4	0	0	2	1	3	5	1	20
1970	114	92	10	1	2	6	3	4	8	4	31
1975	156	106	47	3	9	23	10	11	20	30	67
					Central Luzon and Laguna						
1966	70	49	4	0	0	6	1	3	6	1	13
1970	88	61	8	0	1	9	3	5	10	3	17
1974	66	83	34	3	7	18	4	7	18	4	40

[a]For land preparation and threshing: [b]Seedbed preparation, seedling care, pulling, transplanting. [c]Hand weeding, spreading or spraying fertilizer and chemicals. This underestimates the amount of labor input for weeding because of the practice of contracting weeding and harvesting to the same person and paying at the time of harvest. For the same reason, it overestimates the harvest labor costs.

Table 9. Cost of rice production for share-tenants in two samples of Philippine rice farms, current prices, 1966–76 wet seasons.

		Paid-out cost of production ($/ha)									
								Hired labor			
Year	Farm (no.)	Land rent	Fertilizer	Herbicides	Insecticides	Machinery[a]	Irrigation	Land preparation	Seedlings[b]	Crop care[c]	Harvest, etc.
					Laguna						
1966	104	64	4	0	0	2	1	3	5	1	19
1970	96	105	10	1	2	6	3	3	8	4	32
1975	68	129	40	3	8	19	9	9	20	37	57
					Central Luzon and Laguna						
1966	50	60	4	0	0	5	1	3	5	1	13
1970	44	75	7	0	1	9	2	3	10	2	18
1974	19	142	35	3	7	15	2	6	10	2	43

[a]For land preparation and threshing, [b]Seedbed preparation, seedling care, pulling, transplanting. [c]Hand weeding, spreading or spraying fertilizer and chemicals. This underestimates the amount of labor input for weeding because of the practice of contracting weeding and harvesting to the same person and paying at the time of harvest. For the same reason, it overestimates the harvest labor costs.

three tenure classes in Laguna substantially reduced their input of family labor between 1966 and 1970. At the same time, they held constant or slightly increased their use of hired labor. Between 1970 and 1975, family labor input remained nearly constant while hired labor increased by 40% on the average. Those changes, described by Barker and Cordova (this volume), seem to reflect a substitution of other activities for rice farm labor by farm families in the Laguna sample area.

Table 10. Cost of rice production for leasehold tenants in two samples of Philippine rice farms, current prices, 1966-75 wet seasons.

Year	Farm (no.)	Paid-out cost of production ($/ha)									
								Hired labor			
		Land rent	Fertilizer	Herbicides	Insecticides	Machinery [a]	Irrigation	Land preparation	Seedlings [b]	Crop care [c]	Harvest, etc.
						Laguna					
1966	8	35	4	0	0	1	1	6	4	2	21
1970	13	29	9	1	1	6	3	9	8	4	30
1975	81	99	56	4	10	28	12	13	21	38	66
						Central Luzon and Laguna					
1966	11	39	3	0	0	6	2	4	7	1	15
1970	36	60	8	0	1	9	3	3	11	5	19
1974	36	83	31	3	8	20	6	6	18	2	40

[a] For land preparation and threshing. [b] Seedbed preparation, seedling care, pulling, transplanting. [c] Hand weeding, spreading or spraying fertilizer and chemicals. This under estimates theamountof labor input for weeding because of the practice of contracting weeding and harvesting to the same person and paying at the time of harvest. For the same reason, it overestimates the harvest labor costs.

In contrast, the CL/L sample shows a trend of increasing use of family labor by all tenure classes between 1966 and 1974. The use of hired labor likewise increased over the period. It is surprising that the level of labor input (both family and hired) was far lower than that in Laguna in 1966, but by 1974 it was at about the 1970 Laguna level.

Machinery use. The proportion of costs for mechanized land preparation and threshing registered a slight increase over the study period, from 2 to 7% of costs in Laguna and from 7 to 8% of costs in CL/L (Table 7). Two forces affected the changes. First was the trend toward greater use of custom-hired machinery for land preparation, which tended to increase the paid-out cost for

Table 11. Family and hired labor for rice production in two samples of Philippine rice farms, 1968-75 wet seasons.

Year	Labor use in rice production per season (man-days/ha)								
	Owner-operators		Share-tenants		Leaseholders		All		
	Family	Hired	Family	Hired	Family	Hired	Family	Hired	Total
					Laguna				
1966	79.3 [a]	87.7	45.5	54.8	45.4	71.7	46.1	46.6	92.7
1970	18.6	69.7	29.1	61.6	22.8	67.3	27.8	62.7	90.5
1975	25.1	97.5	27.8	78.5	23.5	94.1	25.9	87.5	113.4
					Central Luzon and Laguna				
1966	16.2	44.4	23.2	39.1	17.8	52.6	21.5	41.9	63.4
1970	15.3	45.0	28.5	46.6	27.9	51.3	27.0	48.4	75.4
1974	20.4	84.6	32.9	58.6	32.5	59.3	30.6	63.3	93.9

[a] Only two farmers are represented in this subclass.

machinery. Offsetting that trend was an increase in the number of tractors, especially hand tractors, owned by farmers. The latter entailed increased expenditures for fuel, but the capital cost was not reflected in paid-out cost.

Table 12 shows the change in the use of machinery for land preparation and the associated paid-out costs of land preparation for farms using tractors and farms using animals. Land preparation was mechanized (hand tractors or power tillers) for nearly 40% of the Laguna sample in 1966 and for 75% in 1970. In the CL/L sample, 4-wheel tractors were common. Between 1966 and 1970, 30% of the sample began using tractors for land preparation. Paid-out costs of land preparation were substantially higher with mechanization. In addition to what they spent for machinery, the farmers who mechanized spent about two-thirds as much for hired labor as the group that used animal power.

Table 13 shows the implications of mechanized land-preparation operations for labor use in the samples. Family and hired labor use and plowing and harrowing operations are separated. The farms that mechanized plowing and harrowing used about 10% more hired labor than did the farms that used animal power, but the nonmechanized farms used twice as much family labor as the mechanized. The tendency showed up in both regions for mechanized harrowing, but somewhat less strongly for mechanized plowing in CL/L.

The total labor use for land preparation declined over time for both mechanized and nonmechanized groups. In Laguna, family labor use declined by 50% on mechanized farms between 1966 and 1970, and hired labor use declined by about 10%. On nonmechanized farms, family labor use declined by 30% and hired labor by 15 %. A similar trend occurred between 1966 and 1970 in CL/L, but with a somewhat greater reduction in hired labor. Between 1970 and 1974, the labor input remained fairly stable.

Threshing machines were used by some farmers in Central Luzon, but not by Laguna farmers in the area studied. Table 14 Shows the cost data for the thresh-

Table 12. Paid-out costs of land preparation with tractor and animal power. Two samples of Philippine rice farms. 1986-75 wet seasons.

Year	Mechanized				Animal-powered		
		Paid-out cost ($/ha)				Paid-out cost ($/ha) for	
	Farms (%)	Labor	Machinery	Yield (t/ha)	Farms (%)	labor & animals	Yield (t/ha)
			Laguna				
1966	38	3	6	2.2	62	3	2.5
1970	75	3	9	3.4	25	5	3.3
			Central Luzon and Laguna				
1966	18	2	10	2.6	82	3	2.2
1970	48	3	9	2.8	52	3	2.4
1974	56	8	22	2.7	44	6	2.1

Table 13. Family and hired labor[a] for land-preparation operations by farmers using tractors or animals for power. Two samples of Philippine rice farms, 1966–75 wet seasons.

Operation	Family and hired labor (man-days/ha)											
	Laguna				Central Luzon and Laguna						Both samples (av.)	
	1966		1970		1966		1970		1974			
	F	H	F	H	F	H	F	H	F	H	F	H
Mechanized plowing	6.1	2.1	3.2	2.6	4.5	2.7	1.3	1.2	0.6	0.8	3.1	1.9
Nonmechanized plowing	7.3	1.5	5.3	1.4	5.1	2.4	5.5	1.6	5.5	2.1	5.7	1.8
Mechanized harrowing	4.3	3.3	2.1	2.2	3.5	3.6	2.8	3.0	1.8	3.9	2.9	3.2
Nonmechanized harrowing	10.4	3.1	6.8	2.5	5.0	4.6	5.2	2.0	5.6	2.3	6.6	2.9
Mechanized plowing and harrowing	10.4	5.4	5.3	4.0	8.0	6.3	4.1	4.2	2.4	4.7	6.0	5.1
Nonmechanized plowing and harrowing	17.7	4.6	12.1	3.9	10.1	7.0	10.7	3.6	11.1	4.4	12.3	4.7

[a] F = family workers, H = hired workers.

ing operation of farmers using machines and those using manual methods. The proportion using mechanized threshing declined from about two-thirds to less than half of the sample during the period, despite the reported substantially lower cost of mechanized harvesting and threshing than of hand methods. The decline may be related to the change in tenure status. With share-tenancy the landlord arranged for the large threshing machine to thresh the crop under his supervision. That usually involved some period of waiting. With the change in tenure, apparently farmers preferred to use labor to thresh their crops immediately.

Table 14. Paid-out costs of harvesting and threshing with machines and with manual methods. Central Luzon/Laguna, Philippines, 1966–75.

Year	Mechanized threshing				Manual threshing			
	Farms (%)	Paid-out harvest and threshing cost ($/ha)		Yield (t/ha)	Farms (%)	Paid-out harvest and threshing cost ($/ha)		Yield (t/ha)
		Labor	Machinery			Labor	Machinery	
1966	65	8	6	2.3	35	25	1	2.2
1970	60	9	8	2.6	40	24	0	2.6
1974	43	15	14	2.0	57	60	0	2.8

CAPITAL EQUIPMENT AND NET INCOME

As pointed out earlier, the ownership of capital equipment has implications for income calculations, but data on capital equipment are not as available as the data on other income-related items. Data on the number and value of capital equipment for the CL/L sample are available only for 1966 and 1974 (Table 15); those for the Laguna sample, only for 1975. The latter data are not examined here.

Table 15 shows that in 1966, none in the CL/L sample owned tractors, threshers, or irrigation pumps but by 1974. one-fourth of the owner-operators owned tractors and irrigation pumps. In 1974, 6% of the leaseholders owned tractors, and 11 % owned irrigation pumps. In 1966, nearly all farmers in the sample owned plows and harrows, and nearly as high a proportion owned carabaos. But by 1974, only 74% of share-tenants and 58% of leaseholders continued to own carabaos, having replaced them by custom-hired equipment for mechanical land preparation. The owner-operators continued to maintain carabaos even though they also owned proportionately the largest number of tractors. The number of sprayers also increased rapidly. In 1966, only 17% owned sprayers, but by 1974, the majority had them. Ownership of weeders changed little over the period.

The imputed cost of capital equipment has been calculated to adjust income for the differences in capital ownership. In the survey, we obtained the farmer's estimate of the present value and remaining years of life of each item of capital and applied the straight-line depreciation method. Interest was calculated at 15% a year. Table 16 summarizes the capital value and costs. The 1974 capital value of the tractors, threshers, and pumps of the owner-operators was far above the 1966 levels and far higher than the levels for share-tenants and leaseholders. The effect of the imputed capital cost for the CL/L sample is in Table 17.

Comparing the paddy equivalent of GFFI per farm for the wet season shows an increase of about 3% between 1966 and 1974. Owners suffered a reduction

Table 15. Proportion of farms owning one or more items of capital equipment, Central Luzon/Laguna sample, 1966 and 1974.

Capital item	Percent that reported owning capital equipment							
	1966				1974			
	Owner-operator	Share-tenant	Lease-holder	All	Owner-operator	Share-tenant	Lease-holder	All
Tractor	0	0	0	0	27	5	6	6
Thresher	0	0	0	0	9	0	2	1
Irrigation pump	0	0	0	0	27	0	11	10
Plow	100	96	93	96	91	95	86	89
Harrow	100	96	93	96	91	95	86	89
Weeder	22	8	53	17	27	21	19	21
Sprayer	17	19	7	17	73	42	58	56
Carabao	89	96	93	94	91	74	58	68

Table 16. Imputed capital costs per farm for Central Luzon/Laguna sample, 1966 and 1974.

Item	1966				1974			
	Owner	Share-tenant	Lease-holder	All	Owner	Share-tenant	Lease-holder	All
Farms (no.)	9	50	11	70	11	19	36	66
Area planted (ha/yr)	3.5	3.3	2.9	3.3	3.4	3.7	3.0	3.3
Capital/farm ($)	166	150	116	144	3455	358	365	878
Depreciation/ farm ($)	19	18	13	17	375	37	48	115
Capital cost ($/ha)	6	5	5	5	110	10	16	45

Table 17. Gross farm family income (GFFI) and net family farm income (NFFI), imputing depreciation costs for all capital, Central Luzon/Laguna sample, wet seasons of 1966 and 1974.

Item	1966				1974			
	Owner	Share-tenant	Lease-holder	All	Owner	Share-tenant	Lease-holder	All
	Current price terms							
GFFI/ha per season ($)	132	63	52	51	222	46	130	122
NFFI/ha per season ($)	126	58	47	46	112	35	114	87
GFFI/ per season ($)	367	152	121	124	636	99	323	299
NFFI/ per season ($)	351	139	110	112	321	77	283	213
	1966 constant price terms							
GFFI/ per season ($)	367	152	121	124	219	34	111	103
NFFI/ per season ($)	351	139	110	112	153	26	97	73
	Paddy-equivalent terms							
GFFI/farm per season (kg of paddy)	5996	2481	1984	2038	4445	696	2257	2090
NFFI/farm per season (kg of paddy)	5742	2273	1803	1827	2242	541	1976	1489

of 30%, share-tenants a reduction of 65%, but leaseholders enjoyed an increase of 11 %. The paddy equivalent of NFFI of owners fell 60% and that of share-tenants, 76%; but that of leaseholders increased about 9%. The average for the entire sample fell by 18%. Thus, the net income figures show that incomes fell in spite of slightly higher yields, more capital inputs, and more current inputs. The condition is traceable to the abnormally low yields in 1974.

SUMMARY AND CONCLUSIONS

Two quite different pictures emerge from the two study areas — Laguna and Central Luzon/Laguna — despite the superficial similarities. In both, the modern varieties were rapidly adopted, but the adoption was completed earlier in Laguna. The use of modern inputs associated with the new varieties increased at similar rates and to similar levels in the two areas — from $8/ha to $27/ha in

Laguna and from $11/ha to $24/ha in CL/L (in constant prices) during the period studied. Both areas had considerable modification in tenure and an increase in the use of machinery for land preparation. Hired labor inputs also increased.

The differences between the areas are best related to yields. In Laguna in the wet season, yields increased from 2.4 t/ha in 1966, to 3.3 t/ha in 1970, to 3.6 t/ha in 1975. In the wet season in CL/L, they increased from 2.3 t/ha in 1966 to 2.6 t/ha in 1970, then fell to 2.4 t/ha in 1974. The poor yield was related to the occurrence of seven typhoons during the harvest season of September-December 1974. (During the previous 8 years there had been at most 2 typhoons/year, and in half the years none.) That poor CL/L yield performance resulted in low income in 1974, especially because the level of inputs had gone above the 1970 level. In addition, the use of an increased amount of both family and hired labor lowered returns per day of contributed family labor.

Between 1970 and 1975 in Laguna, the rent of share-tenants increased by 23% (in current price terms). Between 1970 and 1974 in CL/L, it increased, further reducing GFFI for share-tenants. In a normal year, income results in CL/L would have been more similar to those in Laguna.

In Laguna, where yields increased substantially, real gross farm family income per hectare between 1966 and 1975 nearly doubled. The amount of hired labor was increased and family labor was reduced. Modern varieties which were unknown in 1966, covered nearly 100% of the area in 1970. Share-tenants made up 85% of the sample in 1970 and 50% in 1974. It appears that the combined technological, institutional, and climatological forces made 1975 a favorable year for Laguna, relative to the earlier years, but the same forces made 1974 a rather unfavorable year for the CL/L sample.

REFERENCES CITED

Barker, R., and V. Cordova. 1978. Labor utilization in rice production. Pages 114–136 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

Bernsten, R.H. 1976. Rice farming in Central Luzon: input usage, cultural practices and yield constraints. Paper presented at an IRRI Saturday. seminar, March 20, 1976. International Rice Research Institute, Los Baños, Philippines.

Guino, R., E. A. Labadan, and R. Barker. 1975. Approaches to problems of data collection. Department of Agricultural Economics Paper no. 74–19. International Rice Research Institute, Los Baños, Philippines. (mimeo.)

Ranade, C.G., and R. W. Herdt. 1978. Shares of farm earnings from rice production. Pages 87–104 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

Roxas, N.M. 1976. Calibration of instruments. Draft paper, Multiple Cropping Program, International Rice Research Institute, Los Baños, Philippines.

COMMENTS ON
COSTS AND RETURNS FOR RICE PRODUCTION

P.H. CALKINS

THE ISSUES ADDRESSED by Herdt are fundamental to an understanding of the benefits from, and reasons for, the adoption of the new rice technology. Yet, while the paper is written with great energy and insight, it seems to suffer from an identity crisis. The author treats at least one analytical method, a host of possible hypotheses, two farm samples, three tenure groups, two production seasons, data that span a land reform period, speculations on mechanization, and a wealth of descriptive information in the mere space of ten pages. The paper contains valuable statistics, but information deficiencies still lead the author to compare data that are not strictly comparable. Thus, while the paper is impressive, I feel its main topic could be developed with more direction.

METHODOLOGY

Herdt introduces five different accounting systems for measuring farm costs and returns. These accounting systems, given in graphic form in Herdt's Figure 1, are of immense potential use for the analysis of differences in factor shares accruing to various subdivisions of land, labor, capital, and management. They offer a choice of formats, which allows not only for standardized comparison across countries of disparate data, but also for comparison within a region or country of costs and returns of different tenure-status groups. The last two types, particularly, offer simple yet effective methodological tools.

Gross farm family income (GFFI) is defined as the residual received by the farm operator after paying out all costs of inputs in cash and kind. Net farm family income (NFFI), on the other hand, is calculated by subtracting depreciation from GFFI. Each is subdivided into cash and kind, and there is even the category *imputed land rent.* Thus, with a given year and a given set of policy parameters constituting an economic environment, the format is valuable for comparative purposes. As an example, Herdt points out that by subtracting imputed land rent from NFFI to compute so-called *labor income,* it is possible to compare the productivity of tenants and of owner-operators. There had been no convenient yardstick to do that in the past.

Associate agricultural economist, Asian Vegetable Research and Development Center, Taiwan, Republic of China.

In addition to the definitions of GFFI and NFFI, valuable methodological procedures are outlined throughout the paper. For example, the procedure for deflation of each category of inputs by separate price indices instead of using a single index is sound.

But after defining the five analytical techniques, it would be instructive to apply them to the sample to show the differences they point out. Thus, especially where the analyst has access to comparable data (this possibility exists for part of the time period under consideration, but is unexploited) over a period of technological or institutional change, or both, the paper could be a textbook for choosing and applying the appropriate technique. That could lend further insight into what farmers endeavor to maximize under changing constraints.

PURPOSE

The avowed purpose of the paper is to determine the changes over time in costs and returns of rice production and to suggest some possible causes for those changes. Two samples of Filipino farmers are chosen for comparison: from 81 to 156 farmers in selected wet and dry seasons in Laguna sampled six times between 1966 and 1975; and from 66 to 88 farmers in Central Luzon and Laguna sampled only in the wet season in the three years 1966, 1970, and 1974. Here is where the problem of an inconsistent data base enters. The only two seasons in common for the two samples are the 1966 and 1970 wet seasons. Any cross-sectional analysis should properly be confined to those two years because of the great variability and obvious importance of weather variables between the 1974 and 1975 wet seasons. Yet in the concluding section the author persists in comparing the good agricultural year for Laguna (1975) with the admittedly poor agricultural year for Central Luzon and Laguna (1974).

Moreover, the author states his interest in the increasing use of inorganic fertilizer, government policies with regard to rice, infrastructural investment, and noncollateral loans in terms of their effects on costs and returns over time. It is possible to describe, as Herdt does, the differing rates of adoption in the two samples and the shifts over time in tenurial status, but it does not seem justified to use the costs and returns technique to make further inferences about the investment structures of the two samples and their relationships with differing tenurial structures, again because of the disparate nature of the final years compared.

It would, however, be justified to perform such an analysis on the data from 1966 and 1970. Indeed, the results for those periods would be quite revealing, because the upswing in adoption of modern varieties (MV) was far more dramatic in the Laguna sample, while land reform progressed more rapidly in the Central Luzon/Laguna sample. Thus, the paper does seem a suitable forum for the discussion of the impact on costs and returns both of different adoption rates of the MV and of differing tenurial structures between the two samples, provided the time period is limited to 1966–70.

It is in fact with some reservation that one must regard Herdt's last sentence, "Thus, it appears that the combination of technological, institutional, and climatological forces combined to make 1975 a very favorable year for Laguna, relative to the earlier years, while those forces made 1974 a rather unfavorable year for the CL/L sample." It would be more appropriate to leave out the adjectives technological and institutional unless they had been proven significant in making 1970 more favorable for one sample than the other.

SUGGESTIONS

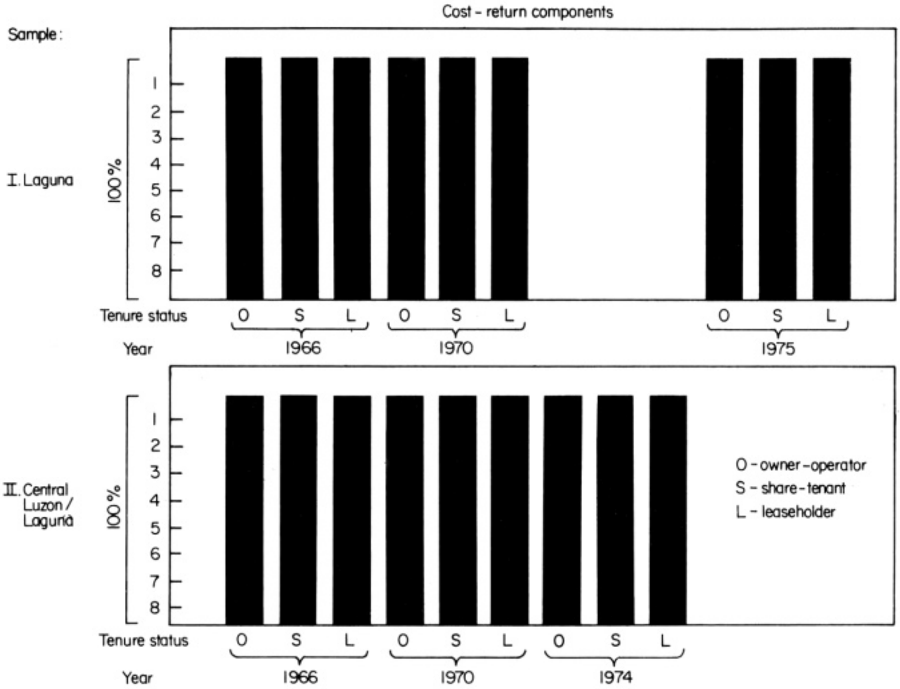
The Herdt paper could be of more value if several items had been added:

1. a clear introduction to the methodological tool to be employed, and the possibilities and limitations of its use;
2. a statement that each sample would be studied separately except where data for comparable years are available;
3. a set of hypotheses for the study:
    - The adoption of MV leads to an increase in weeding labor, but a small overall change in total labor utilization.
    - Returns to labor are higher for owner-operators than for tenants.
    - The interrelationships between factor prices and shifts in factor use over time suggest a keen economic awareness of the farmer (and hence high levels of managerial skill).
    - The change within a locality in the percentage of farmers in different landholding categories (made voluntarily) is motivated by an awareness of new factor-factor price relationships attendant upon the modern technology.
    - Because of the differences in capital expenditure among tenure groups, NFFI are much more comparable between tenure groups than are GFFI.
    - There is less variability in the dry-season cost structures for 1967, 1971, and 1975 in Laguna than for the wet season in the same locale.

Many of the above relationships are actually treated in the paper, but it is hard to sort out the conclusions from the discussion of various relationships by season, year, location, and factor input.

4. a composite chart. To the extent possible, the data should be arranged according to the methodological tools adopted (i.e., the last two in Herdt's Figure 1). Figures 3 and 4 at the end of Herdt's paper begin to show the changes over time in cost structure, but it would seem fruitful to present the data in a format consistent with that introduced in his Figure 1, especially to give focus to the 17 tables presented in the paper. Thus, a revised Figure 1 could include, for each sample, the eight items:

- labor paid in cash,
- labor paid in kind,
- current inputs paid in cash – machine, animal, fertilizer, others,
- current inputs paid in kind – machine, animal, fertilizer, others,
- depreciation on capital – landlord's, operator's,



1. Farmer income account structure by location, year, and tenurial status.

- imputed land rent,
- imputed cost of family labor, and
- residual.

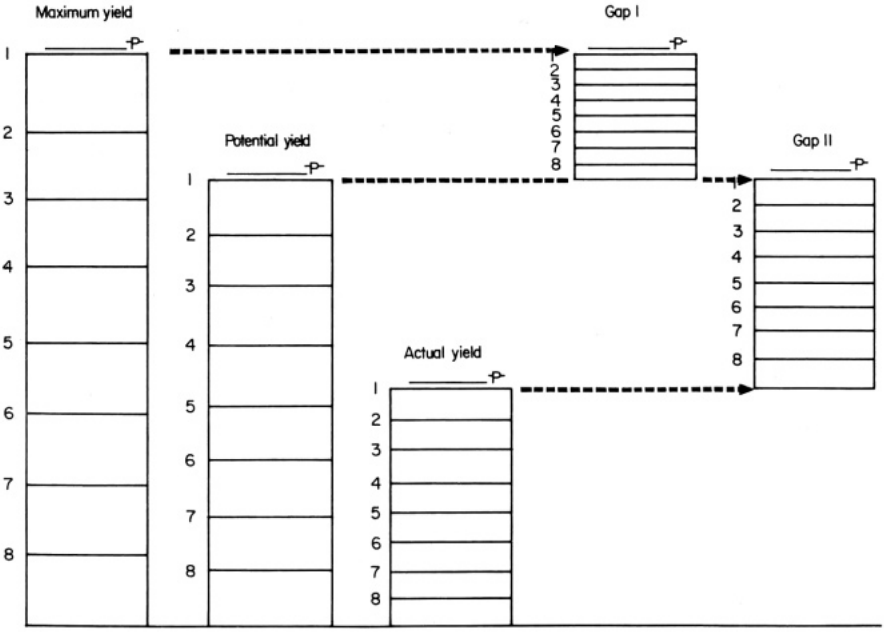
With Figure 1 one could assess at a glance many of the issues addressed in the paper (including mechanization) for comparative analysis.

Even given the existing figures, more could be done in the way of analysis. With Herdt's Figure 3 (Laguna), for example, it is clear that harvest labor costs are constant except for a reduction for owner-operators in 1970 followed by an increase in 1975. Other labor costs are also constant except in the same two cases. Purchased input costs rise uniformly over time. Land rents peaked in 1970 and then declined, except for the case of leaseholders who show the opposite pattern. The situation suggests

- owner-operators, who are not confronted with land rent costs and their peaking pattern, decrease labor while increasing purchased inputs;
- share-tenants and leaseholders take advantage of the new technology by increasing other labor and purchased inputs and holding harvesting labor constant; and
- the optimal cost-allocation strategies for leaseholders and share-tenants have been the same over time, even though leaseholders have more favorable land rents.

If elaborated in this way Herdt's analysis could be used in a macroeconomic analysis of the effects of land reform and other changes in tenure pattern. Or perhaps, given that harvest labor has become an income redistribution measure and that its wage in kind has gone down over time, as mentioned earlier in this conference, one could perceive where and why manual threshing has persisted. It is also advisable to use the suggested format to compare the dry with the wet season, since one knows, also mentioned earlier in this conference, that risk in the former is low and stays low even with large increases in purchased inputs. Thus, despite the fact that the cost structure in Laguna is similar in the wet and dry season in aggregate, one might see differences evolving over time by tenure group.

5. a comparison of yield gap and cost structures. Perhaps the most interesting question that faces the reader is how the analysis of costs and returns is related to the yield gap research also being conducted at IRRI. The Herdt and Wickham paper (this volume) on yield gap suggested that physical, biological, economic, and other constraints effectively reduce the actual yield the farmer obtains, given either his own agronomic maximum or that of the experiment



2. An application of farm income accounts to the analysis of yield gaps for a given tenure, location, and seasonal sample in a given year. Yield and other physical quantities are valuated at prices in the given year.

station. These influences have been quantified as water (23%); solar radiation (19%); biological variability (19%); profit, risk, and other economic factors (17%); and the lack of inputs (22%). It should be possible to relate the two concepts, so that each component of the cost structure has an accompanying yield cost. It might be necessary to translate the yield gaps from physical terms into monetary terms and to call them the gaps between the maximum, potential, and actual gross values (see Fig. 2). The size and nature of the gap are intimately connected with changes in factor prices and tenurial status over time attendant upon such technological and institutional changes that occurred in the period 1966–75. Such an integrated analysis could link understanding of investments by government policymakers and research institutions with the microlevel cost structure faced by the individual cultivator, and thereby reflect the interplay of social or macrocosts with private and microcosts.

The above suggestions are made in the belief that the issues and analyses presented are of great potential value. I look forward to their further development.

Shares of farm earnings from rice production[1]

C.G. RANADE AND R.W. HERDT

AS THE NEW RICE and wheat technology spread throughout Asia between 1966 and 1970, pressures for increased food grain production slackened and concern about the distributional impact of the new cereal technology mounted. Even in 1973 and 1974, when pressure on production again became acute, concern with the distributional implications continued. Several widely read critiques of the new technology, emphasizing its possible distributional effects, have appeared (Frankel, 1971; Griffin, 1974) but their empirical evidence is weak.

One theme that runs through the literature criticizing the high yield, seed-fertilizer technology is that it has a labor-saving bias that reduces returns to labor and increases returns to other factors. A few empirical studies consider the bias in technological change by measuring either changes in factor shares or elasticities of substitution (Kelly et al., 1972; Rao, 1971; Srivastava and Heady, 1973; Thirsk, 1974). Such data, especially those on gains or losses in labor's share of output, have been used to imply the technology's effects on personal income distribution. Several efforts have calculated and compared the relative share of output going to each earner in the production and modern and traditional cereal varieties (IRRI, 1970; Mellor and Lele, 1973).

Also concerned with distributional impact, but using a quite different approach are two studies that computed Gini coefficients for rural income groups, and related the magnitude of those coefficients to the degree of acceptance of new technology (Raju, n.d.; Singh, 1972). Using still a different technique, Hayami and Herdt (this volume) formulated a model exploring the indirect distribution effect of technological change.

Indian Institute of Management, Vastrapur, Ahmedabad, India; and agricultural economist, Department of Agricultural Economics, International Rice Research Institute, Los Baños, Philippines.

[1] This research is reported in more detail in Ranade (1977a, b).

The existing studies provide some insights into the distribution of benefits from new technologies. We wish to add to that understanding by focusing on the distribution of returns among the *direct participants* in production and on some factors affecting the distribution. Thus, our paper is directed at factors affecting income distribution at the farm level. We examine the distribution of income originating in rice production by calculating the share of output received by various earners.

The data from the two periodic International Rice Research Institute (IRRI) surveys, the Laguna and Central Luzon/Laguna (CL/L) surveys, are ideally suited for the analysis.

METHODOLOGY

Our study uses two different approaches to estimate the distribution of farm earnings: By using an accounting technique, the observed distribution of farm earnings among the direct participants and among the factors of production is estimated. By using a production function approach, the production elasticities of different inputs in traditional and modern technologies are estimated.

The first approach allows us to see which participants have actually benefited and how the benefits are related to ownership of factors of production and institutional arrangements prevailing in regions undergoing technological change. The second approach gives us an idea of the distribution of output among inputs that would prevail if each input were paid based on its marginal product.

Accounting for the distribution of earnings. The first approach calculated the real income, and the share of output accruing to the three main classes involved in agricultural production — landlords, hired laborers, and operators — and the share of output and real income transferred outside the agricultural sector to purchase current inputs. Changes in the earnings thus divided are one useful measure, although imperfect, of changes in personal income distribution. They are an imperfect measure because individuals who belong to more than one class may change the proportion of their time spent in different activities. For example, a farm operator may increase the time he spends as a hired laborer.

Consider a tenant farm operator whose landlord shares some of the production costs and compute the following, using the average prices paid and received by the operator.

a. Payment to the landlord as the value of output given as rent on land *minus* production cost shouldered by landlord.

b. Payment to hired labor as the sum for all operations of wage rate *times* man-days employed in an operation plus value of output given to harvesters.

c. Payment to the operator and family as the value of output *minus* the sum of payment to landlord, hired labor, and current inputs.

d. Payment to current inputs as the sum of expenses on fertilizer, insecticide, pesticide, herbicide, *plus* irrigation cost and rents on tractor and mechanical thresher, whether paid by landlord or tenant.

The sum of payments *a* through *d* thus exhausts the total value of output, and is one method of allocating income to the earners. Dividing each payment by the total gives the share going to each earner. The sum of a, b, and c gives the value added in agriculture. Measuring the share of each class of earner in value added is useful in a technologically dynamic setting because it adjusts for increases in output directly traceable to inputs manufactured by the industrial sector. Dividing each payment by an appropriate price index gives the real income going to each earner. In this case, the farm price of rice was used, so the real income measure is equivalent to a given quantity of rice.

In addition to output shares to earners, factor shares can be calculated directly with the use of certain assumptions. The first step is calculating imputed costs for family labor, owned land, and capital. The imputed wage rate to family labor is calculated as the total cost of hired labor divided by the total man-days of hired labor for each farm. The imputed cost of land is calculated as the average rental paid by all farmers in the sample who rented land. The imputed cost of capital may be taken as depreciation, plus repairs, plus the opportunity cost of capital. Using these imputed costs, one may calculate:

e. Payment to land as the payment to landlord plus imputed rent of owned land.

f. Payment to labor as the payment to hired labor *plus* imputed value of family labor.

g. Payment to capital as the imputed value of the service of capital equipment.

h. Operator's profit as the value of output *minus* (d + e + f + g).

The shares of land, labor, and capital can then be measured by dividing e, f, and g by their sum. The factor shares thus derived are compared with econometrically estimated production elasticities.

It was impossible to calculate factor shares for all our samples because of lack of comparable capital data. Still, it was possible to determine the imputed wage rate and the imputed land rent, and therefore, to calculate the payment and share of land and labor. The amount remaining after deducting costs of current inputs, land, and labor is simply called operator's residual:

j. Operator’s residual as the value of output minus (d + e + f).

The production function approach. Production elasticities were estimated for Cobb-Douglas and different variants of the translog function.[2] In general, these functional forms are specified as follows:

$$lnQ = a_0 + \sum_{j=1}^{3} a_j \, lnX_j + e \tag{1}$$

$$\begin{aligned} lnQ = a_0 &+ \sum_{j=1}^{3} a_j \, lnX_j + b_{12}\,(lnX_1 - lnX_2)^2 + b_{13}\,(lnX_1 - lnX_3)^2 \\ &+ b_{23}\,(lnX_2 - lnX_3)^2 + e \end{aligned} \tag{2}$$

---

[2] Choice of functional forms and related issues are discussed in Ranade’s work (1977). Also see Kmenta (1967) for linearized CES functions, which are similar to the translog function specified in our study.

where Q = yield in kilograms;
X_1 = land in hectares;
X_2 = sum of expenditures on fertilizer, insecticide, and herbicide deflated by the farm level prices of rice;
X_3 = total labor (man-days);
e = independent residuals with zero means and finite variance; and
a and b = parameters to be estimated.

The preceding functional forms have distinct features with respect to production elasticities. In the Cobb-Douglas function the production elasticities are constant; in the translog function they vary with input level. For example, the elasticity of labor in the Cobb-Douglas, a_3, is constant at all levels of inputs; for the translog function it is $a_3 + b_{12}(lnX_1 - lnX_2) + b_{13}(lnX_1 - lnX_3)$, which varies with the ratios of input quantities. Thus by using the production function approach one can not only estimate a potential distribution of output but also test how sensitive such distribution is to changes in the levels of input applied with a given technology.

The above forms were fitted separately for traditional and modern technologies. In particular, the translog function was fitted in various ways, first by considering all three possible interaction terms, and then by dropping some interaction terms. Furthermore, the actual specification of these forms involved slope and interaction dummy variables according to the characteristics of sample forms with respect to irrigation and mechanization.

The data base. The same two sets of data from the Laguna and the CL/L survey are used for this analysis, except that for Laguna we restrict this analysis to a comparison of 1966 and 1970 because our primary interest is with the impact of technological change. As shown earlier, most varietal change in Laguna occurred between 1966 and 1970. The 1974 comparison is retained for Central Luzon because it was only in 1974 when 75% or more of the farmers adopted the new varieties. For a detailed description of surveys related to Laguna and Central Luzon, see Johnson (1969), Liao (1968), and Ranade (1977a).

DIRECTLY MEASURED SHARES OF EARNINGS

Laguna. Table 1 shows what happened to the real earnings of those sharing in the production process in the CL/L sample. The absolute amount of output going to both landlords and hired laborers increased between 1966 and 1970 in both the wet and dry seasons. Nearly three times as much output was used for current inputs in 1970 as in 1966. Landlords' earnings increased by 17% in the wet season, and 6% in the dry season. Hired labor gained more than 50% in real income for the wet-season crop, and 30% for the dry-season crop. The operators (mainly tenants) had an increase of nearly 30% in their real incomes in the wet season, and about 25% in the dry season. In the sample, 70% of the farmers had two crops, Averaged across seasons the increase in absolute earn-

Table 1. Average real earnings and contributing factors, Laguna, Philippines.

	Average real earnings					
	Wet season			Dry season		
	1966 (kg/ha)	1970 (kg/ha)	Change (%)	1966 (kg/ha)	1971 (kg/ha)	Change (%)
			Earners			
Landlord	831	971	17	927	986	6
Hired labor	570	871	53	583	755	30
Operator and family	807	1072	29	953	1183	24
Current inputs	166	436	162	185	361	95
			Factors			
Land	846	1005	27	938	1019	9
Labor	974	1172	20	1017	1019	0
Operator's residual	388	737	90	510	886	74
Current inputs	166	436	162	185	361	95
	1966	1970	Change (%)	1966	1971	Change (%)
Yield (kg/ha)	2374	3349	41	2649	3286	24
Price ($/ha)[a]	0.06	0.07	11	0.06	0.10	59
Current wages ($/man-day)[a]	0.61	0.84	48	0.59	1.10	87

[a] Converted at P6.5 = $1.00.

ings amounts to 40% for hired labor, 25% for operators, and 10% for landlords.

Allocating the real earnings among factors by imputing costs to land and labor shows that the operator's residual (return to operator's capital and management) increased by nearly 90% in the wet season, and about 70% in the dry season. Thus, it appears that operators made their greatest gains as suppliers of management and capital, not as suppliers of labor.

Table 2 shows the changes in the relative shares of output to earners and factors. The share of landlords decreased about 15% between the periods in both seasons, while the share paid to current inputs increased substantially. This, in fact, is the nature of the new technology — the new varieties are more productive than the traditional ones but use greater amounts of off-farm inputs. Despite the increase in the share going to current inputs, there was a small increase in the share of earnings paid to hired labor in both seasons.

Farm operators and their families appear to have lost modest amounts. In the wet season their share went from 35 to 32% of output whereas it remained constant in the dry season. However, when the operators' share was adjusted for contributions of family labor, the operators' residual increased appreciably between 1966 and 1970.

The decline in the relative share of landlords can be explained by changes in tenure. The proportion of share-tenants declined from about 90% to about

Table 2. Relative share of earnings, Laguna, Philippines.

	Wet season			Dry season		
	1966	1970	Change	1966	1970	Change
	Relative share of earners (%)					
Landlord	.35	.29	–17	.35	.30	–14
Hired labor	.24	.26	8	.22	.23	5
Operator and family	.35	.32	–8	.36	.36	0
Current inputs	.07	.13	85	.07	.11	57
	Relative share of factors (%)					
Land	.36	.30	–17	.35	.31	–11
Labor	.41	.35	–14	.38	.31	–18
Operator's residual	.16	.22	38	.19	.27	42
Current inputs	.07	.13	85	.07	.11	57

80% of the sample; with the remaining share-tenants, the landlord's share in output fell from 37 to 34%. The average rent paid by leaseholders was lower than that by share-tenants. The combination of a larger proportion of leasehold tenants who paid a somewhat lower rent and a slight reduction in share rents tended to reduce the landlord's share.

In addition, the use of tractors for land preparation and the use of hired labor increased substantially in the second period (Table 3). Even though *total* labor use declined, *hired* labor use increased. As already noted, the use of other purchased inputs also increased markedly. Because landlords of share-tenants in the Laguna areas share in the costs of inputs and hired labor, they assumed more costs in 1970 than in 1966 but received the same proportionate share in total production. The sharing arrangement in Laguna is usually 50:50. In the case of leasehold, the share of land rent in the total farm production tends to be less than 50% in a normal weather year. If fixed after the land reform of 1972, leasehold rent amounts to 25% of the average production of the three years preceding land reform.

Table 3. Changes in labor and machinery use in Laguna, Philippines, between 1966 and 1970.

Year	Labor (man-days/ha)						Tractors used in land preparation[a]	
	Land preparation		Preharvest labor		Total labor			
	All	Hired	All	Hired	All	Hired	No.	%
				Wet season				
1966	21	5	67	23	99	55	41	36
1970	12	5	61	34	97	70	81	71
% change	–43	0	–9	48	–2	27	98	
				Dry season				
1966	21	5	70	26	103	58	22	27
1970	11	5	62	38	87	64	52	64
% change	–47	0	–11	46	–15	10	136	

[a] Where used, tractors usually were supplemented with animal power.

Table 4. Shares of value added, Laguna, Philippines, 1965–70.

Share of	Wet season			Dry season		
	1965	1970	Change	1966	1970	Change
	Shares allocated among owners (%)					
Landlord	.37	.33	–12	.37	.36	–3
Hired labor	.26	.29	12	.24	.26	8
Operator and family	.37	.36	–1	.39	.40	3
	Shares allocated among factors (%)					
Land	.39	.35	–11	.37	.35	–9
Labor	.44	.40	–10	.41	.35	–17
Operator's residual	.17	.25	47	.20	.30	50

When the effect of the increased contribution of purchased inputs is removed by computing shares in value added, the picture becomes somewhat more stable (Table 4). The share of landlords and land decreased slightly. Hired labor gained slightly, but when a return equal to that of hired labor was imputed to family labor contribution, the share of total labor declined. The share of added value going to the operator and his family was virtually unchanged, but his share as an operator was greatly increased over its 1965 level.

Central Luzon/Laguna. The allocation of real earnings in the CL/L sample is shown in Table 5. These data are somewhat more interesting than the Laguna

Table 5. Average real earnings and contributing factors, Central Luzon/Laguna, Philippines.[a]

	Average real earnings				
	1966 (kg/ha)	1970 (kg/ha)	Change (%)	1974 (kg/ha)	Change (%)
			Earners		
Landlord	664	777	17	471	–39
Hired labor	435	569	31	413	–27
Operator and family	961	880	–8	850	–3
Current inputs	229	362	58	417	15
			Factors		
Land	774	855	11	565	–34
Labor	570	751	32	619	–17
Operator's residual	715	620	44	549	–11
Current inputs	229	363	58	417	15

	Contributing factors				
	1966	1970	Change (%)	1974	Change (%)
Yield (kg/ha)	2288	2589	13	2149	–17
Price ($/kg)[b]	0.07	0.07	11	0.18	139
Current wages ($/man-day)[b]	0.58	0.84	37	1.18	37

[a] The exact figures in this table and in others for Central Luzon/Laguna do not agree with those in the principal work (Ranade, 1977a, b) because all farms in the sample were included here, whereas in the principal work only farms still in the sample in 1974 were included in the earlier years.
[b] Converted at P6.5 = $1.00.

data because they show the situation in 1966, 1970, and 1974. Only wet-season comparisons are available because dry-season irrigated farms were few in the early years.

Between 1966 and 1970, landlords and hired laborers experienced an increase in real earnings. Real earnings to current inputs increased by nearly 60%. Yields in 1974 were lower than in 1966 because of the number and intensity of typhoons that damaged the crop. Because farmers had greatly increased their use of current inputs by 1974, the low yields resulted in lower returns, and hence lower real earnings to all groups in 1974 than in either 1966 or 1970.

The 15% increase in real returns to current inputs indicated a continuing trend of intensification of production. Earners all suffered a reduction in real returns. The reduction in landlords' share can be traced partly to rent and tenure changes, while the reduction in labor's share can be traced to the reduced yield in 1974.

The relative shares of earnings distributed among owners and among factors is shown in Table 6. As in Laguna, the share of current inputs increased substantially, and the share of landlords and land decreased. The share of hired labor increased between 1966 and 1970. Operator's residual share declined between 1966 and 1970, contrasting with the Laguna results, but between 1970 and 1974 operators experienced a large increase in their shares, despite the low yields of 1974.

Several interesting forces at work affected the comparison of 1970 and 1974 in CL/L. The depressed yields resulting from an unusually large number of typhoons have been mentioned. In 1970, 51% of the sample were share-tenants; in 1974 the percentage declined to 28. The rental rates also changed between the two periods. The use of machinery for land preparation increased, but the total use of labor and the use of hired labor also increased (Table 7).

We tried to identify the effects of some of those forces to determine their importance. To calculate the effect of the depressed yield, farmers were asked

Table 6. Relative shares of wet season earnings, Central Luzon/Laguna, Philippines.

				Actual yields		Expected yields	
	1966	1970	Change	1974	Change	1974	Change
	Shares allocated among earners (%)						
Landlord	.29	.30	3	.22	–33	.21	–30
Hired labor	.19	.22	16	.19	–13	.20	–9
Operator and family	.42	.34	–19	.40	18	.47	38
Current inputs	.10	.14	40	.19	35	.13	7
	Shares allocated among factors (%)						
Land	.34	.33	–3	.26	–25	.25	–24
Labor	.25	.29	16	.28	3	.28	3
Operator's residual	.31	.24	–23	.26	8	.34	42
Current inputs	.10	.14	40	.19	35	.13	7

Table 7. Labor ad machinery use, Central Luzon/Laguna, 1966–70.

	Labor use				
	1966 (man-d/ha)	1970 (man-d/ha)	Change (%)	1974 (man-d/ha)	Change (%)
Land preparation					
All	17	9	–47	13	44
Hired	8	4	–50	8	100
Preharvest					
All	47	46	0	63	37
Hired	27	29	7	33	14
Total					
All	65	66	0	93	41
Hired	44	44	0	63	43

	Machinery use (%)		
	1966	1970	1974
Tractor [a]	12	42	66
Thresher	62	61	55

[a] For plowing (more common than for harrowing, as in Laguna).

what they thought their yields would have been without the typhoon damage but with the inputs they had used. Their responses indicated that about half expected substantially higher yields.

Because of the substantial effect of typhoons on yields, we recalculated the results using expected yield data for the farmers reporting damage. The procedure seems justified on several grounds. Expected yields of farmers reporting damage were only 12.8% higher than what the same farms had reported in 1970, and did not appear to be overestimated; those farmers used higher inputs in 1974 than in 1970; and the typhoon damage occurred at the end of the cropping season, just before harvest when farmers would have a good basis for estimating expected yields.

The earnings for 1974 were recalculated on the assumption that the labor required for harvesting would have increased in proportion to the yield, and that share-tenants would have paid their landlords the resulting greater rentals. The results, shown in the last column of Table 6, indicate that had they harvested their expected yields of 3.2 t/ha, operators would have substantially increased their share while current inputs' relative share would have fallen. Table 8 shows the distribution of absolute earnings based on those assumptions. Landlords and hired labor both would have increased their earnings by about 50% over the actual, while operators would have gained even more.

Table 6 shows that the share of hired labor declined somewhat between 1970 and 1974, but Table 7 shows an increase in the amount of hired labor. That implies a declining real wage rate, which is confirmed by the data in Table 5. At least part of the decline was due to the reduction in 1974 of harvesting labor — which commands a premium wage — along with the depressed harvest. The

Table 9. Real earnings (kg/ha) under actual and two alternative sets of assumed conditions, Central Luzon, 1974.

Condition	Landlord	Hired labor	Operator and family	Current inputs
Actual earnings	471	413	850	417
Earnings with expected yields	675	646	1525	417
Earnings at 1970 tenure	665	413	654	417

actual wage was ₱7.64/day; but with the expected yield and the prevailing wage for harvesting, it would have averaged ₱9.29/day.

We examined the impact of tenurial change by calculating what the earnings would have been, assuming the proportion of share and leasehold tenants between the two dates as unchanged, using the actual 1974 rental rates, and assuming all other facts as unchanged. The results in Table 8 indicate that the change toward leaseholding has clearly benefited the operators rather than the landlords.

Table 9 gives the relative shares of value added for the 3 years, and suggests an interesting comparison with Table 4, which has data for Laguna. In both samples, the share of land and landlords in value added was constant between 1966 and 1970. (As has been pointed out, the landlord's earnings would have been higher in CL/L in 1974 if the tenure conditions of a substantial proportion of farmers had not changed.) In both Laguna and CL/L, the share of hired labor in value added increased and the share of the operator decreased, between 1966 and 1970. These trends were reversed in 1974 in CL/L, despite the poor yields and changes in tenure. Had yields been as expected by the operators, the share of landlords would have been lower and the share of operators higher.

Share-tenants. Changes in tenure and the unusual weather of 1974 appear to be. major factors leading to changes in the share of earnings in the comparisons made above. We attempted to abstract from these changes by making various assumptions, but a direct comparison is also desirable. Share-tenants made up the largest proportion of farm operators in the samples for 1966 and 1970.

Table 9. Relative shares of value added, Central Luzon/Laguna, Philippines, 1966-74.

Share of	1966	1970	1974 actual yields	Expected yields
	Shares allocated among earners (%)			
Landlord	.34	.34	.27	.24
Hired labor	.20	.25	.23	.23
Operator and family	.45	.39	.49	.53
	Shares allocated among factors (%)			
Land	.38	.38	.32	.29
Labor	.32	.34	.35	.32
Operator's residual	.30	.26	.32	.39

Table 10. Allocation of earnings on shareholder-operated farms. Laguna and Central Luzon/Laguna. 1966–74.

	Laguna wet season		Laguna dry season		Central Luzon/Laguna		
	1966	1970	1966	1970	1966	1970	1974[a]
	Real earnings allocated among earners (kg)						
Landlord	826.4	112.2	972.4	1139.6	800.8	708.4	946.0
Hired labor	536.8	884.4	580.8	770.0	422.4	545.6	598.4
Operator and family	796.4	950.4	893.2	1073.6	778.8	704.0	1201.2
Current inputs	140.8	440.0	184.8	369.6	224.4	321.2	409.2
	Shares allocated among earners (%)						
Landlord	.37	.33	.37	.34	.36	.31	.30
Hired labor	.23	.26	.22	.23	.19	.24	.19
Operator and family	.34	.28	.34	.32	.35	.31	.38
Current inputs	.06	.13	.07	.11	.10	.14	.13
	Shares allocated among factors (%)						
Land	.37	.33	.37	.34	.36	.31	.30
Labor	.41	.36	.38	.32	.26	.35	.27
Operator‘s residual	.16	.18	.18	.23	.27	.20	.30
Current inputs	.06	.13	.07	.11	.10	.14	.13
	Shares in value added allocated among factors (%)						
Land	.39	.38	.40	.38	.40	.36	.34
Labor	.43	.41	.41	.36	.29	.41	.31
Operator’s residual	.17	.21	.19	.26	.30	.23	.34

[a]For the expected yield levels.

Because they are a group whose welfare is of primary concern, we compared the allocation of earnings on sharehold farms for the two periods. The number of either owner-operated or leasehold farms was not enough to make valid comparisons for the tenure classes separately.

Table 10 shows a consistent pattern of changes in the allocation of earnings on farms of share-tenants in the two samples. Landlords’ shares declined, hired labor’s and purchased inputs’ share increased, and operators’ share decreased between 1966 and 1970. But hired labor’s share declined and operators’ share increased between 1970 and 1974 in CL/L.

Yields in the Laguna samples increased substantially, but in the CL/L sample yields increased only marginally to 1970. Reflecting that, the share-tenants in Laguna gained real income, while those in the CL/L sample suffered a reduction between 1966 and 1970, as did landlords in that sample. Had they harvested their expected yields, the CL/L share-tenants would have made real gains. The use of hired labor increased by more than 15% in all three groups, and its real earnings increased substantially in all cases. These changes are generally consistent, indicating that changes in technology did not work to the disadvantage of either hired labor, or in most cases operators, but, if anything, worked to the disadvantage of landlords.

ESTIMATES OF PRODUCTION ELASTICITIES

The Cobb-Douglas and translog production functions were fitted to the Laguna data for the wet seasons of 1966 and 1970. The specification of functional forms were modified to account for differences in the intensity of irrigation facilities among the three municipalities (Biñan, Cabuyao, and Calamba) covered in the Laguna data and differences among farmers with respect to mechanization.

Because the 1966 Laguna data did not diverge from the Cobb-Douglas function, their estimates are reported (Table 11). The 1970 data showed a significant interaction of chemicals (current inputs) and labor; the translog production function including that interaction is reported. In particular, the production functions (1) and (2) were respecified as follows:

Cobb-Douglas (1966)

$$lnQ = a_0 + a_{01}D_1 + a_{02}D_2 + \sum_{j=1}^{3} a_{1j} lnX_j + \sum_{j=1}^{3} a_{2j} D_3 lnX_j + e \qquad (3)$$

Translog (1970)

$$lnQ = a_0 + a_{01}D + a_{02}D_2 + \sum_{j=1}^{3} a_{1j} lnX_j + \sum_{j=1}^{3} a_{2j} D_3 lnX_j$$

$$+ b_{23}(lnX_2 - lnX_3)^2 + b_3 D_3 (lnX_2 - lnX_3)^2 + e \qquad (4)$$

where Q, X_1, X_2, X_3, a's, b's and e are as defined before. D_1 and D_2 are zero-one dummy variables for identifying three municipalities. D_3 is equal to zero for nonmechanized farms and to one for mechanized farms. Because of heterogeneity in the residual variance across three municipalities, the functions were fitted by the Generalized Least Squares method.

Table 11. Estimates of production functions for old and new technologies In Laguna, Philippines.[a]

Explanatory variable[b]		Cobb-Douglas function (1966)		Translog function (1970)	
		Coefficient	t-value[c]	Coefficient	t-value[d]
Constant	(a)	3.3049	7.83	3.2213	4.95
Dummy: Biñan	(a_{01})	0.1378	1.15	–0.0913	0.85
Dummy: Calamba	(a_{02})	0.3190	3.00	0.4875	5.96
Land	(a_{11})	0.8548	8.57	0.4635	1.80
Current inputs	(a_{12})	0.0502	1.25	1.3478	1.75
Labor	(a_{22})	0.1051	1.19	-0.7471	1.22
D_3 × land	(a_{21})	-0.2342	1.37	0.1408	0.45
D_3 × current inputs	(a_{22})	-0.0389	0.62	-1.0617	1.34
D_3 × labor	(a_{23})	0.0342	1.24	0.8161	1.52
(Current inputs-labor)^2	(b_{23})			0.2287	1.67
D_3 × (Current inputs-labor)^2	(b_3)			-0.2077	1.50

[a]Adapted from Ranade (1977a,b). [b]All variables are in natural logarithms. [c]Degrees of freedom for t-statistics are 98. [d]Degrees of freedom for t-statistics are 101.

Table 12. estimate of production elasticities at mean level of inputs in old (nonmechanized 1966 farms) and new (1970) technologies in Laguna, Philippines. [a]

Input	1966 nonmechanized farms		1970 mechanized farms	
	Relative share	Production elasticity	Relative share	Production elasticity
Land [b]	0.5500	0.8548	0.5400	0.6043
Current inputs [c]	0.0400	0.0502	0.0800	0.1140
Labor [d]	0.4100	0.1051	0.3800	0.2817

[a] Adapted from Ranade (1977a.b). [b] Relative share of land equals the sum of relative shares of landlord, operator's residual, and irrigation. [c] Relative share of current inputs is the relative share of current inputs shown in Table 2 minus the relative share of irrigation. [d] Relative share of labor man-days for 1970 equals the sum of relative shares of human labor, animal labor, and tractors.

Production elasticities for the two technologies were calculated from the production function estimates in Table 11 at the mean level of inputs. Because most farms that were mechanized in 1970 were not mechanized in 1966, the elasticities were calculated for the dominant conditions prevailing in each year. The production elasticities are compared with the calculated relative share of each factor in Table 12.

In Table 12 the relative share of land is considered equal to the sum of the relative shares of landlord, operator's residual, and cost of irrigation. This adjustment is made because the operator's residual is believed to include a part of the return to land that tenants obtain because of the present institutional arrangement with landlords. Even with the adjustment, the relative factor shares are substantially different from the production elasticities. The difference is large for traditional than for modern technology. In particular, the share of land is lower while the share of labor is higher than the corresponding production elasticity. If the operator's residual is excluded from the sum, the difference between the relative share of land and the production elasticity will be further magnified,

The relative share of labor is higher than the production elasticity for both technologies. It appeared that institutional factors might predominate in determining farm wages. However, the difference between the relative share and production elasticity of labor decreased after technological change. This indicates that wages have tended to become more responsive to market forces and less dependent on institutional arrangements as farmers changed from old to new technologies. Since the production elasticity increased, labor earnings were closer to their marginal product after the technological change. Only for current inputs, which are usually purchased from the market, was the change in the production elasticity of a similar magnitude and direction as the change in the factor's relative share in output.

Furthermore, since the Cobb-Douglas function fitted traditional technology well, production elasticities are apparently not sensitive to changes in quantities of inputs for traditional technology. In contrast, because for modern technology the interaction term between the current inputs and labor is significant and positive (b_{23} + b_3), the production elasticity of labor would increase while that of current inputs would decrease if farmers increased the quantity of labor more than they did current inputs. This implies that to increase the production elasticity of labor, farmers should be encouraged to reduce the quantity of current inputs and increase farm employment. However, that will cause a reduction in output because the marginal product of current inputs is much higher than that of labor in modern technology, as Ranade (1977a) showed.

The production function analysis for CL/L was conducted on the 1966 and 1974 data because the adoption of new technology was much more complete in 1974, and more comparable with the 1970 Laguna situation. Nearly half the CL/L farms were rainfed, so irrigation was explicitly introduced as a variable. This variable was unnecessary in Laguna because all farms were irrigated. No location dummy variables were included in the CL/L analysis because the sample was widely spread over a wide geographic area. The analysis was conducted using expected yield as the dependent variable for reasons discussed earlier. Furthermore, the labor input for harvesting and threshing was not analyzed because some farmers had used mechanical threshers. Because the sample was small, it was not possible to introduce slope and intercept dummies to identify those farmers. Exclusion of labor man-days for harvesting and threshing does not create a bias in the analysis because such labor per se does not increase crop production.

For the 1966 data it was not possible to choose an acceptable production function because the estimates of the coefficients for labor input either were statistically insignificant or gave negative marginal product of labor. For the 1974 data, however, the translog function with interaction between labor and current inputs was chosen as best (Table 13). The production elasticities of the three major categories of inputs computed at their mean levels are compared with their calculated relative shares in Table 14.

For the 1970 Laguna data, the production elasticity of land is greater than its relative share. This supports our view that the operator's residual includes a part of the returns to land that the tenant cultivates through institutional arrangements. As before, the relative share of labor is greater than its production elasticity. The difference is, however, less than the difference between the production elasticity and the relative share of labor in Laguna. Note that for CL/L, we have excluded harvesting labor. Thus, it appears that preharvest labor wages are determined largely through market forces.

As in the case of modern technology in Laguna, the interaction term between current inputs and labor is significant and negative. Thus, again we find that the production elasticity of current inputs would increase while that of labor would decrease if farmers increased the use of current inputs more than they increased farm employment.

Table 13. Estimates of translog production function for new technologies In 1974, Central Luzon/Laguna, Philippines (Ronede, 1977a).

Explanatory variables	Coefficient	t-value [b]
R^2	0.88	
Constant	–7.73	1.91
D_2 (unirrigated) [c]	11.35	2.39
D_3 (mechanized) [c]	12.08	2.91
D_4 (= $D_2 \times D_3$)	–13.92	2.76
Land	0.68	2.14
Current inputs	–7.04	3.05
Labor	8.18	3.01
D_2 × land	0.08	0.22
D_2 × current inputs	6.84	2.29
D_2 × labor	–7.59	2.35
D_3 × land	0.12	0.34
D_3 × current inputs	8.03	3.14
D_3 × labor	–8.16	3.05
D_4 × land	–0.51	1.04
D_4 × current inputs	–7.89	2.47
D_4 × labor	8.96	2.62
(Current inputs-labor) ^{2}	–1.54	2.89
D_2 × (Current inputs-labor)^2	1.42	2.32
D_3 × (Current inputs-labor)^2	1.65	2.97
D_4 × (Current inputs-labor)^2	–1.63	2.52

[a] Land, labor, and current inputs are in logarithms. [b] Degrees of freedom are 43. [c] D_2 and D_3 are zero-one dummy variables such that they equal one whenever the corresponding observation is for unirrigated and mechanized farms, respectively.

Table 14. Estimates of production elasticities at mean level of Inputs In new (mechanized) technology, 1974 Central Luzon/Lagune, Philippines (Ranade, 1977a).

Input [a]	Relative share	Production elasticity
Land	0.7541	0.8009
Current inputs	0.0871	0.0715
Preharvest labor	0.1459	0.1183

[a] Definition of input shares are in Table 12.

SUMMARY AND CONCLUSIONS

The distribution of absolute earnings and share of output among landlords, hired laborers, operators, and current inputs was examined for two samples of Philippine farms for 1966 and 1970, and for one of the samples for 1974. Production elasticities obtained from estimated production functions are reported.

Both samples show a substantial increase in the use of purchased farm inputs, hired labor, machinery for land preparation, and modern rice varieties. Some changes in tenure occurred between 1966 and 1970, and rather more substantial changes between 1970 and 1974 for the CL/L sample.

Between 1966 and 1970 in the Laguna sample, real per-hectare earnings distributed to hired labor increased by 50%, those to operators by 30%, and those to landlords by 17%. Real earnings distributed to landlords and hired labor also increased between 1966 and 1970 in the CL/L sample, but fell for all three groups between 1970 and 1974 because severe crop damage reduced yields in the area that year. When yields were adjusted to an undamaged basis, real earnings were shown to have increased.

In both areas, the share of output used for purchasing current inputs increased substantially between 1966 and 1970; in CL/L they continued to increase through 1974. The landlords' share was modestly reduced in both areas, while hired labor's share was maintained at about 20% of the total value of output across the samples. Shares in added value changed relatively little between 1966 and 1970, and the changes that did occur were remarkably similar in the two regions.

The decline in landlords' relative share is traced to increased use of hired labor and purchased inputs under share-tenancy in Laguna, and to a substantial change in the tenurial conditions in Central Luzon. The use of tractors was not accompanied by a reduction in the use of hired labor; instead, both mechanization and hired labor increased over the period. Between 1966 and 1970, share-tenants experienced real income gains in Laguna, but a slight decrease in Central Luzon.

Some clear-cut facts emerge with respect to changes in income distribution originating in rice production.

First, landlords, tenants, and hired labor, in general, belong to the top, middle, and lowest income groups. Because the relative share of landlords declined, due partly to land reform, and partly to the nature of new technologies, and because that decline was transferred to tenants in the post-technological change period, the income distribution originating from rice production was less skewed than before.

Second, even though the relative share of total labor declined and because employment of hired labor increased, hired laborers became relatively better off. In Laguna especially, hired laborers benefited in terms of income also because their relative share increased.

Third, the changes in shares were caused simultaneously by biological and mechanical innovations. The latter directly substitutes capital for labor. The relation of biological innovations and corresponding cultural practices to employment exists mostly for operations other than land preparation, This implies that if we remove the effect of tractors, the biological innovations would increase the relative share of family plus hired labor in both Laguna and CL/L.

Some argue that the direct impact of mechanization has been to decrease the relative share of labor. Thus mechanization works against laborers and lowers their income levels with respect to those of other participants (Frankel, 1971; Griffin, 1974). The highest percentage of landless labor is used for harvesting and hand threshing and the lowest for land preparation. This implies that mechanization of land preparation works against landless laborers relatively less than does mechanization of threshing.

Thus, our study finds that for the samples the distribution of benefits from modern varieties and tractors was skewed only against landlords.

The findings sharply contradict the doubt raised by Griffin (1974) that the new technologies are landlord-biased. They also do not confirm the conclusion of Librero and Mangahas (unpubl.) that new technologies have no income redistribution effect. The findings are also substantially different from those of C. H. H. Rao (1971) on Indian agriculture.

The consumption linkage of new technologies with the non-foodgrain sector postulated by Mellor and Lele (1971) seems to be less strong in the Philippines than in India because in the Philippines, the relative share of tenants increased but that of landlords did not. Because tenants belong to a higher income group than landless labor, the effect of such linkages is present to some extent in the Philippines.

The comparison of econometrically estimated production elasticities and calculated relative factor shares implied that in traditional technology wage rates were determined more by institutional forces than by the market mechanisms. This aspect of the labor market seems to have changed since the introduction of technological change, as indicated by the closer relationship between marginal productivity of labor and wage rates.

Furthermore, although the relative share of labor was constant, its production elasticity increased substantially after technological change. For current inputs, however, production elasticity increased at the same time as their relative share in output increased. Thus in traditional technology the increases in production were achieved mostly through increase in area under cultivation, while in modern technology increases could be achieved through increased use of current inputs and labor. Thus the market-determined distribution of output would have been more favorable to land with traditional technology, but with modern technology, current inputs and labor would generate higher marginal productivities.

Our analysis of the available data gives little support to the hypothesis of radical changes in the share of earnings going to various groups. There is no evidence that labor has suffered either an absolute or relative decline in earnings since the introduction of modem rice varieties in the two study areas of the Philippines. Instead, use of labor has increased along with mechanization and current inputs. Thus, if anything, the new rice technology seems to be labor using. There also seems to be a substantial income effect in that the farm operators are willing to substitute hired labor for family labor when incomes increase.

REFERENCES CITED

Frankel, F. 1971. India's green revolution: economic gains and political costs. Princeton University Press, Princeton, New Jersey.

Griffin, K. 1974. The political economy of agrarian change. Harvard University Press, Cambridge, Massachussetts.

Hayami, Y., and R. W. Herdt. 1978. Market price effects of new rice technology on income distribution. Pages 283–302 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

International Research Insititute. 1970. Annual report 1969. Los Baños, Philippines. 266 p.

Kelly, A.C., J. G. Williamson, and R. J. Cheetham. 1972. Dualistic economic development: theory and history. University of Chicago Press, Chicago.

Johnson, S. 1969. Terminal report on general engineering and economic research portion of contract no. ASS/csd 834. International Rice Research Institute, Los Baños, Philippines.

Kmenta, J. 1967. On estimation of the CES production function. Int. Econ: Rev. 8(2):180–189.

Liao, S. H. 1968. Factors affecting productivity and adoption of improved farm practices in rice farms. M.S. thesis, University of the Philippines, College of Agriculture, Los Baños, Philippines. (unpubl.)

Librero, A. R., and M. Mangahas. n.d. Socioeconomic implications of high yielding varieties: evidence from primary data. (unpubl.)

Mellor, J. W., and U. J. Lele. 1973. Growth linkages of the new feedgrain technologies, Indian J. Agric. Econ. 28(1):35–55.

Raju, V. T. n.d. Income distribution and employment effects of the new agricultural technologies in the I. A. D. P. District West Godavari. MS. thesis, G.B. Pant University of Agriculture and Technology, Pantnagar, U. P., India.

Ranade, C. G. 1977a. Distribution of benefits from new agricultural technologies: a study at farm level. Ph.D. dissertation, Department of Agricultural Economics, Cornell University. (unpubl.)

Ranade, C. G. 1977b. Distributive bias of new rice technologies in the Philippines. Occasional Paper No. 92, Cornell-USAID Poor Rural Households, Technical Change and Income Distribution in LDCs Project, Department of Agricultural Economics.

Rao, C. H. H. 1971. Green revolution and the labor's share in output. Agric. Situation India:283–284.

Singh, K. 1972. The impact of new agricultural technology on farm income distribution in the Aligarch District of Uttar Pradesh, India. Ph.D. thesis submitted to the University of Illinois, Urbana-Champaign. (unpubl.)

Srivastava, U., and E. O. Heady. 1973. Technological change and relative shares in Indian agriculture. Am. J. Agric. Econ. 55(3):509–514.

Thirsk, W. 1974. Factor substitution in Colombian agriculture. Am. J. Agric. Econ. 56(1):73–84.

COMMENTS ON SHARES OF FARM EARNINGS FROM RICE PRODUCTION

R.S. SINAGA AND B.M. SINAGA

THE MAIN OBJECTIVES of the Ranade and Herdt paper are to show the distribution of returns from new seed-fertilizer technology among the direct participants in rice production and to indicate some of the factors affecting the distribution of the returns among those participants. Ranade and Herdt used both a production function and an accounting approach.

In this paper we confine ourselves to the accounting approach. We apply their calculation procedure to Indonesian data and compare the results with those of the Philippines.

INDONESIAN CASE STUDY

We present some figures from a village in Central Java, Indonesia, to compare with Ranade and Herdt's data on employment opportunity and the shares of earnings divided among direct participants in production after the innovation of modern varieties (MV).

Source of the data. From the 1968-69 wet season until the 1972 dry season the Agro-Economic Survey (AES) in Indonesia had a research project called the Rice Intensification Study. Its main objective was to evaluate the impact of new production technology on rice farming. The study covered 37 villages in eight provinces known to be the most important rice-producing areas in Indonesia. Surveys were made twice a year (one in each season). Thirty farmers from each village were chosen by stratified random sampling. The farmers in each village were divided into three strata: large farmers, BIMAS farmers, and non-BIMAS farmers. BIMAS is an extension-type program similar to Masagana 99 in the Philippines. Sample farms were taken at random from each stratum: 5 large farms, 15 BIMAS, and 10 non-BIMAS farms. Samples in each village were maintained for the entire study period.

Using the AES questionnaire in 1974, Irlan Soejono collected data for crop year 1973-74 from farm samples in eight villages of AES in Central Java. His Ph. D. dissertation "Growth and distributional changes of paddy farm incomes in Central Java, 1968-74" was produced from the study. The basic data we use

Agricultural economists and faculty members, Department of Agricultural Economics and Rural Sociology, Bogor Agricultural University, Bogor, Indonesia.

Table 1. Characteristics of sample farms in Central Java, Indonesia.

Crop year	No.	Percent of sample	Farm size[a] (ha)		Payment to landlord (kg/ha)	Share of landlord in output (%)	Farmers growing modern varieties (%)
			Range	Av.			
						Pure owner-operators	
1968–69	11	36	.50 - 2.14	1.14	000	.00	0
1973–74	16	53	.70 - 2.42	1.45	000	.00	100
						Owner-operetors and leaseholders	
1968–69	14	47	.57–3.60	1.88	890	.27	11
1973–74	7	23	.36 - 4.00	1.43	1637	.39	96
						Pure leaseholders	
1968–69	5	17	.9 5.70	2.33	1010	.28	.3
1973–74	7	23	1.00 –3.13	1.79	1620	.33	93

[a] Average rice farm size in Java is about 0.4 ha.

below came from one of those villages. The village was selected because in 1968-69 almost none of its farmers used MV, but in 1973-74 almost all of them did. There was no sharecropper among the sample farmers during the two periods of observations. Characteristics of the sample are in Table 1.

AES carried out the study twice a year (wet and dry season), but Irlan Soejono collected data for the whole year's operation. Therefore our analysis is averaged for wet and dry seasons. All farmers in the sample grow rice twice a year.

To make the Indonesian case study comparable with that of the Philippines we present the Indonesian data in a way similar to Ranade and Herdt's (Table 2).

Results of the case study. Table 2 shows that the average rice yield increased about 30% between the 1968-69 and 1973-74 crop years. The

Table 2. Some of the factors contributing to the distribution of earnings among the earners and the factors of production, Central Java. Indonesia.

	1968–69	1973–74	Change (%)
Yield of rice (kg/ha)	3681	4802	30
Price of rice (US/kg)[a]	.035	.004	141
Current wages (US/men-day)[a]	.157	.301	92
Real wages (kg rice/man-day)	4.50	3.60	–20
Bawon (kg/ha)[b]	3.54	3.53	0.3
Share of bawon (% of yield)	10	7	–30
Total labor (man-day)	252	237	–6
Hired	239	221	–8
Family	13	16	23
Fertilizer price (US$/kg)[a]	.076	.096	27
Fertilizer price (kg rice/kg fertilizer)	2.19	1.15	–47
Land rent (kg/ha)	1166	1629	40

[a] Conversion from Indonesian rupiah US$1.00 = Rp415. [b] Bawon s a harvesters share of the crop.

Table 3. Directly measured average mal earnings, Central Java, Indonesia.

	Real earnings		
	1968–69	1973–74	Change (%)
	Allocated among earners (kg/ha)		
Landlord	1011	1565	55
Hired labor	1431	1149	–20
Operator and family labor	708	1681	137
Current inputs	530	407	–23
	Allocated among factors (kg/ha)		
Land	1166	1629	40
Labor	1494	1231	–18
Operator's residual	491	1535	213
Current inputs	530	407	–23

absolute real earning of earners and factors also increased (Table 3) except for hired labor, labor, and current inputs. The absolute real earnings of hired labor, labor, and current inputs all decreased by about 20% and the real earnings of the other earners and factors increased by at least 40%. The absolute real earnings of the land factor increased by 40%, i.e., by more than the yield increment. The nominal value of the land tax remained the same; the nominal price of the rice increased about 140% between the 1968-69 and 1973–74 crop years, hence the real value of the land tax in terms of rice decreased about 60%.

Despite the increased application of fertilizers (about 1.5 times more) and other agricultural chemicals (insecticides, pesticides, etc.) between the 1968-69 and 1973–74 crop year, the allocation of absolute real earnings to current inputs decreased about 25%. The decrease was mainly due to the improved terms of trade between rice and agricultural chemicals at the farm gate brought about by heavy subsidies on agricultural chemicals. During that time, the price of rice increased about 140%, but the price of fertilizers increased only about 27%.

Table 2 shows that the amount of hired-labor use decreased only about 8%; however, the absolute share of hired labor in the real earnings decreased about 20% (Table 3). There are two main reasons for the decrease: the real wage rate per man-day decreased about 20%, and the relative share of the harvesters in the yield (*bawon*) decreased about 30% (Table 3). The decrease is about the same as the rate of increase of the yield.

In the 1973–74 crop year, the operators gained the most from the higher yield of the MV. Their absolute share in the real earnings increased about 140% between 1968-69 and 1973–74. At least six factors contributed to the absolute high increment:

- higher yield of the MV varieties,
- increase in the real value of land rent only slightly higher than the yield increment,
- slight reduction in the amount of hired labor,

Table 4. Directly measured relative shares of earnings, Central Java, Indonesia.

	Share of earnings		Change (%)
	1968–69	1973–74	
Allocated among earners (%)			
Landlord	.27	.33	22
Hired labor	.39	.24	–38
Operator	.19	.35	84
Current inputs	.14	.08	.43
Allocated among factors (%)			
Land	.32	.34	6
Labor	.41	.26	–37
Operator’s residual	.13	.32	146
Current inputs	.14	.08	–43

- a significant reduction in the real wage rate per man-day,
- lower total real cost of current inputs, and
- lower relative share of the hired-labor harvesters in the yield.

The absolute share of operator’s residual increased much more than the absolute share of the operator’s and his family labor in the real earnings. The increase was mainly due to the six factors cited plus two others:

- There was a slight decrease in the total labor employed in the 1973–74 crop year; and
- the proportion of family labor participation to the total labor employed remained the same in the two crop years.

Table 4 shows the relative shares of the earners and factors in the real earnings. The relative share of the land increased slightly (about 6%), and that of the operators and the managers (operator’s residual) increased about 80% and 150%, respectively.

Table 5 shows how the total added value is shared among the earners and the

Table 5. Directly measured share of added value, Central Java, Indonesia.

	Share of added value		
	1968-69	1973-74	Change (%)
Added value (kg/ha)	3150	4395	40
Allocated among earners (%)			
Landlord	.32	.36	13
Hired labor	.45	.26	–42
Operator	.22	.38	73
Allocated among factors (%)			
Land	.37	.37	0
Labor	.47	.28	–40
Operator’s residual	.16	.35	119

factors. The total added value increased about 40% between 1968–74 and 1973–74, but the share of both hired labor and labor decreased about the same rate (40%). The share of land remained unchanged. The share of landlords increased slightly, and the share of both the operators and operator's residual increased substantially.

CONCLUSIONS

In contrast to our Indonesian case, the Philippine cases analyzed by Ranade and Herdt provide evidence that MV required more labor than traditional varieties. However, total labor input for rice production per hectare did not increase significantly because tractors and threshers reduced the employment opportunity created by the MV. Nevertheless substantial increases in the real wage rates resulted in the increase in the income share of labor in the Philippines, both absolutely and relatively.

In Indonesia the benefit from the MV went to the operators and the landlords at the expense of the laborers, despite the fact that the labor requirement for rice production did not decline. The declining share of the laborers in Indonesia was due mainly to the ever decreasing real wages in the rural area as the consequence of the continued population pressure on limited employment opportunities.

LABOR AND MECHANIZATION

Labor utilization in rice production

R. BARKER AND V.G. CORDOVA

THE RAPIDLY EXPANDING labor force coupled with limited growth in nonfarm employment opportunities in the developing countries means that the agricultural sector could remain as the residual claimant of increments in the labor force for a good many years. At the same time the expansion of cultivated land areas, which has absorbed much of the labor force in the past, is gradually ending in many Asian countries. With less opportunity for migration to unsettled areas, a growing population pressure on the land can result in smaller or more fragmented farms and in a growing number of landless laborers.

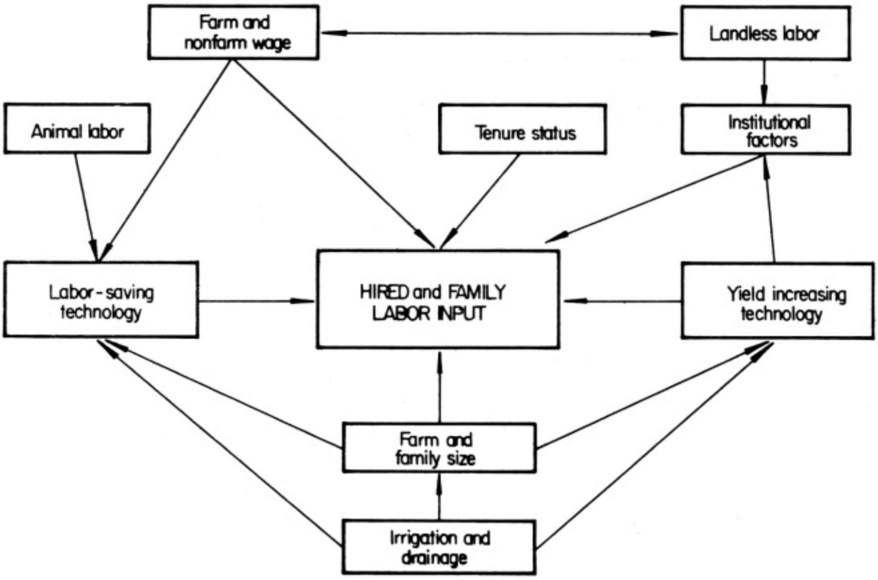
We are concerned with the changes in labor utilization since the introduction of modern varieties (MV). Our objective is to identify that contribution of modern technology and other factors to the change in labor input. First, we construct a graphic model of factors influencing labor utilization in rice production. Next we compare labor utilization in different rice-growing areas in Asia and show how variation in the factors described in our model — over location and through time — results in different levels of labor input per hectare, per farm, and per ton of rice produced. Our major focus is on the Philippines, where data have been collected periodically for selected locations since 1966. Using regression analysis, we estimate the contribution of selected variables to the change in input of labor after the introduction of MV.

A MODEL OF LABOR UTILIZATION

The level of input of family and hired labor in rice production is influenced by a number of factors that vary across regions or through time in a given region. The factors affecting labor use are shown in Figure 1.

Some factors such as MV or irrigation development, tend to increase the productivity of land, and hence the level of labor input per hectare. But factors

Agricultural economist and senior research assistant, Department of Agricultural Economics, International Rice Research Institute, Los Baños, Philippines.



1. Factors influencing labor use in rice production.

such as mechanization may reduce labor inputs. Total labor use can change and so can the proportion that is met with family and hired labor. Labor input may differ by farm size or tenure status. Many labor tasks and payment for those tasks are governed by institutional or contractual arrangements between laborers and farm operators.

The growth in the size of the landless labor force and the introduction of yield-increasing technology may change the relationships between factors affecting labor use by changing both the demand for and the supply of labor. For example, the adoption of the *tebasan* system of sale of the standing rice crop in some parts of Indonesia, which is associated to some degree with MV, reduces the labor required for harvesting (Ihalauw and Utami, 1975).

The model helps separate changes in labor use that are associated with the MV from those that appear to be independent of the MV. Of course, many of the linkages between factors in the model are not well understood and may vary from one location to another. For example, in one area the motivating force behind tractor adoption may be the shortage of labor. In another area, the additional profit from irrigation development may generate funds with which to purchase a tractor.

REGIONAL COMPARISON OF LABOR USE

In their seminal work on agricultural development, Hayami and Ruttan (1971) include a comprehensive analysis of differences in the level and intensity of

Table 1. Annual compound growth rate (%) in productivity and factor proportions, 1955 to 1965 (Hayami and Ruttan, 1971).

Group of countries[a]	Output/ male worker	Output/ ha	Land area/ male worker	Fertilizer/ ha	Machinery/ male worker
Developed countries	4.7	2.1	2.6	5.1	9.8
Intermediate countries	4.4	2.0	2.4	5.8	15.8
Less developed countries	1.4	2.1	−0.4	10.9	6.4

[a] Developed countries have per capita GNP higher than US$700 and less than 30% of male workers engaged in agricultural occupations: Australia, Belgium, Canada, Denmark, France, Germany, the Netherlands, New Zealand, Norway, Sweden, Switzerland, UK, and USA. Less developed countries have per capita GNP lower than US$350 and more than 35% of male workers engaged in agricultural occupations: Brazil, Ceylon, Colombia, India, Mexico, Peru, the Philippines, Syria, Taiwan, Turkey, and United Arab Republic. Intermediate countries do not belong to either developed or less developed categories: Argentina, Austria, Chile, Finland, Greece, Ireland, Israel, Italy, Japan, Portugal, South Africa, Spain, and Venezuela.

input use in agriculture. They show that productivity increases were achieved by some countries through intensification of biochemical input—which is also labor intensifying—and by other countries through intensification of mechanical input. They relate the development path taken by the different countries to relative factor prices, which are related in turn to relative factor scarcities. The Hayami and Ruttan analysis shows a wide range between developed and less developed countries in growth in output per worker, even though growth in output per hectare is the same (Table 1). In the developed countries, labor intensity declined (land per worker increased), and fertilizer intensity increased from 1955 to 1965. Because of the continuing decline in land area per worker in the less developed countries of the world, considerable intensification in output per hectare will be required to raise the rate of growth in total labor productivity.

These aggregate data illustrate the range of conditions existing for groups of countries in different stages of development. Among the developing countries themselves, there is still a wide degree of variability in resource use. The variability in labor use and productivity in rice is shown for seven rice farming areas in Asia (Table 2). Information is based on farm surveys differing considerably in their nature and scope. (More detailed information from each of the surveys is presented in Appendix A–G.) Nevertheless, the data provide a crude indication of the wide differences in labor productivity among rice-growing regions.

The seven sites in Table 2 are ranked from low to high according to the man-days required to produce 1 t of rice. The locations differ in resource mix, institutional structure, and opportunities for nonfarm employment and, hence, in production and labor use for rice growing, Despite comparatively small farms, Taiwan and Korea have excellent irrigation systems and excellent opportunities for nonfarm employment, Labor input per hectare is fairly high but declining. The high wage rates reflect the good off-farm employment

Table 2. Farm size, yield, wage rate, and labor input for rice in seven lowland irrigated rice-growing areas in Asia (Fujimoto, 1976).

Study site[a]	Year	Season	Farm size (ha)	Yield (t/ha)	Farm wage[b] (US$/ day)	Hired labor (%)	Labor (man-days)		
							Per ha	Per farm	Per ton
Central Korea	1974	Summer	1.2	5.9	2.50	30	129	155	22
Central Taiwan	1972	1st crop	1.2	5.7	3.75	38	125	150	22
Central Luzon	1974	Wet	2.5	2.4	0.80	66	82	205	38
Central Thailand	1972	Wet	5.8	2.3	0.80	–	92	534	40
Sri Lanka	1972–73	Wet	0.8	3.0	0.80	65	172	138	57
Malaysia	1973	Dry	0.7	2.4	0.80	14	214	150	89
Java[c]	1969–70	Wet	0.8	3.5	0.40	71	360	288	103

[a] For other sites, see Appendix A–G. [b] Based on rough estimates from unofficial sources in March 1975. [c] Assuming 120 man-days of labor for harvesting and threshing in addition to the 240 man-days preharvest labor.

opportunities. High rice yields give labor productivity higher than that in the other regions.

Central Luzon and Central Thailand with large farm size and low labor input per hectare are typical of many South and Southeast Asian rice-growing regions. Population pressures are causing a gradual decline in farm size, wage rates are low, and off-farm exployment opportunities are limited. The poorly developed irrigation systems limit opportunities for use of labor on the farm throughout much of the year. Farm yields are low, and it is evident that any increase in productivity of available labor must be achieved through increases in land productivity. The direction of land productivity change can be through increased yields, expansion in area double-cropped, or both.

Java and, to a lesser extent, Sri Lanka show the effect of population pressure. Labor productivity is lowest in Java where labor is used most intensively. Farm yields have increased, in part through the intensive application of labor, but they are not at the level experienced in Taiwan and Korea. Off-farm opportunities for employment are limited. Not only are farm sizes small, but there is a growing landless labor class that now includes about half of the households in many Javanese villages (Ihalauw and Utami, 1975).

An important characteristic of rice production in many parts of South and Southeast Asia is the large percentage of hired labor as a proportion of total labor used (Table 2). The farm operator frequently subcontracts 60% or more of the work to family members from other farms, or to the growing number of landless laborers. In Taiwan, Korea, and Malaysia, on the other hand, a major portion of labor input has traditionally come from the farm family.

The set of institutional arrangements that govern the use of hired labor varies widely from one area to another. These institutional relationships determine who can participate in the labor force and how they will be paid for their labor.

The process of "involution" described in Java (Geertz, 1963) involves the sharing of employment and output to guarantee a livelihood to the poorer members of the community. A recent paper by Collier (1977) suggests that institutional arrangements for sharing of work are highly variable over time and location, and that the actual sharing of work and output seems to be more prevalent among those of the same social group, e.g., among landless workers or among small farmers. Many of the institutional arrangements by which hired laborers obtain employment, described by Collier (1977) and Clay (1976), are similar to those that appear to be emerging in the Philippines as a result of increased supply of labor.

Structural changes in the labor market may occur not only as a result of factors that affect supply, but also as a result of factors that affect demand, such as the introduction of MV. We examined a number of recent surveys conducted in seven Asian countries to compare labor input for MV with that for local varieties (Table 3). In the areas where MV were introduced, labor use per hectare increased. New technology, if it is economically more efficient, must lower the cost per ton of rice produced. Since labor is a major component of that cost, one would anticipate a decline in labor input per ton of rice due to the adoption of MV. That occurred in six out of seven areas. In Suphan Buri, Thailand, the yield gain due to MV was not sufficient to offset the increase in labor input. In Thailand, in general, adoption of MV has been minimal.

CHANGES IN LABOR UTILIZATION IN THE PHILIPPINES

Until 1960, land was relatively abundant in the Philippines. Rice production increased principally through the expansion of the traditional inputs of land

Table 3. Labor input for modern (MV) and traditional (TV) varieties of rice in rice-growing areas in Asia.

Study site[a]	Year	Season	Labor input					
			Man-days/ha		MV÷TV (%)	Man-days/t		MV÷TV (%)
			MV	TV		MV	TV	
Central Korea	1974	Summer	139	126	110	19	23	83
Laguna, Philippines	1975 vs 1966	Wet	110	86	128	31	34	91
Central Thailand	1972	Wet	117	81	144	40	39	103
Java[b]	1969/70	Wet	262	235	111	57	71	78
Mymensingh, Bangladesh	1969/70	Dry	194	137	142	57	62	92
Ferozepur, India[c]	1967/68 to 1969170	Wet	92	79	116	22	29	76
Hyderabad, Pakistan[d]	1972	Wet	58	49	118	29	35	83

[a] In all sites except Laguna, labor input for area in MV is compared with labor requirement for area in TV during the same season. In Laguna, the same farms are compared with zero MV in 1966 and 95% MV in 1975. For other study sites see Appendix C–G. [b] Preharvest labor only. [c] S. Mehra (1976). Original source of information is "Studies in Economics of Farm Management in Ferozepur District (Punjab) and in Mazaffarnagar District (U.P.)," combined reports. [d] M. H. Khan (1975).

and labor. The amount of labor required per hectare and per ton of rice remained fairly constant. The closing of the land frontier brought a shift in resource use in agriculture. Growth in rice production came to depend on measures designed to increase the productivity of the land. The Philippine government gave strong support to the introduction of modern rice varieties following the release of IR8 by the International Rice Research Institute in 1966.

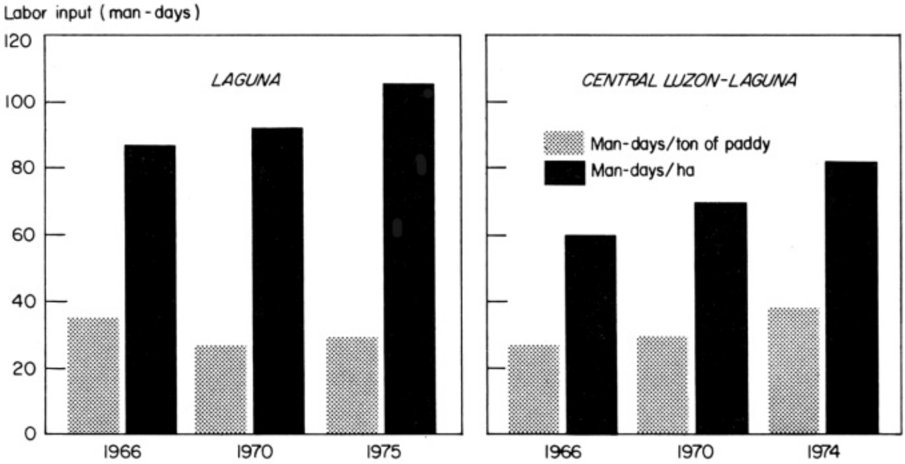
The original sample consisted of 155 farms in the Laguna survey and 114 farms for the Central Luzon-Laguna (CL/L) survey. Over the years some farms were dropped or were rotated out of the samples. Our analysis used data for only those farms whose owners had been interviewed in all of the three years that the surveys were conducted — 62 farms in Laguna and 63 farms in CL/L. (All but seven of the farms in the CL/L survey were located in Central Luzon.) The loss of information and some bias that may have occured in choosing the farms in this manner are compensated for by the fact that the changes occurring can be traced through a group of the same farms over the entire survey period. The breakdown of sample farms according to the number in each municipality in Laguna — Biñan, Cabuyao, Calamba — and in each water control category in the CL/L survey — irrigated two crops, irrigated one crop, and rainfed — is shown in Table 4.

TRENDS IN LABOR USE, AND TECHNOLOGICAL AND INSTITUTIONAL CHANGES

Labor use in both survey areas showed a significant increase (Fig. 2). The percentage gain was 20% in Laguna and 38% in CL/L. Labor input per ton of rice produced dropped somewhat in Laguna, but it increased sharply in CL/L in 1974 because of the low rice yields in Central Luzon after heavy typhoon damage.

Table 4. Total farmers interviewed in all three years for Laguna survey by municipality, and for Central Luzon-Laguna survey by irrigation type. Philippines, 1966 to 1974-75.

Item	Farmers interviewed (no.)
Municipality	*Laguna survey*
Biñan	15
Cabuyao	19
Calamba	28
Total	62
Irrigation	*Central Luzon-Laguna survey*
Rainfed	25
Irrigated — 1 crop	13
Irrigated — 2 crops	25
Total	63



2. Labor input in man-days/ha and man-days/t of paddy, Laguna and Central Luzon-Laguna surveys, Philippines, 1966–75 wet season.

To explain the changes in labor input per hectare, it is first necessary to examine the changes that have taken place in the introduction of modern technology and in institutional arrangements. The changes are summarized in Table 5. Both survey areas experienced a rapid spread in the use of MV and related yield-increasing inputs. The use of herbicide — either yield increasing or labor saving, or both — also spread. Tractors and threshers were principally labor saving. The use of tractors for land preparation increased. However, at the time of the last Laguna survey threshers were still not used in the area, and their use in Central Luzon was declining. The reasons for that will be explained later.

Because of land reform legislation, a rapid change occurred in tenure status during the decade. But the spread of the *gama* system seems to have had much greater impact on labor use.

In the following subsections we discuss the effect on labor use of

- The introduction of new technology, both yield increasing and labor saving; and
- The changes in tenure status and institutional arrangements that affect the way in which the crop harvest is shared. We also show how these changes have influenced the relative amounts of family and hired labor use in rice production.

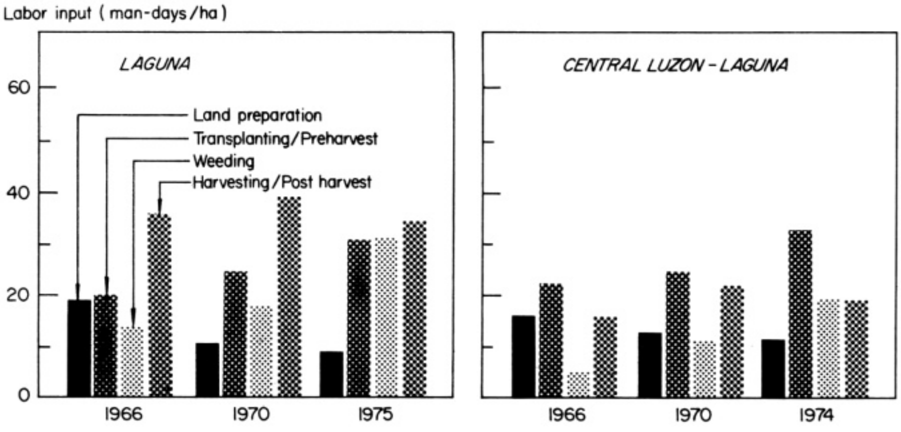
Technology effects. The effect of modern varieties, tractors, herbicides, and threshers on labor use is examined. Figure 3 summarizes the changes in labor inputs for specific activities in both surveys. Labor requirements for various activities in the two surveys show some noticeable differences. Labor used in pulling and transplanting seedlings was considerably higher in the CL/L survey largely because of method of seedbed preparation.

Table 5. Percent of farms by technology adopted, tenure class, and labor contract; 62 Laguna farms and 63 Central Luzon-Laguna farms, Philippines, 1966–75 wet and dry season.

Technology/ tenure class/ labor contract	Farms (%)					
	Laguna			Central Luzon-Laguna		
	1966–67	1970–71	1974 Dry 1975 Wet	1966–67	1970–71	1974–75
			Technology – wet season			
MV (100%)	0	76	94	0	57	64
MV (partial)	0	19	5	0	10	19
Herbicides	86	97	92	19	41	61
Tractors	26	71	90	17	43	57
Threshers	0	0	0	72	69	42
			Technology – dry season			
Dry-season farms (no.)	45	54	51	15	14	26
MV (100%)	0	76	94	7	93	n.a.[a]
MV (partial)	0	24	4	13	0	n.a.
Tractors	24	65	n.a.	62	80	81
Herbicides	87	97	93	62	50	n.a.
Threshers	0	0	0	46	50	19
			Tenure – wet season			
Share-tenant	90	80	38	73	54	52
Leasehold	10	18	60	13	36	30
Owner-operator	0	2	2	14	10	18
			Labor contract – wet season			
Gama[b]	0	40	85	0	5	11

[a] n.a. = no available information. [b] An arrangement whereby the hired laborer contracts ahead of time to weed a plot of rice in return for the right to harvest and thresh the plot and obtain 1/6 share.

The labor required for harvesting and threshing is higher in Laguna, first because the yields are higher, and second because a significant portion of the Central Luzon harvest is threshed mechanically (Table 5).



3. Labor input by task and by year, 62 Laguna farms and 63 Central Luzon-Laguna farms, Philippines, 1966–75 wet season.

Modern varieties. More farmers in Laguna than in Central Luzon have adopted MV (Table 5). The majority of farmers in both surveys are full adopters, in contrast with the experience in many other parts of Asia where, particularly in the wet season, most farmers are partial adopters. The MV adoption in Central Luzon is much higher among farmers with two crops, irrigated or rainfed, than among farmers with one irrigated crop. The low rate of adoption among the latter group probably reflects the poor drainage on the one-crop irrigated farms, which are located near highway embankments along the survey route.

The increase in labor use has been associated largely with care-of-crop activities, including weeding (Fig. 3). It is, therefore reasonable to hypothesize that labor increase is in turn associated with the adoption of MV. The MV effect is fairly easy to establish in Laguna where nearly all farmers were planting 100% of their area to MV in 1975. That almost-complete adoption was accompanied by a doubling of labor use for care-of-crop practices — including weeding—from 24 to 48 man-days/ha. The increase in labor input in Central Luzon, on the other hand, was more modest in an absolute sense — around 16 man-days—but also represented more than a doubling of input over the 1966 level.

Tractorization. Tractors have been adopted by the majority of farmers in both areas (Table 5). Their use is confined almost entirely to land preparation, and the general practice is to rent tractor services for only a portion of land preparation tasks. Only 10 farmers in the Laguna survey and 3 in the CL/L survey owned tractors in 1975. In Laguna, nearly all of the tractors are light, 2-wheel power tillers that are used primarily for harrowing, after plowing with carabao. In Central Luzon, on the other hand, 70-hp 4-wheel tractors are much more common and are hired by farmers for primary tillage, plowing, or rotovating. In both areas, carabaos continue to be used by farmers for a portion of the land preparation job, including final harrowing before transplanting.

To examine the effect of tractors and power tillers on labor use in land preparation, we grouped farmers according to the period of tractor adoption (Table 6.) In both surveys labor input was lower after adoption. There was, of course, a wide degree of variability in the individual farm estimate of labor requirements. But with the predominant use of 4-wheel tractors in Central Luzon, it seems reasonable to expect a bigger impact on labor reduction. Even on the farms that did not use tractors, and on farms that used tractors in as early as 1966, the labor input for land preparation declined in both surveys over the past decade.

Herbicide. The majority of farmers were using herbicides in Laguna before the introduction of MV. Herbicide use was less common in Central Luzon. Table 7 suggests that hand weeding has increased despite the expanded use of herbicides. Herbicides appear to be used more as a supplement to, rather than as a substitute for, hand weeding.

Threshing. Threshing is mechanized in Central Luzon, but not in Laguna. Its mechanization in Central Luzon occurred long before 1966 and is associated

Table 6. Relationship between tractor adoption and man-days of labor used in land preparation, farms grouped by periods of adoption. Laguna and Central Luzon-Laguna surveys, Philippines, 1966–75 wet season.

Year[a]	Tractor used[b]	Man-days/ha for land preparation	
		Laguna	Central Luzon-Laguna
		4 farms	*19 farms*
1966	no	24.0	17.9
1970	no	16.8	13.8
1974–75	no	15.8	10.6
		8 farms	*13 farms*
1966	no	18.1	15.6
1970	no	13.8	15.2
1974–75	yes	12.8	8.5
		26 farms	*17 farms*
1966	no	20.0	17.8
1970	yes	9.0	6.3
1974–75	yes	9.0	2.4
		17 farms	*4 farms*
1966	yes	15.5	7.7
1970	yes	8.8	3.5
1974/75	yes	8.2	4.1

[a] 1975 for Laguna, 1974 for Central Luzon-Laguna. [b] Seven farms in Laguna and 10 farms in Central Luzon-Laguna surveys followed another adoption pattern.

Table 7. Relationship between herbicide used and labor input for weeding, farms grouped by date of herbicide adoption, Central Luzon-Laguna survey, Philippines, 1966–75 wet season.

Year[a]	Herbicide used[b]	Laguna		Central Luzon-Laguna	
		Herbicide (US$/ha)	Weeding (man-days/ha)	Herbicide (US$/ha)	Weeding (man-days/ha)
				9 farms	
1966	no	–	–	0.0	16.6
1970	no	–	–	0.0	16.9
1974–75	no	–	–	0.0	13.6
				9 farms	
1966	no	–	–	0.0	3.5
1970	no	–	–	0.0	9.7
1974–75	yes	–	–	4.5	11.8
		7 farms		*7 farms*	
1966	no	0.0	17.8	0.0	7.2
1970	yes	1.30	16.7	0.30	10.9
1974–75	yes	3.40	35.5	5.10	18.2
		49 farms		*7 farms*	
1966	yes	0.60	15.5	0.40	9.1
1970	yes	1.20	19.4	0.60	13.8
1974–75	yes	3.50	34.2	4.70	30.2

[a] 1975 for Laguna, 1974 for Central Luzon-Laguna. [b] Six farms in Laguna and 31 farms in Central Luzon-Laguna surveys followed other patterns.

with the landlord-tenant system in the region. Landlords in Central Luzon frequently have large holdings — 100 ha or more — operated by a large number of tenants (Griffin, 1972). Landlords in Laguna, on the other hand, typically owned 10 to 20 ha operated by just a few tenants (Barker and Cordova, 1969). In Central Luzon, the introduction of threshers was encouraged by the landlords, who saw them as a means of better control over the sharing of the crop at the time of the harvest. The primary purpose was not to save labor.

The use of the large mechanical threshers underwent a substantial decline between 1966 and 1974 (Table 5). Of the 44 farmers using threshers in the 1970 wet season, 15 discontinued the practice in 1974. Thirteen of the 15 farmers were asked why they stopped using threshers. Their main reasons were the desire to provide work for landless laborers, and the difficulty of using the heavy threshing machines in the field during the wet season. However, it should also be noted that there was a shift from share-tenancy to leasehold (fixed rent) under the land reform program implemented since 1972, and thresher use by landlords to control the sharing of the crop was no longer necessary.

The decline in labor use due to mechanical threshing has been fairly modest (Table 8). (The 1974 data are omitted because there was a substantial error in the reported data. See Table 13 footnote.) The relationship between harvesting and threshing labor and rice yield is based on 1970 data shown in Table 8 (See footnote a. The formula was used to correct the coefficient for labor use in 1974).

Since the 1974 and 1975 survey a number of small threshers have been introduced into Central Luzon and Laguna. These threshers are easy to move

Table 8. Relationship between thresher use and labor input per hectare for harvesting and threshing in farms grouped by date of adoption, Central Luzon-Laguna survey, Philippines, 1966 and 1970 wet season.

Year	Mechanized threshing	Labor input	
		Man-days/ha[a]	Man-days/t
	Farms – 40		
1966	yes	15.0	6.8
1970	yes	18.1	6.6
	Farms – 5		
1966	yes	15.0	4.6
1970	no	19.8	8.0
	Farms – 14		
1966	no	23.3	11.4
1970	no	21.5	7.7

[a] Varies according to yield based on estimated regression for 1970 data as follows:
Without mechanical threshing: $Y = 13.8 + 0.11\ X$
With mechanical threshing: $Y = 14.7 + 0.05\ X$
where:
Y = labor for harvesting and threshing (man-days/ha)
X = yield of rough rice in cavans/ha (1 cavan = 44 kg rice).

Table 9. Labor input per hectare on share-tenant and leasehold farms, Laguna and Central Luzon-Laguna surveys, Philippines, 1970–75 wet season.

	Laguna				Central Luzon-Laguna			
	1970		1975		1970		1974	
	Share-tenant	Lease hold	Share-tenant	Lease hold	Share-tenant	Lease-hold	Share tenant	Lease-hold
Farms (no.)	50	11	25	36	34	23	19	33
				Man-days/ha				
Total pre-harvest	55	54	69	75	42	49	56	60
Total	94	86	95	114	60	71	82	81

from one field to another and require only two or three men to operate.

Institutional factors. As noted in Table 5, important changes have occurred in tenure status and sharing of the harvest due to land reform and the spread of the *gama* system. Even though there ·has been no significant change in size of sample farm during the study period, we examine the effect of farm size on labor use per hectare.

Tenure. In both surveys, the land reform program caused a significant shift from share-tenancy to leasehold. The effect of the shift on the sharing of output among landlords, tenants, and hired laborers is documented elsewhere in this volume (Ranade and Herdt). No consistent pattern of differences in labor use has emerged as a result of the change in tenure status (Table 9), but it may be too soon to detect such a change.

Gama. In both regions, most of the increase in hired labor is associated with weeding. The sharp rise in hired weeding labor in Laguna is due to the expansion of a contractual arrangement known as *gama.* With a *gama* contract, hired laborers agree to weed a field in exchange for the right to harvest the crop and receive one-sixth of the produce. In addition, if the harvest is good, the *gama* usually earns one-fourth of a sack (44 kg/sack) of rice for every paddy field weeded. A majority of those who seek employment under the gama system are landless laborers. Between 1970 and 1975, the farmers in the Laguna survey using *gama* increased from 33 to 85%. There is little doubt that the increase is due to the increase in size of the landless labor class.

The increase in landless laborers can be documented by a case study in Laguna. In late 1966 and early 1967, Umehara (1967) surveyed Barrio Tubuan, municipality of Pila, Laguna, and found that out of 63 households, 19 (30%) were headed by landless laborers. In November 1974, Hayami (1975) resurveyed the same barrio and found that out of 95 households, 41 (43%) were headed by landless laborers.

Table 10 shows the use of inputs, farm size, and yield per hectare for the farms in the Laguna survey, with and without *gama. Gama* farms seem to have higher yields, but there is no clear association between the yield level and the

Table 10. Use of inputs by farms with and without gama contractual arrangement for weeding and harvesting. Laguna, Philippines, 1970 and 1975 wet season.

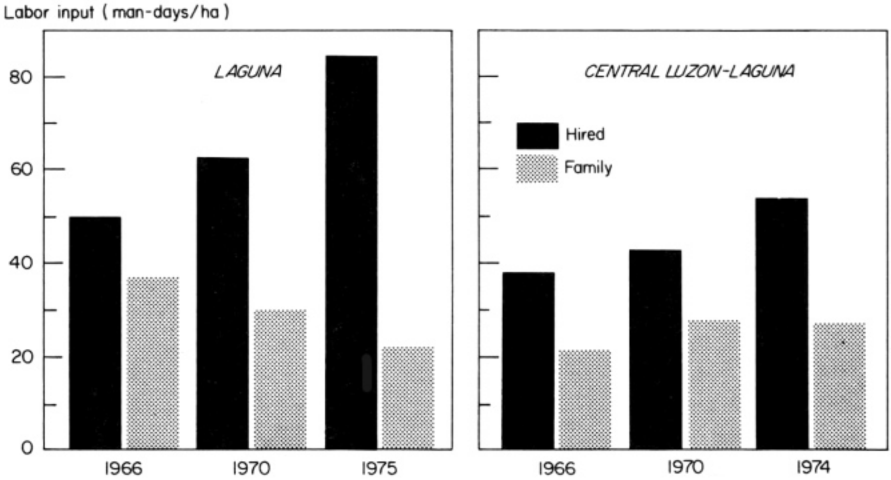
	1970 wet season		1975 wet season	
	With *gama*	Without *gama*	With *gama*	Without *gama*
Farms (no.)	21	41	53	9
Farm size (ha)	2.1	2.2	2.2	2.5
Yield (t/ha)	2.0	1.7	1.9	1.6
Weeding labor (man-days/ha)				
Family	6	12	4	17
Hired	15	6	28	15
Total	21	18	32	32
Fertilizer cost ($/ha)	12.85	9.40	53.00	52.00
Cost of herbicide ($/ha)	1.00	1.30	4.00	4.30

adoption of *gama. Gama* farms have almost the same level of labor input per hectare for weeding as other farms, and despite reports by herbicide dealers to the contrary, use almost the same level of herbicide. But for those farms employing *gama* workers, the proportion of weeding done by hired labor is much greater than that by family labor.

Farm size. Farm size affects the use of both technology and labor (Table 11). In Laguna, a greater percentage of medium and large farms used tractors and herbicides in 1975. In Central Luzon-Laguna, tractor and herbicide use was

Table 11. Farm size, input, and labor use per hectare, 62 farms in Laguna, 1975, and 63 farms in Central Luzon-Laguna, Philippines, 1974 wet season.

	Laguna			Central Luzon-Laguna		
Farm size (ha)	below 1.6	1.6–2.5	above 2.5	below 1.6	1.6–2.5	above 2.5
Farms (no.)	21	21	20	17	21	25
Yield (t/ha)	3.6	3.8	3.1	2.8	2.1	1.8
MV users (%)	100	100	95	76	86	84
Tractor users (%)	62	95	95	47	62	76
Herbicide users (%)	81	95	95	47	67	72
Thresher users (%)	0	0	0	47	43	40
Hired labor (%)	76	81	83	59	73	84
Preharvest labor (man-days/ha)	82	79	53	63	51	48
Total labor (man-days/ha)	118	117	88	95	78	79
Total labor (man-days/t)	33	31	28	34	37	43



4. Labor inputs by type of labor and by year, 62 Laguna farms and 63 Central Luzon/Laguna farms, Philippines, 1966–75 wet season.

more common on the medium than on the small farms, and more common on the large than on the medium farms.

Labor input per hectare tended to decrease with increase in farm size in both surveys, but the percentage of hired labor was greater on the large farms. The large farms also reported lower yields, perhaps because of differences in quality of the crop environment, in capital inputs, or in labor input. With respect to crop environment, large farms are frequently located in poorer soil and water environments. For example, rainfed and poorly irrigated farms tend to be larger than well-irrigated farms. Thus, differences in productivity per hectare tend to be greater than differences in productivity per farm.

Labor productivity (man-days per ton of rice) does not differ much between small and large farms in Laguna. But due to much lower yields on large farms in the CL/L survey, man-days per ton of rice are much higher.

Family versus hired labor. The trend in the amount of family and hired labor is shown in Fig. 4. The percentage of hired labor in the CL/L rose gradually but that in Laguna rose sharply between 1970 and 1975.

The transplanting and the harvesting and threshing tasks are traditionally done by hired labor (Tables 12 and 13, year 1966). The care-of-crop labor is traditionally provided by the tenant. Exchange labor, which is generally small, has been included in family labor.

Hired laborers were principally tenant-farmers and members of their family, or landless laborers and their family. A recent survey conducted in three municipalities of Laguna showed that among laborers interviewed, about 80% were landless (Wickham et al., 1974). Hired labor normally is arranged either by an individual or by a group. Most of the group workers tend to be female. Transplanting, which is normally contracted by the group, is one of the lowest

Table 12. Breakdown of family and hired labor by task, 62 Laguna farms, Philippines, 1966-75 wet season.

	1966		1970		1975	
Task	Family	Hired	Family	Hired	Family	Hired
			Man-days/ha			
Land preparation	14.4	4.3	6.4	4.7	4.0	5.0
Repair and cleaning of dikes	4.5	0.5	4.3	0.8	3.5	1.1
Rolling of seedlings and transplanting	0.8	9.4	0.2	10.0	0.1	10.8
Care of crop	4.3	0.1	8.7	1.0	7.3	8.3
Weeding	12.1	1.7	8.5	9.3	6.0	25.3
Total preharvest	36.1	16.0	28.1	25.8	20.9	50.5
Harvesting and threshing	0.0	31.6	0.0	33.6	0.1	31.5
Other (postharvest)	0.6	3.8	1.6	3.8	0.7	2.7
Family and hired (man-days/ha)	88.1		92.9		106.4	
Yield (t/ha)	2.5		3.4		3.5	
Total labor/t	35.2		27.3		30.4	

paid jobs. Harvesting and threshing, which are normally arranged individually, are among the highest paid jobs. Harvesters typically receive one-sixth of the total produce.

Table 13. Breakdown of family and hired labor by task, 63 farm, Central Luzon-Laguna survey, Philippines, 1966-74 wet season.

	1966		1970		1974	
Task	Family	Hired	Family	Hired	Family	Hired
			Man-days/ha			
Land preparation	9.6	6.2	9.4	3.4	5.9	4.0
Repair and cleaning of dikes	3.0	0.9	2.6	0.5	2.4	0.9
Rolling of seedlings and transplatning	0.3	14.3	0.3	15.8	0.4	20.1
Care of crop	4.1	0.3	5.4	0.5	7.6	1.8
Weeding	3.5	1.6	0.7	2.4	10.9	8.3
Total preharvest	20.5	23.3	26.4	22.6	27.2	35.9
Harvesting and threshing	0.9	15.5	1.1	19.8	0.1[a]	18.2[a]
Other (postharvest)	0.0	0.0	0.4	0.7	0.1	0.1
Family and hired (man-days/ha)	60.2		71.0		81.6	
Yield (t/ha)	2.3		2.4		2.2	
Total labor/t	26.2		29.6		37.1	

[a] The initial coefficient was unreasonably high because of an error in data collection. This coefficient is based on 1970 data adjusting for yield and percentage of mechanical threshing (see footnote a, Table 8).

The following trends were observed in hired labor use. In the Laguna survey, hired labor for land preparation has remained unchanged, but family labor has declined as a result of the introduction of tractors. Hired labor is now principally the power-tiller operator. Hired labor for weeding and other care-of-crop practices has increased, and the proportion of hired to family labor has also increased. In the CL/L area, family and hired labor for land preparation have decreased. That for weeding and other care-of-crop practices has increased, but the proportion of family to hired labor has remained fairly constant. As noted previously the increase in the proportion of hired labor to family labor in Laguna is closely associated with the spread of *gama.*

CONTRIBUTIONS OF OTHER FACTORS TO CHANGE IN LABOR USE

In this section we employ regression analysis on the labor use data from the surveys to identify the contribution of labor-saving and yield-increasing technologies to the change in preharvest labor input. We develop separate models for total and hired labor with a procedure similar to that of Staub (1973). Regression models were estimated for each survey, separately pooling the data for the three survey years (Table 14).

Yield-increasing factors associated with the new rice technology are positive and, thus, associated with the higher input of labor. They include the adoption of MV and use of fertilizers, insecticides, and herbicides. Herbicides can, in many circumstances, be labor saving and are treated as a separate variable. But we have previously noted the complementarity of herbicides and increased use of weeding labor in these surveys (Table 7). Labor-saving technology includes use of tractor for plowing and for harrowing. The coefficients are not significant for the total preharvest labor equations, but the signs are negative, conforming with our expectations. For the regression of hired labor, however, the signs are mixed and the *t*-values are smaller because tractor power has mainly substituted for family rather than hired labor.

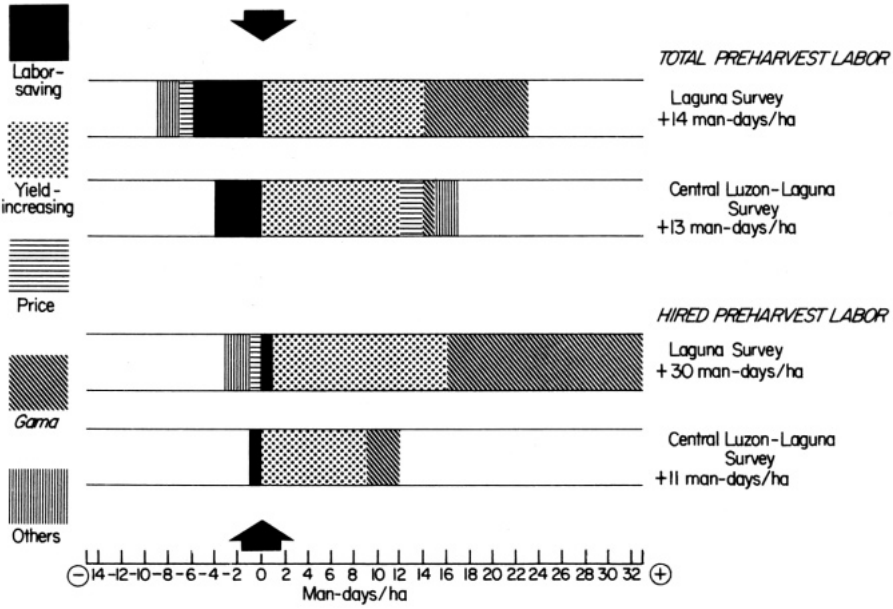
The introduction of the *gama* system of contracting labor, associated principally with the growth in landless laborers, is significantly related to the increase in hired labor. But because the process involves some substitution of hired for family labor, the coefficient for increase in total labor is smaller and statistically less significant.

As expected, the price elasticity of labor demand is negative with the fall in the real wage rate being associated with an increased use of labor. The variable “family labor” in the hired labor regressions is, in a strict sense, not predetermined, but simultaneously determined with the dependent variable “hired labor.” Our purpose here, however, is not to identify the supply and demand relationships for labor, but to identify the impact of the introduction of new technology in the use of labor. Hence, the specification of the model appears adequate.

Table 14. Regression equation estimating log of preharvest hired and total labor input per farm as a function of specified variables, Laguna (1968–75) and Central Luzon, Laguna (1966–74). Philippines. wet season.[a]

Category, variables	Laguna		Central Luzon-Laguna	
	Hired	Total	Hired	Total
labor-saving				
Tractor used for plowing	–0.051	–0.066	–0.024	–0.078
	(–0.963)	(–1.819)	(–0.437)	(–1.972)
Tractor used for harrowing	0.037	–0.047	–0.028	–0.028
	(0.927)	(–1.764)	(–0.493)	t0.687)
Yield-increasing				
Log fertilizer & insecticide cost = (US$/farm and deflated by consumer price index [CPI])	0.052	0.027	0.137	0.091
	(1.290)	(0.974)	(3.789)	(3.512)
Log herbicide cost = (US$/farm deflated by CPI)	0.134	0.009	0.004	0.038
	(2.024)	(0.207)	(0.055)	(0.661)
MV adoption	0.112	0.050	0.008	0.074
	(2.238)	(1.451)	10.202)	(2.590)
Price				
Log wage = (US$/day deflated by CPI)	–0.565	–0.180	–0.583	–0.350
	(–5.570)	(–2.589)	(–6.507)	(–5.440)
Institutional				
Gama	0.238	0.065	0.149	–0.089
	(5.414)	(2.262)	(2.055)	(–1.733)
Others				
Log area = (total rice area in hectares)	1.301	0.936	1.108	0.769
	(11.011)	(13.505)	(15.770)	(15.342)
Cropping intensity = (1 crop = 50%; 3 crops in 2 years = 75%; and 2 crops = 100%)	0.0004	0.00001	0.001	0.002
	(0.4220)	(0.00000)	(1.754)	(2.912)
Log preharvest family labor (man-days per farm)	–0.313	–	–0.143	–
	(–4.554)	–	(–2.994)	–
Intercept in log form (a)	1.278	1.643	1.030	1.356
Coefficient of determination (R^2)	.69	.60	.75	.75
Durbin-Watson Statistics	1.787	1.675	2.131	1.820

[a] 183 observations in Laguna; 189 observations in Central Luzon-Laguna; figures in parentheses are *t*-values.



5. Contribution of labor-saving and yield-increasing technology to increase in man-days labor input per hectare in rice production.

By putting mean values for 1966 and for 1974–75 into each equation, we can estimate the change in labor input associated with changes in technological, institutional, and other factors (see mean values in Appendix H). During the 1966–74/75 period, the principal changes that affected preharvest labor use were the introduction of MV and associated inputs, the adoption of tractor power, and the spread of the *gama* system in Laguna (Table 5).

The estimated effect of those factors on the changes in the level of total and hired labor input is summarized in Figure 5 (man-days/ha) and Table 15 (% contribution). The estimated effect of the changes in the level of total and hired labor based on these regressions is reasonably close to the actual differences over the period 1966 to 1974 or 1975 (see Tables 12 and 13, total preharvest labor). The change in total labor based on the equation — 14 man-days in Laguna and 13 man-days in CL/L — tends to be underestimated. Nevertheless, despite the substantial unexplained variance, the magnitude of the contribution of various factors to the change in labor input seems reasonable.

In both surveys, the introduction of yield-increasing technology contributed to the increase in total and hired labor input per hectare. But the more rapid increase in hired labor input in Laguna, compared with that in Central Luzon, seems to be associated almost entirely with the introduction of the *gama* system. The spread in the use of tractors for plowing and harrowing reduced labor input by 30 to 40% (Table 15). However, tractor power substituted largely for

Table 15. Relative contribution of labor-saving and yield-increasing technology to increase in man-days labor input per hectare in rice production from 1966 to 1975 in Laguna, and from 1966 to 1974 in Central Luzon-Laguna, wet season.

Category	Total preharvest		Hired preharvest	
	Laguna (%)	Central Luzon-Laguna (%)	Laguna (%)	Central Luzon-Laguna (%)
Labor-saving technology	–43	–31	3	–9
Yield-increasing technology	100	92	50	82
Price	7	15	–3	0
Institutional factor	64	8	57	27
Others	–14	15	–7	0
Total	100	100	100	100

family labor, suggesting that the farm operator placed a fairly high opportunity cost on the use of his labor for land preparation. The most common procedure was for the farmer to hire a tractor for half of the land preparation work (either plowing or harrowing) and to do the remaining work himself with his carabao.

CONCLUSIONS

The introduction of MV has, in general, increased labor input per hectare, but decreased labor input per ton of rice produced. In the decade ahead, we hope to see, in most developing countries in the region, a continuing gain in labor productivity through gains in yield rather than through a decline in labor input per hectare. But there appears to be, on the one hand, a decline in labor input due to mechanization and, on the other, strong pressure on the part of landless laborers to increase the level of employment. The result has been fairly substantial gain in hired labor utilization, but a tendency for family labor to decline.

The spread of the *gama* system suggests that while traditional patterns of dependency between landlord and tenant are breaking down under land reform, new patterns of dependency among tenants, farm operators, and hired landless laborers are developing. We must be conscious of these changes in the development of future rice technology.

REFERENCES CITED

Barker, R., and V. Cordova. 1969. Decision-making with respect to the use of inputs on Laguna farms. Pages 13–16 *in* Seminar on economics of rice production in the Philippines. December 11-13, 1969. International Rice Research Institute, Los Baños, Philippines.

Clay, E.J. 1976. Institutional change and agricultural wages in Bangladesh. Bangladesh Dev. Stud. 4(4):423–440.

Collier, W.L. 1977. Agricultural evolution in Java: the decline of shared poverty and involution.

Collier, W.L., and A.T. Birowo. 1973. Comparison of input use and yields of various rice varieties by large farmers and representative farmers. Agro-Economic Survey. Bogor, Indonesia. (mimeo.)

Fujimoto, A. 1976. Rice operation and labor input among Malay peasants in Kelantan. Jpn. J. Trop. Agric. 20(1):35–44.

Geertz, C. 1963. Agricultural involution. University of California Press, Berkeley. 80 p.

Griffin, K. 1972. The green revolution: an economic analysis. United Nations Research Institute for Social Development, Geneva.

Hayami, Y. 1975. The socioeconomic characteristics of a rice village in Southern Luzon. Paper no. 75–11. The International Rice Research Institute, Los Baños, Philippines. (mimeo.)

Hayami, Y., and V.W. Ruttan. 1971. Agricultural development in international perspective. Johns Hopkins Press, Baltimore.

HERDT, R.W. 1978. Cost and returns for rice production. Pages 63–80 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

Ihalauw, J., and W. Utami. 1975. Klaten, Central Java. Pages 149–177 *in* International Rice Research Institute. Changes in rice farming in selected areas of Asia. Los Baños, Philippines.

Izumi, R., and A.S. Banatunga. 1974. Cost of production of paddy, Maha 1972–73. Agrarian Research and Training Institute, Colombo, Sri Lanka.

Khan, M.H. 1975. The economics of the green revolution. Praeger Publishers, Inc., USA.

Mehra, S. 1976. Occasional paper no. 88, Cornell University.

Muqtada, M. 1975. The seed fertilizer technology and surplus labor in .Bangladesh Agriculture. Bangladesh Dev. Stud. 3(4):403–428.

Sajogyo, and W.L. Collier. 1973. Adoption of new high yielding varieties by Java's farmers. Pages 80–107 *in* R.T. Shand, ed. Technical change in Asian agriculture. ANU Press, Canberra.

Sriswasdilek, J. 1973. The yield performance and economic benefits of the high yielding rice varieties in Don Chedi, Suphanburi, Thailand. M.S. thesis, University of the Philippines at Los Baños, Philippines.

Staub, W.J. 1973. Agricultural development and farm employment in India. US Department of Agriculture Foreign Agricultural Economics Report No. 84.

Suh, Wan Soo. 1976. Factors affecting the rate of adoption of Tongil rice variety in selected locations of Korea. M.S. thesis, University of the Philippines at Los Baños, Philippines.

Tsai, L.S. 1976. Production costs and return for rice farmer in Central Taiwan, 1895–1976. M.A. thesis, School of Economics, University of the Philippines, Diliman, Quezon City, May 1976.

Umehara, H. 1967. Rice farming villages in the Philippines. Pages 140–205 *in* T. Takigawa and K. Saito. Land-tenure system and the structure of rural society in Asia [in Japanese]. Institute of Developing Economies, Tokyo.

Wickham, G., E.B. Torres, and G.T. Castillo. 1974. The farmer's laborer, an exploratory study in Laguna, Philippines. University of the Philippines at Los Baños, Philippines. (mimeo.)

APPENDICES

Appendix A. **Farm size, yield and labor use, 114 farm record-keepers in five districts in Sri Lanka, 1972–73 (Izumi and Banatunga, 1974).**

Location	Observations (no.)	Farm size (ha)	Yield (t/ha)	Labor (man-days/ha)		Hired labor (%)
				Total	Hired	
Hambantota	14	1.9	3.9	129	111	86
Folomaruwa	18	1.6	–	174	135	78
Flahera	12	1.6	–	167	106	63
Kurunegala	25	0.8	2.9	162	102	63
Kandy	21	0.5	3.4	159	140	88
Colombo	24	0.4	2.3	152	85	56
Av.		0.8	3.0	172	112	65

Appendix B. **Farm size, yield, and labor input of rice farms in Central Taiwan, 1967 and 1972, first crop.**[a]

Year	Observations (no.)	Farm size (ha)	Yield (t/ha)	Labor (man-days/ha)						Hired labor (%)
				Weeding		All preharvest		Total labor[b]		
				Total	Hired	Total	Hired	Total	Hired	
1967	211	0.9	5.1	27	9	73	24	113	35	31
1972	206	1.2	5.7	18	10	105	35	125	48	38
Av.		1.0	5.4	23	10	89	30	119	42	35

[a] Farm income survey from a cooperative project of National Taiwan University, National Chung Hsing University and Provincial Department of Agriculture and Forestry. [b] Includes harvest and postharvest labor.

APPENDIX C. **Farm size, yield and preharvest labor use in rice farming in Java, Indonesia, 1969–70 wet season (Sajogyo and Collier, 1973).**

Type of variety[a]	Observations (no.)	Farm size (ha)	Yield[b] (t/ha)	Preharvest labor (man-days/ha) Total	Hired	Labor hired (%)
		West Java				
Local	121	0.83	2.9	218	172	79
NI	35	0.76	3.3	206	136	66
IR	25	0.59	5.2	340	241	71
		Central Java				
Local	161	0.62	3.5	234	168	72
NI	77	0.77	3.4	239	208	87
IR	7	0.80	4.8	197	171	87
		East Java				
Local	61	0.67	3.4	253	213	84
NI	75	0.94	3.4	258	212	82
IR	99	1.11	4.5	247	215	87
Average						
Local/NI	530	0.75	3.3	235	185	79
IR	131	0.99	4.6	262	190	72
Av.		0.80	3.5	240	186	78

[a] NI =national improved varieties; IR = varieties introduced from IRRI. [b] Average yields for four seasons.

APPENDIX D. **Farm size, yield and labor use, 86 irrigated rice farms, Don Chedi, Suphan Buri. Thailand, 1972 wet season (Sriswasdilek, 1973).**

Type of variety	Observations (no.)	Land area	Yield (t/ha)	Labor (man-days/ha) Preharvest	Total
		Rai Rot			
Local	39	3.6	2.4	49	86
HYV[a]	39	2.4	4.2	66	120
Both	39	6.0	2.7	56	100
		Nong Sarai			
Local	47	4.3	1.8	50	76
HYV	36	1.8	2.6	69	115
Both	A7	5.7	2.0	55	85

[a] High yielding varieties.

APPENDIX E. **Yield and labor use, panel sample of 62 farms in Laguna and 63 farms in Central Luzon, Philippines, 1966 to 1975 wet season (Agricultural Economics Department, International Rice Research Institute, Los Baños, Philippines).**

Year	Farm size (ha)	Modern varieties (%)	Yield (t/ha)	Labor (man-days/ha)[a]						
				Weeding		All preharvest		Total labor[b]		Labor hired 1%)
				Total	Hired	Total	Hired	Total	Hired	
				Panel of 62 farms in Laguna						
1966	2.2	0	2.5	14	2	54	18	88	51	58
1975	2.2	95	3.5	25	19	64	44	106	85	80
				Panel of 63 farms in Central Luzon and Laguna						
1966	2.4	0	2.2	5	2	44	23	60	39	65
1970	2.5	56	2.7	11	2	49	22	71	43	61
1974	2.2	65	2.2	19	8	63	36	82	54	67

[a]Average labor in the wet season. [b]Indudes harvest and postharvest labor.

APPENDIX F. **Farm size, yield and labor use on rice farms in Hwasunggun, South Korea, 1974 (Wan Soo Suh. 1976).**

Type of variety	Area (%)	Farm size (ha)	Yield (t/ha)	Labor (man-days/ha)	
				Preharvest	Total
Modern variety	22	1.2	7.2	89	139
Traditional variety	78	1.2	5.6	83	126
Av.	–	1.2	5.9	85	129

APPENDIX G. **Farm size, yield, and labor use on rice farms in Mymensingh, Bangladesh, boro, 1969–70 (Muqtada, 1975).**

Type of variety	Area (%)	Farm size (ha)	Yield (t/ha)	Labor (man-days/ha)		Labor hired (%)
				Preharvest	Total	
MV	50	1.5	3.4	142	194	59
ILV	50	1.5	2.2	95	137	52
Av.		1.5	2.8	118	165	56

[a]Assuming 50% in modern variety (MV) and 50% in improved local variety (ILV).

APPENDIX H. Mean values of variables used in estimating preharvest hired and total labor input per farm, Laguna and Central Luzon-Laguna, 1966–75 wet season.

Variable	Laguna		Central Luzon-Laguna	
	1966	1975	1966	1975
Preharvest family labor (man-day)	85.080	43.948	43.772	50.099
Preharvest hired labor (man-day)	36.176	101.657	61.725	90.227
Area (total rice area in ha)	2.365	2.271	2.441	2.509
MV adoption	0.000	1.000	0.000	0.825
Wage (US$ & deflated by CPI[a])	0.460	0.482	0.371	0.291
Tractor for plowing	0.066	0.230	0.111	0.524
Tractor for harrowing	0.377	0.852	0.127	0.476
Herbicide cost (US$ & deflated by CPI)	2.493	3.035	0.195	3.126
Fertilizer and insecticide cost (US$ & deflated by CPI)	9.272	48.083	10.433	35.767
Cropping intensity (%)	87.164	98.623	61.905	69.841
Gama	0.000	0.852	0.000	0.111
Log — preharvest family labor	1.823	1.552	1.515	1.551
Log — area	0.325	0.315	0.301	0.321
Log — herbicide cost	0.397	0.482	–0.710	0.495
Log — wage	–0.337	–0.317	–0.431	–0.536
Log — fertilizer and insecticide cost	0.967	1.682	1.018	1.553
Log — preharvest hired labor	1.455	1.913	1.610	1.756

[a] Consumer price index.

COMMENTS ON LABOR UTILIZATION IN RICE PRODUCTION

K. GRIFFIN

THE BARKER-CORDOVA PAPER "Labor Utilization in Rice Production" is the story of a *révolution manque.* The days of euphoria have vanished and with them, almost, the vocabulary used to discuss the consequences of technical change. The terminology employed by social scientists has become markedly more sober and realistic. *Miracle seeds* have given way, first, to *high yielding varieties* and then, more recently, to *modern varieties;* the *green revolution* has become, in the title of this conference, simply a *new rice technology.*

Even in the Philippines, the country where much of the original research on the modern rice varieties occurred and where 60% of the rice area is sown with modem varieties, the aggregate effects of the new technology on production, trade and prices have been modest. Rice has not become abundant, prices have not fallen, and imports of rice have not been eliminated. Most ironical of all, notwithstanding their considerable biological potential, the physical yields of modern varieties (MV) in the fields of the farmers are little higher than those of the traditional varieties (TV). Between 1968 and 1972, average yields of MV and TV in the lowland rainfed areas of the Philippines were identical; in the irrigated areas the yield of the MV was 2.0 t/ha and that of the TV 1.7 t/ha, a difference of 21% (Herdt and Wickham, this volume).

There are assurances that returns on the investment in agricultural research are high in the Philippines and elsewhere (Evenson and Flores, this volume), and no doubt this is true. But the significance of this isolated fact is unclear until the wider context in which such investment occurs is specified, and in particular until one examines the distribution of the benefits of research among the various social classes.

EVIDENCE FROM FARM SURVEYS

The paper by Barker and Cordova is concerned with changes in the level and pattern of employment in rice cultivation in Laguna and Central Luzon.

The two sample areas, although close to one another, are distinct. Laguna is a small, compact province, close to Manila, and is the home of IRRI and the Los

Economist, Oxford University, Oxford, England.

Baños campus of the University of the Philippines. Thus it benefits from nearness to the largest market in the country and from the new knowledge and technical assistance emanating from the two centers of research and dissemination. Moreover, the structural characteristics of the farming system are exceptional; the distribution of land in the province is less unequal than in other regions of the Philippines, and partly because of this, relatively labor-intensive techniques of production are used.

Central Luzon, on the other hand, is a larger and less homogeneous area. It is the rice bowl of the country and, in general, is well suited for the cultivation of MV. The ownership of land, however, is highly concentrated and the techniques of production are relatively well mechanized.

Thus the samples are from two of the best rice areas of the Philippines, ones where considerable technical change has occurred in recent years. The Laguna sample is indicative of the best that has been achieved in the Philippines in terms of employment, equality, and output per hectare, whereas the Central Luzon sample sheds light on what happened after MV were introduced in a less atypical area.

Between 1966 and 1975 yields in Laguna during the wet season increased 40% and employment per hectare rose by about 21 %. By 1975 the intensity of cultivation in Laguna, measured in terms of man-days/ha, was about 33% higher than the average for Central Luzon. This appears to be a pretty good record. But the rate of increase in employment on the Laguna rice farms was considerably lower than the growth rate of the labor force, and hence even in this exceptional area there may have been a tendency for the expansion of demand for farm labor to fall short of the potential growth of supply.

There was a sharp rise in the amount of labor used in care of the crop (seedbed preparation, replanting, fertilizing, spraying, and weeding) as one would expect from the nature of the MV technology. Part of that rise, however, was offset by a 50% decline in the amount of labor required for land preparation. That is significant. If the labor required for land preparation in 1975 had been the same as in 1966, labor use would have been about 9.7 man-days/ha higher. The increase in total employment between 1966 and 1975 would have been 54% higher.

In other words, if there had been no change in the method of land preparation, the rate of growth in the demand for labor would have exceeded by a comfortable margin the rate of growth of labor supply. Under such circumstances, the introduction of MV would have been associated clearly with some combination of a reduction in unemployment, an increase in the number of days of employment per person, and higher real wages for agricultural laborers, all of which would have helped to reduce poverty and improve the distribution of income in the countryside.

The speed of introduction of MV was considerably faster in Laguna than in Central Luzon, although the rate of growth of employment was faster in Central Luzon than in Laguna. In Central Luzon employment per hectare during the wet season increased 22 days between 1966 and 1974. In this sample the demand for labor certainly grew more rapidly than the supply. It should be noted, however, that even after this fairly rapid growth, the 82-day/ha employment in Central Luzon in 1974 was still significantly lower than it had been in Laguna nearly a decade earlier.

The change in the pattern of employment in Central Luzon was similar to that in Laguna. Labor utilization for pulling or rolling seedlings, transplanting, and care of the crop increased substantially, whereas the amount of labor for land preparation fell by about a third. Thus in both samples the only operation which had a fall in employment was land preparation. Barker and Cordova attribute that fall, surely correctly, to increased use of tractors.

The tractor issue. The question then is whether the use of tractors is inherent in the introduction of MV. Certainly the use of the former has expanded parallel to the diffusion of the latter. In Laguna, during the 1965–66 wet season, 26% of the farms used tractors (typically of 7–10 hp), but by 1974–75 that figure had increased to 90%. In Central Luzon, over the same period, the use of tractors (typically of 70 hp) increased from 17 to 57% during the wet season and to 81% during the dry season.

Nonetheless, it probably is true, as the authors claim, that the use of tractors is in some sense independent of the MV. First, technologically, there is little evidence that the successful cultivation of the new seeds requires tractors. Second, historically, there is considerable evidence that the introduction of tractors preceded that of the MV, not only in the Philippines but elsewhere. For example, Ahmed (1976) surveyed the evidence from South Asia and concluded that "tractorization was almost as rapid before as after the introduction of Green Revolution technology."

A consensus seems to have emerged that in many underdeveloped countries a socially undersirable substitution of capital for labor in agriculture has taken place — particularly on farms owned by large landlords — because of government policies, which have created a set of incentives favoring labor-displacing mechanization (International Labor Organization, 1973). Low and even negative real rates of interest, overvalued currencies combined with import quotas and foreign exchange licensing systems, and international aid programs that subsidize imported equipment have resulted in a set of relative-factor prices that discourages the use of labor and encourages so-called progressive farmers to *modernize.*

It is less widely recognized that this set of relative-factor prices reflects the balance of political forces in society and that the latter, in turn, is greatly affected by the concentration of landownership. As Raj (1973) noted,

> "The imperfections in the market for land are perhaps the most serious of all, since the amount of land owned governs to a large extent the ability to lease in land and to borrow capital. Owners of small holdings have therefore only limited access to resources (irrespective of their willingness to pay a high price) and may therefore not be in a position to undertake even highly pro-

> ductive forms of mechanization on their farms. On the other hand, for the owners of large holdings there is usually no serious resource constraint as such on mechanization . . . A pattern of agricultural mechanization that is more meaningful and desirable on broader social considerations would therefore perhaps require something more than a mere 'correction' of market prices; one of the basic preconditions appears to be certain minimal changes in the pattern of land ownership and in the resulting economic equations."

The political forces that have promoted and prospered from labor-displacing mechanization, be it in the form of tractors or mechanical threshers — as on the large farms of Central Luzon — are the same political forces responsible for public investment in irrigation schemes and the promotion of MV. In this sense, *modernization* in the Philippines and the rest of contemporary Asia is a seamless web; tractors and the MV are politically linked (Gotsch, 1973; Dasgupta, 1977; Griffin, 1974; Edwards, 1974).

Several implications follow from this. First, it is naive to imagine that one can readily eliminate the undesirable aspects of modernization, e.g., tractorization, while retaining the desirable aspects, e.g., the MV. The large landowners will defend the economic system that encourages both. Second, it is unrealistic to think that technical changes by themselves, independently of the sociopolitical context in which they occur, are likely quickly to transform a society and markedly improve the well-being of its poorest members. Third, it is quite probable that in the particular context of contemporary Asia, modernization of agriculture, of which the MV are a part, has led to a deterioration in the relative and even absolute position of the poor.

Pauperization of the landless. The Philippines is an especially interesting country to study in this connection because the modern rices are so much more widely used there than in the rest of Asia. Moreover, the period covered in the Barker-Cordova paper includes the years of maximum impact of the new rice technology; in the future the rate of innovation is likely to decline. Thus if modernization of agriculture within the present socioeconomic structure is capable of overcoming demographic pressures and raising the well-being of the poor, it should have done so in the Philippines in recent decades.

On the surface the national data appear encouraging. Between 1957 and 1974 physical output in agriculture increased 3.4% a year, clearly in excess of the growth of the agricultural (and national) population and labor force. Moreover, between 1957 and 1971, thanks in part to an improvement in the sector's terms of trade, real income per head in rural areas increased 2.3% a year, a remarkable performance. Beneath the surface, however, there are indications that all is not well.

Toward the end of their paper Barker and Cordova call attention to the increase in the landless labor class and the expansion of a contractual arrangement known as *gama,* which exploits the existence of such a class to ensure that fields are weeded and harvested correctly. Barker and Cordova also refer to studies that suggest that in Laguna, a region where income inequality is probably less acute than average, the number of landless households increased from 30 to 43% of the total between 1966–67 and 1974.

These are disquieting facts. My unease is further increased by an examination of the data reported in Herdt's (this volume) study. Herdt reports that in Central Luzon, in the wet season, the paddy-equivalent gross farm family income of small owner-operators and share-tenants was higher in 1966 than in either 1970 or 1974. Measured in terms of 1966 prices, the real income for the average of all farms in the sample — owner-operators, share-tenants, and leaseholders — was higher in 1966 than in 1970 or 1974, regardless of whether income is expressed in terms of dollars per hectare, per farm, or per man-day of family labor.

Another study of Central Luzon by Ranade and Herdt (this volume) suggests that the real wage rate of laborers was lower in 1974 than in 1966. There is thus considerable fragmentary evidence indicating that the poorest groups in the rural areas of the Philippines probably have become further impoverished even in those provinces where the use of MV is virtually universal.

A careful study of the available evidence leaves no room for doubt that, in the nation as a whole, the pauperization of the landless and near-landless continues (Khan, 1976). The share of the poorest 20% of households in rural areas has fallen steadily from 7.0% of total income in 1956–57 to 4.4% in 1970–71. More significantly, over the same period the real income of the bottom quintile, measured in 1965 prices, fell by about 11%. Finally, between 1957 and 1974, the index of daily real wages of all agricultural operations fell by 61%, with the sharpest fall occurring after 1967, i.e., precisely in the period when the new rice technology was introduced.

CONCLUSIONS

Events in the Philippines illustrate the proposition that aggregate production per head can increase at the same time that the incomes of specific classes fall. Throughout most of Asia the rise in output attributable to the MV has been small, while the impact of the process of modernization on the well-being of the poor has been negative. To believe this, contrary to Ruttan (this volume), is not to suffer from schizophrenia or to propose a *curious dichotomy.*

Indeed, research at the ILO (Griffin and Khan, 1976) provides empirical support for Ruttan's assertion that there are substantial areas in almost every country in Asia where the rural poor, primarily the landless, are worse off both relatively and absolutely than two decades ago (Ruttan, this volume). I do not claim, however, that the MV have been responsible for a worsening of income distribution in rural areas. The impoverishment of the poor is traced, not to the new seeds but to the system in which the seeds are planted.

It does not advance the understanding of what has been happening to claim that policies have been based on a substantial misunderstanding and a massive disregard of the welfare of food producers (Ruttan, this volume). Those who rule in Asia — typically some combination of traditional rural elite-commercial-bureaucratic-military coalition — have well understood what is in their interest, and they have pursued policies which, if not favoring food producers in general, certainly have favored the large landowning class. Policies have been formulated not by simple fools but by wicked knaves.

The political and economic system that has been erected in Asia in the post-independence period is experiencing severe internal stress and conflict. Inequality is increasing; the incomes of the poor are falling; rural unrest is rising. Those who rule have responded, not by reforming the system — although they have adopted the rhetoric of reform — but by suppressing dissent, incarcerating opponents, creating an authoritarian state, and by using their monopoly of the instruments of violence to wage war on the poor.

These considerations may seem far removed from the issues discussed in Barker and Cordova's useful paper, but they are in fact central to the question of labor utilization. The problem in the Philippines and the rest of Asia is not that the rural poor are unable to engage in the process of production but that the terms on which they are engaged yield an extremely low and declining income. One is not concerned therefore with creating employment but with redistributing value added or net income. The only way this can be done on a large scale, however, is by redistributing the stock of wealth that generates the flow of income. This, in turn, requires either an ultra-egalitarian redistribution of land (as in Taiwan), or the formation of a communal land system (as in China). Neither solution is possible within the established sociopolitical context, and thus one is forced to conclude that either impoverishment will continue or the existing systems will be overthrown.

REFERENCES CITED

AHMED, IFTIKHAR. 1976. The green revolution and tractorisation, the mutual relation and socioeconomic effects. Int. Labour Rev. 114(1):83–93.

DASGUPTA, BIPLAB. 1977. Agrarian change and the new technology in India. United Nations Research Institute for Social Development.

EDWARDS, E. O., ed. 1974. Employment in developing nations. Columbia University Press.

EVENSON, R.E., and P.M. FLORES. 1978. Social returns to rice research. Pages 243–265 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

GOTSCH, C. H. 1973. Tractor mechanization and rural development in Pakistan. Int. Labour Rev. 107(2):133–166.

GRIFFIN, K. 1974. The political economy of agrarian change. Macmillan.

GRIFFIN, K., and AZIZUR RAHMAN KHAN, ed. 1976. Poverty and landlessness in rural Asia. ILO, Geneva. (mimeo.)

HERDT, R. W. 1978. Costs and returns for rice production. Pages 63–80 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

HERDT, R. W., and T. H. WICKHAM. 1978. Exploring the gap between potential and actual rice yields: the Philippine case. Pages 3–24 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

INTERNATIONAL LABOR ORGANIZATION. 1973. Mechanization and employment in agriculture. Geneva.

KHAN, AZIZUR RAHMAN. 1976. Growth and inequality in the rural Philippines. *In* K. Griffin and A. Rahman Khan, ed. Poverty and landlessness in rural Asia. ILO. Geneva. (mimeo.)

RAJ, K. N. 1974. Mechanization of agriculture in India and Sri Lanka (Ceylon). *In* Mechanization and employment in agriculture, International Labor Organization, Geneva.

RANADE, C. G., and R. W. HERDT. 1978. Shares of farm earnings from rice production. Pages 87–104 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Banos, Philippines.

RUTTAN, W. W. 1978. New rice technology and agricultural development policy. Pages 367–381 *in* International Rice Research Institute. Economic consequences of new rice technology Los Baños, Philippines.

Mechanization and use of modern rice varieties

B. DUFF

ONE OF THE MOST controversial aspects of the seed-fertilizer revolution is the degree of mechanization it requires to realize the production potential of the modern varieties (MV). While much of the controversy centers on the impact of mechanization on employment and distribution of income, there are also unresolved issues involving interactions between use of improved varieties and mechanical technologies. Unlike nitrogenous fertilizers, which are a direct technical complement to plant growth and for which there exist limited substitutes in the production function, agricultural mechanization, broadly defined, may

- complement, as in the case of pump irrigation in rainfed areas,
- substitute for, as in the case of tractors for animal power and labor,
- or supplement, as illustrated by use of manual rotary weeders, other factors in the production relationship.

This paper focuses on the relationship observed between use of MV and the nature and degree of mechanization associated with their adoption. Major emphasis is placed on the role of land preparation, because it is an operation that has been examined in many IRRI surveys and experiments.

The first section reviews the empirical evidence describing causal relations between mechanization and MV. The second section examines the possible output effects of MV with the use of a range of innovations in mechanization. The final section suggests areas for further research to properly identify and measure the effects of mechanization on output of MV.

CAUSAL RELATIONS BETWEEN MODERN VARIETIES AND MECHANIZATION

The large number of studies of mechanization at IRRI and elsewhere suggests a relationship between mechanization and the adoption and use of MV. In a

Agricultural economist, Department of Agricultural Engineering, International Rice Research Institute, Los Baños, Philippines.

Table 1. Adoption of tractors by farmers who grew modern rice varieties (MV) during the wet season, 1971–72 (IRRI, 1975).

Location	Villages (no.)	Tractor users before MV adoption (%)	Tractor users in survey year	First users of tractors (%) in	
				Year when MV were generally adopted in village	Year after MV were generally adopted
India	12	7	23	3	13
Indonesia	5	1	3	2	12
Malaysia	2	10	96	10	30
Pakistan	2	70	71	1	5
Philippines	9	27	58	19	14
Thailand	2	18	22	7	12
All villages	32	16	37	8	17

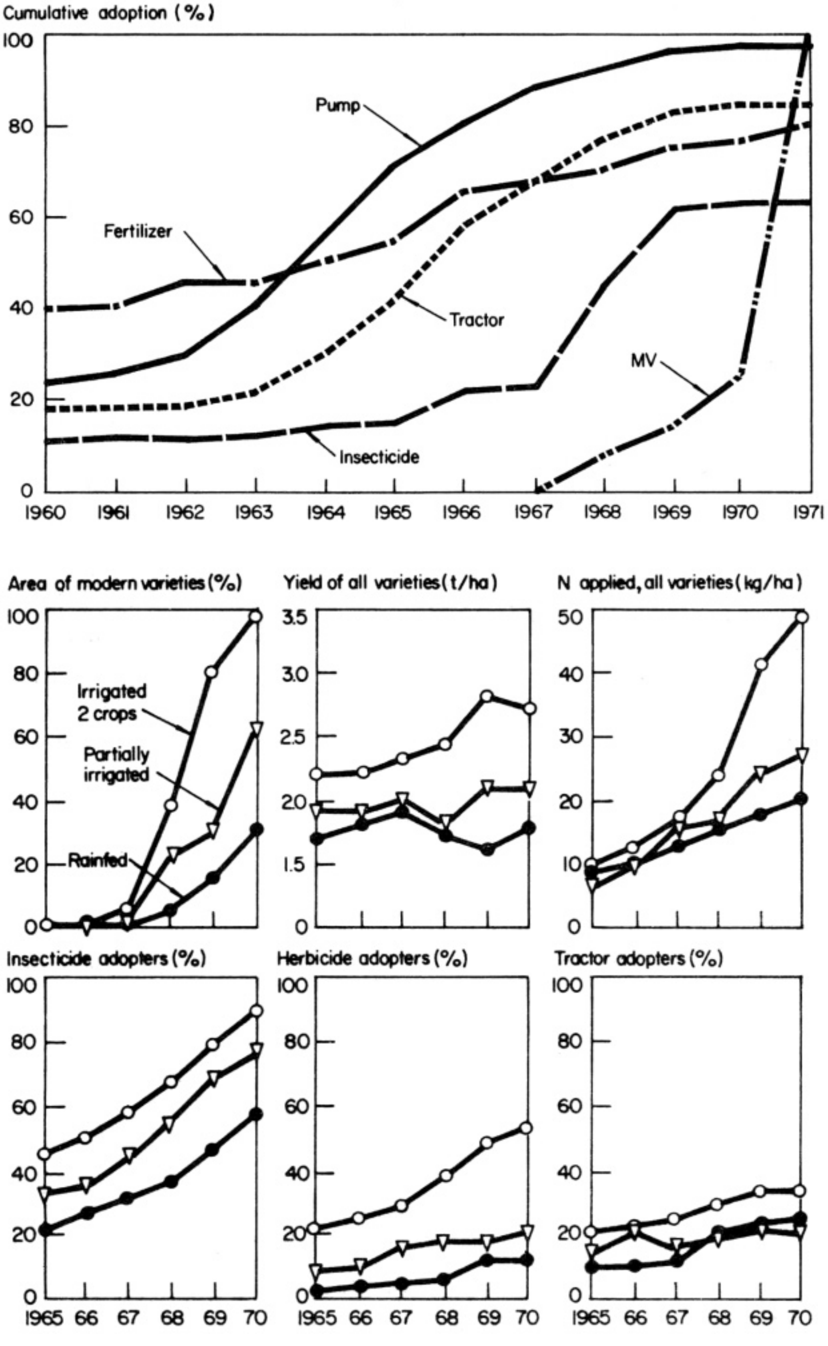
cooperative study by IRRI and institutions in six Asian countries (IRRI, 1975), the sequence and rate of adoption of MV and other improved production inputs were analyzed. The degree of tractor adoption in relation to the adoption of MV in those areas is shown in Table 1.

Tractor use was generally low before MV were introduced except in Pakistan. There is no conclusive evidence that mechanization was a necessary condition for the successful adoption of the MV. In countries where tractor use increased, it appears to have followed introduction of the new varieties rather than preceded or paralleled their adoption. Examination of factors other than adoption of the MV that have influenced the growth and pattern of mechanization is beyond the scope of this study. Much of the growth in the use of tractors in Pakistan and the Philippines can, however, be attributed to the availability of concessional credits provided through a series of loans sponsored by the World Bank. Other factors that influenced the adoption of mechanization are distortions in the relative prices of capital and labor, and overvalued exchange rates.

Figure 1 illustrates the time sequence and rate of adoption of specific practices in two villages surveyed in Pakistan. Except for insecticides, the adoption rate for most practices showed little change from previous trends after 1967 when MV were initially introduced. Use of tractors for land preparation reached a high level before introduction of MV.

Figure 2 presents comparable data from three of the villages in the Philippines (Barker et al., 1974), but with a breakdown based on water source. Use of complementary inputs such as nitrogen and insecticides increased as the MV spread, particularly in the irrigated areas. But as in Pakistan, the Philippines data show no correspondence in the adoption of MV and the purchase or use of tractors.

Table 2 gives a composite picture of adoption by farm size for the 32 villages included in the six-country regional study. While there is some clustering of



2. Proportion of area planted to high yielding varieties, yield, input use, and tractor adoption for all varieties by type of irrigation for the wet season, Nueva Ecija, Philippines.

Table 2. Use of specified practices by farm size from a sample of 32 villages in six Asian countries, 1971–72 (IRRI, 1975).

Practice	Farms (%) using practice		
	Less than 1 ha	1-3 ha	More than 3 ha
Modern varieties			
Wet	84	86	93
Dry	89	91	89
Fertilizer			
Wet	76	75	82
Dry	84	83	85
Insecticide	79	81	83
Herbicide	6	20	29
Hand weeding	82	83	87
Rotary weeding	3	20	37
Tractors	13	41	57
Mechanical thresher	36	43	63

farms in certain farm-size categories for a number of countries, the evidence clearly indicates that the use of mechanical techniques (rotary weeding, tractors, threshers) is more pronounced on larger than on smaller farms. In contrast, the use of MV, fertilizer, or insecticides did not significantly differ among the farm sizes.

One piece of mechanical equipment that has grown rapidly in popularity is the Japanese rotary weeder. One series of surveys in the Philippines showed that use of mechanical weeders increased rapidly between 1966 and 1970 in areas with MV and where rice was transplanted in straight rows. In a Central Luzon-Laguna survey of 76 farmers, users of mechanical weeders increased from 9 to 17%; in a survey of 153 farmers in Laguna, users increased from 42 to 84% (Barker et al., 1974).

Yields and intensity of rice cultivation have increased more in Laguna than in Central Luzon, although adoption of MV was rapid in both areas. Different soils and different socioeconomic conditions may have contributed to the observed differences in straight-row planting and rotary weeding. However, high fertilizer rates and the semidwarf plant type have invariably increased the need for weed control inputs, which stimulated the use of small rotary weeders.

The MV are generally not sensitive to day length and can be planted and harvested anytime during the year. Coupled with increased irrigation, that characteristic created a need for harvesting and threshing throughout the year. Thus, one could hypothesize that the introduction of MV would increase the use of mechanical threshers.

The evidence available, however, shows no direct correlation between mechanical threshing and use of MV in the Philippines (Barker and Cordova, 1978). Large mechanical threshers had long been used in some areas of the Philippines, but the practice has been disrupted in recent years by land reform.

Mechanical threshing actually declined in some areas because small owner-operators no longer required the landlord's presence at threshing.

Many researchers emphasize the role of controlled water supplies in expanding total rice production (Barker et al., 1975; Herdt and Barker, 1977). Adequate and timely irrigation has two primary effects on output.

1. It raises yields by reducing stress days and decreasing the risk of using the modern technology, particularly fertilizer.
2. It increases the potential for double or multiple cropping.

While in the long run, major expansion in irrigation must be financed by investments from the public sector, the remarkable increase in the sale and use of low-lift and deep well pumping units over the past 20 years indicates a strong awareness among farmers of both the priority of water and its availability as a precondition for the successful use of other innovations including the MV.

Under similar environmental conditions and levels of inputs, the MV have a higher marginal response to water inputs than the traditional varieties (TV). For this reason, there appears to be no ambiguity regarding the high degree of complementarity between pump sets and use of MV, particularly for increasing cropping intensity. In a study of lowland pump-irrigated farms in the Philippine's Laguna province. Toquero (1974) showed a sizable increase in the double-cropped area as the result of pump installations. The increase in effective cropped area took place largely during the dry season when the yield potential from the MV is highest. During the study yields of MV users rose an average of 40% over those of TV users under similar conditions of water availability. There was a high degree of coincidence between the installation of the pumping units and the rapid adoption of the MV. Mechanization techniques to lift, measure, and deliver water may be the most effective and lowest cost means of achieving yield gains in the short run.

POSSIBLE OUTPUT EFFECTS

In the previous section, I examined a number of possible causal relationships between mechanization and the MV. In this section, I review the evidence on mechanization's impact on the output of the MV through its effect on rice yield, cropping intensity, and expansion in cultivated area.

Repeated reference has been made to the need for timeliness in operations associated with the MV. Timeliness affects production by increasing crop yields and increasing crop intensification, or both. The distinction is not clear. In tasks such as land preparation, both yield and intensity may be affected. Mechanization can reduce the time variance of selected operations, improve resource use efficiency, and reduce the risk in use of modern rice technology inputs.

The importance of timeliness is conditioned by the physical environment within which a rice crop is grown, and by the characteristics of the varieties themselves. Differences in topography, degree of water control, soil type, and seasonality interact differently with the timing of individual operations. For example, a single-crop regime may not be affected as adversely by the degree of precision in scheduling operations as a double- or triple-crop pattern. An important exception is found in comparing single-crop irrigated and rainfed rice production systems. Programming of land preparation and transplanting by a farmer with irrigation may be determined to some degree by the timing and availability of water deliveries. But the irrigated rice farmer has greater flexibility in this regard than the rainfed rice farmer who is constrained by the availability and quantity of rainfall and must prepare his land quickly to take advantage of that moisture. In this regard, the short-season varieties may reduce the urgency of early land preparation and transplanting in rainfed areas where farmers do not attempt to grow a succeeding crop. The opposite is true when rainfed rice farms initiate double-cropping. Binswanger (pers. comm. with H. Binswanger, ICRISAT, July 14, 1977) mentioned that the timeliness factor in crop establishment becomes more imperative in rainfed areas characterized by permeable soils with their low moisture-retention characteristics.

Correct timing of the harvest may interact singly or in combination with both yield and intensity, depending again on the environment. Optimal timing of harvest maximizes yields, is a precondition for high grain quality, and reduces the turnaround time between crops in double-cropping.

Yield effects. The possible effects of mechanization on yields are examined at two levels—performance of field production operations, and postproduction operations.

Increased yields are often cited as a major reason for mechanization. For some upland crops, operations such as deep plowing have demonstrated significant yield advantages over traditional methods. For wetland rice, the advantages are less clear-cut.

To determine the effects of land preparation techniques on the yield of IR20, a series of field experiments and a survey were conducted in 1973 (Orcino and Duff, 1974; Bautista and Wickham, 1974). Replicated plots with five tillage treatments were laid out at four sites (three villages) with variable soil and

Table 3. Alternative land preparation treatments, 3 villages, Philippines, 1973 wet season (Orcino and Duff, 1974).

Treatment	Land preparation method			
	Primary		Secondary[a]	
	Power source	Implement	Power source	Implement
1	64-hp tractor	rotary tiller	carabao	comb harrow
2	14-hp tiller	rotary tiller	carabao	comb harrow
3	7-hp tiller	moldboard plow	7-hp tiller	comb harrow
4	carabao	moldboard plow	7-hp tiller	comb harrow
5	carabao	moldboard plow	carabao	comb harrow

[a] Secondary tillage consists of two passes over the field repeated three times at 1-week intervals.

Table 4. Site characteristics, soil conditions, and level of inputs used in land preparation trials, three villages (four sites), Philippines, 1973 wet season (Orcino and Duff, 1974).

Site treatment	Labor input (h/ha)			Fuel consumption (liter/ha)	Weed wt[a] (g/0.2 m²)	Mean[a] yield (t/ha)
	Plow	Harrow	Total			
Baluarte (shallow hardpan)						
T1	4	30	34	13	16.0	3.85
T2	6	30	36	12	12.1	3.80
T3	12	12	24	32	16.5	3.65
T4	27	11	38	17	13.5	3.88
T5	27	31	58	–	12.6	3.74
Pulo I (medium hardpan)						
T1	5	40	45	19	16.3	3.97
T2	8	41	49	16	15.0	4.00
T3	13	21	34	47	8.6	4.14
T4	34	20	54	32	10.9	4.01
T5	32	40	72	–	25.4	3.94
Pulo II (deep hardpan)						
T1	4	42	46	19	8.1	3.53
T2	7	42	49	13	9.6	3.57
T3	9	20	29	31	8.1	3.65
T4	27	21	48	27	6.6	3.57
T5	27	39	66	–	5.9	3.71
Kapalangan (rainfed)						
T1	7	47	54	28	9.8	3.08
T2	11	53	64	20	12.7	2.93
T3	–	–	–	–	–	–
T4	61	21	82	28	12.4	2.97
T5	63	66	129	–	27.7	3.01

[a] Averaged over three weeding treatments.

water characteristics (Table 3). Soil depth varied. One rainfed site was included to measure the effect of uncontrolled water supply on tillage requirements. The results of the experiments are summarized in Table 4. Grain yield data do not support the hypothesis that mechanization increases rice yields. Mean yields were not significantly different across treatments and showed a minimal variation. Survey data from the same locality indicated that the main reason for using tractors was ease of land preparation; timeliness and quality of work were secondary considerations. Rainfed farmers, however, indicated they used tractors primarily to save time and maximize the area of land planted after the onset of the rainy season.

It was also hypothesized that land preparation may have an indirect effect on yield through more effective weed control, an issue mentioned earlier and which is influenced directly by the higher rates of fertilizer used with MV. Evidence from the field experiments showed that the differences in mean yields for different land preparation measures were statistically significant, but quantitatively small (Table 5). In this study, the weed population was primarily a sedge,

Table 5. Average grain yield (t/ha) from alternative tillage and weeding trials[a] (Orcino and Duff, 1974).

Site	Tillage treatment	Yield (t/ha)			Treatment mean	Site mean
		Hand weeding	Chemical weeding	Control		
Marilo (shallow hardpan)	T_1	3.78	3.77	4.01	3.86 b	
	T_2	4.40	3.58	3.42	3.80 b	
	T_3	3.64	3.78	3.54	3.65 b	
	T_4	4.17	4.16	3.32	3.88 b	
	T_5	3.92	3.69	3.60	3.74 b	3.79 b
	Weeding means	3.98 a	3.80 ab	3.58 b		
Pulo I (medium hardpan)	T_1	4.30	4.07	3.53	3.97 a	
	T_2	4.46	3.86	3.69	4.01 a	
	T_3	4.46	4.19	3.76	4.14 a	
	T_4	4.23	4.04	3.75	4.00 a	
	T_5	4.52	3.52	3.78	3.94 a	4.01 a
	Weeding means	4.39 a	3.94 b	3.70 b		
Pulo II (deep hardpan)	T_1	3.85	3.77	2.97	3.53 b	
	T_2	4.03	3.54	3.13	3.57 b	
	T_3	3.96	3.85	3.14	3.65 b	
	T_4	3.94	3.80	3.16	3.56 b	
	T_5	3.80	3.90	3.43	3.71 b	3.61 b
	Weeding means	3.88 a	3.77 a	3.16 b		
Kapalangan (rainfed)	T_1	3.40	3.16	2.68	3.08 c	
	T_2	3.10	2.94	2.74	2.93 c	
	T_3	–	–	–	–	
	T_4	3.28	2.98	2.66	2.97 c	
	T_5	3.36	2.93	2.66	2.98 c	2.99 c
	Weeding means	3.28 a	3.00 ab	2.68 b		

[a] LSD$_{.05}$ (Weeding means at each S × T) 0.77 t/ha. Weeding means at each location followed by a common letter are not significantly different at the 5% level.

a weed type that affects yields only slightly. Hence, although weed weights were affected by the land preparation techniques, with the advantage given to tractors, yields were not (Table 5).

Table 6 shows yield changes from a sample of 241 Filipino rice farmers using various methods of land preparation between 1968 and 1974 (King, 1974). While the figures show yields for all groups improving over time, there\was\no advantage for those using tractors or power tillers. These studies demonstrate few direct yield advantages from mechanized land preparation compared with traditional methods.

In the areas of crop establishment, crop protection and fertilizer application, no evidence is available to suggest a strong interaction between choice of technique and resulting yields. Weed control has been repeatedly mentioned as an operation that provides high returns when used in conjunction with MV. The method chosen, however, appears to reflect relative costs rather than an inherent technical advantage of one method over another. The same is true of crop establishment. The MV tend to be relatively insensitive to row spacing and

Table 6. Rice yields under various levels of mechanization, 241 farmers, Philippines, 1968–73 (King. 1974).

Mechanization level	Rice yields (t/ha)					
	1968		1973		% change	
	Wet	Dry	Wet	Dry	Wet	Dry
Tractor[a]	1.87	2.17	2.56	3.04	37	40
Tiller[a]	2.0	2.61	2.65	3.04	33	16
Mechanical control[b]	1.78	2.09	3.0	3.08	12	48
Carabao control[a]	2.04	2.21	2.60	3.43	27	55

[a]Farmers who adopted mechanized land preparation after 1968. [b]Farmers in the mechanical control group were using or renting machinery for land preparation in 1968 or before, and were using it at the time of survey. Those in the carabao control group used animal power continuously during the period covered by the study.

seedling density in respect to yield. There is, however, a strong degree of interaction between method of stand establishment and the use of mechanical weed control. Row-sown transplanted rice tends to give higher yields than either broadcast or direct-seeded rice if weed control is a limiting factor (IRRI, 1972).

Agronomists have long recognized the yield effects of delays in planting. Table 7 shows the depression in yield for IR5 as planting is delayed in upland fields where soil moisture tends to be depleted during the later stages of plant growth. A similar, but less dramatic decrease can also be shown for irrigated rice. Delay that results in inefficient use of solar energy during grain formation is the primary reason, a phenomenon that is most striking during the dry season when sunlight is most intense. Thus, timely crop establishment is the basis for obtaining more than one crop; however, other factors following planting delays may also adversely affect yields.

Pest control and fertilizer application have markedly affected yield response in respect to level of application, timing, and placement (Heinrichs et al., 1977). Equipment that can accurately meter and place chemicals under a flooded soil lowers both yield variability and the frequency of application. Reductions in application rates of 50 and 70% for fertilizer and insecticides are possible without sacrifices in yield. As the prices of chemicals continue to rise and irrigation development becomes increasingly expensive, mechanization that increases the application efficiency of cash inputs such as pesticides and fertilizers becomes increasingly important.

For tasks such as water delivery, weed control, crop protection, and fertilizer application, both timing and frequency ensure optimal yields from MV. Untimely water delivery subjects the rice plant to moisture stress and can cause significant yield reductions, particularly if the stress occurs at flowering, when MV are particularly susceptible (De Datta et al., 1973). Mechanized pump irrigation in Pakistan and India has helped to reduce the risks associated with

Table 7. Effect of planting date on yield of IR5 grown in upland field. 1970 wet season.[a]

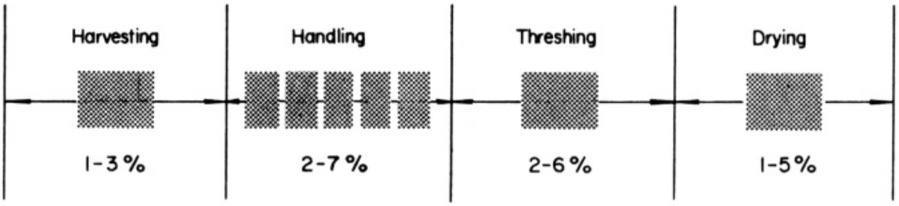
Site[b]	Planting date (week)	Grain yield (t/ha)[c]
IRRI	22	3.2
	24	3.1
	26	2.5
	29	2.1
Maligaya	22	6.1
	24	5.8
	26	5.8
	28	6.1
Pili	23	4.2
	26	3.9
	30	2.5
La Granja	21	1.5
	24	1.0
	27	1.2

[a] From unpublished data, IRRI Agronomy Department. [b] Bureau of Plant Industry rice research station in Maligaya, Nueva Ecija; in Pili, Camarines Sur; and in La Granja, Negros. [c] Nitrogen applied at 60 kg/ha.

water deficiencies. The same innovations were a major factor in raising and stabilizing China's rice output (Timmer, 1975).

Efficient performance of harvesting, threshing, drying, and storage is also important to achieve optimum crop yields. The range of losses that can be expected using traditional technologies from harvest onward is summarized in Figure 3.

Table 8 presents the level of grain loss from use of alternative systems of technology for a series of village-level pilot trials in 1975–76 (Toquero et al., 1977). Introduction of a mechanical thresher or mechanical dryer, or both, significantly reduced losses and improved yields by as much as 9%, primarily through reduction in the number of intermediate handling steps between harvesting and threshing. Laboratory analysis of paddy samples taken from the same trials showed 6% increase in total milled rice and 12% in head rice with



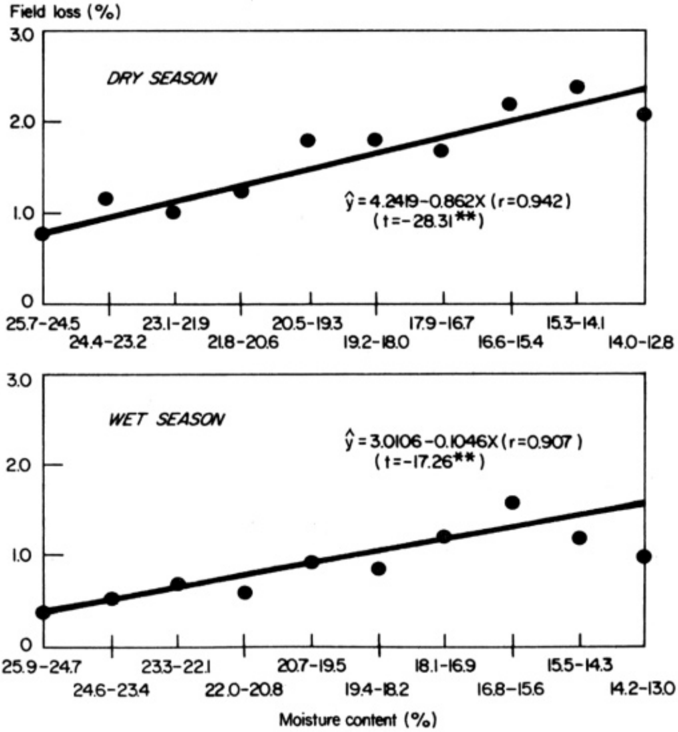
3. Range of loss incurred in harvest and postharvest operations using traditional technologies.

Table 8. Percent grain loss from four alternative postproduction systems, Philippines, 1975–76 (Toquero et al., 1977).

Stage	Grain loss (%) with			
	Manual threshing and solar drying	Manual threshing and mechanical drying	Mechanical threshing and solar drying	Mechanical threshing and drying
Harvesting to threshing	11.0	11.8	1.7	2.5
Threshing to drying	15.3	1.2	11.4	8.2
Harvesting to drying	24.6	12.9	12.9	10.5

the mechanized systems compared with manual harvesting-threshing and solar drying.

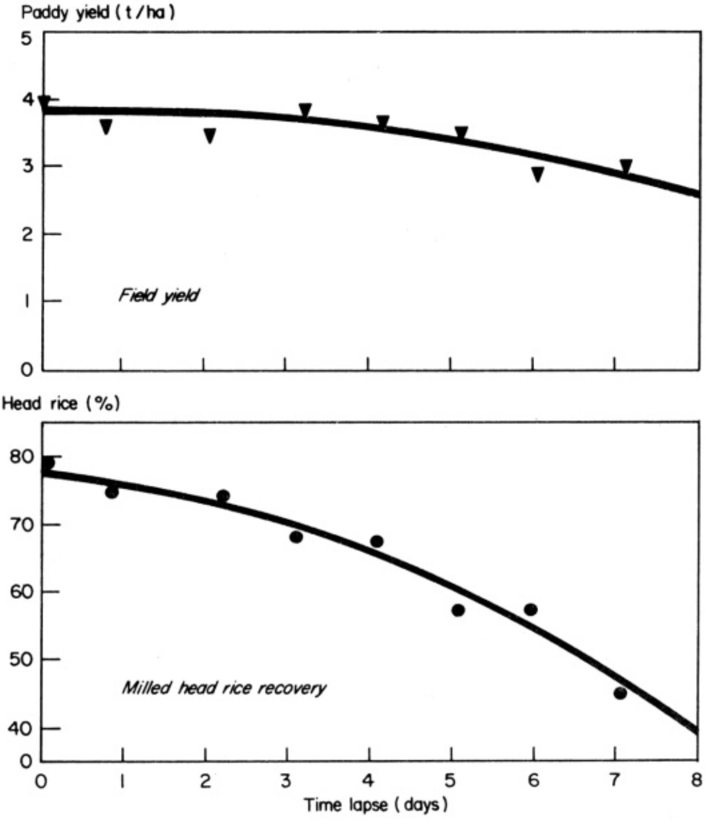
An experiment in the 1972 wet and 1973 dry seasons examined the effect of harvest date in field losses and milled rice recovery on 50 farms in Central Luzon (Samson and Duff, 1973). Figure 4 shows the effect of delayed harvest on the level of grain loss. The figures confirm earlier estimates that delays of



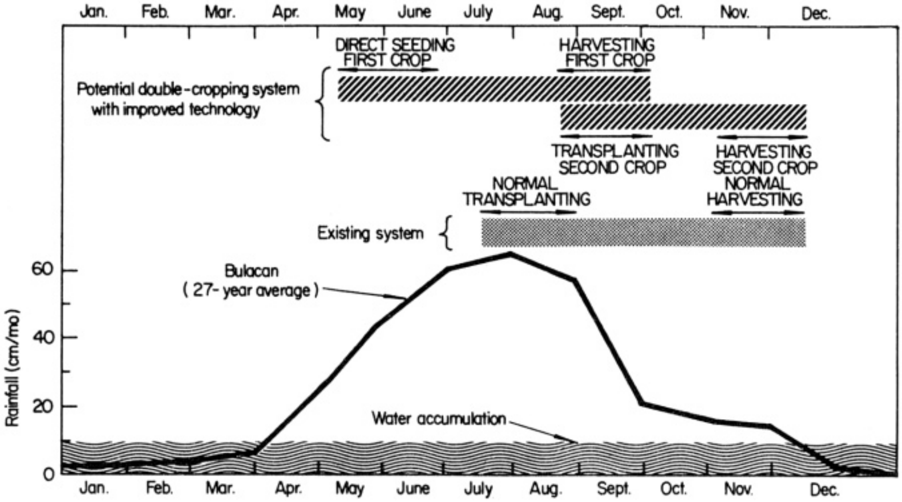
4. The relationship of field grain losses to moisture content at the time of harvest, Gapan, Philippines, 1972 wet and 1973 dry seasons.

even a few days can significantly increase field losses. It is also clear that losses are higher in the dry season than in the wet. Losses of the magnitude shown might be considered small, because they are conservatively measured by the experiments. Also, only the harvesting loss is shown. When yields increase from 1.5 to 3.5 t/ha with use of MV, the small percentage of loss becomes relatively large in terms of quantity and value, In a corollary survey associated with the field-loss assessment, more than 35% of the farmers interviewed were forced to delay harvest beyond the optimal date because of adverse weather or lack of labor.

Mechanization of postproduction operations significantly reduces grain losses, primarily through better timing of the harvest and through a reduction of the period between harvesting and drying. Data from the series of field trials mentioned earlier (Toquero et al., 1977) indicated that the aggregate time for all postproduction operations was reduced from more than 4 to less than 2 days by the introduction of mechanical threshing and drying. The effect of timeliness in the systems is shown in Figure 5. Note also the significant improvement in



5. Qualitative and quantitative effects of timeliness in postharvest operations. Average of 52 sites, Nueva Ecija, Philippines, 1975 wet season.



6. Actual and potential rice production systems under rainfed conditions in Central Luzon, Philippines.

grain quality as reflected in higher head rice recoveries as the time lapse is reduced.

Reductions in qualitative and quantitative losses in postproduction operations seem particularly amenable to engineering solutions. Use of mechanized equipment is, however, sensitive to economic factors. Premiums for high quality paddy provide an added incentive for farmers to exercise care in the operations following harvest. Enactment and enforcement of grading and quality standards for paddy entering commercial markets would have a similar effect.

Cropping intensity effects. Introduction and use of short-season varieties insensitive to day length offer not only the prospect of higher yields but greater crop intensification. Undoubtedly, much of the intensification will take place in irrigated areas. However, combining biological technology with machine techniques for early land preparation, crop establishment, and rapid turnaround at the peak of the rainy season may permit crop intensification in areas with poor water control.

Figure 6 contrasts a traditional, rainfed, cropping system with an improved double-cropped system. In the traditional system, crops are normally planted near the peak of the rainfall distribution and harvested when rainfall is declining. With the improved system, two crops can use the moisture usually used for a single crop. With the new system, land is prepared dry at the end of the rainy season, and moisture conservation practices are used during the dry season. The first crop is direct seeded at the start of the wet season and harvested at the peak of the rainy season. A second crop is immediately transplanted. Subsequent operations for the second crop are similar to those in the traditional cropping system.

Effective use of this cropping system will require changes in cultural practices and the scheduling of operations. Some degree of mechanized land preparation and planting for the first crop may be necessary. Because the first crop is direct seeded; weed control will become a greater problem. Threshing and drying equipment are needed for this crop.

IRRI is presently redirecting resources, including mechanization research, to this environment. Intensification, however, remains closely associated with irrigation development.

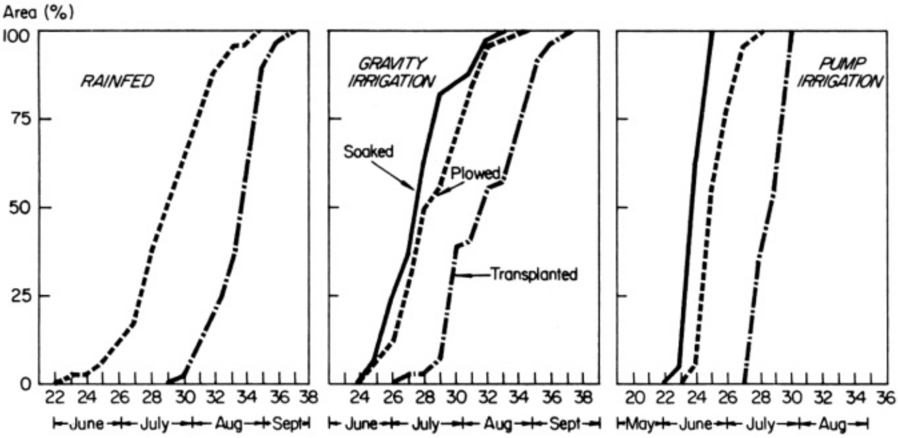
A 1974 study of mechanization in the Philippines attempted to assess changes in land-use intensity resulting from the introduction and use of mechanization for land preparation (King, 1974). Table 9 summarizes the results of the survey. Rice farms were cross classified on the basis of power source and quality of irrigation. All categories showed some increase in land use intensity, but the increase on mechanized farms was slightly more than on farms using water buffalo. The increases in cropping intensity, however, were more a direct result of improved irrigation than use of mechanization. In 1973, the rank order for cropping intensity was exactly the same as that for irrigation quality. The study showed that 84% of the increase in cropping intensity for tractor adopters is explained by changes in irrigation quality. For power-tiller adopters, only 25% of the shift is explained by the irrigation variable, but the greatest changes in intensity were confined to the high quality irrigation category. Power tillers evidently contributed to increased intensity, but only after a well-developed irrigation system was available.

No evidence supports the hypothesis that increased intensity results from mechanized land preparation. When farmers in the study were asked for their opinion regarding the effect of mechanization on land-use intensity, most said that without increased availability and control of irrigation water, they could achieve little increase in cropping intensity.

Table 9. Rice cropping intensity by level of irrigation[a] and type of mechanization. Philippines, 1968–73 (King, 1974).

Power source	Rice cropping intensity (%)							
	1968				1973			
	Low	Medium	High	Overall	Low	Medium	High	Overall
Tractor	88	116	190	129	104	122	181	145
Tiller	108	176	162	149	108	176	177	165
Mechanical control[b]	102	147	171	143	110	147	168	148
Carabao control[b]	103	128	166	130	103	100	170	138

[a] Irrigation quality is defined as low (0–25% irrigated), medium (25–75% irrigated), and high (above 75%).
[b] The mechanical control group consisted of farmers who were using machinery before and during the 1968–73 period of the study. The carabao control group consisted of farmers who employed only animal power.

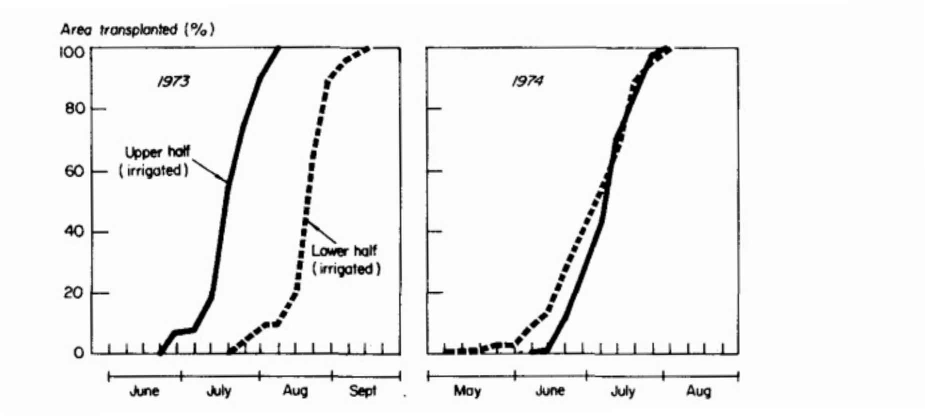


7. Timing and duration of land preparation and transplanting under three alternative water supply regimes. Central Luzon, 1973 wet season (Valera and Wickham, 1974).

In a similar study conducted in Nepal, farms using tractors tended to have higher cropping intensities than those employing traditional techniques of land preparation (Pudasaini, 1976). The study used a sampling design that included observations from all combinations of users and nonusers of tractors and irrigation (in the form of irrigation pumps). Increases in cropping intensity were highest on farms that had both irrigation pumps and tractors, and a significant difference in output was noted between farms with tractors and no pumps and those without tractors.

In a 1973–74 study of irrigation systems in the Philippines, Valera and Wickham (1974) presented information describing the relationships between the timing of water deliveries, land preparation, and transplanting. Data for the analysis were collected from rainfed, gravity irrigation, and pump irrigation sites (Fig. 7). On traditional rainfed sites, land preparation and transplanting generally followed the rainfall distribution pattern. Land preparation is delayed until sufficient moisture accumulates to allow plowing with water buffalo. The total duration of the two operations is considerably longer for the rainfed site than for the irrigated areas. The long interval between plowing and transplanting may partially reflect the practice of allowing weeds to germinate between primary and secondary tillage operations. It may also indicate a lack of power and labor to carry out the two operations. From a related study, it is noted that only farmers with tractors were able to transplant earlier than they used to before adoption of the MV (Bautista and Wickham, 1974).

Both irrigated areas showed a close relationship between the timing of water deliveries and land preparation, although the gravity irrigation site had a longer overall interval for completion of those tasks. One conclusion was that water-use efficiency may be improved by reducing the land preparation-transplanting interval through improved techniques for plowing and transplanting. With the



8. Area transplanted in the upper and lower half of Lateral C, Peñaranda River Irrigation System, Gapan, Philippines, 1973 and 1974 wet seasons. Source: Valera et al., 1975.

gravity irrigation system, it was estimated that a reduction of 3.5 weeks in the land preparation-transplanting phase would save 200 to 600 mm/ha of water from that actually observed.

During the 1974 wet season, water was reallocated within the irrigation system to allow recipients at the lower reaches to obtain water with the same timing and volume as those near the head of the canal. The change in the timing of transplanting was dramatic (Fig. 8). By transplanting earlier in the season, farmers in the lower half of the system not only raised their yields but were able to plant a much larger area to the dry-season crop than in the previous year.

Table 10 contains estimates of the stock of power required to complete land preparation within specified time periods using alternative power sources. With the existing 12-week interval found in the gravity system, use of water buffalo appeared adequate, assuming a buffalo:land ratio of 0.7. To shorten the time period to 6 weeks requires either an increase in the buffalo population or provision of additional power from tillers or tractors. To duplicate the rapid rate of land preparation observed in the pump area (4 weeks) also requires a significant increase in power, generally in excess of 1 hp/ha. The higher cost of water at the pump site apparently made farmers in the area more conscious of the need for improved water-use efficiency, in contrast with farmers in the gravity system where water prices were much lower.

Although I have cited a number of instances in which yields and cropping intensity can be increased by shortening the time interval between crops or by close adherence to recommended scheduling in the time of planting, the actual impact of intensification through reductions in turnaround time is extremely hazy.

It is difficult to find in survey data from the Philippines instances where the interval between crops has been appreciably decreased since the introduction

Table 10. Number of power units required with alternative combination of land preparation techniques to prepare 5,000 hectares of irrigated and rainfed rice land within specified time intervals. [a]

Power source	Power units (no.) [b]					
	irrigated			Rainfed		
	12 wk	8 wk	4 wk	12 wk	8 wk	4 wk
Water buffalo	1170	1945	5800	2000	3333	10000
	(.23)[c]	(.39)	(1.16)	(.4)	(.66)	(2.0)
7-hp power tiller	225	375	1126	416	694	2083
	(.045)	(.075)	(.23)	(.083)	(.14)	(.42)
14-hp rotary tiller [c]						
Rotary tiller (primary)	58	97	292	83	139	417
	(.012)	(.02)	(.06)	(.02)	(.08)	(.08)
Water buffalo (secondary)	666	1111	3333	750	1250	3760
	(.13)	(.22)	(.66)	(.15)	(.25)	(.75)
65-hp 4W tractor						
Tractor (primary)	30	49	147	50	83	250
	(.006)	(.009)	(.03)	(.01)	(.02)	(.05)
Water buffalo (secondary)	666	1111	3333	750	1250	3760
	(.13)	(.22)	(.66)	(.15)	(.25)	(.75)

[a] Includes a 1-week interval between plowing and harrowing, and 1 week between first and second harrowing. [b] Numbers in parentheses refer to the ratio of the number of power units to the total area covered, or the "population density" of the power units. [c] Both the 14-hp rotary tiller and the 65-hp four-wheel tractor perform only primary tillage. The water buffalo is commonly used to harrow and finish the paddy after the initial tillage operation.

of the MV. The reasons are unclear because there does not seem to be serious lack of labor, power, or water to retard intensification.

Hoskins (1973) used statistical analysis to show that small tube well-irrigated farms in Kosi District, India, had the opportunity to move from two to three crops per year using modern wheat and rice varieties. However, the farmers failed to take advantage of the potential because of the tight time schedule allowed for harvesting the first crop and the land preparation and transplanting of the second rice crop.

In the present analysis, it has been difficult to establish a direct link between mechanization and MV with respect to either yield grains or crop intensification. In the future, however, a shortening in the crop growing season to less than 100 days, combined with imaginative agronomic and engineering development, may provide opportunities for further crop intensification, particularly in rainfed areas.

Area effects. The ability to expand the cultivated area is limited by the availability of additional land resources and the complementary inputs necessary to bring the area into production. A careful distinction is necessary between expansion in total cultivated area involving new land (expanding the land frontier) and expansion in farm size by renting land or obtaining it from other producing units. In the latter case, area expansion may be profitable for the individual farmer, but may contribute nothing to increases in aggregate output.

Table 11. Changes in farm size (ha) for 171 farmers in four regions of tho Philippines after introduction of tractors and tillers, 1968-73 (King, 1974).

		Changes in farm size (ha)			
		Iloilo	Laguna	Nueva Ecija	Pangasinan
Tractors —	1973	15.7	14.0	20.3	10.6
	1968	10.7	14.0	18.5	7.5
Tillers —	1973	8.1	3.2	13.4	3.4
	1968	7.7	3.5	12.5	3.4

A study in the Philippines showed that both tractor and power-tiller users increased the size of their holdings by increasing the land they owned (Table 11). A control group associated with the study group showed much less change in operational holding size. Farmers using tractors in rice-growing areas increased their operational holdings by 14.5% and those using power tillers increased theirs by only 4.5%. Most increases in farm size were the result of either renting in existing rice producing areas or the purchase of neighboring farms. This study gives no evidence that any *new* land had been placed under cultivation as a result of mechanization (King, 1974).

Morris (1975) felt that the transmigration areas on the less populated outer islands of Indonesia might provide an opportunity for the successful introduction and use of mechanization to expand the land area cultivated by a single farm family. Under the Indonesian resettlement program, farmers are given farms as large as 5 ha, mostly undeveloped. Using manual and animal power most families are able to crop only about 2 ha effectively. Morris indicated that the introduction and use of suitable small-scale mechanization for land preparation would increase the power available for this task and expand both area and cropping intensity. In projecting the effects of mechanization on output, he also noted that concomitant use of the improved rice varieties would contribute significantly to the income-generating capacity of the farmers and improve their ability to support mechanization.

From the available statistics on the rice area in Asia, it appears there is little hope for major additions to the land area. In most countries, the cultivated area has been a negative factor in contributing or increasing rice output. While the MV have increased the returns to land, the adjustments in land holdings have been primarily the consolidation of holdings, eviction of tenants, or renting of land, rather than new land development.

SUMMARY AND CONCLUSIONS

This paper has surveyed the possible relationships between use of the MV and adoption of agricultutral mechanization. The major findings are as follows:

- There is little evidence to indicate a strong causal relationship between adoption of the MV and use of mechanization, particularly tractors. Adoption of tractors for land preparation appears to be primarily a result of economic factors such as credit availability and distortions in relative factor prices. Complementary mechanical technologies, such as water pumps and mechanical weeders, have increased returns from use of MV.

- In areas where water pumps have become available, both yields and cropping intensity have increased. The direct complementarity between water control and adoption of MV is widely recognized. Also, water tends to be utilized more efficiently in pump-irrigated systems. Pumping units have reduced the risk of drought and improved both the level and stability of yields on farms using the MV.
- For MV grown under flooding, mechanical land preparation does not appear to increase yields as compared with traditional land preparation techniques; however, mechanical preparation provides somewhat better weed control. Mechanization to shorten the time required for land preparation and transplanting, may, however, significantly reduce overall water requirements.
- The MV have significantly increased the returns from proper use of fertilizer and insecticides. Experimental evidence indicates that substantial yield gains or cost reductions, or both, are possible through precision placement of those chemicals. Equipment to permit root-zone placement is needed.
- Higher fertilizer rates used in conjunction with the MV have significantly increased returns from better weed control. In areas of the Philippines where straight-row planting is practical, use of the Japanese rotary-type weeders has increased.
- Reduction in postproduction losses has become economically more significant with the increased yields from the MV. Mechanized threshing, drying, and milling equipment results in marked gains in both yield and grain quality, compared with traditional methods.
- In the rainfed rice crop environment where the greatest potential for future intensification is found, adequate mechanization, together with genetic and agronomic improvements to further reduce the growth duration and improve the adaptability of the rice plant, will boost rice output.
- The effect of mechanization on expansion in both cultivated and cropped rice area appears to be relatively small on an aggregate basis. In many areas, such as Burma and the outer islands of Indonesia where labor and power are constraints, however, labor- and power-augmenting mechanization techniques may be required to increase output.

REFERENCES CITED

Barker, R., and V. G. Cordova. 1978. Labor utilization in rice production. Pages 114–136 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

Barker, R., H. E. Kauffman, and R. W. Herdt. 1975. Production constraints and priorities for research. Paper No. 75–8. Department of Agricultural Economics, International Rice Research Institute, Los Baños, Philippines. 10 p.

Barker, R., W. H. Meyers, C. Crisostomo, and B. Duff. 1974. Employment and technological change in Philippine agriculture. Int. Labour Rev. 106:2–3.

Bautista, F., and T. Wickham. 1974. The tractor and the carabao: a socioeconomic study of choice of power source for land preparation in Nueva Ecija. Paper No. 74–13. The International Rice Research Institute, Los Baños, Philippines. (mimeo.)

De Datta, S. K., W. P. Abilay, and G. N. Kalwar. 1973. Water stress effects in flooded tropical rice. Pages 19–35 *in* International Rice Research Institute. Water management in the Philippine irrigation systems: research & operations. Los Baños, Philippines.

Heinrichs, E. A., G. B Aquino, J. A. McMennamy, J. Arboleda, N. Navasero, and R. Arce. 1977. Increasing insecticide efficiency in lowland rice. Agric. Mech. Asia 8(3):41–47.

Herdt, R. W. and R. Barker. 1977. The status and potential of food production in Asia. International Rice Research Institute, Los Baños, Philippines. 26 p. (mimeo.)

Hoskins, M. D. 1973. The green revolution and cropping intensity. IDS Bull. :43–51.

International Rice Research Institute. 1972. Annual report for 1971. Los Baños, Philippines. 420 p.

International Rice Research Institute. 1975. Changes in rice farming in selected areas of Asia. Los Baños, Philippines. 377 p.

International Rice Research Institute. 1976. Annual report for 1975. Los Baños, Philippines. 479 p.

King, F. 1974. Evaluation of the CB:IBRD agricultural credit program in the Philippines. International Bank for Reconstruction and Development, Operations Evaluation Department, Washington, D.C. (mimeo.)

Morris, R. A. 1975. The potential impact of mechanical land preparation in the Indonesia small-holder rice producing sector. IRRI/IPI, Bagan, Indonesia. (mimeo.)

Orcino, N., and B. Duff. 1974. Experimental results from alternative techniques of land preparation. Department of Agricultural Engineering, International Rice Research Institute, Los Baños, Philippines. (mimeo.)

Pudasaini, S. 1976. Resource productivity, income and employment in traditional and mechanized farming of Bara District, Nepal. Master's thesis July 1976. 175p. Agricultural Economics Department University of the Philippines at Los Baños, Laguna, Philippines. (mimeo).

Samson, B., and B. Duff. 1973. The pattern and magnitude of field grain losses in paddy production. Department of Agricultural Engineering, International Rice Research Institute. 11 p. (mimeo.)

Timmer, C. P. 1975. Food policy in China. Divison of Nutritional Sciences, Cornell University, Ithaca, New York. (mimeo.)

Toquero, Z. 1974. The economics of pump irrigation in lowland rice .production, Cabuyao, Laguna, 1964–69. Pages 232–246 *in* H. Southworth and M. Barnett, ed. Experience in farm mechanization in South East Asia. Agricultural Development Council, New York.

Toquero, Z., C. Maranan, L. Ebron, and B. Duff. 1977. Assessing quantitative and qualitative losses in rice production systems. Agric. Mech. Asia 8(3):31–40.

Valera, A., D. Tabbal, R. Reyes, and R. Barker. 1975. The effect of improved water control in irrigation canals on crop production. Paper No. 75–12. International Rice Research Institute, Los Baños, Philippines. (mimeo.)

Valera, A., and T. Wickham. 1974. Land preparation in lowland rice: its speed in relation to rate of water supply. International Rice Research Institute, Los Baños, Philippines. (mimeo.)

COMMENTS ON MECHANIZATION AND USE OF MODERN RICE VARIETIES

R. A. MORRIS AND AFFENDI ANWAR

IN THIS DISCUSSION, modern rice technology is taken to be the fertilizer-responsive modern rice variety (MV) technology and the issue is whether this MV technology has led to increased mechanization of rice production and processing operations. Our focus is on the Indonesian experience with mechanization of rice production.

Although Duff has given evidence that mechanization of rice production can increase yields, he has not convincingly shown that adoption of mechanical technology is induced by the adoption of MV technology or is a necessary requirement for adoption of MV technology. Such MV-mechanization relationships are either obscure or nonexistent. Three points, which apply elsewhere as well as to Indonesia, are worth making before looking at the Indonesian case:

1. Relationships similar to those found between modern rice technology and nitrogen fertilizer consumption, and between modern rice technology and irrigation expansion [David and Barker (this volume); Wickham and Barker (this volume)] should not be expected for mechanical technology (with the exception of pump irrigation). The underlying basis for the increased use of nitrogen fertilizer and the expansion of irrigation is derived from the physiological requirements of the MV. Nitrogen and water have no simple biological substitutes in crop growth. Mechanization does not fall in a similar category; traditional methods of land preparation, harvesting, and threshing are technically adequate in most cases. Therefore, with the exception of irrigation pumps, little increased demand for mechanization can be expected solely on the basis of increased crop-production potential. Duff does not clearly state this point, although he does state that land preparation by tractor or tiller vs. traditional techniques gives no distinct yield-increasing effect. Apparently similar relationships hold for other rice production operations that could be mechanized; the farmer's traditional methods are at least satisfactory, if not superior in most instances.

2. The timeliness factor is not important in most one-crop or two-crop systems that have been dictated by the first-generation MV (e.g., IR5, and Pelita),

Agronomist, Department of Multiple Cropping, International Rice Research Institute, Los Baños, Philippines; and agricultural economist, Institute Pertanian Bogor, Indonesia.

most of which are only 15 to 25 days shorter in maturity than the varieties they displaced. Only a small portion of most lowland rice areas possesses critical irrigation durations (255 to 280 days) where a premium on timeliness might be obtained for growing 135-day crops. In areas with longer or shorter irrigation periods, traditional methods remain satisfactory and less costly. With second-generation MV of 100- to 110-day maturities, time savings in land preparation, harvesting, threshing, and drying should become more important over a wider area. However, the dispersion of such varieties is too recent and too limited to verify this hypothesis.

3. Relationships between the rate of mechanization adoption and the rate of adoption of MV technology at national and provincial levels will be difficult to show in the incipient adoption stage. They are best examined in small areas where the economic and physical factors conditioning adoption are more homogeneous. Analyses of large heterogeneous areas will not be sufficiently sensitive for detection of changes. This last point will be apparent in the discussion of power-tiller adoption in Indonesia.

THE INDONESIAN SETTING

How does the Indonesian experience compare with the Philippine experience? An overview of the Indonesian situation is appropriate, before we attempt to answer the question.

Indonesian agriculture consists of a combination of small subsistence and nearly-subsistence farms and large export-oriented producing estates. About 50% of Indonesia's million ha of cultivated land is devoted to rice production. The great majority of the rice land consists of small holdings on relatively fertile soil. Seventy percent of the holdings are less than 1 ha each and the majority are on the inner islands of Java and Bali. These islands are under a heavy population pressure because 65% of Indonesia's 130 million population is concentrated on them. Rice production there is labor intensive. Table 2 of Barker and Cordova (this volume) shows the Java rice farming situation compared with that in six other rice-producing regions in Asia. Although crude indicators, those figures show the difference in labor productivities and hint at the opportunities for mechanization in rice culture. Labor productivity is lowest in Java where labor use is most intensive. Off-farm opportunities for productive employment are almost nonexistent; hence, introduction of labor-saving technology would cause unemployment under most inner island conditions. On the other hand, more than 40 million ha remains underutilized outside Java and Bali.

Adoption of the small rice-milling unit on Java. Java provides us an example of adoption of new technology. Timmer (1973) reported that a rapid change in Java's rice processing technique occurred during 1970–72. The adoption of small milling units caused displacement of the traditional hand-pounding method. Table 1 shows the sales of rice processing equipment on Java and Bali by a major supplier in Indonesia. The supplier sold almost 3,000 rubber roll

Table 1. Sales of rice miling equipment on Java and Bali by a major supplier, 1970 to 1972 (Timmer, 1973).

Type	Sales (no. of units)			
	1970	1971	1972	Total
Rice milling unit				
200 kg rice/h	621	107	65	793
400 kg rice/h	450	4	10	464
700 kg rice/h	69	11	11	91
Rubber roll huller				
Paddy input, 1,500 kg/h	1,144	782	692	2,918
Separator brown rice output				
1,000 kg/h	59	61	10	130
Pneumatic polisher				
brown rice input 500 kg/h	182	130	21	333
Rice milling plant				
2,000 kg paddy/h	4	–	–	4
4,000 kg paddy/h	2	–	–	2

hullers (RRH) during the 3-year period. The total number of units installed on Java, — about 6,000 — increased rice milling capacity by 9,000 t rough rice/hour. The capacity from the new RRH alone could absorb 70 to 80% of the entire Java rice crop. With the number of rice milling units already in existence, the combined mechanical milling capacity could absorb the entire Java rice crop.

During 1970–72, small rice-milling units not only rapidly replaced hand pounding of rice on Java, but led to overcapacity and produced severe competition among processors. Some processors neglected capital cost considerations and operated mills to recover only variable costs. Loan repayments for mill purchases became a problem. The situation was perhaps due partly to the distributor's extensive marketing efforts and partly to government assistance in providing attractive credit for *modernizing agriculture.*

Timmer's analysis of the widespread changes in rice processing also showed that costs favored the adoption of small-size over medium-size rice mills and hand-pounding. He further noted the social consequences of the change from traditional hand-pounding to mechanical milling, especially labor displacement.

Was the dispersion of mills a direct response to the spread of modern rice technology? In 1970, mechanical milling capacity on Java could process 20% of the rice crop; by 1973, the capacity had increased to almost 100%. During the same interval, however, the area of harvested MV increased from slightly less than 20% to only 40%. It is obvious that the dispersion of the new MV technology did not directly induce the expansion of small rice-milling units, although the goverment and agribusiness sectors may have anticipated second-generation MV problems.

Land preparation. Undoubtedly power-tiller adoption has been the most controversial modern, mechanized, rice technology development. In Indonesia, tillers were not readily adopted by farmers. Recent visits to three areas included in a 1971 – 72 study (IRRI, 1975) showed that not one of the five Javanese villages had adopted tillers in the intervening period, although farmers in Cidahu (Subang Regency) could, if desired, use a few custom-tiller operators from a neighboring community.

Official attempts to introduce power tillers in several regions have been successful only in two areas where human and animal land-preparation capacity is short. In high population areas, there is little incentive to have power tillers repaired when major parts fail, because former tillage methods can be quickly re-employed. Information presented by Rollinson and Nell (1973) indicate that the number of draft animals has declined in recent years at an average annual rate of about 3%. Most of the land preparation tasks formerly performed by animals are now done manually. During the decline, MV were adopted on 20% of the rice-growing area. Evidently, the MV did not increase the demand for draft capacity.

In contrast with this general national trend, two areas, one in the rather sparsely populated Subang Regency of West Java and the other in the Sidrap Regency of South Sulawesi, have had tiller introduction programs that have met with moderate success. Both regencies are producers of surplus rice. Small 4-wheel tractors and large tillers were the main units introduced in South Sulawesi, and medium-sized 2-wheel units were introduced in Subang Regency.

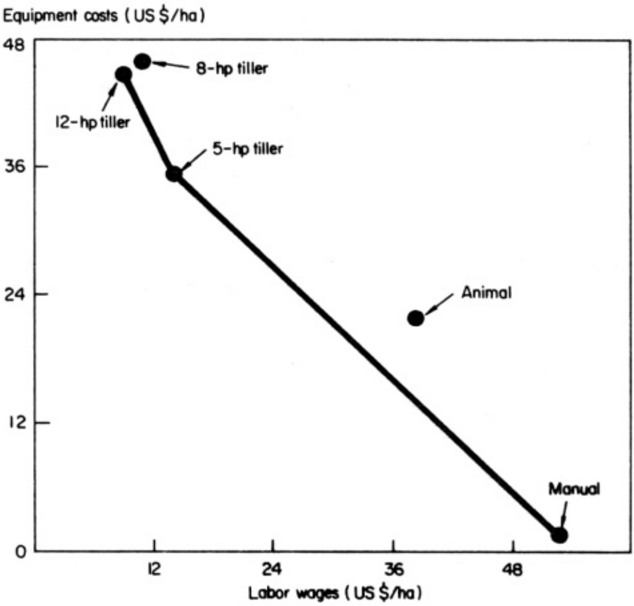
In Subang, the number of tillers increased from 36 units in 1971 to 106 in 1976 (Dinas Pertanian Kabupaten Subang, 1976). However, the land preparation capacity of the present units is not sufficient to meet 5% of the regency's land preparation requirements. In Subang, 60% of the rice area is planted to MV.

At present Sidrap Regency has 142 small tractors and large tillers compared with only 2 units in 1974 (Pemerintah Daerah Sidenrang Rappang, 1976). It is estimated that the equipment is sufficient to prepare less than 15% of the rice crop land of the regency. Although the number of tractors and tillers has substantially increased over the last 2 years, their rate of adoption has lagged far behind the initial rapid dispersion of MV and, in terms of area of application, has not been equal to that occupied by MV.

No doubt the introduction of MV technology has played a role in drawing tractors and tillers into Subang and Sidrap regencies. In fact, government agencies at the regency level, which support the power-unit introduction programs, have stressed an increased cropping frequency and additional area that could be exploited if power units were introduced. Both regencies have also rehabilitated and extended irrigation systems, simultaneously increasing the effective area suitable for rice and reducing drought risk. The improvements in irrigation facilities are, no doubt, in response to the higher yield benefits obtained from MV where water control is good.

To determine the possible effects of power-tiller adoption by Indonesian rice farmers, Morris (1975) used estimates of land-preparation capacities and costs, crop inputs, and crop yields to calculate potential changes in labor wages (LW) and returns above variable costs (RVC) as large tillage units displaced small units. The estimated costs were broken into labor wage and equipment components (Fig. 1) for equipment use at 75% capacity. From the farmer's cost perspective, it appears that land preparation by 5-hp tillers would be most efficient. However, the limits of these estimates must be recognized; it may be stated that land preparation requirements can be met with different mixes of labor and equipment for roughly the same cost. The ultimate choice of technique depends on many factors.

The same crop production and cost estimates were used to examine the cases of crop intensification and extensification. Changes in LW and RVC were general indicators of adoption effects. Crop intensification should be possible if larger or more tillage units are adopted, assuming land tillage capacity is a constraint. For irrigated or high rainfall areas (2,400 mm annual average)



1. Equipment cost and labor wage combinations for preparing 1 ha of land at 75% capacity.

replacing animals with power tillers would increase RVC by about $80/ha per year and decrease LW by $22/ha per year. Where power tillers replace manual hoeing, RVC would increase by about $52/ha per year, but LW would decrease by $120/ha per year.

In moderate rainfall areas (1,875 mm annual average), RVC would be negative for many years because of frequent low yields or failures of crops following rice. However, introducing power tillers to produce two short-duration rice crops in place of a single medium-duration rice crop would increase RVC and LW by $62/ha per year respectively. Where animal power is replaced by power tillers, the corresponding increases would be $69 and $78/ha per year. To make adoption feasible, the net increase in field duration of the two crops over the single crop should not exceed 45–50 days. The bulk of the time-saving would arise from varieties of shorter maturity, but some time-saving must arise from more rapid land preparation before seeding.

Opposite production intensification lies production extensification, i.e. increasing production by utilizing more land. The increase in RVC for power-tiller use over that obtained from the land area that could be operated with one animal was estimated to be $910/year for a 5-hp tiller, $1,280/year for an 8-hp tiller, and $1,810/year for a 12-hp tiller. For the respective cases, LW would increase by $400, $640, and $880/man per year.

To estimate the provincial-level effects of power-tiller introduction in West Java and in South Sulawesi, estimates of wage and man-day losses per hectare and per tiller adopted (ignoring intensification and extensification effects) were based on provincial population and area statistics. Relevant statistics are presented in Table 2. West Java is heavily populated, has more land currently in production than is potentially suitable for mechanization, and has more than sufficient man and animal power to prepare the land. It is estimated that 64% of the land in West Java is prepared manually. South Sulawesi, on the other hand,

Table 2. Estimated population densities, current and potential food crop production areas, and land preparation capabilities of West Java and South Sulawesi, Indonesia.

Factor	West Java	South Sulawesi
Population density (people/km^2)	400	63
Current food crop area (ha)	1,700,000	710,000
Potential food crop area suitable for mechanization (ha)	977,000	999,000
Men in the food crop sector (no.)	2,304,000	599,000
Draft animals (no.)	3 95,000	390,000
Land preparation capacity (man-equivalents)	2,996,000	1,282,000
Area prepared manually (%)	64	16

is lightly populated and has more land suitable for mechanization than is currently used for production, although estimated land-preparation capacity greatly exceeds the requirements of the current production area. Estimates are that 16% of the land in South Sulawesi is prepared manually. With these figures, it is estimated that man-day and wage losses from adoption in West Java would be about double those in South Sulawesi (Table 2). Note that these estimates assume neither an intensification nor an extensification effect. It appears, however, that South Sulawesi would respond more positively to power-tiller and tractor introduction programs. Moreover, it shows a greater potential for cropping intensification than West Java does.

Comparisons of the Sidrap and Subang man:land ratios with those for other provinces are helpful in understanding differences in adoption. The regency of Sidrap has only 4.3 persons/ha of cropped land, whereas the province of South Sulawesi has 7.3 persons/ha. The corresponding man:land ratio for the regency of Subang and the province of West Java are 7.3 and 12.8, respectively. The ratios partially explain the differences in adoption of power units for land preparation, both between each regency and its parent province and between the two regencies. Both regencies recently had increases in the areas planted to rice each year, reflecting local improvements in irrigation and the opportunity of growing two 135-day-duration rice crops on much of the land. Under the circumstances, power units have been used for a small amount of land preparation.

It should be emphasized, however, that the labor-short Subang and Sidrap cases are exceptional and almost infinitesimal when Indonesia is viewed as a whole. The comparison between the regencies and the provinces also points out the shortcomings of examining extensive areas for general relationships. Analysis of data obtained from small, homogeneous areas may expose some changes that are overwhelmed by data from more extensive, heterogeneous areas.

In discussing the potential benefits of mechanization, Duff recognized the importance of MV and associated production-increasing technology. He has singled out timeliness as an important factor, which is, however, *conditioned by physical environment and by the characteristics of the varieties themselves.* The importance of timely field operations to realize the full potential of the management-responsive MV has been well documented. Whether timeliness is appreciably yield-increasing, production-increasing, or quality-improving under a farmer's management; whether farmers actually use the timeliness afforded by mechanization; and whether the same degree of timeliness can be achieved with existing labor and a combination of traditional and mechanized techniques, are controversial subjects that require further investigations at the farm level. The low level of machinery adoption leads one to conclude that the Indonesian rice farmer has in only rare cases found any form of mechanical technology necessary or even simply profitable in relation to MV adoption. Nevertheless, this situation may change as the spread of varieties with shorter maturities opens new opportunities for double-cropping, especially in selected areas of the outer islands where mechanical technologies would be labor augmenting.

REFERENCES CITED

BARKER, R., and V. CORDOVA. 1978. Labor utilization in rice production. Pages 114–136 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

DAVID, C. C., and R. BARKER. 1978. Modern rice varieties and fertilizer consumption. Pages 175–211 *in* International Rice Research Institute. Economic consequences of new rice technology Los Baños, Philippines.

DINAS PERTANIAN KABUPATEN SUBANG. 1976. Pengembangan traktor kecil di Kabupaten Daerah Tinkat II Subang. (mimeo.)

INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI). 1975. Changes in rice farming in selected areas of Asia. Los Baños, Philippines. 377 p.

MORRIS, R. A. 1975. The potential impact of mechanical land preparation in the Indonesian small-holder rice producing sector. IRRI/IPI Bogor, Indonesia. (mimeo.)

PEMERINTAH DAERAH SIDENRANG RAPPANG. 1976. Mekanisasi Pertanian Terbatas. (mimeo.)

ROLLINSON, D.H.L., and A.J. NELL. 1973. The present and future situation of working cattle and buffalo in Indonesia. Working paper UNDP/FAO Project INS/72/009, Jakarta, Indonesia. (mimeo.)

TIMMER, P. C. 1973. Choice of technique in rice milling on Java. Bull. Indones. Econ. Stud. 9(2):57–76.

WICKHAM, T. H., R. BARKER, and M. W. ROSEGRANT. 1978. Complementarities among irrigation, fertilizer, and modern rice varieties. Pages 221–232 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

FERTILIZER AND WATER

Modern rice varieties and fertilizer consumption

C.C. DAVID AND R. BARKER

A PRINCIPAL DISTINCTION between modern and traditional rice varieties that is emphasized by rice scientists is the greater yield response of the modern varieties (MV) to fertilizer. This is a particularly important attribute in view of the land constraint that increasingly impedes agricultural growth in many less developed countries. The supply of fertilizer is more elastic than that of land. A greater use of yield-increasing inputs, such as fertilizer, to raise the productivity of the existing land base, can meet the increasing demand for food.

Growth in aggregate fertilizer consumption among Asian countries has been fairly rapid since the introduction of MV, but fertilizer input per hectare has remained low. Empirical studies have invariably shown that rice farmers who adopt MV apply fertilizer at a much lower rate than that predicted by economic theory, given the prevailing market prices and the experimental response.

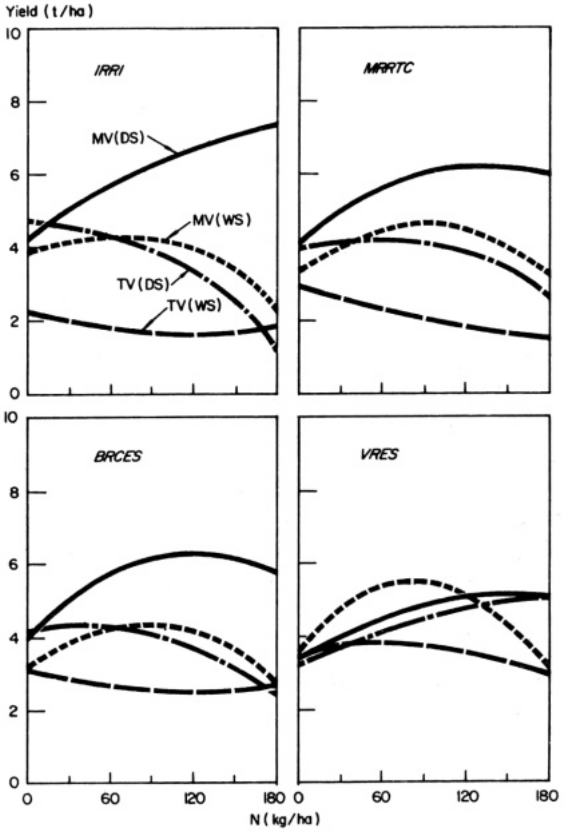
In this paper, we analyze the effects of MV on fertilizer consumption in the Asian rice economy. Experimental and on-farm fertilizer-response functions of MV and TV are compared, and their theoretical implications for fertilizer demand are analyzed. Then, we estimate fertilizer-demand functions directly using both aggregate and farm-level data. A great number of variables may explain differences in fertilizer demand across farm, location, and time. They include fertilizer:product price ratios, MV, and other factors affecting the fertilizer-response function. In the fertilizer-demand specification, we take account of as many of those factors as possible in order to derive an accurate measure of the relative contribution of MV to increase in fertilizer demand.

Assistant professor and chairman, Department of Economics, Institute of Agricultural Development and Administration. University of the Philippines at Los Baños, Philippines; and agricultural economist, Department of Agricultural Economics, International Rice Research Institute, Los Baños, Philippines.

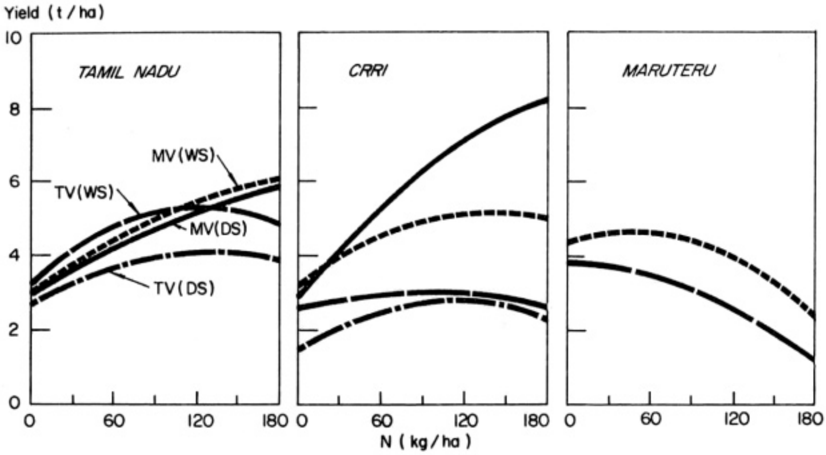
PRODUCTION FUNCTIONS

Data in this section are based on fertilizer-response experiments in experiment stations, field experiments, and yield observations in farmers' fields. The experiment station data are far more available than the field data; however, the environment on the experiment station is frequently superior to that of the farmers' in terms of soil and water conditions and control of pests. Experiments, even those in farmers' fields, normally use high levels of inputs other than fertilizer. Thus, one must interpret with great caution the data obtained from those sources. On the other hand, the high degree of interfarm variability makes it even more difficult to estimate a production function based on farm-survey data that will provide a reliable measure of fertilizer response.

In this section, we compare the response of MV and TV to nitrogen, using



1. Average yield response to nitrogen of modern varieties (MV) IR8 (dry season) and IR20 (wet season), and traditional variety (TV) Peta at 4 experiment stations in the Philippines, 1968–75.



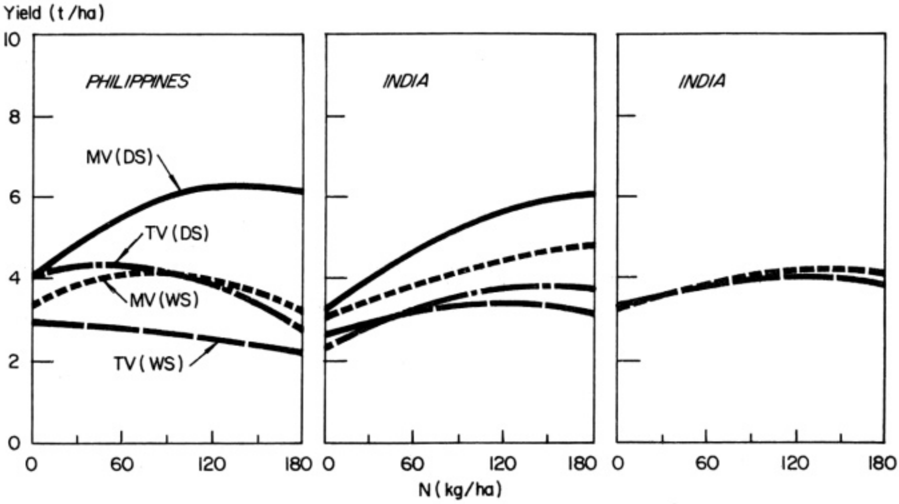
2. Average yield response to nitrogen of modern variety (MV) IR8 and of traditional varieties (TV) at Tamil Nadu and CRRI, India, 1967–69 dry (DS) and wet (WS) seasons; and of MV Pankaj and TV Mahsuri at Maruteru, India, 1971–75 wet season.

experimental data from several locations in India and the Philippines. Then we synthesize a series of farm-level production functions for Philippine conditions based on a number of studies that provide farm-level data. Using this information, we estimate the likely shift that has occurred in the fertilizer-demand function as a result of the introduction of MV.

Experiment station response. Agronomists throughout Asia have generated a substantial body of evidence on the productivity of fertilizer on rice. The International Rice Research Institute (IRRI) has compiled the results of nitrogen-response experiments in selected areas in Asia. We compare the performance of the MV and TV only for the Philippines and India because of lack of information on nitrogen response for TV in other areas.

Figures 1, 2, and 3 show the average response functions of MV and TV based on experiments conducted for several years at several sites. In Figures 1 and 2, the response functions are several years' averages from experiments conducted annually at a given location. In Figure 3, data are pooled across locations. The coefficients of the various functions, implied maximum yield (Y_m), nitrogen at maximum yield (N_m), and average efficiency of fertilizer (Y/N) are in Table 1 (the Philippines) and 2 (India). (The individual annual response functions of varieties at each location are in Appendix A and B, together with the procedures used in calculating the average functions.)

The greater yield response to fertilizer of MV compared with that of TV grown in the same season clearly emerges from the figures. Yield response to fertilizer for the TV Peta declined in most of the Philippine functions. Peta is one of the less fertilizer-responsive TV, but as one of the parents of IR8 — the first MV released by IRRI — it has a number of favorable features. Together



3. Average yield response to nitrogen of modern variety (MV) IR8 and traditional variety (TV) Peta at several locations in the Philippines, 1968–75; of MV IR8 and TV in India, 1967–69, and of MV Pankaj and TV Mahsuri in India, 1971 wet season. DS = dry season; WS = wet season.

with IR8, it has been included for several years in fertilizer-response trials at IRRI, and three other Philippine experiment stations.

Yield maximums for MV ranged from about 4.5 t/ha to 6:5 t/ha, and were generally higher in the dry than in the wet season. The maximum level is 1 to 2 t/ha more than the maximum for TV except in Maruteru in eastern India during the wet season. The fertilizer input required to obtain maximum yield of MV is about 80 kg N/ha in the Philippines in the wet season, but about twice as high in India. In the dry season, maximum yield is also achieved in India at a much higher nitrogen level, reflecting the difference in soil conditions between the countries. Fertilizer efficiency (*Y/N*) is higher in the Philippines than in India, particularly in the wet season.

The Central Rice Research Institute and the Maruteru Agricultural Research Station in eastern India are located in the delta regions of Orissa and Andhra Pradesh. MV in those regions are not generally accepted during the wet season, even though they are widely adopted on the same farms during the dry season. They do not seem to perform well because of poor drainage on most farms in the regions. The results in Table 2 and Figure 2 show that even with the more favorable experiment station environment, the advantage of MV over TV appears to be slight. Based on data from 1967 to 1969, the maximum wet-season yield of IR8 at CRRI is only slightly above that of the TV. Pankaj (a sister line of IR5), one of the more popular MV in the CRRI area, performed somewhat better than Mahsuri in the 1971–75 experiments (Fig. 2), but for eight locations in 1971, the fertilizer response of the two varieties was almost identical (Fig. 3).

Mahsuri has become popular in Andhra Pradesh and other parts of India, in Bangladesh, Burma, and Malaysia (where it was originally developed and

Table 1. Average fertilizer-response functions with their implied maximum yield (Y_m), nitrogen level at maximum yield (N_m). and averege efficiency of fertilizer (Y/N) for modern (wet season IR20 and dry season IR8) and traditional (Peta) varieties et selected experiment stations in the Philippines, 1988–75.[a]

	Coefficients of response function					
Site, variety	a	b_1	b_2	Y_m (kg/ha)	N_m (kg/ha)	Y/N
WET SEASON[b]						
IRRI, Laguna						
Modern	3797	19.68	–0.149	4447	€6	10
Traditional	2235	–7.45	0.028	2235	0	–
MRRTC, Nueva Ecija						
Modern	3442	29.75	–0.164	4791	91	15
Traditional	2950	–7.12	–0.001	2950	0	–
BRCES						
Modern	3141	28.13	–0.163	4355	86	14
Traditional	3089	–6.87	0.023	3089	0	–
VRES						
Modern	3567	47.68	–0.274	5641	87	24
Traditional	3691	4.03	–0.041	3790	49	2
Philippines						
Modern	3487	31.31	–0.188	4791	a3	17
Traditional	2991	–4.35	0.002	2991	0	–
DRY SEASON[c]						
IRRI, Laguna						
Modern	4203	30.38	–0.068	7596	223	15
Traditional	4780	1.17	–0.111	4783	5	1
MRRTC, Nueva Ecija						
Modern	4238	30.00	–0.105	6381	143	15
Traditional	3974	12.33	–0.104	4339	59	6
BRCES						
Modern	4081	37.28	–0.148	6429	126	19
Traditional	4129	9.44	–0.105	4341	45	5
VRES						
Modern	3517	22.67	–0.075	5230	151	11
Traditional	3300	76.90	0.039			
Philippines						
Modern	4010	30.08	–0.099	6295	152	15
Traditional	4046	9.95	–0.090	4321	55	5

[a] The fertilizer response function is based on the quadratic equation:

$$Y = a + b_1N + b_2N^2$$

where Y denotes kg rice/ha and N denotes kg nitrogen/ha. From the estimated coefficients of this function, we can calculate the following:

$$N_m = -\frac{b_1}{2b_2}$$

$$Y_m = a - \frac{b_1}{4b_2}$$

$$\frac{Y}{M} = \frac{Y_m - a}{N_m}$$

The experiment stations arb the International Rice Research Institute (IRRI), Maligaya Rice Research Training Center (MRRTC), Bicol Rice and Corn Experiment Station (BRCES), and Visayas Rice Experiment Station (VRES). [b]Covers the period 1968–75 for all stations except for IRRI (IR20) 1969–75 and BRCES (traditional] 1968–69, 1971–75. [c]Covers the period 1968–75 for all stations except for VRES (IR8) 1970–75 and VRES (traditional) 1971–75.

Table 2. Average fertilizer response functions with their implied maximum yield (Y_m), nitrogen level at maximum yield (N_m), and average efficiency of fertilizer (Y/N) for modern (IR8 or Pankaj) and traditional (CO32, ADT27, or Mahsuri) varieties at selected experiment stations in India, 1967–75.[a]

Site, variety, year	Coefficients of response function			Y_m (kg/ha)	N_m (kg/ha)	Y/N
	a	b_1	b_2			
WET SEASON						
TNPBS, Tamil Nadu (1967–69)						
Modern (IR8)	3070	24.86	–0.048	6289	259	12
Traditional (CO32)	3235	31.50	–0.125	5232	126	16
CRRI, Orissa (1967-69)						
Modern (IR8)	3314	24.73	–0.082	3389	151	1
Traditional (Local)	2509	11.47	–0.058	3076	99	6
MARS, Andhra Pradesh						
Modern (Pankai 1971, 1974–75)	4407	12.16	–0.127	4698	48	6
Traditional (Mahsuri 1971-75)	3853	-0.336	–0.084	3853	0	–
India (19 locations 1967-69)						
Modern (IR8)	2985	17.46	–0.045	4679	194	9
Traditional (Mixed)	2592	15.08	–0.065	3467	116	8
India (8 locations 1971)						
Modern (Pankaj)	3445	7.41	–0.017	4252	218	4
Traditional (Mahsuri)	3265	11.24	–0.043	4000	131	6
DRY SEASON						
TNPBS, Tamil Nadu (1967–69)						
Modern (IR8)	3086	21.11	–0.035	6269	302	11
Traditional (ADT27)	2751	17.87	–0.059	4104	151	9
CRRI, Orissa						
Modern (IR8, 1967–69)	3058	42.69	–0.078	8899	274	21
Traditional (Local 1968-69)	1551	21.74	–0.090	2864	121	11
India (19 locations 1967–68)						
Modern (IR8)	3242	28.30	–0.071	6062	199	14
Traditional (Mixed)	2315	19.33	–0.061	3846	158	10

[a] The experiments stations are Tamil Nadu Plant Breeding Station, Coimbatore (TNPBS), Central Rice Research Institute at Cuttack, Orissa (CRRI), and Maruteru Agricultural Research Station, Andhra Pradesh (MARS). The functions are based on results of 1968 experiments of All India Coordinated Rice Improvement Project, av. of several locations. (See *Progress Report of the All India Coordinated Rice Improvement Project,* Vol. 1 and 2,1968, Indian Council of Agricultural Research, New Delhi, India.)

released in 1965), because farmers say it performs well with low levels of nitrogen. Mahsuri has good seedling vigor and tillers well even with extremely poor drainage. It is a fine-grained rice and is popular for its good taste.

Mahsuri's excellent yield performance with low levels of nitrogen raised the question of how MV compare in general with TV in that respect. The question received particular attention as a result of the recent fertilizer shortage and of reports from some areas that farmers who could not obtain fertilizer, or were unwilling to pay the high price, were switching back to TV.

The values of the intercepts in the experimental data suggest the conclusion that MV do as well as or somewhat better than TV at zero nitrogen. Although that may be true for some conditions, it should be remembered that all other inputs are held at high levels at experiment stations. With the farmers' level of inputs and cultural practices, the performance of MV may differ considerably.

The MV have generally shown the greatest response to fertilizer in the dry season. Yields in the dry season exceed those in the wet season throughout the entire range of the functions depicted in Figures 1, 2, and 3. The higher yield is the result of higher solar radiation levels and the generally lower damage due to weather, and to disease and insect attacks in the dry season. On farms, however, the contrast between dry- and wet-season response may not necessarily be as great, primarily because the dry-season irrigation is often inadequate.

To indicate the year-to-year variability in fertilizer response with *controlled* experimental conditions, the annual response functions for MV are shown for experiments conducted at the Maligaya Rice Research and Training Center (MRRTC) in Central Luzon, Philippines. The functions are for IR20 in the wet season and IR8 in the dry season for the period 1968–75 (Fig. 4). One would expect the variability in response in farmers' fields to be even greater.

Farm-level response. To understand the impact of the introduction of MV on fertilizer consumption, we need to know the yield response at farmers' conditions. No study in the Philippines has systematically attempted to derive farm-level response functions. There are a few studies, however, from which one can synthesize the basic nitrogen-response functions for MV and TV under rainfed and irrigated conditions.

We start with two equations for irrigated conditions, the first for MV, the latter for TV.

Modern varieties:

$$Y = 2100 + 18N - 0.09N^2 \tag{1}$$

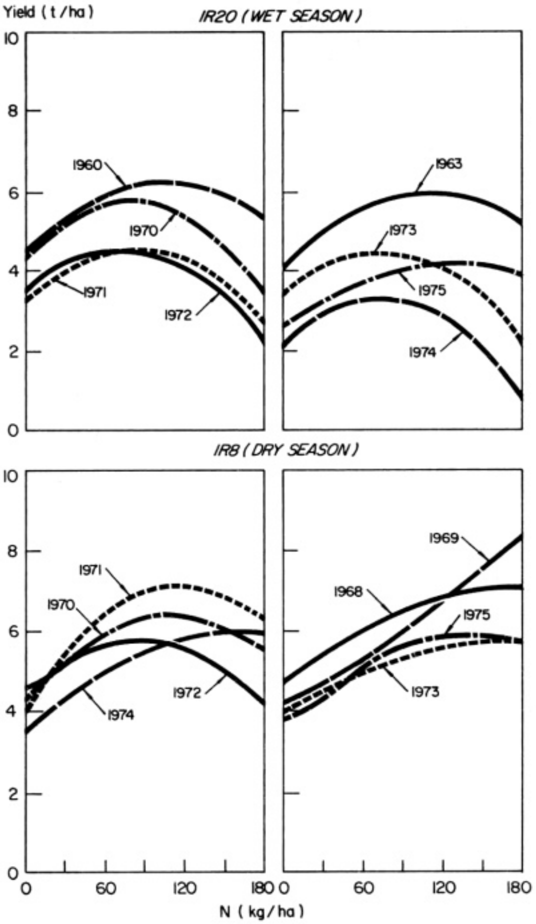
Traditional varieties:

$$Y = 2100 + 11N - 0.13N^2 \tag{2}$$

where Y denotes yields of rough rice in kilograms per hectare and N is nitrogen in kilograms per hectare.

The first equation is based on Atkinson and Kunkel's (1974) data from a subsample of 320 farms from the annual nationwide farm survey conducted by the Bureau of Agricultural Economics in the first semester, 1969-70. The second equation is based on Pisithpun's (1974) estimates of an average response function from 200 fertilizer experiments with TV, conducted at IRRI between 1962 and 1972. The intercept for the TV response function was assumed to be equal to the intercept of Atkinson and Kunkel's functions, i.e., MV and TV were assumed to have the same yield at zero nitrogen level.

We next determined the nature of the response for MV and TV as rainfed rice. With rainfed conditions, the rice plant encounters more stress due to lack of water. From experiments conducted by Mandac (1974) with irrigated and rainfed rice, the following function was derived to reflect the interaction between yield (Y), nitrogen (N), and water stress (S). Water stress is measured by the number of days the field is without standing water during the ripening



4. Annual yield response to nitrogen of modern varieties IR20 (wet season) and IR8 (dry season), Maligaya Rice Research and Training Center, Philippines, 1968–75.

period (60–30 days before harvest) when lack of water has its greatest effect on yield.

$$Y = 1946 + 14N - 0.036N^2 - 64S - 0.229NS - 0.0000847N^2S^2 \qquad (3)$$

Equation (3) represents a *collapsed* version of a function containing 17 variables (see Appendix C). Values for other variables were substituted at their mean values to single out the effect of water stress on nitrogen response. Assuming on the average that rainfed fields experience 10 days of stress, we calculated the coefficients for the quadratic function $Y = a + b_1N + b_2N^2$ and compared them with those for zero stress as follows:

Stress days	*a*	b_1	b_2
1. 0	1946	14	–0.036
2. 10	1311	12	–0.045
Line 2 as a percent of line 1:			
	67	85	125

Using the percentage values shown in the last line, we adjusted the coefficients of equations 1 and 2 to derive response functions for rainfed conditions.

The following four equations (graphed in Fig. 5) reflect our best judgment regarding the difference in fertilizer response between MV and TV for irrigated and rainfed conditions on Philippine farms.

Modern varieties in irrigated fields:

$$Y = 2100 + 18N - 0.09N^2 \tag{4}$$

Modern varieties in rainfed fields:

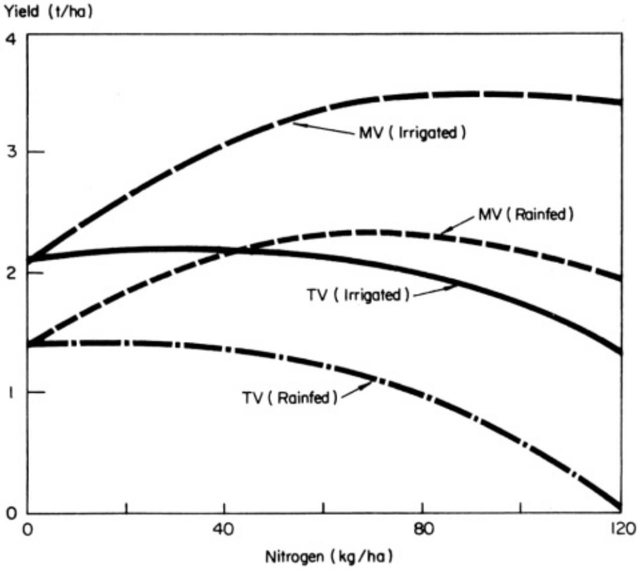
$$Y = 1400 + 15N - 0.11N^2 \tag{5}$$

Traditional varieties in irrigated fields:

$$Y = 2100 + 11N - 0.13N^2 \tag{6}$$

Traditional varieties in rainfed fields:

$$Y = 1400 + 9N - 0.16N^2 \tag{7}$$



5. Yield response of rice to nitrogen, by variety and type of irrigation, synthesized farm-level functions for the Philippines. MV = modern varieties; TV = traditional varieties.

Table 3. Optimum level of nitrogen at selected fertilizer:rice price ratios (4.5:1,9:1) using farm-level functions for traditional and modern varieties, Philippines.[a]

Rice-growing condition	4.5:1 Optimum N level (kg/ha)	4.5:1 Yield (kg/ha)	4.5:1 Kg rice/ kg N	9:1 Optimum N level (kg/ha)	9:1 Yield (kg/ha)	9:1 Kg rice/ kg N
			Modern variety			
Irrigated	75	2944	11	50	2775	14
Rainfed	48	1867	10	27	1725	12
			Traditional variety			
Irrigated	25	2294	a	8	2180	10
Rainfed	14	1495	7	0	1400	—

[a] Based on the following response functions:

Irrigated modern $Y = 2100 + 18N - 0.09N^2$
Rainfed modern $Y = 1400 + 15N - 0.11N^2$
Irrigated traditional $Y = 2100 + 11N - 0.13N^2$
Rainfed traditional $Y = 1400 + 9N - 0.16N^2$

Note that a separate wet- or dry-season function is not specified. With well-irrigated conditions, the response to nitrogen in the dry season is much greater, but the fact that national average yields are not significantly greater in the dry than in the wet season suggests that the dry-season crop experiences considerable stress due to lack of water. On the average, therefore, the response of MV in the dry season with farmers' conditions is assumed to be about the same as that in the wet season.

Using these synthesized farm-level response functions, we estimated the implied shift in the demand for fertilizer as a result of the introduciton of MV. The optimum level of nitrogen input per hectare was calculated for two nitrogen-to-rice price ratios, 4.5:1 and 9:1 (Table 3). The lower ratio is a fairly close approximation of the prevailing price ratio, which has normally been around 4 or 5 to 1, excluding any allowance for cost of credit that may be involved in the purchase of fertilizer. The higher ratio represents the upper limit that farmers experienced during the peak of the oil crisis in 1973.

Shifting to MV is expected to triple fertilizer consumption if the farmers apply fertilizer at economically optimum levels. At the high fertilizer rates, each additional kilogram of nitrogen returns about 3 kilograms more rice to MV than to TV. However, farmers may hesitate to apply that much more fertilizer because they want to avoid risks (note the variable response shown in Fig. 5), because they cannot obtain the fertilizer credit, or because they lack knowledge regarding the potential gain in profits.

To obtain an estimate of the change in fertilizer consumption per hectare for lowland rice in the Philippines, it is necessary to consider the percentage of the land area in TV and MV with rainfed and irrigated conditions. This is shown for each of the two assumed price ratios in Table 4. The land-use weights applied after MV are based first on the proportion of the area in rainfed and irrigated rice before the introduction of MV (1962–64) in order to net out the effect of

Table 4. Weighted average optimum fertilizer input end yield from fertilizer at 4.5:1 and 9:1 nitrogen:rice price ratios, using synthesized functions for traditional (TV) and modern varieties (MV), Philippines.[a]

Nitrogen: rice price ratio	Before MV		After MV			
			Irrigation unchanged		Irrigation increased	
	Kg N/ha	Kg rice/ha	Kg N/ha	Kg rice/ha	Kg N/ha	Kg rice/ha
4.5:1	17	126	40	401	44	441
9:1	2.5	25	21	272	21	308

[a] Weighting based on the following proportion of rainfed and irrigated areas

Before MV = irrigation at 1962–64 level : 69% rainfed,
31% irrigated

After MV = irrigation level unchanged : 37% rainfed-traditional,
32% rainfed-modern, 7% irrigated-traditional,
24% irrigated-modern.

After MV = irrigation increased to existing level 1972–74:
31% rainfed-traditional, 28% rainfed-modern,
10% irrigated, traditional, 31% irrigated-modern.

increased irrigation. Then the weighted average is determined based on the proportion of the TV and MV on rainfed and irrigated fields after the introduction of MV (1972–74).

The implied magnitude of change is not greatly different regardless of the price ratio assumed. Even from the limited information, it seems reasonable to assume that the introduction of MV increased nitrogen input in a range of 20 to 25 kg/ha. The current level of nitrogen applied on a national average is probably close to the 24 kg N/ha obtained at the 9:l price ratio. In time, of course, farmers would move toward the optimum implied by the 4.5:1 ratio as knowledge of fertilizer increases, as the fertilizer and credit distribution system is improved, and as better management of the irrigation system reduces risk.

Based on the function at the 9:1 price ratio,. average yields would have increased by 21.5% (from 1642 to 1995 kg/ha) as a result of both the use of more fertilizer and the expansion of irrigation, which would have followed the introduction of MV. The contribution of fertilizer and irrigation to the yield gain can be partitioned as follows:

Due to added fertilizer with existing irrigation	15.0%
Due to added fertilizer with new irrigation	2.2%
Due to new irrigation	4.3%
Total yield gain	21.5%

This estimated yield gain, computed from the synthesized functions, is comparable with the trends in the official statistics reported by the Philippine Bureau of Agricultural Economics (BAEcon). National average rice yields increased from 1,300 to 1,600 kg/ha, or 23% from 1965–66 to 1974–75. The level of yield, however, is considerably lower than our estimate partly because of the inclusion of upland rice in the national estimates.

The synthesized farm-level production functions appear to give a fairly realistic impression of the shift that occurred in the demand for fertilizer over the past decade. Our analysis thus far indicates that with existing technology and present irrigation facilities, the level of nitrogen application could economically be increased up to about 45 kg/ha.

DEMAND FUNCTIONS

The *indirect* approach to analysis of the effect of MV on fertilizer use in the first section of this paper suffers from at least two limitations, The first stems from the required assumption that farmers maximize profits with no consideration of risk, that they do not lack knowledge of fertilizer technology, and that no other factors may prevent them from using optimum levels of fertilizer. There is a substantial amount of evidence in the United States and from the relatively fewer studies undertaken for less developed countries to show that farmer's marginal revenue from additional fertilizer use substantially exceeds their marginal cost (Timmer, 1974). This disequilibrium indicates the importance of factors such as risks associated with yield and price variability, level of knowledge, and possibly other constraints, which have been largely ignored in this approach.

The second problem lies in the difficulty in choosing the appropriate fertilizer-response function. A high degree of arbitrariness is undoubtedly involved in this task because of the wide diversity of response functions reported from experiments and more so from farm-level studies of selected locations in the same country and from a single site at different points in time.

An alternative approach in analyzing the effects of MV is to estimate fertilizer-demand function directly where a measure of diffusion of MV is explicitly specified in the model. [1] Actual differences in fertilizer demand across time, farms, villages, or countries are, of course, influenced by factors other than MV: the price of fertilizer relative to price of rice, the use of other inputs complementary to fertilizer, or the existence of supervised credit schemes that reduce the effective price of fertilizer to farmers. Changes in some of those factors, however, may have been related indirectly to government efforts in promoting the adoption of MV.

We have attempted to measure the effects of fertilizer:rice price ratio, MV, other factors responsible for shifts in fertilizer response functions and farmers' liquidity position on fertilizer demand in the Asian rice economy by using one aggregate and two farm-level sets of data. The aggregate-level data consist of time-series observations of rice production, crop area, fertilizer input, proportion of area planted to MV, and fertilizer and rice prices from 1950 to 1972 for

---

[1] This part of the paper is based on the study of fertilizer demand by Cristina C. David (1975).

12 Asian rice-growing countries. The major sources of the aggregate data are the *Production Yearbook* and the *Annual Review of Fertilizer* of the U.N. Food and Agriculture Organization. Two sets of farm-survey information available at IRRI provided a unique opportunity to investigate the role of various factors influencing farmers' demand for fertilizer. An Asian farm survey during the crop year 1971–1972 covered about 2,000 rice farmers in 36 villages located in the Philippines, Indonesia, Thailand, Malaysia, India, and Pakistan. A Laguna (Philippines) survey of about 150 farmers from 1966 to 1971 generated cross-section and time-series farm data. Because these surveys were originally conducted for different purposes, the scope of our analysis and the empirical model have been somewhat limited by data availability.

Empirical models. An important set of factors affecting fertilizer demand in our data relates to the shifts or differences in fertilizer-response functions over time or across locations or both. The shifts may be due to differential adoption of MV or to differences in the environmental factors—climate, soil fertility, and irrigation. Two demand models distinguished by the way differences in fertilizer-response functions among countries (Asian cross-country, time-series aggregate data), villages (Asian cross-country, cross-village farm survey), and years (cross farm, time-series Laguna farm survey) have been estimated. Because the estimating equations and definitions of the variable differed for each set of data, only the basic outline will be discussed here; details of the models are presented in Appendix J.

The first demand model (Model I) specifies the estimated parameters of the response function explicitly in the equation. The equation expressed in double-log form is:

$$\begin{aligned}\log f = {} & \log a + b_1 \log P + b_2 M + b_3 \log I \\ & + b_4 \log E + b_5 \log V + u\end{aligned} \tag{8}$$

where f is fertilizer input/ha,
P is relative price of fertilizer to rice,
M is proportion of area planted to MV,
V is value of output (proxy variable for farmers' ability to finance fertilizer), and u is a disturbance term.

The variables I and E are the estimated parameters of the underlying production function estimated by covariance analysis.[2] I is the value of the intercept of the response function and E is the production elasticity of fertilizer.

---

[2] A Cobb-Douglas production function is specified as:

$$\begin{aligned}\log Q = {} & \log a + b_1 \log H + b_2 \log F + b_3 M \\ & + \sum_{i=2}^{m} c_i D_i + \sum_{i=2}^{m} d_i (D_i \log F) + u\end{aligned}$$

where Q denotes rice production, H crop areas, F fertilizer, D_i and ($D_i \log F$) intercept and slope dummy variables to distinguish intercountry, intervillage, or interyear differences in the productivity of fertilizer.

This demand specification, equation (8), suffers from an errors-in-variables problem. Because both the production function and demand function have been fitted to the same set of data, the estimated intercept terms and production elasticities of fertilizer are stochastic variables, possibly not independent of the disturbance term in the demand equation.

A second fertilizer demand model (Model II), formulated to overcome the statistical problem of the first model, has been specified in two ways depending on available data.

In the aggregate data and Laguna survey analyses, variations in fertilizer-response functions are assumed to be reflected in the differences in the intercept levels and price elasticity of the fertilizer demand function. Instead of log *I* and *E* as independent variables as in equation (8), we apply covariance analysis again by including intercept and slope (pertaining to the variable *P*) dummy variables by country in the aggregate analysis, and by year in the Laguna data. The estimating equation may be expressed as:

$$\log f = \log a + b_1 \log P + b_2 M + b_3 \log V + \sum_{2}^{m} c_i D_i + \sum_{2}^{m} d_i (D_i \log P) + u \qquad (9)$$

where D_i and D_i log P are dummy variables to distinguish the intercountry or interyear differences in the level and price elasticity of fertilizer demand. The other variables are defined in equation (8).

This procedure cannot be applied to the Asian farm survey; the price data are already village-specific, and specifying dummy variables to distinguish differences in price elasticity by village will lead to a singular model. In the second demand specification for the Asian village survey, therefore, four explanatory variables are substituted for the estimates of fertilizer-response parameters. Expressed in double-log form we have:

$$\log f = \log a + b_1 \log P + b_2 M + b_3 \log N + b_4 \log W + b_5 R + b_6 \log V + u \qquad (10)$$

where *N* is nitrogen required to obtain maximum yield based on experimental response functions from experimental stations located near the study village,

R is the average proportion of rainfall for the 2 months prior to harvest (1967–71), and

W is the index of quality of irrigation (from 1 to 5, where 1 means well-irrigated and 5 means poorly irrigated or rainfed).

Statistical results. Both the aggregate and farm-level regressions of the fertilizer demand equation based on Model I (Table 5) consistently showed that

Table 5. Fertilizer demand functions based on Model I estimated from the Asian aggregate data (DI), Asian farm survey (DII), and Laguna survey (DIII).[a]

	log *a*	Fertilizer: rice price	Response coefficients[b]				
			Intercept	Production elasticity	Modern varieties	Value of output	R^2
ASIAN AGGREGATE DATA							
DI-1	2.003	–0.870 (–3.490)	–	–	–	–	0.064
DI-2	1.339	–0.482 (–2.754)	0.428 (1.517)	5.874 (5.163)	–	–	0.564
DI-3	0.577	–0.274 (–2.010)	–0.217 (–0.967)	1.890 (1.991)	0.949 (11.014)	–	0.742
ASIAN FARM SURVEY							
DII-1	2.035	–0.863 (–7.874)	–	–	–	–	0.170
DII-2	1.562	–0.691 (–6.245)	0.584 (7.368)	2.326 (8.739)	–	–	0.252
DII-3	1.520	–0.650 (–5.528)	0.580 (7.307)	2.336 (8.768)	0.038 (0.037)		0.253
DII-4	1.302	–0.598 (–5.057)	0.540 (6.728)	2.294 (8.620)	0.373 (1.014)	0.091 (3.224)	0.262
LAGUNA SURVEY							
DIII-1	2.005	–0.800 (–14.586)	–	–	–	–	0.217
DIII-2	-3.731	–0.560 (–9.972)	1.680 (10.878)	2.951 (9.777)	–	–	0.326
DIII-3	-3.747	–0.558 (–9.787)	1.676 (10.778)	2.940 (9.638)	–	0.009 (0.252)	0.326
DII-4	0.343	–0.709 (–12.828)	0.436 (2.325)	0.223 (0.576)	0.287 (10.448)	0.003 (0.098)	0.410

[a] Figures in parentheses are *t*-values. [b] The estimated values of the production functions are presented in Appendix D-I.

prices, MV, and the variables representing shifts in the fertilizer-response function are highly significant factors explaining variations in the rate of fertilizer application in the Asian rice economy. These results strongly support the hypothesis that rice farmers' demand for fertilizer responds to changes in the relative price of fertilizer to rice. Variables representing shifts in response functions (*I, E, M*) improved the goodness of fit of most equations dramatically, and the generally higher *t*-values of these variables indicate their greater precision of fit relative to price parameters in the regressions.

Note that the spread of MV appears to explain most of the shift in the fertilizer-response function in the aggregate data and the Laguna survey. The highly significant coefficient of proportion of area used for MV dominates the explanatory power of the fertilizer-response coefficients (log *I* and *E*). In the Asian farm survey, intervillage differences in log *I* and *E* seem to capture the effects of MV because little within-village variation in the adoption of MV exists in the data.

Although the coefficient of value of output is statistically significant in the Asian farm survey, its inclusion in the demand equation did not contribute much to the R^2, and did not give statistically significant coefficients in the Laguna analysis. This result suggests either that financing of fertilizer purchase is not a constraint to farmers' effective demand or that value of output is not an appropriate proxy variable for the farmers' liquidity position, at least in the Laguna data.

The price elasticity derived from the simple relation between fertilizer use per hectare and fertilizer:rice price ratio, which is remarkably stable (–0.8 to –0.9) across the three sets of data, reflects the long-run response to a price change. This result should not be interpreted as the response of farmers to a unit change in price in any particular country, village, or year, because the estimation was based on farmers' behavior in situations of varying fertilizer productivity. As expected, the estimated short-run price elasticity of demand (–0.3

Table 6. Fertilizer demand function based on Model II and estimated from aggregate Asian data, 1950–72. [a]

	log *a*	Fertilizer: rice price	Modern varieties
Japan	1.660 [0.312]	–0.723 [–0.191]	1.191 (3.927)
South Korea	1.389 (0.157]	–0.931 [–0.345]	
Taiwan	1.727 [0.397]	–0.968 [–0.382]	
Sri Lanka	2.332 [1.230]	–0.818 [–0.262]	
Indonesia	1.198 [–0.402]	–0.186 [0.243]	
Thailand	–0.277 [–2.563]	1.192 [1.412]	
Philippines	1.482	–0.492 [–0.416]	
Burma	–0.200 [–2.394]	0.563 [0.875]	
India	2.045 [0.704]	–1.671 [–0.845]	
Pakistan-Bangladesh	0.217 [–1.781]	2.309 [2.078] R^2 = 0.928	

[a] The figures in parentheses refer to *t*-values of the variables above but those in brackets refer to *t*-values of the dummy variables and thus provide a test of significance of the difference between the value of the coefficient for country *i* with the coefficient of the "base" country, in this case the Philippines.

to–0.7), which takes into account shifts in fertilizer-response functions, is lower than the long-run estimates, particularly when a variable for MV is added in the equation.

Results for the second model of demand — based on the aggregate data, the Asian farm survey, and the Laguna survey — are reported in Tables 6,7 and 8, respectively. These are characterized by a better fit to the data than is shown in the demand model where the estimated parameters of the response function (log *I* and *E*) are specified. This implies that log *I* and *E* may not have been accurately estimated because data limitations may have led to measurement and specification errors. The parameters of the fertilizer-response function

Table 7. Fertilizer demand function based on Model II and estimated from farm data of 33 selected villages in Asia (DII). 1971–72 wet season.[a]

	log *a*	Fertilizer: rice price ratio	Modern varieties	Maximum nitrogen	Rainfall	Irrigation	Value of output	R^2
DII-1	2.035	–0.863 (–7.874)	–	–	–	–	–	– 0.170
DII-2	3.113	–0.381 (–3.444)	0.472 (12.196)	1.986 (10.475)	3.481 (22.635)	–0.803 (–8.240)	– –	0.505
DII-3	2.870	–0.225 (–1.933)	0.457 (11.868)	1.687 (8.737)	3.444 (22.570)	–0.942 (–9.481)	0.153 (5.957)	0.517

[a] Figures in parentheses are *t*-values.

Table 8. Year-specific estimates of the parameters of the fertilizer-demand function based on Model II and estimated from data of the Laguna survey (DIII), 1966–71.

	log a	Fertilizer: rice price ratio	Value of output	Modern varieties
1966	1.713	–0.908 (–7.535)	0.023[b] (0.743)	0.218[b] (7.134)
1967	1.592 [–1.218]	–0.312 [3.564]		
1968	1.934 [1.840]	–0.837 [0.335]		
1969	1.776 [0.636]	–0.642 [0.374]		
1970	1.044 [1.190]	–0.816 [0.475]		
1971	1.681 [–0.319]	–0.605 [1.512]		

$R^2 = 0.463$

---

[a] Figures in parentheses refer to *t*-values of the variables above; those in brackets refer to *f*-values of the dummy variables, which provide a test of significance of the difference in value between the coefficients for year and the coefficient of the base year, 1966. [b] Assuming that the coefficients for value of output and modern varieties do not vary by year.

theoretically should have been the best descriptive measure of the productivity of fertilizer.

Covariance analysis requires relatively more observations to obtain meaningful estimates of short-run price elasticity since this procedure is equivalent to estimating a separate equation for each group characterized by the same response function. The shorter available time-series data are the primary reason for the insignificant and positive estimates of price elasticities in four of the countries (Indonesia, Thailand, Burma, and Pakistan-Bangladesh) shown in Table 6. The values of the estimated price elasticities for the other countries are all negative and are generally consistent with the results obtained in Model I. Among the countries with negative price elasticities, there appears to be sensitivity to price changes where fertilizer is relatively more important in the budget — Japan, Taiwan, and South Korea — in contrast with countries where fertilizer application is much lower — the Philippines or Indonesia.

The estimated intercepts for the Laguna data (Table 8) show a rightward shift in the short-run demand function through time. Given the same relative price of fertilizer to rice, fertilizer demand is greater in 1971 than in 1966. When both the level of the intercept and the price elasticity are allowed to vary, the fertilizer-demand function appears to shift rightward through the years while the price elasticity of demand for fertilizer declines from –0.9 to –0.6.

When, as in the Asian farm survey, explanatory variables such as quality of irrigation and MV are used to represent differences in the productivity of fertilizer, the policy implications are more directly derived from the analysis. Except for the positive sign for rainfall, the direction of relationship among the variables shown in Table 7 met our expectations. Maximum nitrogen, quality of irrigation, proportion of area grown to MV, and the measure of farmers' liquidity position (value of output) are all positively related to fertilizer demand. An inverse relationship between rainfall and fertilizer demand is expected because high rainfall prior to harvest implies low solar enery and, thus, low productivity of fertilizer. A slightly more inelastic short-run fertilizer demand (–0.2 vs.–0.3) is implied in Model II than in Model I.

Sources of fertilizer demand. Table 9 contains estimates of the relative contributions of each of the explanatory factors to the gap in fertilizer consumption between the *average* and *heaviest* fertilizer users. The differences in the rate of fertilizer applied per hectare are substantial — more than 200% in each case. Some significant differences in the estimated contribution of each factor are found between the two alternative demand functions and across the three data sets. The results generally indicate, however, that differences in the fertilizer-response functions — as represented by the estimated parameters of the response function, dummy variables, or the four explanatory variables including MV — provide the major explanation for the wide gap in fertilizer application. The intercept and production elasticity showed negative contributions in a number of cases. More important, however, is the sum of the contributions, since the inverse relationship between the trends in the values of the intercept

Table 9. Percentage of contribution of the various factors explaining differences in level of fertilizer use between two groups of fertilizer users in each set of data.

Variable	Means[a]		Contribution (%) to change in fertilizer input	
	First group	Second group	Model I[b]	Model II[c]
Asian aggregate data				
Fertilizer: rice price ratio	3.2	0.8	13	40
Intercept[d]	–0.7 (1.5)	–1.8 (1.7)	18	16
Elasticity[d]	0.1 (-0.5)	0.3 (–0.7)	32	–10
Modern varieties	0.5	1	37	54
Asian farm data				
Fertilizer: rice price ratio	3.2	3.0	36	4
Intercept	0.2	0.6	300	–
Elasticity	0.1	0.1	–260	–
Modern varieties	0.1	0.78	9	25
Maximum N (kg N/ha)	126	180	–	77
Quality of irrigation	2.7	2.0	–	47
Rainfall	0.23	0.17	–	–68
Value of output ($/farm)	485	1208	15	15
Fertilizer per hectare (kg NPK/ha)	63	130		
Laguna farm data				
Fertilizer: rice price ratio	4.7	2.2	34	34
Intercept[a]	3.1 (1.7)	3.0 (1.6)	–7	–5
Elasticity[d]	0.1 (–0.9)	0.2 (–0.6)	5	34
Modern varieties	0	0.9	69	35
Value of output (₱/farm)	2517	4563	0	2
Fertilizer per hectare (kg N/ha)	17	63		

[a] In the Asian aggregate data, the first group refers to the values of the variables for the Philippines, which represents the country with an intermediate level of fertilizer application per hectare. The second group refers to Japan, the country with the highest fertilizer consumption. In the Asian farm data, the first group refers to the average values of the variables and the second group to the top four villages in terms of fertilizer use. In the Laguna farm data, the first group refers to the average values of the variables in 1966 and the second group to the values in 1971. [b] Based on the estimated coefficients of the demand specification where differences in fertilizer-response functions were represented by the estimated fertilizer-response coefficients, the intercept (log /) and production elasticity (*E*). [c] The calculations for the Asian a aggregate data and the Laguna survey data were based on the estimated coefficients of the demand specification where differences in the fertilizer-response functions are represented by shifts in the intercept and the slope (price elasticity) of the demand function. For the Asian aggregate data, the calculations were based on the demand specifications where four explanatory variables represent differences in the fertilizer-response functions. [d] Figures in parentheses are the values of the intercept and coefficient of fertilizer:rice price ratio in Model II, Those outside the parentheses refer to the values of intercept and production elasticities in the production function estimated in Model I.

and elasticity estimates is simply a statistical phenomenon that does not have an economic interpretation.

The spread of MV appears to be the dominant factor responsible for the shifting of the fertilizer-response functions based on aggregate data and on the Laguna farm survey. MV also include the effects of omitted variables in the demand function correlated with the adoption of MV such as irrigation, which may be particularly important for the aggregate data. In the Asian farm survey, intervillage differences in the fertilizer- response parameters in the first model, and maximum nitrogen (relating to the quality of environment) and quality of irrigation in the second model, contribute more to the difference in fertilizer consumption than MV do, partly because the data show little within and between-village variation in the adoption of MV.

Differences in the fertilizer:rice price ratio explain about one-third of the variations in fertilizer consumption in most of the calculations. The estimates based on Model I for the aggregate data (13%) and Model II for the Asian farm data (4%) are much lower than the others. It is interesting to note the high contribution (60%) of the differences in the productivity of fertilizer to the differences in fertilizer consumption between the Philippines and Japan, despite the wide range in the relative fertilizer:rice price ratio (3.2 vs. 0.8) between the two countries. Filipino farmers apply much less fertilizer, not only because of unfavorable prices but also because of the smaller yield response of rice to fertilizer, given the type of varieties and quality of environmental conditions in the Philippines in contrast with those in Japan.

SUMMARY

The effects of the new rice technology on fertilizer consumption in the Asian rice economy were examined first by comparing experimental and on-farm fertilizer-response functions of modern (MV) and traditional varieties (TV), and secondly by directly estimating fertilizer-demand functions where MV are explicitly included as an explanatory variable.

The experimental data in the Philippines indicate the greater yield response of MV to fertilizer even at zero nitrogen. Indian experimental data show only a slight advantage of MV over TV, particularly during the wet season. In general, yield response to fertilizer is substantially higher in the dry season than in the wet season because of greater solar energy and lower damage due to weather and insect infestation. But these favorable dry-season conditions may not be able to offset the problems arising from inadequate irrigation at the farm level.

The synthesis of farm-level fertilizer-response functions for the Philippines gave a fairly realistic measure of the shift that has occurred in the demand for fertilizer during the past decade. The introduction of MV increased nitrogen input by 20 to 25 kg/ha, and led to about 75% contribution to the yield gain between 1965–66 and 1974–75.

The importance of MV in explaining the differences in fertilizer consumption over time as well as across locations is clear from the directly estimated fertilizer-demand functions based on aggregate and farm-level data. Among the explanatory factors of the demand function, MV accounted for a third or more of the variation in fertilizer use between the *average* and *heaviest* fertilizer users.

REFERENCES CITED

ATKINSON, L. J., and D. E. KUNKEL. 1974. HYV in the Philippines: progress of the seed-fertilizer revolution. Bureau of Agricultural Economics, Quezon City. (mimeo.)

DAVID, C. C. 1975. A model of fertilizer demand of the Asian rice economy (a macro-micro analysis). Ph. D. dissertation, Stanford University, California.

MANDAC, A.M. 1974. An economic analysis of factors affecting yield of rice in 1973–74 Central Luzon farmers' field experiments. Paper presented at a Saturday seminar, December 7, 1974. International Rice Research Institute, Los Baños, Philippines, 34 p. (mimeo)

PISITHPUN, S. 1974. Fertilizer response of rice under varying environmental and management practices. M.S. thesis, University of the Philippines at Los Baños, Philippines.

TIMMER, C. P. 1974. The demand for fertilizer in developing countries. Food Res. Inst. Stud. Stanford Univ. 13(3):197–224.

APPENDICES

APPENDIX A. **Fertilizer response functions with their implied maximum yield (Y_m) and nitrogen level at maximum yield (N_m) by variety and year at seven experiment stations and other locations in Asia, 1968–75 wet season.[a]**

	Coefficient				
Country, variety, year	a	b_1	b_2	Y_m (kg/ha)	N_m (kg/ha)
PHILIPPINES					
International Rice Research Institute, Laguna					
IR8					
1968	3981	31.18	–0.117	6058	133
1969	4878	12.52	–0.034	6031	184
1970	4094	6.09	–0.057	4367	90
1971	3584	1.79	–0.067	3584	0
1972	3245	25.41	–0.125	4536	102
1973	1784	6.61	–0.002	9030	1652
1974	2998	10.26	–0.043	3610	119
1975	2921	38.43	–0.213	4654	90
Av. 1968–75	3436	16.54	–0.068	4472	125
IR20					
1969	5097	13.23	–0.234	5284	28
1970	4542	30.41	–0.172	5886	88
1971	3701	6.58	–0.054	3901	61
1972	4087	29.15	–0.142	5583	103
1973	2879	22.05	–0.159	3643	69
1974	3345	9.69	–0.128	3528	38
1975	2928	26.43	–0.151	4084	88
Av. 1969–75	3797	19.68	–0.149	4447	66
Peta					
1968	2948	–12.37	0.068	2385	91
1969	3039	–11.29	–0.010	3039	0
1970	1919	0.064	–0.039	1919	1
1971	1316	0.056	0.037	1316	1
1972	2905	–11.63	0.026	1604	224
1973	1471	8.11	0.049	1135	83
1974	1681	0.97	–0.057	1681	0
1975	2601	–7.69	–0.032	2601	0
Av. 1968–75	2235	–7.45	0.028	2235	0
Maligaya Rice Research and Training Center, Central Luzon					
IR8					
1968	3543	23.40	–0.067	5586	175
1969	5056	15.04	–0.550	5159	14
1970	4361	21.40	–0.178	5004	60
1971	2348	16.78	–0.114	2965	74
1972	3424	–0.15	–0.043	3424	0
1973	3357	26.00	–0.175	4323	74
1974	2421	10.86	–0.084	2772	65
1975	2889	16.07	–0.039	3252	206
Av. 1968–75	3425	16.17	–0.156	3844	52

(continued on opposite page)

APPENDIX A continued

Country, variety year	Coefficient			Y_m (kg/ha)	N_m (kg/ha)
	a	b_1	b_2		
IR20					
1968	4036	33.07	–0.137	6032	121
1969	4458	30.49	–0.138	6146	111
1970	4316	36.52	–0.227	5785	80
1971	3196	30.91	–0.182	4508	85
1972	3424	26.55	–0.177	4420	75
1973	3357	26.90	–0.167	4440	81
1974	2125	32.18	–0.209	3364	77
1975	2628	21.34	–0.072	4209	148
Av. 1968–75	3442	29.75	–0.164	4791	91
Peta					
1968	4010	15.48	–0.072	4842	108
1969	4091	–19.93	0.073	2731	136
1970	2951	–18.54	0.038	690	244
1971	3029	–10.84	–0.031	3029	0
1972	3141	–5.36	0.001	3141	0
1973	1843	–14.86	0.079	1144	94
1974	1650	–5.74	0.020	1238	144
1975	2887	–2.81	–0.024	2887	0
Av. 1968–75	2950	–7.12	–0.001	2950	0
	Bicol Rice and Corn Experiment Station, Bicol				
IR8					
1968	3973	28.32	–0.076	6611	186
1969	4640	40.16	–0.240	6320	84
1970	2706	12.55	–0.130	3009	48
IR8					
1971	3114	15.06	–0.107	3645	70
1972	4319	30.78	–0.186	5592	83
1973	IR8 not planted				
1974	2501	23.15	–0.118	3636	98
1975	2656	32.25	–0.187	4046	86
Av. 1968–75	3416	26.04	–0.149	4554	87
IR20					
1968	4373	26.09	–0.124	5745	105
1969	3811	36.66	–0.215	5374	87
1970	1919	12.68	–0.102	2313	62
1971	2894	31.08	–0.174	4282	89
1972	3554	47.44	–0.260	5718	91
1973	3489	18.54	–0.137	4116	88
1974	2290	31.85	–0.206	3521	77
1975	2800	20.71	–0.067	4032	119
Av. 1968–75	3141	28.13	–0.163	4355	86
Peta					
1968	3843	9.67	–0.103	4070	47
1969	3318	3.54	–0.002	4884	885
1971	3232	17.13	0.093	4021	92
1972	4100	–13.37	0.039	5246	171
1973	2871	–10.67	0.032	3760	167
1974	1932	–4.54	0.031	2098	73
1975	2328	–15.57	0.071	3182	110
Av. 1968–69, 71–75	3089	–6.87	0.023	3089	0

(continued on next page)

APPENDIX **A continued**

Country, variety year	Coefficient			Y_m (kg/ha)	N_m (kg/ha)
	a	b_1	b_2		
	Visayas Rice Experiment Station, Visayas				
IR8					
1968	2950	34.58	–0.076	6883	228
1969	4032	17.99	–0.108	4781	83
1970	2192	–0.86	0.019	2182	23
1971	3908	8.37	–0.081	4124	52
1972	3079	32.65	–0.161	4734	101
1973	3468	–1.92	0.050	3450	19
1974	2968	23.18	–0.085	4548	136
1975	3478	40.87	–0.228	5310	90
Av. 1968–75	3259	19.38	–0.084	4377	115
IR20					
1968	3170	25.75	–0.025	3833	52
1969	4989	55.18	–0.285	7655	97
1970	3103	72.00	–0.492	5737	73
1971	4039	31.01	–0.180	5374	86
1972	3563	30.66	–0.127	5413	121
1973	3543	43.10	–0.167	6324	129
1974	2848	53.59	–0.297	5265	90
1975	3278	51.45	–0.306	5441	84
Av. 1968–75	3567	47.68	–0.274	5641	87
Peta					
1968	2598	19.53	0.023	2598	0
1969	4439	–14.36	0.033	2877	218
1970	3433	–12.16	0.016	1123	380
1971	4756	–8.07	–0.011	4756	0
1972	3634	21.83	–0.113	4688	96
1973	4564	3.07	–0.036	5218	43
1974	2881	6.59	–0.085	3009	39
1975	3225	15.80	–0.157	3622	50
Av. 1968–75	2691	4.03	–0.041	3790	49
INDIA					
	Maruteru Agricultural Research Station, Andhra Pradesh				
Pankaj					
1971	4467	5.26	–0.026	4733	101
1974	4456	12.00	–0.184	4652	33
1975	4299	9.25	–0.004	9647	1156
Av. 1971, 1974–75	4407	12.16	–0.127	4698	48
Mahsuri					
1971	4832	–1.71	–0.046	4832	0
1972	4121	–8.34	–0.061	4121	0
1973	3348	1.89	–0.015	3408	63
1974	3378	–20.13	0.046	1176	219
1975	3587	26.59	–0.343	4102	39
Av. 1971–75	3853	–0.336	–0.084	3853	0
	Central Rice Research Institute, Orissa				
IR8					
1967	3561	21.72	–0.056	5667	194
1968	3738	16.74	–0.075	4672	112
1969	2644	35.73	–0.115	5419	155
Av. 1967–69	3314	24.73	–0.082	3389	151

(continued on opposite page)

APPENDIX **A continued**

Country, variety year	Coefficient			Y_m (kg/ha)	N_m (kg/ha)
	a	b_1	b_2		
Local					
1967	2733	14.48	–0.053	3722	137
1968	2435	16.44	–0.060	3561	137
1969	2360	3.48	–0.060	2410	29
Av. 1967–69	2509	11.47	–0.058	3076	99
Tamil Nadu Paddy Breeding Station, Coimbatore					
IR8					
1967	2312	29.12	–0.057	6031	255
1968	2849	26.20	–0.049	6351	267
1969	4049	19.25	–0.038	6487	253
Av. 1967–69	3070	24.86	–0.048	6289	259
C032					
1967	2299	35.57	–0.129	5834	138
1968	3382	32.12	–0.134	5307	120
1969	4024	27.11	–0.113	5650	120
Av. 1967–69	3235	31.60	–0.125	5232	126
INDIA	*19 locations*				
IR8					
1967	2911	18.38	–0.047	4708	196
1968	3034	20.89	–0.056	4982	186
1969	3010	13.11	–0.033	4312	199
Av. 1967–69	2985	17.46	–0.045	4679	194
Mixed					
1967	2631	14.57	–0.057	3562	128
1968	2572	18.05	–0.075	3616	116
1969	2574	12.60	–0.060	3236	105
Av. 1967–69	2592	15.08	–0.065	3467	116
INDIA	*8 locations*				
Pankaj					
1971	3445	7.41	–0.017	4252	218
Mahsuri					
1971	3265	11.24	–0.043	4000	131

[a] The fertilizer response function is based on the quadratic equation:

$$Y = a + b_1N + b_2N^2$$

where Y denotes kg rice/ha and N denotes kg nitrogen/ha. From the estimated coefficients of this function, we can calculate the following:

$$N_m = -\frac{b_1}{2b_2}$$

$$Y_m = a - \frac{b_1}{4b_2}$$

$$\frac{Y}{N} = \frac{Y_m - a}{N_m}$$

APPENDIX B. **Fertilizer response functions with their implied maximum yield (Y_m) and nitrogen level at maximum yield (N_m), variety, and year at six experiment stations and other locations in Asia, 1968–75 dry season.** [a]

Country, variety year	Coefficient			Y_m (kg/ha)	N_m (kg/ha)
	a	b_1	b_2		
PHILIPPINES					
	International Rice Research Institute, Laguna				
IR8					
1968	3657	37.74	–0.024	18494	786
1969	5140	38.96	–0.130	8059	150
1970	4574	48.89	–0.162	8263	151
1971	5615	555.79	–0.241	8844	116
1972	IR8 not planted				
1973	2953	20.53	0.013	2953	0
1974	2824	30.05	–0.133	4521	113
1975	4941	35.61	–0.136	7263	130
Av. 1968–75	4203	30.38	–0.068	7596	223
IR20					
1969	3531	48.33	–0.163	7113	148
1970	5388	38.25	–0.175	7478	109
1971	5665	35.71	–0.146	7848	122
1972	5013	26.70	–0.054	8313	247
1973	3531	24.86	–0.061	5438	153
1974	3836	34.64	–0.100	6836	173
1975	4878	25.82	–0.085	6839	152
Av. 1970–75	4718	31.00	–0.107	6963	145
Peta					
1968	4967	26.71	–0.179	5963	75
1969	5348	–1.03	–0.136	5348	0
1970	5272	2.65	–0.198	5281	7
1971	5517	–39.70	0.042	5517	0
1972	4367	0.88	–0.122	4369	4
1973	3283	24.25	–0.166	4169	73
1974	4470	11.76	–0.069	4971	85
1975	5017	–16.17	–0.059	5017	0
Av. 1968–75	4780	1.17	–0.111	4783	5
1970–75	4654	–2.72	–0.095	4654	0

(continued on opposite page)

APPENDIX B **continued**

Country, variety year	Coefficient			Y_m (kg/ha)	N_m (kg/ha)
	a	b_1	b_2		
Maligaya Rice Research and Training Center, Central Luzon					
IR8					
1968	4890	24.90	–0.063	7366	198
1969	4324	18.81	0.026	4324	0
1970	4362	37.54	–0.168	6459	112
1971	4233	53.08	–0.232	7269	114
1972	4581	28.03	–0.163	5786	86
1973	4033	20.10	–0.056	5837	179
1974	3713	28.48	–0.086	6071	166
1975	3752	29.28	–0.096	5985	152
Av. 1968–75	4238	30.00	–0.105	6381	143
IR20					
1970	3732	32.16	–0.150	5456	107
1971	4130	22.23	–0.082	5637	136
1972	4802	21.31	–0.124	5718	86
1973	3392	19.76	–0.038	5961	260
1974	2802	39.76	–0.106	6530	186
1975	2838	20.62	–0.018	8743	573
Av. 1970–75	3616	25.97	–0.086	5576	151
Peta					
1968	4406	15.62	–0.118	4923	66
1969	4939	7.92	–0.150	5044	26
1970	4368	24.43	–0.204	5099	60
1971	3937	7.02	–0.116	4043	30
1972	3746	23.93	–0.200	4462	60
1973	3199	28.00	–0.165	4387	85
1974	3195	–2.86	–0.011	3195	0
1975	4000	0.33	–0.056	4000	3
Av. 1968–75	3974	12.33	–0.104	4339	59
1970–75	3741	12.52	–0.094	4158	67
Bicol Rice and Corn Experiment Station, Bicol					
IR8					
1968	3552	38.81	–0.149	6079	130
1969	3326	41.05	–0.154	6062	133
1970	4814	39.33	–0.138	7626	143
1971	3670	36.62	–0.146	5968	125
IR8					
1972	6369	29.43	–0.135	7977	109
1973	4517	27.41	–0.114	6162	120
1974	3263	42.10	–0.173	5820	121
1975	3137	43.51	–0.172	5889	126
Av. 1968–75	4081	37.20	–0.148	6429	126
IR20					
1970	3653	39.75	–0.115	7088	173
1971	3405	36.91	–0.167	5444	111
1972	5157	40.58	–0.212	7099	96
1973	4112	30.37	–0.123	5987	123
1974	3945	39.26	–0.160	6353	123
1975	3381	32.54	–0.103	5951	158
Av. 1970–75	3942	36.57	–0.147	6216	124

(continued on next page)

APPENDIX B **continued**

Country, variety year	Coefficient			Y_m (kg/ha)	N_m (kg/ha)
	a	b_1	b_2		
Peta					
1968	3162	28.67	–0.180	4304	80
1969	3414	10.46	–0.105	261	50
1970	5007	–3.24	–0.041	5007	0
1971	3350	7.86	–0.095	3512	41
1972	6224	7.41	–0.116	6342	32
1973	4280	16.24	–0.152	4714	53
1974	3246	8.86	–0.091	3462	49
1975	4349	–0.76	–0.062	4349	0
Av. 1968–75	4129	9.44	–0.105	4341	45
1970–75	4409	6.06	–0.093	4508	32
Visayas Rice Experiment Station, Visayas					
IR8					
1970	3631	45.17	–0.148	7078	153
1971	4471	13.51	–0.074	5088	91
1972	3021	39.13	–0.888	7371	222
1973	4380	4.81	0.007	4380	0
1974	3886	8.76	–0.032	3946	14
1975	1933	19.67	–0.092	2984	107
Av. 1970–75	3517	22.67	–0.075	5230	151
IR20					
1970	3394	48.88	–0.0171	6887	143
1971	4681	46.83	–0.212	7267	110
1972	3573	23.29	–0.051	6232	228
1973	4527	21.65	–0.052	6780	208
1974	2899	17.47	–0.042	4716	208
1975	3110	12.29	–0.042	4009	146
Av. 1970–75	3697	37.88	–0.411	4570	46
Peta					
1971	4401	33.24	0.118	2060	141
1972	2834	4.21	–0.097	2880	22
1973	4111	–20.73	0.021	4111	0
1974	2011	–16.22	0.105	1384	77
1975	3142	–18.52	0.049	1392	189
Av. 1971–75	3300	–16.90	0.039	5131	217
INDIA					
Central Rice Research Institute, Orissa					
IR8					
1967	2394	29.49	–0.009	26551	1638
1968	3013	50.12	–0.094	9694	266
1969	3767	48.46	–0.132	8215	184
Av. 1967––69	3058	42.69	–0.078	8899	274
Local					
1967	1239	11.71	–0.016	3382	366
1968	1862	31.77	–0.163	3410	97
Av. 1967–69	1551	21.74	–0.090	2884	121

(continued on opposite page)

APPENDIX B **continued**

Country, variety year	Coefficient			Y_m (kg/ha)	N_m (kg/ha)
	a	b_1	b_2		
	Tamil Nadu Paddy Breeding Station, Coimbatore				
IR8					
1967	2771	24.25	–0.036	6855	337
1968	2711	25.36	–0.029	8255	437
1969	3776	13.71	–0.040	4951	171
Av. 1967–69	3086	21.11	–0.035	6269	302
ADT27					
1967	1964	21.20	–0.065	3693	163
1968	3093	20.64	–0.070	4614	147
1969	3196	11.77	–0.041	4041	144
Av. 1967–69	2751	17.87	–0.059	4104	151
INDIA	*19 locations*				
IR8					
1967	2715	27.33	–0.077	5140	177
1968	3769	29.17	–0.064	7116	229
Av. 1967–68	3242	28.30	–0.071	6062	199
Local					
1967	1936	15.14	–0.036	3528	210
1968	2694	23.52	–0.085	4321	138
Av. 1967–68	2315	19.33	–0.061	3846	158

[a] The fertilizer response function is based on the quadratic equation:

$$Y = a + b_1N + b_2N_2$$

where Y denotes kg rice/ha and N denotes kg nitrogen/ha. From the estimated coefficients of this function, we can calculate the following:

$$N = -\frac{b_1}{2b_2}$$

$$Y_m = a - \frac{b_1}{4b_2}$$

$$\frac{Y}{N} = \frac{Y_{,m} - a}{N_m'}$$

APPENDIX C. **Estimated equation models for 1973–74 Central Luzon field experiments.**

	Coefficients[a]	Collapsed	
Intercept (a)	1268	1666	1946
Nitrogen in kilogram/hectare (N)	–6.65 (–1.22)	–6.56	14.17
(N^2)	–0.036 (–2.32)*	–0.036	–0.036
Early stress days (S_1) measured from 0–60 days after transplanting (DT)	–29.60 (–2.35)**	–29.60	
Late stress days (S_2) measured from 60 DT	143.11 (4.51)**	–63.52	–63.52
Interaction between nitrogen and early stress days (NS_1)	0.573 (3.41)**	0.573	
Interaction between nitrogen and late stress days (NS_2)	–0.229 (1.37)	–0.229	–0.229
Solar energy (SR) in Kcal/sq cm at 45 DBH	1.97 (0.95)	1.97	
Interaction between nitrogen and solar energy (NSR)	0.103 (3.68)**	0.103	
($N^2 S^2_2$)	–0.0000847 (–1.56)	–0.0000847	
Age of seedlings (A) at transplanting (days)	–11.30A (–1.84)		
Hopperburn (H) damage in percent of hills damaged	–26.90 (–4.83)**		
P_2O_5 (P) in kg /ha	4.97 (5.48)**		
Dummy variable (W_1) for one application of 2, 4-D granule	356.1 (5.40)**		

[a] Figures in parentheses are *t*-values. *Significant at the 5% level. **Significant at the 1% level.

APPENDIX D. **Rice production function estimated from the Asian aggregate data (PI), 1950–72.**[a]

	log *a*	Land	Fertilizer	Modern varieties	R^2
PI-1	0.089	0.859 (68.857)	0.143 (15.072)	–	0.946
PI-2	–1.793	1.444 (14.047)	0.073 (7.302)	–	0.991
PI-3	–1.402[b]	1.286 (15.197)	0.106[b] (4.105)	–	0.995
PI-4	0.729[b]	0.564[b] (2.989)	0.184[b] (5.968)	–	0.996
PI-5	0.702[b]	0.684[b] (3.629)	0.100[b] (2.486)	0.155 (3.220)	0.996

[a] The figures in parentheses are t-values. [b] The Philippines has been assigned as the base country in the covariance analysis; thus, these particular coefficients pertain to the Philippines.

APPENDIX E. **Country-specific coefficients of the rice production function estimated from the aggregate Asian data (PI-5) 1950–72.**[a]

Country	PI-5		
	log *a*	Land	Fertilizer
Japan	–1.802 [–2.33]	1.107 [1.298]	0.314 (3.5131
South Korea	–2.559 [–2.709]	1.673 [2.247]	0.166 [1.228]
Taiwan	–0.402 [–0.404]	0.469 [–0.231]	0.420 [5.531]
West Malaysia	0.223 [–0.686]	0.875 [0.661]	0.104 [0.095]
Sri Lanka	–2.845 [–5.272]	1.471 [2.881]	0.383 [4.158]
Indonesia	–3.341 [–2.720]	1.917 [2.758]	0.013 [–1.530]
Thailand	–2.830 [–4.206]	1.737 [4.051]	0.060 [–0.916]
Philippines[b]	–0.702	0.684 (3.629)	0.100 [2.486]
Burma	–0.137 [–0.604]	1.061 [0.914]	0.032 [–1.497]
India	–7.253 [–2.438]	2.650 [2.495]	–0.015 [–1.896]
Pakistan-Bangladesh	–2.259 [–1.866]	1.577 [2.069]	0.027 [–1.600]

---

[a] The figures in parentheses refer to *t*-values of the variables above; those in brackets refer to *t*-values of the dummy variables, which provide a test of significance of the difference in value between the coefficient for country *k* and the coefficient for the base country. [b] The Philippines has been assigned as the base country in the covariance analysis.

APPENDIX F. **Rice production function based on farm data of 33 selected villages in Asia (PII), 1971–72 wet season.**[a]

	log *a*	Land	Fertilizer	Modern varieties	R^2
PII-1	0.204	0.813 (57.261)	0.124 (13.933)	–	0.754
PII-2	0.036[b]	0.837 (48.128)	0.095[b] (10.971)	–	0.862
PII-3	–0.645[b]	0.842[b] (43.403)	0.386[b] (4.439)	–	0.869
PII-4	–0.650[b]	0.841[b] (43.372)	0.373[b] (4.283)	0.048 (2.497)	0.870

---

[a] The figures in parentheses are *t*-values. [b] These particular coefficients pertain to Mahipon, which has been assigned as the base village in the covariance analysis.

APPENDIX G. **Village-specific coefficients of the rice production function estimated by covariance analysis from farm data of 33 selected villages in Asia (PII-4), 1971–72.**

	PII–4	
	log^a	Fertilizer
PHILIPPINES		
Gapan, Nueva Ecija		
Mahipon	–0.650	0.373 (4.283)
Malimba	–0.051 [2.249]	0.165 [–1.775]
San Nicolas	0.102 [2.492]	0.183 [–1.457]
Baybay, Leyte		
Canipa	0.120 [3.623]	0.071 [–2.935]
Marcos	0.238 [4.156]	0.106 [–2.477]
Tabang	–0.159 [2.277]	0.095 [–2.746]
Pigcawayan, Cotabato		
Bulucaon	0.316 [4.620]	0.097 [–2.890]
Capayuran	0.279 [4.459]	0.068 [–3.128]
Hagonoy, Davao del Sur		
Beinte Nueve	0.340 [4.9601	0.050 [–3.500]
Sinayawan	0.131 [3.615]	0.131 [–2.383]
INDIA		
North Arcot, Tamil Nadu		
Kariyamangalam	0.035 [2.652]	0.192 [–1.674]
Palvarthuvenran	0.333 [3.115]	0.117 [–1.926]
Manmalai	0.633 [5.192]	0.018 [–3.601]
Cuttack, Orissa		
Kandarpur	0.201 [4.027]	0.079 [–3.078]
Korpada	0.157 [3.926]	0.076 [–3.297]
Shimoga, Mysore		
Gajanur	0.547 [5.309]	0.036 [–3.741]
Hosahally	0.625 [6.053]	0.040 [–3.663]
Ashoknagar	0.419 [5.063]	0.109 [–3.012]
Nainatal & Varanasi, Uttar Pradesh		
Dhanpur Vijaypur	0.464 [–3.659]	0.087 [–2.297]
Tarna	0.326 [4.082]	0.060 [–2.833]

(continued on opposite page)

APPENDIX G **continued**

	PII–4	
	log *a*	Fertilizer
Barain	0.153	0.095
	[3.536]	[2.793]
West Godavari, Andhra Pradesh		
Pedapulleru	0.430	0.063
	[5.218]	[–3.483]
PAKISTAN		
Gujranwala, Punjab		
Aroop[b]	0.160	0.048
Maraliwala[b]	0.565	–0.015
INDONESIA		
Subang, West Java		
Cidahu	0.184	0.118
	[3.899]	[–2.600]
Sidoarjo, East Java	0.562	0.017
Sidomulyo	[5.301]	[–3.336]
Klaten, Central Java		
Nganjat	0.214	0.182
	(3.9421	[–1.825]
Kahuman	0.528	0.081
	[5.232]	[–2.754]
Pluneng	0.435	0.123
	[4.438]	[–2.076]
WEST MALAYSIA		
Kelantan		
Salor	0.019	0.156
	(2.8451	[–2.017]
Meranti	–0.200	0.221
	[1.897]	[–1.370]
THAILAND		
Don Chedi, Suphan Buri		
Rai Rot	0.366	0.043
	[4.795]	[–3.582]
Nong Sarai	–0.177	0.244
	[2.289]	[–1.423]

---

[a] The figure in parenthesis is *t*-value; figures in brackets are also *t*-values which provide a test of significance of the difference in the value of the coefficient for village *j* to the coefficient of the base village, Mahipon. [b] The coefficients were estimated based on separate regressions.

APPENDIX H. **Rice production function estimated from farm data in Laguna (PIII), 1966–71 wet season.**[a]

						Irrigation dummy		
	log *a*	Land	Fertilizer	Other chemicals	Modern varieties	Pump	Good gravity	R^2
PIII-1	3.420	0.712 (20.673)	0.056 (4.838)					0.375
PIII-2	3.389	0.675 (18.380)	0.043 (3.417)	0.049 (2.738)				0.380
Pill-3	3.246	0.731 (20.479)	0.034 (2.810)	0.073 (4.208)		0.119 (5.788)	0.164 (9.126)	0.433
PIII-4	3.1984[b]	0.723 (20.660)	0.030 (2.508)	0.090 (5.122)		0.121 (6.167)	0.161 (9.150)	0.502
PIII-5	3.169[b]	0.701 (19.695)	0.068[b] (2.751)	0.083 (4.679)		0.118 (6.050)	0.153 (8.630)	0.512
PIII-5	3.125[b]	0.692[b] (9.034)	0.056[b] (2.152)	0.152[b] (4.626)		0.112 (5.737)	0.146 (8.205)	0.524
PIII-7	3.109[b]	0.704[b] (9.244)	0.057[b] (2.218)	0.153[b] (4.677)	0.084 (3.638)	0.127 (6.396)	0.753 (8.632)	0.531

[a] Figures in parentheses are *t*-values. [b]Refers to the coefficient of the assigned base year, 1966.

APPENDIX I. **Year-specific coefficients of alternative specifications of the rice production function estimated from farm data in Laguna (PIII-7), 1966–71 wet season.**[a]

	PIII – 7			
	log *a*	Land	Fertilizer	Other chemicals
1966	3.109	0.704 (9.244)	0.057 (2.218)	0.153 (4.677)
1967	3.164 [0.812]	0.659 [–0.4021	0.041 [–0.395]	0.125 [–0.578]
1968	3.317 [2.824]	0.706 [0.0143]	–0.022 [–2.474)	0.074 [–1.403]
1969	3.297 [2.188]	0.721 [0.138]	0.022 [–0.877]	0.087 [–1.033]
1970	3.175 [0.396]	0.725 [0.175]	0.103 [0.746]	0.028 [–1.991]
1971	3.042 [–0.6051	0.865 [1.372]	0.139 [1.445]	–0.091 [–4.307]

[a]Figures in parentheses are *t*-values. Those in brackets are also *t*-values which provide a test of significance of the difference in the value of the coefficient for year *t* to the coefficient of the base year 1966.

APPENDIX J. **Empirical models.**

I. Asian aggregate model

a) Model I

$$(1)\ \log Q_{kt} = \log a + b_1 \log H_{kt} + b_2 \log F_{kt} + b_3 M_{kt} + \sum_{2}^{11} c_k D_k + \sum_{2}^{11} d_k D_k \log F_{kt} + u_{kt}$$

$$(2)\ \log f_{kt} = \log a + b_1 \log P_{kt} + b_2 \log I_k + b_3 E_k + b_4 M_{kt} + u_{kt}$$

b) Model II

$$(3)\ \log f_{kt} = \log a + b_1 \log P_{kt} + b_2 M_{kt} + \sum_{2}^{11} c_k D_k + \sum_{2}^{11} d_k D_k \log P_{kt} + u_{kt}$$

where:

k = the country (= 1, 2, . . . 11);
t = the year (= 1, 2, . . ., 23);
Q = production in thousand metric tons of rough rice;
D_k = intercept dummy variables where D_2 is equal to 1 for country 2 and 0 otherwise, and D_3 is equal to 1 for country 3 and 0 otherwise, and so forth;
H = rice crop area in thousand hectares;
F = fertilizer in metric tons of nutrients(NPK);
$(D_k)\ (\log F_{kt})$ = slope dummy variables to distinguish intercountry differences in the production elasticity of fertilizer;
M = proportion of area under modern varieties;
f = average fertilizer consumption in kilograms of nutrient per hectare;
P = relative price of fertilizer to rice;
I = value of the intercept by country based on the estimate of production function, equation (1), namely $I_1 = \log\hat{a}$, $\log I_2 = \log \hat{a} + \hat{c}_2$. $\log I_3 = \log \hat{a} + \hat{c}_3$, and so forth;
E = production elasticity of fertilizer based on the estimate of production function, equation (l), namely $E_1 = \hat{b}_2$, $E_2 = \hat{b}_2 + \hat{d}_2$, $E_3 = \hat{b}_2 + \hat{d}_3$, and so forth; forth;
$D_k \log P_{kt}$ = slope dummy variables to distinguish intercountry differences in the price elasticity of demand; and
u = disturbance term.

(continued on next page)

APPENDIX J **continued**

II. Asian farm model

a) Model I

$$(4)\ \log Q_{ij} = \log a + b_1 \log H_{ij} + b_2 \log F_{ij} + b_3 M_{ij} + \sum_{2}^{33} c_j D_j + \sum_{2}^{33} d_j D_j \log F_{ij} + u_{ij}$$

$$(5)\ \log f_{ij} = \log a + b_1 \log P_j + b_2 \log I_j + b_3 E_j + b_4 \log V_{ij} + b_5 M_{ij} + u_{ij}$$

b) Model II

$$(6)\ \log f_{ij} = \log a \cdot\cdot b_1 \log P_j + b_2 M_{ij} + b_3 \log N_j + b_4 R_j + b_5 \log W_j + b_6 \log V_{ij} + u_{ij}$$

where:

i = the farm (= 1, 2, . . ., n_j);
j = the village (1, 2, . . ., 33);
Q = production in metric tons of rough rice;
H = rice crop area in hectares;
F = fertilizer in kilograms of plant nutrients (NPK);
M = proportion of area under modern varieties;
D_j = intercept dummy variables where D_2 is equal to 1 for village 2 and 0 otherwise, D_3 is equal to 1 for village 3 and 0 otherwise and so forth;
$D_j \log F_{ij}$ = slope dummy variables to distinguish intervillage differences in the production elasticity of fertilizer;
f = average fertilizer use in kilograms of nutrients per hectare;
P = relative price of fertilizer to rice;
I = value of intercept by village based on the estimate of production function (4): namely $\log I_1 = \log \hat{a}$, $\log I_2 = \log \hat{a} + \hat{c}_2$, $\log I_3 = \log \hat{a} + \hat{c}_3$, and so on;
E = production elasticity of fertilizer based on the estimate of production function, equation (1) namely $E_1 = \hat{b}_2\ E_2 = \hat{b}_2 + d_2,\ E_3 = \hat{b}_2 + d_3,$ and so forth;
V = value of production in \$ per farm;
N = nitrogen input in kilograms per hectare needed to obtain maximum yield based on experimental response functions from experiment stations near village *j;*
R = average proportion of rainfall for the two months prior to harvest (1967–71);
W = index of quality of irrigation (from 1–5) where 1 means well irrigated and 5 means poorly irrigated or rainfed; and
u = disturbance term.

(continued on opposite page)

APPENDIX J **continued**

III. Laguna farm model

(a) Model I

$$(7)\ \log Q_{it} = \log a + b_1 \log H_{it} + b_2 \log F_{it} + b_3 \log C_{it} + b_4 M_{it} + \sum_{2}^{6} c_t D_t + \sum_{2}^{6} d_t D_t \log F_{it} + u_{it}$$

$$(8)\ \log f_{it} = \log a + b_1 \log P_{it} + b_2 \log I_t + b_3 E_t{}' + b_4 \log V_{it} + b_5 M_{it} + u_{it}$$

(b) Model II

$$(9)\ \log f_{it} = \log a + b_1 \log P_{it} + b_2 M_{it} + b_3 \log V_{it} + \sum_{2}^{6} c_t D_t + \sum_{2}^{6} d_t D_t \log P_{it} + u_{it}$$

where:

i = the farm (=: 1. 2, . . . u_t)

t = the year (= 1, 2, . . . 6);

Q = production in kilograms of rough rice;

D_t = intercept dummy variables where D_2 is equal to 1 for observations in year 1967 and 0 otherwise. D_3 is equal to 1 for year 1968 and 0 otherwise, and so forth;

H = land in hectares;

F = fertilizer in kilograms of nutrients (NPK);

C = cost of agricultural chemicals including insecticide and weedicide, in pesos;

($D_t \log F_{it}$) = slope dummy variables to distinguish interyear differences in the production elasticity of fertilizer;

M = proportion of area under modern varieties;

f = average fertilizer consumption in kilograms of nitrogen per hectare;

P = relative price of fertilizer to rice;

I = value of the intercept by year based on the estimate of production function, equation (7): namely $\log I_1 = \log \hat{a}$, $\log I_2 = \log \hat{a} + \hat{c}_2$, so forth;

E = production elasticity of fertilizer based on the estimate of production function, equation (7): namely $E_1 = \hat{b}_2$ $E_2 = \hat{b}_2 + \hat{d}_2$, and so forth;

V = value of production in ₱;

$D_t \log P_{it}$ = slope dummy variables to distinguish interyear differences in the price elasticity of demand; and

u = disturbance term.

COMMENTS ON MODERN RICE VARIETIES AND FERTILIZER CONSUMPTION

G. DESAI

THE DAVID-BARKER PAPER analyzes the effects of modern varieties on fertilizer consumption in the Asian rice economy by examining the response functions of modern (MV) and traditional (TV) rice varieties and by estimating fertilizer-demand functions. The data base of the paper is extremely broad.

The resource paper concludes that the MV have had a substantial impact on fertilizer consumption in the Asian rice economy. I do not disagree with that. But, it seems to me that in certain situations, the impact has not been as much from the increase in the rates of fertilizer application (due to upward shifts in the response functions) as from the accelerated diffusion of fertilizer use on rice. There appears to be little difference between the response functions of the MV and those of the TV in many situations. My position differs from one of the major conclusions of the resource paper—that which attributes growth in fertilizer use mainly to shifts in response functions.

RESPONSE FUNCTION ANALYSIS

The response function analysis in the resource paper raises two main questions. First, how superior are the fertilizer response functions of MV to those of the TV? Second, what sort of fertilizer-demand functions are implied by the fertilizer-response functions of the two groups of varieties?

Other questions arise from the resource paper:

- Is the difference between fertilizer-response functions of the two groups of varieties, as estimated from experiment station data, likely to be greater or smaller on farms?
- Is the response function likely to be more or less stable over time with farm conditions?
- How do fertilizer response functions for rainfed rice compare with those for irrigated rice?

Response functions of modern vis-a-vis traditional rice varieties. Appendix A and B of the resource paper reveal that, even with experiment station conditions, the response functions are not stable over time. Table 1 presents means

Chairman, Center for Management in Agriculture, Indian Institute of Management, Ahmedabad, India.

Table 1. Mean and C.V. of the coefficients given in Appendix A and B of the resource paper[a] "Modern rice varieties and fertilizer consumption" by C.C. David and R. Barker.

Variety	Period	Mean and C.V.	Wet season			Dry season		
			a	*b*	*c*	*a*	*b*	*c*
			Philippines: IRRI, Laguna					
IR8	1968–75	Mean	3436	16.54	–0.066	4243	38.20	–0.116
		C.V.	27	81	129	26	30	73
IR20	1968–75	Mean	3797	19.68	–0.149	4549	33.47	–0.115
		C.V.	21	50	37	20	25	40
Peta	1968–75	Mean	2235	–4.22	0.005	4780	1.17	–0.111
		C.V.	32	179	874	15	1848	71
			Philippines: MRRTC, Central Luzon					
IR8	1968–75	Mean	3425	16.18	–0.156	4236	29.78	–0.105
		C.V.	27	51	108	9	36	77
IR20	1968–75	Mean	3442	29.74	–0.164	3616	25.97	–0.086
		C.V.	23	16	29	21	31	59
Peta	1968–75	Mean	2950	–7.82	+0.011	3974	13.05	–0.128
			30	145	473	15	89	53
			Philippines: BRCES, Bicol					
IR8	1968–75	Mean	3416	26.04	–0.149	4081	37.28	–0.148
		C.V.	26	38	38	27	16	13
IR20	1968-75[b]	Mean	3141	28.13	–0.163	3942	36.57	–0.147
		C.V.	26	39	37	17	11	28
Peta	1968–75	Mean	3089	–1.97	+0.023	4129	9.44	–0.105
		C.V.	25	631	274	26	105	43
			Philippines: VRES, Visayas					
IR8	1968–75[b]	Mean	3259	19.36	–0.084	3554	21.84	–0.071
		C.V.	18	84	106	27	76	75
IR20	1968–75[b]	Mean	3567	45.34	–0.235	3697	28.40	–0.095
		C.V.	19	35	60	20	55	80
Peta	1968–75[c]	Mean	3691	4.03	–0.041	3300	–3.60	–0.039
		C.V.	22	357	171	29	635	219
			India: CRRI, Orissa					
IR8	1967–69	Mean	3314	24.73	–0.082	3058	42.69	–0.078
		C.V.	18	40	7	23	27	80
Local	1967–69	Mean	2509	11.47	–0.058	1551	21.74	–0.090
		C.V.	8	61	7	28	65	116
			India: TNPBS, Coimbatore					
IR8	1967–69	Mean	3070	24.86	–0.048	3086	21.11	–0.035
		C.V.	29	20	20	19	30	16
ADT-27	1967–69	Mean				2751	17.87	–0.059
		C.V.				25	30	26
CO23	1967–69	Mean	3235	31.60	–0.125			
		C.V.	27	13	9			
			India: MARS, Andhra Pradesh					
Pankaj	1971–75	Mean	4407	8.84	0.071			
		C.V.	2	38	138			
Mahsuri	1971–75	Mean	3853	–0.336	–0.084			
		C.V.	2	5128	180			

(continued on opposite page)

Table 1 continued

Variety	Period	Mean and C.V.	Wet season			Dry season		
			a	*b*	*c*	*a*	*b*	*c*
			India: 19 locations					
IR8	1967–69[d]	Mean	2985	17.46	–0.045	3242	28.30	–0.071
		C.V.	2	23	27	23	5	13
Local	1967–69[d]	Mean	2592	15.08	–0.064	2315	19.30	–0.061
		C.V.	1	18	15	23	31	57

[a] Response function: $Y = a + bN + oN^2$, where Y = yield of rough rice (kg/ha) and N = elemental nitrogen (kg/ha). [b] For the dry season, the period is 1970–75. [c] For the dry season, the period is 1971–75. [d] For the dry season, the period is 1967–68.

and coefficients of variation of the coefficients of the estimated fertilizer-response functions of the resource paper. The following conclusions emerge from this analysis.

In the Philippines, the traditional variety Peta does not respond to fertilizer during the wet season. In several cases, the *b* coefficient of the quadratic response function of the variety is negative. Even when it is positive, the value is quite small. In contrast, the mean values of the *b* coefficient of MV IR8 and IR20 are quite high and those of their *c* coefficient are quite small. Therefore, the replacement of Peta by IR8 or IR20 would substantially increase fertilizer use even during the wet season, despite the unstable response functions of IR8 or IR20. In the dry season the impact on fertilizer would be still greater because of the substantially superior and more stable response of the MV.

During the wet season, the situation in India differs from that in the Philippines. Unlike Peta, the Indian local variety responds significantly to fertilizer. More importantly, the response of IR8 to fertilizer is only marginally higher than that of the local variety and even that is coupled with greater instability of the response function. The implications of this for the spread of the MV in situations represented by India, and also for its impact on demand for fertilizer during the wet season are obvious, particularly if the difference between the response functions of the two groups of varieties is less on farms than at experiment stations. This conclusion, based on the comparison of the response functions of IR8 and an Indian local variety, is supported by additional evidence on a number of MV.

In the dry season, however, the situation in India is similar to that in the Philippines. The response function of IR8 is not only much superior to that of the local variety but also much more stable. That explains the more rapid spread of the MV during the dry season than in the wet season, and the higher rates of fertilizer application during the dry season, as shown by the microdata.

Because most of the rice area in India is planted in the wet season, the preceding analysis suggests that until recently the MV did not have a significant impact on fertilizer consumption in the Indian rice economy. Such a conclusion, however, is not supported by the trends in fertilizer consumption in India's major rice-growing states. One possible explanation for the discrepancy between what is indicated by the response functions of the two groups of varieties and the trends in fertilizer consumption could be as follows:

Fertilizer use had not spread to about 75% of India's rice area by 1965–66, when the MV were introduced. That was due to reasons such as the time lag in diffusion of fertilizer use, the rudimentary state of the fertilizer distribution system in most parts of the country, relatively low rice prices, and low responsiveness of the TV to fertilizer (Desai, 1969; Desai and Singh, 1973; Desai et al., 1973).

Because of those reasons, the impact of MV on fertilizer consumption for the Indian rice economy as a whole has been more significant in accelerating the diffusion of fertilizer use on rice than in raising the average fertilizer rates on fertilized rice areas. This was so, not because the response functions of the MV were substantially superior to those of the TV, but because the decision to introduce the MV simultaneously led to policies and programs that accelerated the diffusion of fertilizer use on rice. A favorable rice price further facilitated that process.

NORMATIVE FERTILIZER DEMAND FUNCTIONS IMPLIED BY THE TV AND MV RESPONSE FUNCTIONS

The nitrogen demand function derived from a quadratic nitrogen response function is given by the equation:

$$N = \frac{b}{2c} - \frac{1}{2cP_p} \cdot P_n$$

Where:

N = economic optimum demand for nitrogen in kilograms per hectare,
b & c = coefficients of the nitrogen-response function,
P_p = price of a kilogram of rough rice, and
P_n = price of a kilogram of nitrogen.

Conventionally, studies on demand for fertilizer have used the ratio of fertilizer:product price. In some situations that could be misleading because the same price ratio gives different magnitudes of total net returns from fertilizer use at different combinations of the two prices, even though the optimum rate remains the same. Because the absolute size of the net returns plays an important role in a farmer's decisions about fertilizer use, I have taken the two prices separately. It becomes explicit that a shift in the demand curve for fertilizer is governed by changes in both the parameters of the response function as well as the price of the product. In a world where prices of input and output change at different rates, the importance of recognizing this needs no emphasis.

The equation represents a long-term demand curve for nitrogen for the given values of *b, c,* and P_p. A change in these three parameters could shift the demand curve as well as change its slope. An upward shift of the response function, without any change in P_p, would shift the demand curve to the right and make it flatter. Similarly, an increase in P_p, without any change in the response function, would also shift the demand curve to the right and make it flatter. But the intercept on the N axis will remain unchanged.

The impact of MV on nitrogen-demand functions is examined below by calculating the values of the intercepts on the two axes and slopes of nitrogen demand curves derived from average response functions of different TV and MV given in the resource paper. Table 2, which shows these values, indicates that in the Philippines, the MV have shifted the demand curves for nitrogen substantially upward and to the right in both the wet and the dry season. In fact, in three of the four cases for the wet season, the nitrogen demand curves of Peta have negative intercept on the price axis, indicating zero demand for nitrogen at any price. It is also clear that in most cases, MV have higher, and also flatter demand curves for nitrogen than the TV, implying lower price elasticities of demand for the MV than for the TV.

The situation is quite different in India. The upward shift of the demand curves for nitrogen due to the MV is much smaller than that in the Philippines during both seasons. Similarly, the demand curve of the MV is flatter than that of the TV only during the dry season. Nor is the reduction in the slope of the demand curve as high as that in the Philippines.

The preceding analysis is based on the assumption of the same price for both TV and MV. If this assumption is relaxed to allow for a lower price of the MV, the difference in the slopes of the demand curves of the MV and TV would be reduced. While this may still imply higher and flatter nitrogen demand curves for the MV than for the TV in the Philippines, in India the difference in the slopes of the demand curves of the two groups of varieties may not remain significant.

It was noted earlier that an upward change in the price of rice would shift the demand curve of the same variety outward and make it flatter. The importance of recognizing this is obvious, particularly in a situation represented by India. First, there was a substantial rise in the price of rice after the mid-1960's when the MV were introduced. Second, as the above analysis indicates, the nitrogen demand curves implied by the MV do not have significantly different slopes than those implied by the TV. Therefore, it appears that the rightward shifts in the nitrogen demand curves between the mid-1960's and the early 1970's were due more to increase in rice prices than to change in the nitrogen response functions.

Demand functions estimated from fertilizer consumption data. The analysis based on a fertilizer-demand function derived from a fertilizer-response function focuses on the relationship between demand for fertilizer and physical response of the crop to fertilizer. If the degree of representativeness of the

Table 2. Parameters of the nitrogen-demand curves from average response functions of the traditional and the modern rice varieties. 1967–75.

Variety	Period	Season	Intercepts		Slope[b]
			N axis $\left(\frac{b}{2c}\right)$	P_n axis (bP_p)	$\left(\frac{1}{2cP_p}\right)$
Philippines: IRRI, Laguna					
IR8	1968–75	Wet	125.3	16.54	–7.58
IR8	1968–75	Dry	164.7	38.20	–4.31
IR20	1969–75	Wet	66.0	19.68	–3.36
IR20	1969–75	Dry	145.5	33.47	–4.35
Peta	1968–75	Wet	398.1	–4.22	–94.3
Peta	1968–75	Dry	5.27	1.17	–4.5
Philippines: MRRTC, Central Luzon					
IR8	1968–75	Wet	51.9	16.18	–3.2
IR8	1968–75	Dry	141.8	29.78	–4.8
IR20	1968–75	Wet	90.7	29.74	–3.1
IR20	1970–75	Dry	151.0	25.97	–5.8
Peta	1968–75	Wet	355.5	–7.82	+45.5
Peta	1968–75	Dry	51.0	13.05	–3.91
Philippines: BRCES, Bicol					
IR8	1968–75	Wet	87.4	26.04	–3.36
IR8	1968–75	Dry	126.0	37.28	–3.38
IR20	1968–75	Wet	86.3	28.13	–3.07
IR20	1970–75	Dry	124.4	36.57	–3.4
Peta	1968–75	Wet	4.3	–1.97	+2.17
Peta	1968–75	Dry	45.0	9.44	–4.76
Philippines: VRES, Visayas					
IR8	1968–75	Wet	115.2	19.36	–5.95
IR8	1970–75	Dry	151.3	21.84	–7.04
IR20	1968–75	Wet	96.5	45.34	–2.13
IR20	1970–75	Dry	150.0	28.40	–5.3
Peta	1968–75	Wet	49.2	4.03	–12.2
Peta	1971–75	Dry	–46.2	–3.60	–12.8
India: CRRI, Orissa					
IR8	1957–69	Wet	150.8	24.73	–6.1
IR8	1967–69	Dry	273.7	42.69	–6.4
Local	1967–69	Wet	98.9	11.47	–8.6
Local	1967–68	Dry	120.8	21.74	–5.6
India: TNPBS, Coimbatore					
IR8	1967–69	Wet	253.0	24.86	–10.4
IR8	1967–69	Dry	301.6	21.11	–14.3
ADT27	1967–69	Dry	151.4	17.87	–18.5
CO23	1967–69	Wet	126.4	31.6	– 4.0
India: MARS, Andhra Pradesh					
Pankaj	1971–75	Wet	62.3	8.84	– 7.0
Mehsuri	1971–75	Wet	–2.0	–0.336	– 6.0
India: 19 locations					
IR8	1967–69	Wet	194.0	17.46	–11.11
IR8	1967–68	Dry	199.3	28.3	– 7.0
Local	1967–69	Wet	117.8	15.08	– 7.8
Local	1967–68	Dry	158.2	19.30	– 9.2

[a] The value of the intercept on P_d axis would be the b values in the column, multiplied by P_p [b] The value of the slope would be the value given in the column $\left(\frac{1}{2c}\right)$ divided by P_p.

response function could be ascertained, some useful conclusions about *potential* demand could be drawn from the demand function.

But such a demand function cannot be taken as representing *effective* (or actual) demand because it is derived from a physical as distinguished from a behavioral relationship. Viewed thus, the attempt of David and Barker to estimate demand models that take account of both actual fertilizer consumption and responsiveness of crops to fertilizer use is a contribution in a direction which has not received adequate attention. I feel, however, that some of the results of their attempt might have been affected by the specification of the basic demand model in the resource paper.

The basic demand model in the resource paper specifies fertilizer consumption as a function of

- relative price of fertilizer to rice,
- proportion of area planted to the MV,
- value of production (representing farmers' ability to finance fertilizers),

and

- variables that represent variations in fertilizer-response functions.

The above specification leaves out an important variable that influences effective demand for fertilizers, namely, diffusion of fertilizer use over time. This would be particularly true with the model estimated from the aggregate time-series (1950 to 1972) observations from 12 rice-growing countries. In most of those countries fertilizer use began just in the early 1950's. Furthermore, as the Indian experience reveals, the diffusion of fertilizer use was not complete, even by the late 1960's.

Therefore, it is reasonable to assume that in such situations fertilizer use would increase up to a level even without significant changes in the values of the explanatory variables. That there was significant growth in fertilizer use before 1965. when the MV were introduced in most of those countries, clearly suggests that assumption (Palacpac, 1976). Thus. both logic and empirical evidence seem to suggest a specification error in the basic demand model. The error, in turn. could result in overestimation of the coefficients of the explanatory variables included in the model because of the likelihood of high positive correlations between these variables and those representing diffusion of fertilizer use over time, but which are not present in the model.

Estimates from the aggregate time-series data may pose one more limitation to the basic demand model. The observations on the dependent variable (fertilizer consumption) relate to the entire economy of the countries. The explanatory variables, on the other hand, relate only to their rice economy. This may not be a problem in countries where most fertilizer consumption is for rice. But the 12 countries include India and Pakistan where rice accounts for a relatively small proportion of total fertilizer consumption, and where growth in fertilizer consumption has been governed by crops other than rice. Fertilizer-responsive modern wheat varieties have replaced traditional wheat varieties on a large scale.

Table 3. Growth in fertilizer consumption in some Asian countries. 1–74.

Country	Percent of arable land under rice	Percent of total rice area under modern varieties		Av. annual increment in NPK consumption (kg/ha) between	
		1965–66	1973–74	1950–51 & 1965–66	1965–66 & 1973–74
Bangladesh	n.a.[a]	–	16.1	0.39	1.68
Burma	25	–	5.1	0.04	0.30
India	23	0.02	25.6	0.27	1.50
Indonesia	44	–	36.5	0.41	2.36
Japan	47	n.a.	n.a.	13.77	8.55
Malaysia	21	10.3[b]	37.4[b]	1.28[c]	7.03
Pakistan	8	–	43.2	0.23	2.14
Philippines	49	–	63.3	0.56	2.60
South Korea	50	–	11.8	9.18	221.3
Sri Lanka	30	–	64.5	0.72	0.81
Taiwan	81	n.a.	n.a.	11.05	9.71
Thailand	50	–	5.6	0.19	1.06

[a]Not applicable. [b]Relates to West Malaysia. [c]Between 1961–62 and 1965–66.

My arguments are not meant to challenge the overall conclusion of the demand-function analysis that the MV have made a definite impact on fertilizer consumption in the Asian rice economy. It is, however, not clear to what extent the acceleration in demand for fertilizer, as shown in Table 3, has been due to the superiority of the fertilizer-response functions of MV to those of TV as opposed to such other factors as the diffusion of fertilizer use on rice, the impact of the MV on that process, favorable developments in the economies of other crops, and the price trends favorable to rice farmers between the mid-1960's and early 1970's.

Finally, from the various arguments presented, it seems clear that upward shifts in fertilizer-response functions will play a critical role in further rapid growth in fertilizer use in the Asian rice economy for two reasons. First, there is a finite upper limit to diffusion of fertilizer use, and the past growth might have exhausted much of the effective potential. Second, the relative price situation has dramatically changed because of the impact of the oil crisis on prices of agricultural inputs.

REFERENCES CITED

Desai, G. M. 1969. Growth of fertilizer use in Indian agriculture; past trends and future demand. Cornell Univ. Dep. of Agric. Econ. Occasional paper no. 24. 193 p. (mimeo.)

Desai, G.M., P. N. Chary, and S. C. Bandyopadhyay. 1973. Dynamics of growth in fertilizer use at microlevel. Centre for Management in Agriculture, Indian Institute of Management, Ahmedabad. (mimeo.)

Desai, G. M., and G. Singh. 1973. Growth of fertilizer use in districts of India, performance and policy implications. Centre for Management and Agriculture, Indian Institute of Management, Ahmedabad. (mimeo.)

Palacpac, A. C. 1976. World rice statistics. International Rice Research Institute, Department of Agricultural Economics, Los Baños, Philippines. 112 p. (mimeo.)

Complementarities among irrigation, fertilizer, and modern rice varieties

T.H. WICKHAM, R. BARKER, AND M.V. ROSEGRANT

TWO MAJOR SOURCES of output growth from rice are the expansion of areas adopting the new rice production technology, and the continued spread of irrigation (Hayami et al., 1977). The new rice technology includes the modern varieties (MV) developed since the mid-1960's and their appropriate management and inputs, especially fertilizer nitrogen. Irrigation ranges from hand-lifted buckets to massive reservoir and canal systems, which for some countries constitute their heaviest infrastructural investments. Although other factors can contribute to higher rice production in Asia, application of the new technology and further irrigation development should dominate increases in rice production for the next decade.

Much work has been done to establish the yield performance of the new rice varieties. Most of it has been in the controlled nitrogen-related experiments in which the yield response to nitrogen of the traditional variety (TV) and the MV groups can be compared. The water regime in those experiments is at an ideal level for rice production.

To do experiments in which the water supply is itself a variable raises difficult questions. These cover the extent to which the experimental treatments reflect actual conditions in irrigated areas; the probable water seepage across the borders of adjacent treatment plots; and important, but difficult to quantify, the interactions between water, soils, climate, and other factors.

This paper explores the link between MV and irrigation development. We estimate the production gain that can be attributed to the new rice technology, and to irrigation improvement and expansion.

In the rice-growing areas of tropical Asia, water is available for only a portion of the land to grow a second crop, and is distributed under a low level of

Agricultural engineer, Department of Irrigation and Water Management; and agricultural economist and research scholar, Department of Agricultural Economics, International Rice Research Institute, Los Baños, Philippines.

irrigation system management. There is thus great variability in the extent to which irrigation water actually supplies crop needs in nominally irrigated areas.

In the next section we use a set of response functions estimated to reflect typical rainfed and irrigated conditions in the Philippines, and we determine the contribution of the addition of irrigation, MV, and fertilizer to the increase in yield per hectare. In the subsequent section we use a water-balance model to examine the variation in irrigation performance that results from different levels of management and water adequacy. That allows us to estimate the, impact of modern technology (MV and N) on yield per hectare under typical and ideal irrigation, and to assess the potential benefits of improved water management.

PRODUCTION ATTRIBUTABLE TO OPTIMAL IRRIGATION AND NITROGEN

The typical response functions for rainfed and irrigated rice farms are derived with the procedure described by David and Barker (1978). However, we distinguish between wet and dry season, and have six rather than four functions (Table 1). The rainfed functions are identical to those of David and Barker. There is only a modest difference between the response functions for the irrigated wet and dry seasons. With optimum fertilizer inputs the yields are almost identical because the advantage of higher solar energy in the dry season is offset by yield loss due to drought stress.

The theoretical optimum level of N is that amount of nitrogen at which its marginal cost is equal to the value of the additional rice produced by the nitrogen. It can be calculated once the price ratio of nitrogen to rice — currently about 4.5: 1 — is specified. But that ratio does not account for interest costs, costs of transporting and applying the nitrogen, the possibility of N not being available when needed, and the uncertainty of response due to factors beyond the farmers' control. Thus, more realistic estimates of optimum N can

Table 1. Equations for yield responses to nitrogen of rice at different combinations of varieties, seasons, and irrigation, with corresponding optimum nitrogen-use rates[a] and yields of rough rice. Philip-Dines. 1969–75.

Condition	Equation[b]	Optimum nitrogen (kg/ha)	Grain yield (t/ha)
	Modern varieties		
Irrigated, dry season	$Y = 1900 + 18\,N - 0.06\,N^2$	75	2.91
Irrigated, wet season	$Y = 2200 + 18\,N - 0.10\,N^2$	45	2.81
Rainfed, wet season	$Y = 1400 + 15\,N - 0.11\,N^2$	27	1.73
	Traditional varieties		
Irrigated, dry season	$Y = 1900 + 11\,N - 0.13\,N^2$	8	1.98
Irrigated, wet season	$Y = 2200 + 11\,N - 0.13\,N^2$	8	2.28
Rainfed, wet season	$Y = 1400 + 9\,N - 0.16\,N^2$	0	1.40

[a] Assuming nitrogen: rice shadow price ratio of 9:1. [b] Where Y is in kilograms of rough rice per hectare, and N is kilograms nitrogen per hectare.

Table 2. Yields attributable to irrigation and optimum nitrogen rates, by variety group and season. Philippines, 1969–75.

Season and water status	Traditional varieties: Optimum nitrogen (kg/ha)	Traditional varieties: Grain yield (t/ha)	Modern varieties: Optimum nitrogen (kg/ha)	Modern varieties: Grain yield (t/ha)
Wet season				
Irrigated	8	2.28	45	2.81
Rainfed	0	1.40	27	1.73
Difference	8	0.88	18	1.08
Dry season				
Irrigated	8	1.98	75	2.91
Total per year[a]	11	1.54	43	2.05

[a]Assuming benefits to 100% of the irrigated area in the wet season and 33% in the dry season.

be found at levels lower than the theoretical optima. Therefore an optimum rate of nitrogen use, defined by the point at which the marginal value of rice is two times the marginal cost of nitrogen (computed as the theoretical optimum with a nitrogen:rice price ratio of 9:1), was calculated for each function. Optimum rate of *N* and corresponding yields were calculated for each function (Table 2).

To estimate the benefits of irrigation at optimum *N,* the difference in yields between irrigated and rainfed crops in the wet season was added to the full yield in the dry season. Yield benefits attributable to irrigation and optimum *N* were thus 0.88 (wet season) and 1.98 (dry season) t/ha for TV and 1.08 (wet season) and 2.91 (dry season) t/ha for MV (Table 2). To compute the yearly gain in production, it was assumed that those benefits can be achieved in the whole irrigated area in the wet season, but on only one-third of that area in the dry season because of limited water availability.

The total yearly production increase attributable to irrigation and optimum *N* is thus 1.54 t/ha of irrigated land for TV, and 2.05 t/ha for MV. The shift from the TV to MV group, when accompanied by optimum *N,* increases productivity by about 0.5 t/ha per year, or about 30%, which explains some of the interest in irrigation development since MV have become widely planted.

Although this analysis emphasizes production increments attributable to irrigation, the role of nitrogen should be noted. If farmers who shift from TV to MV do not apply nitrogen at rates greater than the optimum for TV, their yield increase in either season would be less than 0.1 t/ha (5%).

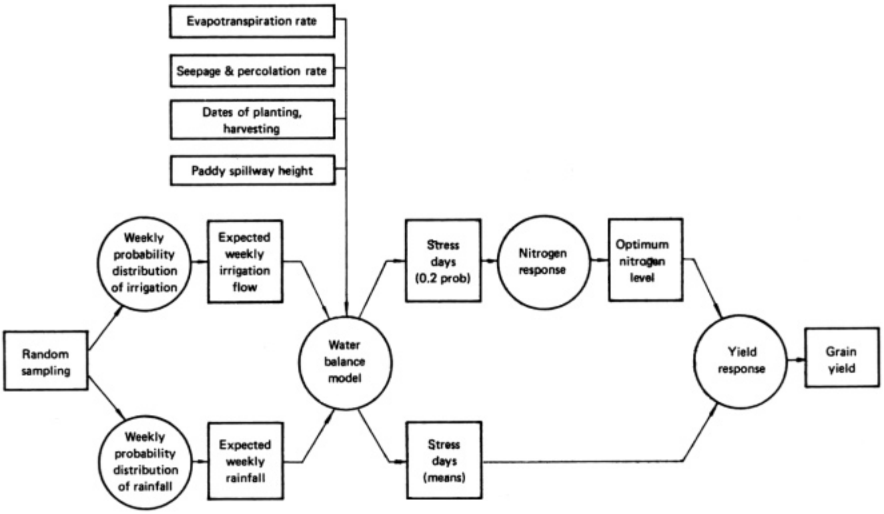
WATER-BALANCE MODEL AND VARIABLE IRRIGATION PERFORMANCE

The yield effects of irrigation discussed in the previous section are limited to comparisons of production with no irrigation and with average irrigation. This section treats the adequacy of irrigation as an explicit variable, and estimates yields for conditions of poor irrigation, average irrigation, and good irrigation. In addition, it analyzes ideal irrigation, reflecting full water adequacy throughout crop growth. The procedure considers the full range of variable irrigation instead of representing all irrigation by a mean value, and can be used with long-term rainfall and irrigation data to derive a long-term expected outcome. (Rosegrant, 1976).

The model is adapted from earlier work (IRRI, 1973; Wickham, 1973) in which the daily water status in the field was computed by the balance of the water sources (irrigation and rainfall) less water sinks—evapotranspiration (ET), seepage and percolation (S&P), and surface drainage. During periods of low supply and high demand, a water deficit develops and stress days—days when the rice fields are continuously without standing water—accumulate.

The model in our analysis was modified, after preliminary testing, to work on a weekly rather than a daily basis. Thus, stress days were computed from weekly data on irrigation, rainfall, and soil and crop-water use. To calculate expected yields, the number of stress days was used together with the computed optimum rates of nitrogen (Fig. 1). Results representing a wide range of physical environments and many years can be simulated by using different estimates of rainfall and irrigation.

Specification of the model's parameters. To quantify conditions of poor, average, and good irrigation, we obtained the mean weekly irrigation flow rates and their variance for 11 sites studied in 1969–70, and for 4 larger sites in the Peñaranda River Irrigation System, for which flows were measured in 1973.



1. Flow diagram of water-balance model used for simulating stress days and yield of irrigated lowland rice.

Wet- and dry-season flow rates were not significantly different because limited water availability usually offsets the greater water requirements of the dry season. The mean flow rate for all sites and weeks was 79 mm, with a standard deviation of 70 mm. Those parameters were used to describe average irrigation flows.

Good irrigation performance was determined by pooling observations from all sites that had mean weekly flows in excess of the 79-mm average. The new distribution had a weekly mean of 119 mm and a standard deviation of 85 mm. The distribution defining poor irrigation performance came from pooled observations from all sites with weekly flows less than 79 mm; it had a mean of 53 mm/week and a standard deviation of 42 mm/week. Random sampling from each distribution generated a series of variable flows corresponding to poor, average, or good irrigation service.

Other parameters were also specified to enable the water-balance model to generate stress days and yields. A probability distribution of weekly rainfall was computed based on data of 26 years from the Cabanatuan City weather station in Central Luzon. Four planting dates in each season were selected to assess variation caused by planting early or late in the season. To simulate the weekly water status, weekly expected irrigation flows were randomly generated for each of the three levels of irrigation performance by sampling from the corresponding probability distribution. The first week of data generation began with one of the four specified planting dates. Simulated rainfall for the same week was generated by sampling from the rainfall distribution. The water-balance model was then operated for 16 consecutive weeks of simulated data by adding expected weekly irrigation and rainfall, and subtracting estimates of ET, S&P, and surface drainage.

ET rates over large field areas are about equal to open-pan evaporation, which for Central Luzon averages about 28 mm/week for the wet season and 40 mm/week for the dry season. Because ET does not vary much within seasons or among years, those constant estimates were used for each week of the season.

S&P are strongly affected by soils and their topographic position. Thus, the model incorporated minimum, moderate, and high S&P estimates. Representative S&P data are not available, but previous studies (IRRI, 1973, 1976) have shown from 0 to more than 20 mm/day of water loss into the soil. Our analysis used 0 mm/week as the minimum S&P rate for both seasons, and 105 mm/week as the high rate, above which commercial rice production in the Philippines is marginal, even with irrigation. Moderate rates of 14 mm/week for the wet season and 32 mm/week for the dry season were selected to represent conditions of substantial but not excessive losses. Most irrigated rice land in South and Southeast Asia has S&P rates between those minimum and moderate values.

The model computes surface drainage flow rates as residuals for weeks when the computed depth of water on the field exceeds 40 mm, which is assumed to be the effective height of the paddy bunds.

Table 3. Response functions for modern varieties (Rosegrant, 1976).

	Estimated function coefficient[a]	Dry-season coefficient	Wet-season coefficient
Intercept	1079.83**	2485.0	2197.0
Nitrogen (kg/ha)		20.6	16.2
Nitrogen × solar radiation[b]	.91**		
Nitrogen squared	–.06**	–.06	–.06
Stress days[c]	110.68**	–91.6	–47.8
Phosphorus (kg/ha)	3.81**		
Weeding dummy 1[d]	160.11**		
Weeding dummy 2[e]	297.94**		
Insect-damage index (% infestation)	–7.87**		
Insecticide (P)	1.47*		
% clay	28.40**		
Nitrogen × stress	–.39**	–.39	–.39
Solar radiation × stress	–8.95**		
R^2 adjusted	.72		

[a] ** = significant at .01 level. * = significant at .05 level. [b] Solar radiation measured in kilo-calories/sq cm during the period 45 days before harvest to harvest. [c] From 60 days after transplanting to 20 days before harvest. [d] One application of herbicide. [e] One application of herbicide plus one hand weeding.

One hundred simulated outcomes for the same set of input conditions proved sufficient for computing stable estimates of stress days. Mean stress days for each season were computed by averaging those for each of the four planting dates. Only the number of stress days computed for the 8th through the 12th week of the crop is used in the analysis, however, because that period is critical for crop growth. Stress during that time most markedly affects yields (IRRI, 1973). Including in the model stress days from the earlier or later periods of crop growth did not add significantly to its precision.

When the number of stress days is known, the optimum nitrogen level and grain yield are calculated with the response function for MV shown in Table 3. This function is estimated from a data set, combined across years and seasons, collected in two IRRI projects:

1. An intensive survey of management practices and environmental factors conducted in Gapan, Nueva Ecija, during the 1972 wet and 1973 dry seasons; and

2. Yield response experiments conducted in farmers' fields in Bulacan and Nueva Ecija during the 1973 wet and 1974 dry seasons (Reyes and Mandac, 1972; Nagaki, 1973; Mandac, 1974). The response functions in Table 3 show only the functional relationship between yield, nitrogen input, and stress days with values of other variables held constant at the mean.

Dry-season simulations. Dry-season simulation gave mean stress days ranging from 2.6 for the most favored combinations of circumstances to 18.8 for the least favorable combinations (Table 4). The year-to-year variation in stress days computed by random sampling from the rainfall and irrigation distributions also permitted estimation of stress days for relatively wet or dry years. Thus the tabulation includes the number of stress days for each set of conditions that could be expected in 20% of years having the least rainfall and irrigation. Stress days expected with 0.2 probability ranged from 3.5 for the most favorable water status to 21.4 for the least favorable, substantially greater than the values reflecting mean irrigation and rainfall (Table 4).

The equation relating stress days and *N* to yield in the dry season is

$$Y = 2485 + 20.6\ N - 0.06\ N - 0.06\ N^2 - 91.6\ S - 0.39\ NS \qquad (1)$$

where Y = kg paddy/ha, N = kg N/ha, and S = number of stress days from the 8th to the 12th week. (Substituting a dry-season average of 7 stress days for *S* makes the equation equivalent to the first equation in Table 1.)

In the previous analysis optimum *N* was defined by equating its marginal cost with the marginal value of rice production, but the resulting *N* level was discounted for risk by assuming that the ratio of the price of nitrogen to that of rice was double the current value (4.5 to 1).

In this analysis, however, there is a direct measure of risk in stress days occuring with 0.2 probability. It is assumed that farmers would prefer to risk using too little N than too much, and that optimum N use should therefore be consistent with stress days expected in years of 0.2 probability of water adequacy. That accounts for risk caused by variable water status, but risks of insect and disease attack, marketing problems, and other factors still exist. Because of that, the shadow price ratio of N to rice was increased only to 6.5:1. Optimum N can then be computed for each combination of conditions (Table 4).

In estimating the yield effects, the optimum rate of *N* use and mean stress days *S* were supplied in equation 1. Resulting yields ranged from 3.65 t/ha for good irrigation and minimum S&P, to 1.26 t/ha for poor irrigation and high S&P. Ideal irrigation, or that amount required to reduce stress days to 0 gave yields of 4.08 t/ha regardless of S&P rate (Table 4). For conditions of minimum S&P, the poorest and ideal irrigation performance gave yields of 2.53 and 4.08 t/ha, or a difference of about 0.5 t/ha for each irrigation performance level.

Improvements in irrigation performance can give greater yield increments for land with moderate and high S&P rates. If irrigation in the Philippines can be characterized by average irrigation performance and minimum to moderate S&P rates, the expected yield in the dry season would be about 2.85 t/ha, which is similar to that estimated directly from the original production functions (Table 1).

Wet-season simulations. Wet-season simulations were made the same way as those for the dry season except that the yield response equation was

$$Y = 2197 + 16.2\ N - 0.06\ N^2 - 47.8\ S - 0.39\ NS. \qquad (2)$$

The different levels of irrigation performance had little effect on stress days or yield; thus, only the outcomes for average irrigation performance and for rainfed conditions in combination with the three S&P rates were included. Rainfed simulations were computed after deleting all irrigation inputs to the

Table 4. Mean stress days at probability levels and corresponding optimum rates of N Use and grain yield,[a] at four levels of Irrigation performance and three rates of seepage and percolation (S&P)[b], with modern varieties and 24 years of rainfall data from Cabanatuan City, Philippines, 1976.

Irrigation perfor mance[c]	Minimum S&P				Moderate S&P				High S&P			
	Stress days (no.)		Optimum N use (kg/ha)	Grain yield (t/ha)	Stress days (no.)		Optimum N use (kg/ha)	Grain yield (t/ha)	Stress days (no.)		Optimum N use (kg/ha)	Grain yield (t/ha)
	0.2 prob- ability	Mean			0.2 prob- ability	Mean			0.2 prob- ability	Mean		
					Dry season							
Ideal[d]	0.0	0.0	118	4.08	0.0	0.0	118	4.08	0.0	0.0	118	4.08
Good	3.5	2.6	106	3.65	8.2	4.9	91	3.24	13.6	9.6	73	2.52
Average	8.7	5.2	89	3.19	14.7	9.7	70	2.48	19.4	15.1	54	1.72
Poor	15.8	9.0	66	2.53	21.1	15.0	49	1.69	21.4	18.8	48	1.26
					Wet season							
Ideal[d]	0.0	0.0	81	3.12	0.0	0.0	81	3.12	0.0	0.0	81	3.12
Irrigated	2.4	1.6	73	2.94	3.1	2.1	71	2.89	11.3	7.9	44	2.28
Rainfed	8.1	5.1	54	2.55	11.6	7.5	43	2.30	20.4	16.8	14	1.52

[a]Means of 100 trials each for 4 planting dates. Stress days include means and expected values for the second year out of 10 (0.2% probability level), and are computed only during the 8th through 12th week of crop growth. Optimum N is computed using 0.2% probability level stress days and shadow price ratio of 6.5:1 of nitrogen to rice with the equations $Y = 2485 + 20{:}6N - 0.06\ N^2 - 91.6S - 0.39\ NS$ (dry season) and $Y = 2197 + 16.2\ N - 0.06\ N^2 - 47.8S - 0.39\ NS$ (wet season). Yield calculations use mean stress days and optimum N. [b]Minimum, moderate, and high rates of S&P are, respectively, 0,32, and 105 mm/week in the dry season and 0, 14, and 105 mm/week in the wet season. [c]Samples from three distribution made up of above-average, average, and below-average (good, average, and poor) discharges measured from several canal systems, 1969–74. [d]Ideal irrigation eliminates all stress days regardless of the amount of water required. Corresponding yields are computed directly without simulation.

model. Yields derived from ideal irrigation were tabulated to show the potential yields with existing farm-level technology where water is not limiting.

For minimum S&P rates, yields were about 2.55 t/ha for rainfed rice, 2.94 t/ha with average irrigation, and 3.12 t/ha with ideal irrigation (Table 4). For moderate S&P rates, rainfed yields were 2.30 t/ha and irrigated yields 2.89 t/ha. For high S&P rates rainfed yields were 1.52 t/ha and irrigated yields 2.28 t/ha. With a national estimate of S&P as between the minimum and moderate rates, the yield benefit from irrigation and optimum N in the wet season averages about 0.5 t/ha, with another 0.2 t/ha attainable if irrigation eliminates all stress days.

The yield benefit attributable to wet-season irrigation by this model is only half that found through the production function approach (Table 2). The difference can be explained by the different soils and topography. Irrigated soils are low-lying and usually have S&P rates between the minimum and moderate levels assumed in the model. Rainfed land is higher and usually lighter in soil texture, with S&P rates between the moderate and high figures used in the analysis. That difference can be reflected in the results from the model, however. Irrigated yields with S&P between the minimum and moderate rates were 2.9 t/ha, compared with 1.9 t/ha for rainfed yields with moderate to high S&P (Table 4). The 1 t/ha difference is the same as that found in the production function analysis.

It is concluded that current wet-season production, using optimum amounts of N will produce about 1 t/ha more yield on irrigated than on rainfed land, but that the construction of new irrigation facilities on existing rainfed land will result in yield increments of only 0.5 to 0.6 t/ha in the wet season.

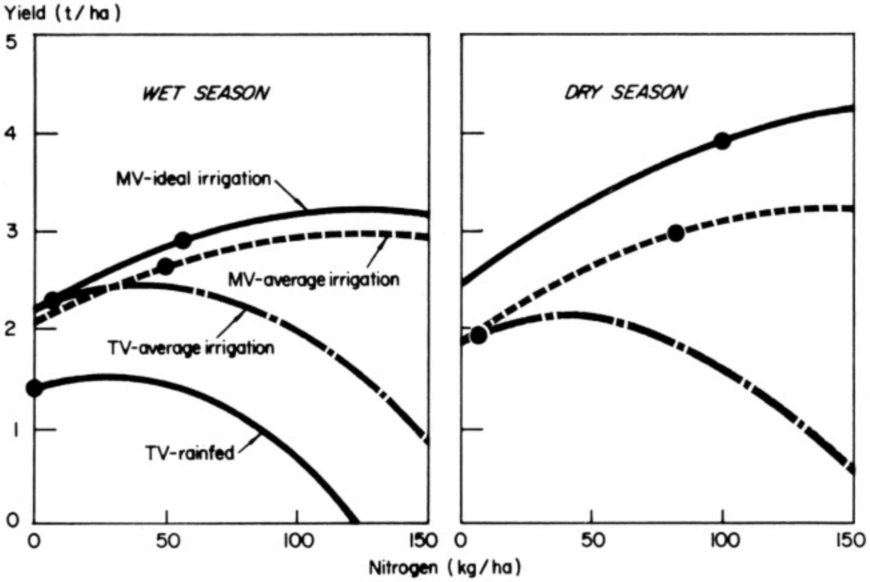
IMPLICATIONS

Our calculations in the previous two sections are summarized in Figure 2 and Table 5. TV functions are based on estimates in Table 1, and MV functions are

Table 5. Mean yields of modern (MV) and traditional varieties (TV) and yield increments due to different levels of irrigation performance[a] at optimum nitrogen rates.

	Yield (t/ha)		
	Dry season	Wet season	Combined[b] seasons
TV – rainfed	–	1.4	1.4
TV – average irrigation	2.0	2.3	3.0
Yield increment – I	2.0	0.9	1.6
MV – average irrigation	2.9	2.9	3.9
Yield increment – II	0.9	0.6	0.9
MV – ideal irrigation	4.1	2.9	4.3
Yield increment – III	1.2	0.2	0.6

[a] TV figures based on Table 1 response function and MV on Table 3, assuming 2 stress days for average wet-season irrigation and 7 stress days for average dry-season irrigation; no stress for ideal irrigation.
[b] Assuming 100% of the command area was served in the wet season and 33% in the dry season.



2. Respons of modern (MV) and traditional varieties (TV) to nitrogen at different irrigation levels. Philippines, 1976 wet and dry seasons.

based on the response equations in Table 3, assuming 2 stress days with average wet-season irrigation and 7 stress days with average dry-season irrigation.

Thus three yield increments are identified in Table 5:

- Yield increment I is the increment due to irrigation of 1.6 t/ha.
- Yield increment II is the increment due to shift to MV after irrigating 0.7 t/ha.
- Yield increment III is the increment due to improved irrigation of 0.6 t/ha.

The link between MV and expanded irrigation can be clearly seen. The introduction of MV increases the output for an additional hectare of irrigation from 1.6 t to 2.3 t, or close to 50%. Assuming a cost of $1000/ha for irrigation, the cost per ton of paddy would be reduced from $625 to $435.

Providing the basic irrigation infrastructure and introducing MV are generally sufficient to achieve the first two yield increments. That assumes that only one-third of the irrigated area is planted during the dry season, a typical situation in many irrigation projects in Asia.

Much less attention has been paid to achieve the third yield increment, which is the difference between yields with basic irrigation and those associated with ideal irrigation. This increment is estimated at 0.2 t/ha in the wet season and 1.6 t/ha in the dry, or 0.74 t/ha a year, after discounting the benefited area in the dry season.

Much remains to be learned about how to provide full water-adequacy throughout irrigated areas, but some general comments can be made.

- In most cases high-performance irrigation is not precluded by insufficient water at the source. The problem appears to be overuse of water along upstream sections of canals, resulting in excessive wastage and, as a result, insufficient supply to farms at the tail end of the canals (IRRI, 1974). There is usually enough total water but it is not equitably distributed along the canals.

- Achieving the second yield increment is largely a problem of management or control of water, and not one of infrastructure. Some rehabilitation of debilitated systems is often necessary, however, before effective water control can be realized.
- Improved irrigation service requires greater emphasis on the manpower requirements of systems, especially their field staff.
- The indirect benefits of more intensive irrigation management include greater rural employment opportunities through increased field staff, more reliance on local rather than foreign resources, and reduced risk in crop production. Thus, farmers can quickly adopt better cultural practices and attain still higher crop yields.

REFERENCES CITED

DAVID, C. C., and R. BARKER. 1978. Modern rice varieties and fertilizer consumption. Pages 175–211 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

HAYAMI, Y., R. BARKER, and E. BENNAGEN. 1977. Price incentives vs. irrigation investments to achieve food self-sufficiency in the Philippines. Am. J. Agric. Econ. 59:717–721.

INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI). 1972. Annual report for 1971. Los Baños, Philippines. 238 p.

INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI). 1973. Annual report for 1972. Los Baños, Philippines. 246 p.

INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI). 1975. Annual report for 1974. Los Baños, Philippines. 384 p.

INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI). 1976. Annual report for 1975. Los Baños, Philippines. 479 p.

MANDAC, A. M. 1974. An economic analysis of factors affecting yield of rice in 1973–74 Central Luzon farmer's field experiments. Paper presented at a Saturday seminar, December 7. International Rice Research Institute, Los Baños, Philippines. 34 p. (mimeo.)

NAGAKI, M. 1973. A biological production function and identification of constraints of on-farm rice yields. Paper presented at the Agricultural Economics seminar, August. International Rice Research Institute, Los Baños, Philippines.

REYES, R. D., and A. M. MANDAC. 1972. Identification of some on-farm constraints to high rice yields: an approach. Paper presented at a Saturday seminar, December. International Rice Research Institute, Los Baños, Philippines. (mimeo.)

ROSEGRANT, M. 1976. The impact or irrigation on the yield of modern varieties. Department of Agricultural Economics Paper No. 76–28. International Rice Research Institute, Los Baños, Philippines.

ROSEGRANT, M. 1977. Risk and farm decision-making: a model of policy analysis. Paper presented at a Saturday seminar, International Rice Research Institute. Los Baños, Philippines.

WICKHAM, T. 1973. Predicting yield benefits in lowland rice through a water balance model. Pages 155–181 *in* International Rice Research Institute. Water management in Philippine irrigation systems: research & operations. Los Baños, Philippines.

COMMENTS ON COMPLEMENTARITIES AMONG IRRIGATION, FERTILIZER, AND MODERN RICE VARIETIES

L. SMALL

WICKHAM, BARKER, AND ROSEGRANT (WBR) use two approaches to estimate the increase in rice yields attributable to irrigation. The first approach is based on a series of simple response functions relating yield to nitrogen. The second approach uses a more complex form of the response function, in which yield is a function of both nitrogen and drought stress. Using simulation analysis with a water-balance model, WBR estimate the impact of irrigation on drought stress, and thus on yield. Three yield components attributable to irrigation are identified: increment I due to the introduction of irrigation in a rainfed area, increment II due to the switch from traditional variety (TV) to modern variety (MV) induced by irrigation, and increment III due to the improvement of irrigation quality from average to ideal.

As with any interacting inputs, a complete separation of the effects of irrigation, nitrogen, and MV is impossible. Allocation of the potential increase in yield due to irrigation requires assumptions about the presence or absence of the other inputs. No one assumption will be appropriate in all circumstances. I propose a more explicit framework for the categorization of the effects of modern inputs on rice yields. With this categorization, estimates of the impact of irrigation, which somewhat differ from the WBR estimates, are developed. Finally, the results are used to suggest an approach to the analysis of the relative impact of extending irrigation to areas with differing initial rates of utilization of MV.

Irrigation may affect rice yields in at least three ways.

- Yields may be improved as a direct effect of more favorable water conditions. This component of yield increase may occur with little active farmer response to irrigation.
- Irrigation may increase yields indirectly by increasing the farmer's incentive to use, or to increase the use of, complementary inputs. This component is realized only to the extent that farmers actually respond to the incentive.
- Irrigation may create the potential for an additional crop. Achieving this component of yield increase often requires that farmers substantially alter their work patterns.

Assistant professor, Department of Agricultural Economics and Marketing, Cook College, Rutgers University, New Brunswick, New Jersey, USA,

Table. 1. Estimated paddy yields at differing levels of modern inputs.

Season and case no.	Description of irrigation and fertilizer input levels	Traditional varieties (TV)		Modern varieties (MV)		Increase in yield due to MV	
		N[a] (kg/ha)	Yield (t/ha)	N[a] (kg/ha)	Yield (t/ha)	t/ha	Percent of yield of TV
Wet season							
1	Rainfed, no N	0	1.90	0	1.90	0	0
2	Rainfed, optimum N[b]	0	1.90	50	2.43	0.53	28
3	Average irrigation, N same as in Case 2	0	2.20	50	2.72	0.52	24
4	Average irrigation, optimum N	8	2.28	72	2.90	0.62	27
5	Ideal irrigation, N same as in Case 4	8	?	72	3.05	?	?
6	Ideal irrigation, optimum N	?	?	81	3.12	?	?
Dry season							
7	Average irrigation, no N	0	1.90	0	1.90	0	0
8	Average irrigation, optimum N	8	1.98	80	2.89	0.91	46
9	Ideal irrigation, N same as in Case 8	8	?	80	3.75	?	?
10	Ideal irrigation, optimum N	?	?	118	4.08	?	?

[a] Elemental nitrogen. [b] Based on a shadow price ratio for the price of N to the price of paddy of 9:1.

These differences in the necessary farmer response to irrigation suggest the usefulness of an approach that permits the estimation of each of the three effects of irrigation.

The basic information necessary for the estimation of these yield effects is in Table 1. In general, the Table 1 figures for TV are based on the simple nitrogen-response equations presented by WBR, while MV figures are based on the more complex nitrogen-drought stress response functions used with the water-balance model. All the figures should have been calculated from nitrogen-drought stress response functions. But that was not possible because WBR limited the analysis of those response functions to MV. According to WBR the stress days are 6.3 for rainfed, 2.0 for wet-season average irrigation, and 7.0 for dry-season average irrigation. Zero stress days are assumed for ideal irrigation. The optimum levels of nitrogen for MV are based on Table 4 of WBR.

The only significant exception in Table 1 to the use of the WBR response functions is for the yield of rainfed TV. The simple nitrogen-response functions indicate that in the absence of nitrogen, the yields of rainfed TV and MV will be equal at 1.4 t/ha. Yet the response function of nitrogen-drought stress for rainfed MV with no nitrogen gives 1.9 t/ha. That illustrates a defect in using simple nitrogen-response functions to estimate the impact of irrigation. The amount of drought stress for a given rainfall situation depends not only on the availability of irrigation, but also on seepage and percolation (S & P) losses.

The simple nitrogen-response function approach measures differences in yields due to both irrigation and the underlying soil conditions. If, as WBR state, irrigated rice tends to be on soils with low S&P losses, while rainfed rice tends to be on soils with higher S&P losses, then the simple nitrogen-response function approach overestimates the impact of irrigation. Raising the rainfed yield of TV to 1.9 t/ha attempts to correct for that bias. WBR do not correct for the bias in their final table summarizing the effects of irrigation. Their figures thus overestimate the impact of irrigation by about 0.5 t/ha.

The various combinations of input levels shown in Table 1 illustrate the three types of effects irrigation may have on yields. The direct effect of improved water conditions is shown by the differences between Cases 2 and 3 with the introduction of irrigation, and by the differences between Cases 4 and 5 (wet season) and Cases 8 and 9 (dry season) with the improvement of irrigation.

The potential yield increases resulting from the increased use of inputs complementary to irrigation (nitrogen and MV) are also shown in Table 1. The impact of the nitrogen input can be observed in the difference in yields between irrigation with nitrogen held constant and irrigation at the optimum level of nitrogen. Information on how irrigation affects the incentive to switch from TV to MV is presented both in absolute and in relative terms in the last two columns of Table 1. It is immediately obvious that the incentive to switch to MV is much greater in the dry season that in the wet season. Also obvious is how slightly irrigation affects the incentive to switch to MV in the wet season. The introduction of irrigation in a previously rainfed area raises the expected differential between TV and MV by only about 90 kg/ha.

Because the wet-season irrigation equations represent some kind of average of highly variable conditions, it seems clear that many farmers in irrigated areas would experience little or no incentive to switch to MV in the wet season. These results are consistent with the frequent observation that many farmers who grow MV in the dry season continue to use TV on part or all of their land in the wet season.

The third effect of irrigation — production of an additional crop — is indicated by Case 7, which shows the yield expected for a dry-season crop assuming that no fertilizer is used. Although it is a large effect, its overall impact is reduced by the fact that irrigation water is seldom adequate to irrigate more than a fraction of the total area in the dry season. WBR estimate this fraction as about one-third.

Because the yield increase attributable to irrigation depends on the sequence of use of complementary inputs, estimates for alternative sequences are presented in Table 2 for both the wet and the dry season. Sequence A involves the use of MV prior to the availability of irrigation. Sequence B involves the introduction of irrigation into an area where TV are grown, followed by a switch to MV, followed by the improvement of irrigation. The *incremental* yields resulting from each indicated step in the technology use sequence, and the total increase in yield attributable to irrigation are shown. The figures in the

Table 2. Estimated components of yield increase attributable to irrigation under alternative sequences of complementary inputs.

Season and sequence[a]	Incremental yields (t/ha) with the adoption of						Total increase in yield due to irrigation	Yield increment[b]		
	Average irrigation	N1	MV	N2	Ideal irrigation	N3		I	II	III
Wet season										
A	0.29	0.18	–	–	0.15	0.07	0.69	0.47	0	0.22
B	0.30	0.08	–0.06	0.68	0.15	0.07	1.22	0.38	0.62	0.22
Dry season[c]										
A	1.90	0.99	–	–	0.86	0.33	4.08	2.89	0	1.19
B	1.90	0.08	0.00	0.91	0.86	0.33	4.08	1.98	0.91	1.19
Total per year[d]										
A_w, A_d	0.92	0.51	–	–	0.44	0.18	2.05	1.43	0	0.62
B_w, B_d	0.93	0.11	–0.06	0.98	0.44	0.18	2.58	1.04	0.92	0.62
B_w, A_d	0.93	0.41	–0.06	0.68	0.44	0.18	2.58	1.34	0.62	0.62

[a] Sequence A: modern varieties (MV) used at optimum N; provision of average irrigation; increase in N to the optimum for average irrigation (N1); improvement of irrigation to ideal; increase in N to optimum for ideal irrigation (N3). Sequence B: N at optimum level for rainfed conditions; provision of average irrigation; increase in N to the optimum for average irrigation (N1); adoption of MV; increase in N to new optimum (N2); improvement of irrigation to ideal; increase in N to optimum for ideal irrigation (N3). [b] Yield increment I=average irrigation + N1; increment II = MV + N2; increment III = ideal irrigation + N3. [c] Per hectare irrigated. [d] Per hectare of command area, assuming benefits to the entire area in the wet season, and to one-third of the area in the dry season. The subscripts w and d refer to the wet and dry seasons, respectively.

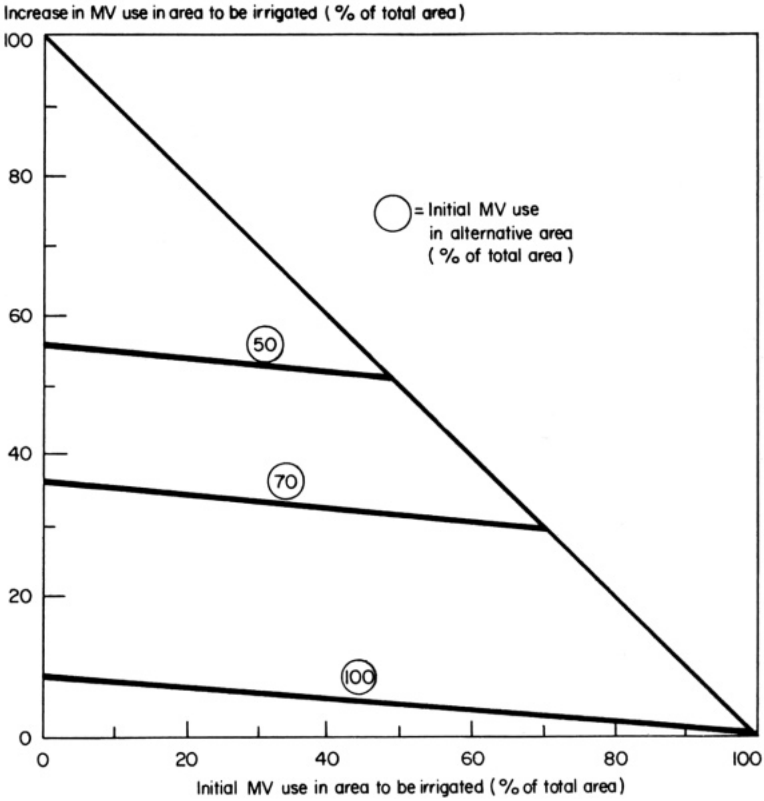
final three columns of the table show the magnitude of yield increments I, II, and III identified by WBR.

The figures in Table 2 show a slight decrease in wet-season yield when MV are adopted after irrigation (sequence B). This results from a peculiarity of the response functions used by WBR. With no nitrogen, the yield of irrigated TV indicated by the simple nitrogen-response function is about 100 kg/ha more than is indicated for MV by the nitrogen-drought stress response function. Thus, at low levels of nitrogen, the equations indicate that yields are higher for the TV.

Alternative estimates of the average annual yield increase due to irrigation are shown in the last three lines of Table 2. These figures assume that water availability limits dry-season irrigation to one-third of the command area. If MV are already grown prior to the introduction of irrigation (sequence A for both the wet and dry seasons), the total yield attributable to irrigation is estimated to be 2.05 t/ha of command area. Alternatively, if irrigation induces a shift from TV to MV in both seasons (sequence B for both seasons) then the comparable yield effect is estimated to be 2.58 t/ha. This is the assumption that WBR used in presenting their estimates of the three yield increments attributable to irrigation. The figures for the three increments in the next to the last line of Table 2 are thus the same as those of WBR, with the exception of the 0.5 t/ha discrepancy for the first increment, which is due to bias as pointed out earlier.

The figures in Table 2 facilitate the comparison of the potential benefits of introducing irrigation into areas where TV are grown and of building irrigation facilities in alternative areas where MV are grown. Considering only yield increment I, the yield effect of introducing irrigation in an area already growing MV is 1.43 t/ha, compared with only 1.04 t/ha for areas where TV are grown. This tends to favor the extension of irrigation into areas already growing MV. But because the construction of irrigation facilities may induce the use of MV, the benefits of irrigation may be larger in areas where TV are grown.

A somewhat different perspective is obtained by recognizing that the sequence of technology adoption in the wet season is likely to be different from that in the dry season. Given the strong incentive to use MV in the dry season, it appears reasonable to assume that sequence A will be followed in the dry season (i.e., MV will be used immediately upon the introduction of irrigation). Combining this sequence of technology utilization with sequence B for the wet-season results in the figures presented in the last line of Table 2. This raises yield increment I in areas where TV are grown to 1.34 t/ha, which is only 0.09 t/ha below yield increment I for areas already growing MV. If there are good



1. Relationship between use of modern varieties (MV) in an unirrigated area and the increased use of MV which must be induced upon the introduction of irrigation if irrigation gross yield benefits per hectare are to equal potential irrigation benefits at an alternative site. (The relationship is shown for three different levels of initial MV use in the *alternative site,* assuming that the entire area of the *alternative site* would be planted to MV after the introduction of irrigation.)

reasons to expect that irrigation will induce a substantial shift to MV, the payoff from extending irrigation into areas where MV are not grown may be greater than that from extending it in areas where MV are already grown as rainfed rice. (This assumes that the cost of extending irrigation into the two areas is the same.) The entire shift to MV must, however, occur in the wet season (by assumption regarding the wet- and dry-season sequences of technology use), when the incentive to switch is relatively small. Given the variability in wet-season conditions, it would be necessary to consider each case separately in terms of the likely incentive to switch to MV after the introduction of irrigation.

The yield increment figures in the last three lines of Table 2 can be converted to estimates of gross irrigation benefits by subtracting from each increment the paddy equivalent of the resource cost of the additional inputs complementary to irrigation used to achieve the increment. It is then possible to determine the magnitude of the switch to MV that would be required for gross irrigation benefits in an area where TV are grown to equal the gross benefits that could be expected in an alternative area where MV are grown. The required switch depends on the proportion of the former area planted to TV (few areas would be completely devoted to TV); the proportion of the alternative area planted to MV; and the proportion of the alternative area which would switch from TV to MV after the introduction of irrigation. These relationships are depicted graphically for certain assumptions in Figure 1. The derivation of the equations showing these relationships is presented in the appendix.

APPENDIX

Derivation of equations graphed in Figure 1

Let:

B_A = per-hectare benefits resulting from the introduction of irrigation in fields where MV are already grown (derived from yield increment I, sequence A_w, A_d in Table 2);

B_B = per-hectare benefits derived from the introduction of irrigation in fields where TV are grown (derived from yield increment I, sequence B_w, A_d in Table 2);

B_C = per-hectare benefits derived from the switch to MV after the introduction of irrigation (derived from yield increment II, sequence B_w, A_d in Table 2);

X_1 = proportion of the proposed area planted to MV prior to irrigation;

X_2 = proportion of the alternative area planted to MV prior to irrigation;

Y_1 = proportion of the proposed area which will shift to MV following irrigation;

Y_2 = proportion of the alternative area which will shift to MV following irrigation.

Then the expected benefits of the introduction of irrigation (including the benefits resulting from the induced switch to MV) are:

$$X_1B_A + (1 - X_1)B_B + Y_1B_C \text{ (for the proposed area)} \tag{1}$$

$$X_2B_A + (1 - X_2)B_B + Y_2B_C \text{ (for the alternative area)} \tag{2}$$

The main interest is knowing the magnitudes of X_1 and Y_1 which will lead to irrigation benefits greater than or equal to the benefits expected from the alternative area (which in turn depend on the magnitudes of X_2 and Y_2). Irrigation benefits will be equal in the two areas when equation 1 equals equation 2, i.e., when:

$$X_1B_A + (1 - X_1)B_B + Y_1B_C = X_2B_A + (1 - X_2)B_B + Y_2B_C \tag{3}$$

Solving for Y_1 in terms of X_1, we have

$$Y_1 = Y_2 + \frac{B_A(X_2 - X_1) + B_B\,[(1 - X_2) - (1 - X_1)]}{B_C} \tag{4}$$

$$Y_1 = Y_2 + \frac{(B_A - B_B)X_2}{B_C} - \frac{B_A - B_B}{B_C}X_1 \tag{5}$$

Thus, for any given values of X_2 and Y_2, Y_1 is a linear function of X_1. Because the incremental cost to society of a switch from TV to MV is essentially zero, the yield figures in Table 2 can be converted to gross irrigation benefits by subtracting the paddy equivalent of the additional nitrogen. Using the actual price ratio of nitrogen to paddy of 4.5: 1, gross irrigation benefits calculated from the yield increments in Table 2 are 1.21, 1.18, and 0.33 t/ha for B_A, B_B and B_C, respectively. Substituting these figures into equation 5 gives:

$$Y_1 = Y_2 + 0.09X_2 - 0.09X_1 \tag{6}$$

Using the appropriate values for X_2 and Y_2 in this equation gives the equations for the lines plotted in Figure 1, as shown below.

X_2	Y_2	Equation	
1.0	0	$Y_1 = 0.09 - 0.09X_1$	(7)
0.7	0.3	$Y_1 = 0.36 - 0.09X_1$	(8)
0.5	0.5	$Y_1 = 0.55 - 0.09X_1$	(9)

Thus, gross irrigation benefits in the proposed area will be greater than potential benefits in an alternative area whenever Y_1 is greater than the value derived from equation 6.

SOCIAL BENEFITS

Social returns to rice research

R.E. EVENSON AND P.M. FLORES

AGRICULTURAL RESEARCH PROGRAMS have become increasingly subject to economic analysis in recent years. These analyses have also become somewhat more sophisticated through time, moving from simple benefit-cost calculations to statistical models based on technology transfer specifications. Concurrently, investment in research to produce new technology has gained importance in the policy arena. The lessons of many agricultural development programs have shown that little program impact can be expected unless new technology is part of the program. But new technology generally is not easily transferred across differing environments. Consequently, the role of research programs designed to produce new technology for the tropics is now given more prominence in development plans and policies.

The experience of rice research programs in tropical Asia has much to tell us about the process of crop improvement generally. Rice improvement has been characterized by incomplete technology transfer across environmental barriers, by investments in environmental modification to facilitate technology transfer, by the relatively early development of national rice research programs, and, more recently, by the development of the International Rice Research Institute (IRRI) research program.

We draw some policy lessons from that experience. We develop an analytic framework suited to the quantification of costs and benefits associated with rice research, to some of the distributional effects of the new technology produced, and to technology-environment interactions that limit the transfer of new technology across different environments. Empirical sections on costs and estimated benefits follow. A final section discusses organizational possibilities for future rice research.

Visiting professor, Institute of Agricultural Development and Administration, University of the Philippines at Los Baños, Philippines; and research assistant, Department of Agricultural Economics, International Rice Research Institute, Los Baños, Philippines.

INVESTMENT IN RICE RESEARCH PROGRAMS

The investment in research to improve rice technology can be estimated by drawing on a recent survey by Boyce and Evenson (1975) along with detailed data for the Philippines from Flores (1975). Estimates for countries other than the Philippines are based on the data for total research and extension investment by Boyce and Evenson and on an estimate of the proportion of the total directed toward rice improvement based on scientific publications data.[1] The extension investment was estimated by applying to the rice research expenditures data the ratio of total extension expenditures to total research expenditures. The procedures provided estimates that were consistent with the Philippine data.

Table 1 summarizes rice research and extension investment data and reveals the major patterns. The developed countries, chiefly Japan, invested far more in rice research than South Asian and Southeast Asian countries. In the 1900–1940 period, little investment in rice improvement was made in South and Southeast Asia. Since then, investment in those two regions has increased, but is still low. Investment in extension activities, on the other hand, has been high in the developing regions.

The investment in IRRI's research program is now a significant part of the research investment in developing countries, accounting for perhaps 25% of total rice research expenditures. It should be noted that the national programs in the developing countries expanded their rice research at a slower rate after 1960 than has been the case with general agricultural research. The Boyce-Evenson data indicated a growth rate of more than 25%/year in total investment in agricultural research in South and Southeast Asia for the 1951–65 period. That growth declined to about 9% for the 1966–75 period. The comparable growth rates for investment in rice research appear to have been about 5% and 3% for the same periods.

Table 2 provides details for rice production and research by country. The predominance of Asian countries in production is readily apparent, but many important rice-producing nations opted not to aggressively pursue rice research programs. Indonesia, Burma, Thailand, and the Philippines, for example, chose to fund small research programs. Comparisons that are made, however, should recognize that researcher salaries were low in those countries and that a dollar bought more man-years.

In Table 3 we group rice-producing countries (and parts of countries) by a geoclimate classification system. The system (Papadakis, 1966) allows a comparison of different production environments. This is important because of

---

[1] Publication data by commodity orientation of the research were collected from *Plant Breeding Abstracts, Dairy Science Abstracts* — major abstracting journals that screen for international significance and classify by commodity orientation. Utilizing U.S. data on Scientist Man-Years (SMY) by commodity, the publications were standardized to correct for differences in publications per SMY by commodity. The proportion of standardized rice publications to the total commodity-oriented standardized publications estimated the total research oriented to rice.

Table 1. Annual investment in rice research and extension: historical series (million 1970 constant US dollars).[a]

Period	East Asia[b]		Southeast Asia		South Asia		Other developed countries		Developed countries		IRRI research
	R[c]	E[c]	R	E	R	E	R	E	R	E	
1900–20	0.9		–	–	0.1	–	0.5	1.0	1.0	0.5	–
1921–40	2.7	1.9	0.1	0.5	0.3	1.0	1.0	2.0	2.0	1.0	–
1951–55	10.0	3.0	2.1	3.0	1.7	2.7	1.5	3.0	5.0	3.0	
1956–60	17.5	4.9	2.0	3.7	1.8	2.9	1.8	3.5	5.5	3.1	1.0
1961–65	32.0	7.1	2.7	5.7	3.0	4.8	3.0	6.0	7.0	3.5	1.8
1966–70	45.0	17.1	3.2	7.2	4.0	11.0	5.0	10.0	8.0	4.0	2.9
1971–75	48.2	18.3	3.1	7.2	4.4	11.7	7.1	12.0	11.2	5.5	4.0

[a] Computed from Boyce and Evenson (1975). [b] Excluding People's Republic of China. [c] R = research; E = extension.

Table 2. Rice production, yields, and research in selected regions and countries, 1–74.

Region	Average production (thousand t)		Average yield/ha (hundred kg)		Yield ratio 1969–72; 1948–52	Research expenditures (1971 thousand US$)	
	1948–52	1969–72	1948–52	1969–72		1959	1974
Southern Europe	1280	1774	42.9	44.6	1.0	1290	2/73
Oceania	90	280	36.1	58.0	2.1	97	360
USSR		1363		36.6	–	1935	6800
Africa	3400	7368	12.1	18.3	1.5	1050	2308
UAR	971	2552	37.9	52.9	1.4	625	225
Malagasy Republic	829	1881	13.5	19.6	1.4	10	30
USA	1920	3934	25.2	58.9	2.3	1200	2250
Central America	580	1387	15.1	18.2	1.2	100	1200
South America	4120	9838	17.1	16.7	.97	700	3600
Brazil	3025	7165	15.7	14.4	.92	197	1950
Other S. America	1045	2674	22.7	28.8	1.3	300	1330
Asia	141500	275736	16.3	22.8	1.4	25230	60940
Bangladesh	10000	15964	13.8	16.2	1.2	30	120
Burma	5309	7970	14.1	16.7	1.2	20	40
China (People's Republic)	48860	104148	23.4	30.6	1.3	(500)	(5000)
China (Taiwan)	2380	3180	31.0	41.0	1.3	400	1700
India	33382	61771	11.1	16.6	1.5	1600	3900
Indonesia	9441	18566	16.3	22.9	1.4	96	550
Iran	432	1121	16.2	29.9	1.8	50	250
Japan	11939	16081	40.0	55.7	1.4	17000	46000
Khmer Republic	1372	2744	12.2	14.4	1.2	50	100
Korea (North)		2738		39.1		50	200
Korea (South)	2500	5548	27.8	46.1	1.7	100	250
W. Malaysia	629	1496	16.7	28.1	1.7	880	1460
Nepal		2200	n.a.	18.0	–	50	100
Pakistan	2400	3108	13.8	20.7	1.4	144	210
Philippines	2767	5162	11.9	16.1	1.4	900	500
Thailand	6845	13056	13.1	19.3	1.5	70	300
Vietnam (North)		4775	n.a.	9.7	–	20	40
Vietnam (South)		5843	n.a.	23.0	–	20	120
Other Asia	5200	3547	n.a.	n.a.	–	100	200

Table 3. Rice production, yields, and research expenditures by climate zone.

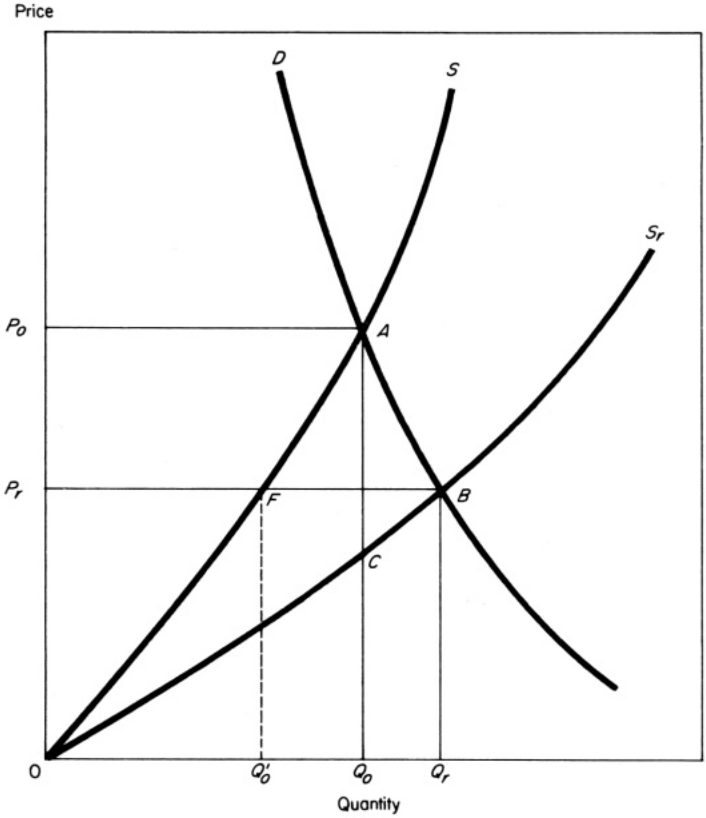
Climate zone[a]		Production (thousand t)		Research expenditures (thousand US$)		Research expenditures per thousand t	
		1959	1970	1959	1974	1959	1974
1.1	Humid semi-hot equatorial	36,841	36,266	1,896	3,038	.06	.09
1.2	Humid semi-hot tropical	4,100	4,100	250	850	.06	.20
1.4	Hot tropical	23,600	34,300	1,190	2,160	.05	.07
1.6	Cool winter – hot tropical	17,647	27,147	360	500	.02	.02
2.1	Highland tropical	2,500	3,500	100	200	.04	.05
3.2	Hot subtropical desert	2,850	4,200	200	500	.07	.11
4.1	Humid sub-tropical	32,000	51,000	1,100	2,750	1.04	.05
4.2	Dry sub tropical	39,000	54,000	1,400	2,600	.04	.05
8.1	Warm humid continental	15,780	27,215	11,150	33,000	.70	1.21
8.2	Semi-warm humid continental	4,100	7,600	6,000	14,000	1.46	1.84
Tropical region production type							
	Upland	27,200	33,800	900	1,000	.02	.03
	Shallow water	53,000	78,500	2,500	9,200	.05	.12
	Intermediate depth water	59,000	82,800	2,400	4,000	.04	.05
	Deep water	12,000	17,000	200	400	.02	.02

[a] Based on Papadakis (1966).

current evidence that relatively little new technology is transferred from one producing environment to another. The data show the glaring differential between the tropical and subtropical regions and the temperate developed-country regions (8.1 and 8.2). The table also provides a breakdown by type of production environment. The relative neglect of upland and deep-water rice is apparent. However, even the investment in shallow-water rice research is low relative to that in the developed-country regions.

MEASURING BENEFITS

Where it is possible to clearly associate a set of improved technologies with a particular research program or program, the analysis of the payoff to research investment is relatively straightforward. Basically, what is required is an estimate of the shift in the supply function due to the improved technology. It is more complex, however, when, because of significant transfer of technology



1. Model for estimating social returns to rice research in the Philippines.

between countries or between regions within a country, it is not possible to associate supply function shifts with specific research programs.

The Marshallian concepts of consumers' and producers' surplus can be applied to the analysis of costs and benefits associated with rice research. In Figure 1, a shift in the aggregate supply curve (from SO to S_rO) is depicted. We can suppose that this shift is the result of the adoption of improved technology developed by a particular rice research program. The shift in the supply curve produces a change in the "consumers' surplus" by the area AP_OP_rB. The same supply shift will produce a change in "producers' surplus" by the area BFO minus the area AP_OP_rF. The total change in economic surplus (producers plus consumers) will be the area AOB.

The model provides a convenient organization of the concepts behind the measurement of benefits from research. The benefits are measured in "welfare units."[2] The division of the gains between consumers and producers is inherent in the measured changes in consumers and producers' surplus. Given estimates of demand and supply, one can allocate the gains to producers and to consumers. It can readily be seen that the producers can sustain losses from technical change.

The model applies to either a closed economy or an open economy. The demand elasticities in an open economy will, of course, be quite high. The model can also be modified to take into account price policies such as those that have been maintained in the Philippines where rice imports have been utilized to maintain a stable price for consumers, and sufficient rice is imported to maintain a target domestic price.

Let P_r in Figure 1 be the target price. With the original domestic supply function, the quantity FB would have been imported. The shift of the supply function to S_rO would eliminate rice imports. Consumers' surplus would remain unchanged, but producers' surplus would increase by the area OFB. This area represents a welfare gain to society and is equal to the change in the resources devoted to domestic rice production $OBR_r - OFQ_o'$ plus the value of the initial imports, Q'_oFBQ_r (an additional gain could be realized if the real value of foreign exchange exceeds the exchange's official value).

This model, however, is basically a static model. It can be made partially dynamic by estimates of annual shifts in supply functions, which are due to research programs. That was done in a number of studies including Griliches' original work measuring the benefits from hybrid corn research.[3] An annual cost series and an annual benefits series can thus be produced. The chief difficulty with the approach is that an essentially arbitrary assumption regarding future benefits and costs must be made in order to compute a benefit:cost ratio or a rate of return to investment.

The usual practice is to adopt a "conservative" assumption regarding future benefits and costs. A number of authors assume that costs and benefits will continue at current levels, and thus no further benefits will be realized. Current research costs then are required to "maintain" the current benefits levels. (That assumption is inconsistent with the evidence on which the cost-benefit calculation is made.)

The model can be applied in cases where supply function shifts can be measured and can be associated with research program costs. For example, we have Philippine data that compare yields of modern rice varieties and traditional rice varieties. The data can be used to estimate annual supply function shifts and a benefit and cost series can be developed. Given the usual assump-

---

[2] See Harberger (1974) for a discussion of the use of consumers' and producers' surplus as welfare measure.

[3] See Griliches (1958). It should be noted that when this computation is applied to a long-time period it becomes very artificial for two reasons. First, demand functions shift over time, and the size of the market to which the technical change applies grows. In many studies an adjustment for thiseffect is not made. Furthermore, available estimates of suppply elasticities tend to be short-run elasticities. The computations, particularly regarding producers' surplus effect, should be carefully interpreted. They are not predictions of what actually happened to producer or consumer surplus over time. They only purport to measure the impact of technical change as reflected in supply curve shifts.

tion about future benefits and costs, an internal rate of return or a benefit:cost ratio (given an external discount rate) can be computed.

Such a computation, even if possible for all rice-producing countries, is not very informative regarding the rice research process itself. It can provide, however, a global estimate of the returns to rice research and an indication of the allocation of the gains (losses) between consumers and producers. But some countries have little or no national rice research capacity, others have strong national programs, and the international rice research programs have contributed new varietal technology. A more complex model is required to associate research costs and benefits for these conditions. The appendix to this chapter reports the development and empirical estimation of a growth decomposition model designed to investigate these activities.

ESTIMATES OF BENEFITS

The estimation of benefits from rice research in Asia can be approached in two ways. First, the comparative performance of modern (MV) and traditional (TV) varieties can be measured and the data can be used to measure the shift in the supply functions. A computation of the benefits from recent rice research could be made from this calculation. Second, the model discussed in Appendix A can be utilized to estimate the benefits associated both with MV and with national research programs.

Comparative yield data. Several sets of data comparing yields per hectare of MV and TV are summarized in Table 4.

Note that, as to be expected, the estimates are quite variable. Each region differs substantially with respect to producing environments and with respect to the actual MV and TV. It appears that the yield advantage in South Asia is substantially above that in Southeast Asia. A rough average of the ratios suggests that MV outyield TV by 60% in South Asia and by only 20% in Southeast Asia. Several studies report costs of production data that allow a rough computation of the ratio of the costs of producing a ton of rice from the MV and TV. The costs represent a more accurate picture of superiority, and suggest that the real South Asian margin of superiority is around 25%, while the Southeast Asian margin is in the 15 to 20% range.

The estimates may be compared with the annual estimates for India, the Philippines, and all Asian countries reported in Table 5, but those estimates do not clarify the picture much. The estimates for India appear to be out of line, but they show the declining margin of superiority with increased adoption levels.

The estimates from the Philippines, on the other hand, appear to be lower than indicated by the studies reported in Table 4. The actual farm survey data from the Bureau of Agricultural Economics (BAEcon) are the most reliable data for the Philippines. They tend to show a fairly constant margin of superiority on irrigated farms over time. We note, however, that the ratio is variable

Table 4. Yield comparison: yields of modern varieties (MV) and traditional rice varieties (TV) from selected studies of farmers' yields.[a]

Region	Yield ratio MV:TV		Costs of production ratio MV:TV	
	Wet Season	Dry season	Wet season	Dry season
India				
Andhra Pradesh	1.29	1.71	1.21	1.55
Tamil Nadu	1.56	1.56	1.19	1.19
Uttar Pradesh	2.01		1.25	
Mysore	1.89			
Orissa		1.41		
Indonesia				
West Java		1.30		1.27
Central Java	1.08	1.16		
East Java		1.07		1.19
West Malaysia				
Kelantan	1.00	1.21		
Pakistan				
Punjab		1.6		
Thailand				
Suphan Buri	1.43			
Philippines				
Nueva Ecija	1.25			
Leyte	1.31	1.36		
Cotabato	1.06			
Camarines Sur	1.04			
Iloilo	1.08			
South Cotabato	1.33			

[a] Data for Camarines Sur, Iloilo, South Cotabato in the Philippines are from Mangahas and Librero (1975); those for other sites are from IRRI (1975).

over time, reflecting the incidence of insect and disease problems. Interestingly, the ratio actually rises for the rainfed hectarage. This reflects the fact that the composition of the MV is not constant and that the more recent MV released from IRRI and other research centers have insect and disease resistance plus other traits, a fact that increases their margin of superiority over TV. The margins of superiority based on the parameters estimated for the complex model discussed in the Appendix are also reported in Table 5.

It is difficult to judge which estimates to use. The Indian estimates are the highest and appear unreasonable. The complex model estimates are also somewhat higher than most of the other estimates. One of the reasons for this is that they are based on data only up to 1971. It appears that after 1970–71 the MV were subject to considerable insect and disease damage, which lowered their superiority. Many of the estimates reported in Table 4 are for 1971 or 1972 when some severe insect and disease problems were encountered.

Thus, it seems wise to regard the complex model estimate as a high estimate. We can then develop a low estimate from the other data. The crude average

Table 5. Estimates of annual yield ratios of modern varieties (MV): traditional varieties from selected sources.

	1966–67	1967–68	1968–69	1969–70	1970–71	1971–72	1972–73	1973–74	1974–75
India	2.58	2.18	2.05	2.26	2.27	2.03	1.76	1.71	n.a.
(% MV)	2.5	4.9	7.3	11.3	14.6	19.3	23.2	25.6	29.9
Philippines									
BAEcon Farm Survey									
Irrigated	–	1.23	1.10	1.14	1.05	1.19	1.12	1.09	1.18
% of area in MV		34.0	61.6	61.4	67.0	73.3	70.3	79.9	78.5
Rainfed	–	1.04	1.03	.97	1.02	1.07	1.15	1.22	1.21
% of area in MV		16.9	31.1	38.9	45.4	54.8	56.1	64.0	63.7
All Asia based on general model	1.50	1.47	1.46	1.46	1.45	1.44	1.44	1.43	1.42

Table 6. Estimated cumulated supply function shifts (in percentage units) due to development of high yielding varieties.

	Estimated cumulated shift (%)									
Region[a]	1965–66	1966–67	1967–68	1968–69	1969–70	1970–71	1971–72	1972–73	1973–74	1974–75
India										
H		1.17	2.28	3.37	5.16	6.60	8.59	9.83	10.85	11.88
L		.70	1.37	2.04	3.16	4.06	5.34	6.19	6.86	7.56
Other South Asian countries										
H			.24	1.64	2.62	4.26	6.01	7.68	9.61	8.95
L			.14	1.01	1.63	2.70	3.89	4.90	6.58	5.71
Philippines										
H		1.26	9.45	17.17	18.23	20.72	22.69	21.92	25.13	24.42
L		.38	2.97	5.68	6.09	7.04	7.88	7.56	8.86	8.61
Other Southeast Asian countries										
H	.11	.18	.28	1.04	2.69	4.07	5.82	7.86	9.94	10.44
L	.05	.07	.12	.43	1.18	1.71	2.47	3.38	4.36	4.61
Latin America and Africa										
H				.53	2.55	3.79	16.77	18.95	17.33	17.51
L				.32	1.54	2.30	11.08	12.55	11.55	11.67
All developing countries										
H	.04	.56	1.27	2.37	4.10	5.55	8.51	10.11	11.56	11.98
L	.02	.31	.67	1.19	2.04	2.73	4.43	5.30	6.84	7.06

ratio for Southeast Asia reported in Table 4 is 1.19. The BAEcon data for irrigated hectarage in the Philippines shows an average ratio of 1.14. The ratio including rainfed hectarage is also roughly 1.14. The average ratio for India from Table 4 is 1.63, but this appears to be too high. The ratio based on costs is 1.28. We will use the ratio of 1.14 for the Philippines, 1.19 for other South Asian countries, and 1.28 for all other regions as our low estimate.

Estimated supply function shifts. In Table 6, we report the estimated supply function shifts from the adoption of all MV for different regions. The figures are cumulative. In 1974–75, for example, for all developing countries, the high (H) estimate (based on the complex model) makes production 11.98% higher than it would be if the same total resources were devoted to rice production and production was based entirely on TV. The low (L) estimate is 7.06%.

Of course the MV represent only part of the impact of the research system in the tropics. The complex model provides estimates of the supply function shifts due to national research programs prior to and after the development of MV. It is possible to compute from the regression results (Appendix) the shift in the aggregate production (and supply) function due to the growth in both A-type (applied agronomy and plant breeding) and S-type (related agricultural science) research. In Table 7 we summarize these computations. Each computation is based on the difference in production associated with the actual increase in the relevant knowledge stock of the period noted. Other factors are held constant at mean levels for the period.

In the case of both A-type and S-type knowledge stocks, part of the supply shift occurs in the country performing the research and part occurs in other countries. At low levels of indigenous (A+S) research, the contribution of A-type research in similar countries is positive, indicating a transfer effect. At

Table 7. Annual supply functions shifts due to research: rice production in all developing countries (expressed in percentage unit).

	Annual supply functions shift (%)			
	1950–1960	1961–1965	1966–1971	1972–1975
National A-type research	.093	.151	.461	.284
National S-type research	.137	.212	.459	.423
HW				
Developed by IRRI				
High estimates			.800	.477
Low estimates			.419	.387
Joint IRRI-National				
High estimates			.127	.222
Low estimates			.066	.182
National				
High estimates			.232	.195
Low estimates			.122	.161
Total supply shifts				
High estimates	.157	.319	2.208	1.591
Low estimates	–	–	1.528	1.437

high levels of indigenous research that effect actually becomes negative, indicating that a research transfer substitutes for indigenous research.

The development of MV affects the contribution of national research programs by raising the productivity of A-type research. And, of course, many of the MV have been developed in the national programs. In Table 7 we break down the supply shift of the MV according to the proportion of hectarage planted to MV produced by IRRI and by joint national-IRRI efforts (i.e. with one IRRI parent or grandparent variety). These proportions are estimated on the basis of footnotes in Dalrymple's reports (1974, 1976).

The reader should note that these estimates of supply shifts are expressed on an annual basis, not on a cumulative basis. They are, of course, subject to error of measurement. But on the whole, they are interesting. The supply shifts attributable to rice research prior to 1960 are low because the research system was much smaller then. The green revolution period, of course, shows a high annual shift factor, probably higher than realized in any other crop for a comparable period, with the exception of the semidwarf wheats. The contribution of the research program diminishes in the late green revolution period because of a slackening in national program development.

Computing benefit streams. The conversion of supply function shift estimates into welfare gains (or losses) requires information about demand and supply elasticities. Note, however, that the total gains can be approximated simply by multiplying the shift factors by the value of production effected. Differing elasticities of demand and supply have only a minor effect on the estimates of total welfare gains (they alter the size of the triangle ABC in Figure 1). Different elasticities will, however, have important influence on the distribution of the gains between producers and consumers. For purposes of measuring the total welfare gains we apply a static model developed by Akino and Hayami (1975). Referring to Figure 1, the relevant areas may be approximated as follows:

$$\frac{\text{area } AFB = p\,q\,[k\ (1+\beta)]}{2(\beta+\eta)}$$

$$\text{area } BFO \cong k\,p\,q$$

$$\text{area } AP_oP_rF \cong \frac{k\,p\,q\,(1+\beta)}{\beta+\eta}\left[\frac{1-k(1+\beta)}{2(\beta+\eta)} - \frac{k(1+\beta)}{2}\right]$$

$$\text{area } BFQ_oQ_r \cong k(1+\beta)\,pq$$

where

p is the price of rice,

q is the output of rice,

k is the rate of shift in the rice production function,

$ß$ is the price of elasticity of rice supply, and

(-h) is the price elasticity of rice demand.

Table 8. Estimated annual additional benefits (million US dollars) from rice research.

	Producers' gain		Consumers' gain		Total	
	High	Low	High	Low	High	Low
National A-type						
1950–60	–10.5		21.0		10.5	
1961–65	–22.2		44.5		22.3	
1966–71	–77.4		155.9		78.55	
1972–75	–52.2		107.2		55.1	
National S-type						
1950–60	–15.4		30.97		15.5	
1961–65	–31.4		62.48		31.3	
1966–71	–77.0		155.23		78.2	
1972–75	–77.5		156.07		78.5	
National HYV[a]						
1966–71	–39.1	–20.6	78.5	41.3	39.4	20.7
1972–75	–35.9	–29.7	72.0	59.5	36.1	29.8
Total national						
1950–60	–25.9		52.0		26.1	
1961–65	–53.1		107.0		53.9	
1966–71	–211.41	–186.6	431.7	374.1	220.3	190.4
1972–75	–403.23	–190.1	414.2	387.0	211.0	196.9
IRRI HYV[b]						
1966–71	–133.4	–70.4	270.2	141.7	136.8	71.3
1972–75	–87.3	–60.7	176.0	141.6	88.7	71.9

[a]Priced at US$110/t of palay. [b]Does not include IRRI-national joint varieties.

The price elasticity of demand for rice is estimated in several studies. Nasol (1971) utilized aggregate time series data and derived estimates ranging from –0.23 to–0.47. Scobie and Posada (1976) report estimates from 0 to –0.5. We used–0.3 as an estimate of the short-run elasticity of demand for our calculations.

Estimates of supply elasticities ranged from 0.1 to 0.6. Mangahas et al. (1967) estimated a short-run supply elasticity of 0.3, and a long-run elasticity of 0.5. The studies of Krishna (1963), Behrman (19681, and Mubyarto (1965) report reasonably comparable estimates for other countries. We adopt an estimate of 0.4 for ß.

The estimated "gains" associated with the shifts reported in Table 7 are tabulated in Table 8. The negative producers' gains are simply the result of inelastic demand. This analysis is appropriate for a supply functions shift in a static context. In a dynamic context, however, the demand function will shift through time, and when that is incorporated into the model actual negative effects of technology are realized only when supply functions shift at high rates.

BENEFIT:COST RATIOS AND RATES OF RETURN

Cost and benefit estimates can be combined to produce benefit:cost ratios or internal rates of return provided that we can effectively match cost and benefit

Table 9. Benefit:cost ratios and internal rates of return to rice research and extension.

	Benefit:cost ratios			Internal rate of return		
		1966 – 1975			1960 – 1975	
	1950-65	H	L	1950-65	H	L
National research + extension	8.0	34.3	30.1	32.0	77.0	74.8
National research + extension (-½ joint IRRI-national)		31.4	27.7		76.0	73.0
National research + adjusted extension	15.1	62.9	55.1	39.0	78.0	76.0
National research + adjusted extension (-½ joint IRRI-national)		57.4	50.7		77.2	74.2
International research		122.6	70.8	—	99.6	82.0
International research + adjusted extension		52.2	30.2	—	97.4	79.0
International research (HYV-IRRI, + ½ joint IRRI-national)		146.0	84.9	—	102.0	84.2

streams. We could simply compute these numbers for all types of research and extension for the 1950–75 period. We believe, however, that sufficient information exists to enable somewhat more detailed computations.

In Table 9 we present benefit:cost ratios and internal rates of returns for two periods for national research and extension programs (pre-green revolution and green revolution), and for investment in international research. Production is valued at 1975–76 prices of US$110/t and research costs are converted to 1975 US dollars. The benefit:cost ratios utilize an external interest rate of 12%. They are defined as

$$\frac{P + F/.12}{C}$$

where P is accumulated past benefits and C is accumulated past costs (both accumulated at 12%), i.e.,:

$$P = \sum_{t=0}^{T} B(1 + .12)^t, \quad C = \sum_{t=0}^{T} C(1 + .12)^t$$

and F is the flow of future benefits.

The internal rate of return is defined as the rate r, which is the solution to

$$\sum_{t=0}^{T} \frac{B_t - C_t}{(1 + r)^t} = 0$$

where B_t and C_t are benefits and costs and T is the year that research ceases to produce returns.

In our calculations we had to first decide whether to include public extension investment in the cost data. Second, we had to determine a reasonable specification regarding future benefit flows.

Extension programs in general do not produce much new technology. However, they enable farmers to adopt and screen potentially valuable new technology faster. It is arguable that part of the effect attributed to A-type research in the general model is actually attributable to extension programs. There is some evidence, however, that the contribution of extension programs is considerably lower than the contribution of research. We have made two computations in this regard. The first includes all extension costs and supposes extension and research investment to be equally productive. The second supposes that extension investment is *one-third as* productive as research investment.[4]

One computation of returns to investment in international rice research attributes the share of the MV benefits from IRRI-produced varieties to IRRI. A second attributes half of the joint IRRI-national contribution to internationally produced benefits. A calculation is made in which one-third of the rice extension investment in the tropics is included in the costs.

For the 1950–65 calculations we suppose that the benefit stream continues at the 1965 level, but that costs do not go beyond those required to generate 1965-level benefits. It is true that benefit streams require maintenance, but the benefit streams that we have measured are presumably adjusted for depreciation. In any given year the yield ratios are based on a mixture of new, undepreciated technology and older, partly depreciated technology. We believe that the low and high estimates provide the reader with sufficient basis for applying a conservative bias to the data.

The second-period national programs returns then are based on added benefits after 1965. The costs associated with these benefits are only those incurred to generate further benefits. We utilized a 10-year distributed lag in computing the cost data for both the first- and second-period computations. Half of the costs in 1960, for example, are attributed to the first period and half to the second.[5]

The international costs are the actual IRRI costs. The international benefit stream is presumed to continue at the 1975 level, and recent IRRI costs (based on a 6-year distributed lag) are not included in the calculation. These costs will be generating future benefits. We do not know how great those future benefits will be, but we speculate that they will be lower than those generated in the 1966–75 period because most environments suited to semidwarf material have already adopted early generation MV. It will probably be more difficult to

---

[4] See Evensonand Kislev (1975) for estimates of the relative contribution of research and extension in India.

[5] 1975 costs are not included in the calculations inasmuch as they did not create any part of the 1975 benefits. We presume that 20% of the 1974 costs, 40% of 1973, etc. did contribute to the 1975 level of benefits.

improve later-generation MV and to produce technology for wider environments, than it was to achieve the initial high yielding material.

The computed returns show that investment in rice research has yielded high rates of return. Even the conservative low estimates for the MV are extraordinarily high compared with returns on alternative investments. Another point of note is that while the rates of return on investment in international research are higher than those realized on national research program investment, the returns to the latter research are also high. In fact, as Table 7 indicates, the national programs can lay claim to the major share of green revolution benefits.[6]

POLICY IMPLICATIONS

These estimates of returns to rice research are probably not surprising to anyone acquainted with recent rice production history. Our purpose in developing them is twofold. First, we believe it important to quantify costs and benefits, to the extent possible, in order to compare this form of investment with alternatives. We have also attempted to identify some characteristics of the process by which organized research produces benefits. Our estimates show that investment in rice research has yielded extraordinarily high returns. These high returns, in turn, indicate too little investment in rice research in the past. In fact, the high returns appear to indicate a very serious degree of resource misallocation by both national and international policy makers.

Research skill production. The judgment on misallocation is leavened somewhat, however, when we consider the supply of research skills. If the supply curve (in the short run) of real research skills is inelastic with respect to wages, the average returns to rice research investment, as we have computed them, can be above equilibrium returns without indicating resource misallocation. The return to research will include a quasi-rent for research skills, which is not actually paid to researchers but which shows up as a return to research. Certainly the costs of producing researcher skill in the short run are high and a national rice research program will face high costs if it plans rapid expansion. And, given these costs, an optimal expansion rate will probably produce quasi-rents to skills that will show up as high returns to research.

A full analysis of optimal national program expansion under the conditions faced in contemporary Asian countries is beyond the scope of this paper. It does seem clear, however, that those conditions call for the national program to rely on researchers with a lower level of skills than those in developed countries where research skills are more abundant. A developing country that does not have indigenous skill-building capability must, in effect, import skills by sending scientists abroad for training. Researcher skills in virtually all Asian coun-

---

[6] These estimated returns play be compared to the estimated returns to research in the Philippines in Flores et al, (1976). A 27% internal rate of return was computed for benefits captured by the Philippines in that study. The returns to all countries from research in the Philippines yield a 72% internal rate of return.

tries are rewarded at rates below what would be required to induce substantial skill acquisition. That is partly because of social factors and partly because of the functioning of international agencies.

International agencies were heavily involved in agricultural research programs long before the development of IRRI and other international centers. A high proportion of the high-level research skills in the developing countries was developed through graduate study fellowships from international agencies. International agencies have also made direct grants to research institutions.

It is perhaps not surprising to find that in many cases. national governments are still unwilling to invest heavily in expansion and development of agricultural research programs. The demonstration that such investment has a high payoff is not meaningful if the high costs of graduate training are not included in the cost calculations. A crude adjustment in our calculations indicates that even a fourfold increase in the costs of national rice research would not render that investment unwise.

It is, we believe, appropriate to conclude that national rice research program expansion should be given very high priority in development planning. The international systems cannot really substitute for national program development. It can, however, complement national programs. Expansion of national rice research programs will require further training of scientists. The international system can complement that training process and lower the costs of researcher skill production.

Technology development shift. The international rice research program has been highly productive to date. It produced significant new technology in the form of the IRRI MV, and established new research procedures. As a result of strengthened national programs and of evolving changes in breeding and selection of technology over the past few years, it appears that the comparative advantage of IRRI itself has shifted considerably. In the early 1960’s, the development of the basic semidwarf high yielding material was of highest priority. IRRI appropriately stressed that development.

But the initial high yielding material proved vulnerable to diseases and insects. Again, IRRI researchers were in a position to screen existing material for resistance and to incorporate at least partial resistance into the modern varieties. IRRI’s collection of genetic material and its ability to organize international screening and testing trials allowed it to achieve results faster than national programs could.

It became clear after a few years of breeding work at IRRI that virtually all of the improved varietal material was suited to a relatively narrow range of production environments. The international rice program, however. is now in a new phase. IRRI has initiated programs to move technology development toward a broader range of environments.

A number of questions present themselves regarding the new strategy. The first is whether one institution can mount effective research programs targeted toward all of the major rice-producing environments. The past history of rice research and of other agricultural research programs indicates that the large university-associated experiment stations, such as the United States state experiment stations, have been most capable of pursuing several major research programs simultaneously.

To date, IRRI has not been able to mount research programs for upland and intermediate deep-water environments with the same intensity managed for the shallow-water program. The upland program, for example, is not an independent program. Upland rice research is part of the broader multiple cropping research program, and while some good work is under way, it is not of the same magnitude and intensity as the mainline work at IRRI. A similar situation exists regarding intermediate- and deep-water rice technology improvement.

A-type to S-type research ratio. It would require a substantial reorganization and further expansion to enable IRRI to pursue truly major new programs in those areas. However, another issue is involved, and this study has addressed it to some extent. This is the role of what we have called S-type or science-related research. The complex quasi-growth model discussed in the Appendix indicated that this work was highly productive in the national systems.

In the context of IRRI's work, the desirable ratio of A-type to S-type work may differ substantially for upland and intermediate-depth rice research from what was required to extend and maintain in the modern semidwarf material once it was developed. And it may differ considerably in the future as regards semidwarf improvement. In particular, a substantial amount of S-type work may be required to lay the groundwork for further productive A-type work. The body of S-type knowledge pertinent for crop production in the tropics is limited. National agricultural research programs in the tropics have not invested heavily in such research. That may be a critical area where IRRI or other international institutes will play the leading role.

There are many factors to consider in the further development of both national and international rice research programs. The quantitative and qualitative implications of our investigation of past rice research suggest some potential directions. The international system has clearly shown its comparative advantages in certain components of rice research, and it is moving toward developing these advantages further as it stresses the provision of genetic materials to national systems.

As the next stages unfold, the role of the international system may change somewhat, but it is likely to continue to be a major role.

REFERENCES CITED

AKINO, M., and Y. HAYAMI. 1975. Efficiency and equity in public research: rice breeding in Japan's economic development. Am. J. Agric. Econ. 57:l–10.

BEHRMAN, J. R. 1968. Supply response in underdeveloped agriculture: a case study of four major annual crops in Thailand 1937–63. North Holland Publ. Co., Amsterdam.

BUREAU OF AGRICULTURAL ECONOMICS. 1965–75. Unpublished data on rice statistics. (mimeo.)

BOYCE, J., and R. E. EVENSON. 1975. Agricultural research and extension systems. University of the Philippines at Los Baños, Department of Agricultural Economics.

DALRYMPLE, D. G. 1974. Development and spread of high-yielding varieties of wheat and rice in the less developed nations. USDA ERS Foreign Agric. Econ. Rep. 95. 77 P.

DALRYMPLE, D. G. 1976. Development and spread of high-yielding varieties of wheat and rice in the less developed nations. USDA ERS Foreign Agric. Econ. Rep. 95. 120 p, Aug. 1976. 5th ed.

EVENSON, R. E. 1976. Comparative evidence on returns to investments in national and international research institutions. *In* T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed. Resource allocation and productivity in national and international agricultural research. University of Minnesota Press, Minneapolis.

EVENSON, R. E., and Y. KISLEV. 1975. Agricultural research and productivity. Yale University Press.

FLORES, P. M. 1975. Social returns to rice research in the Philippines. MS. thesis, University of the Philippines at Los Baños. (unpubl.)

FLORES, P. M., R. E. EVENSON, and Y. HAYAMI. 1976. Social returns to rice research in the Philippines: domestic benefits and foreign spillover.

GRILICHES, Z. 1958. Research costs and social returns, hybrid corn and related innovations. J. Pol. Econ. 66:419–431.

HARBERGER, A. C. 1974. Taxation and welfare. Little, Brown.

INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI). 1975. Changes in rice farming in selected areas of Asia. Los Baños, Philippines. 377 p.

KRISHNA, R. 1963. Farm supply response in India and Pakistan. A case study of the Punjab Region. Econ. J. 73:477–487.

MANGAHAS, M., A. E. RECTO, and V. W. RUTTAN. 1967. Production and market relationships for rice and corn in the Philippines. Int. Rice. Res. Inst. Tech. Bull. 9. 284 p.

MANGAHAS, M., and A. R. LIBRERO. 1975. Socioeconomic implications of high yielding varieties: evidence from primary data. Department of Agricultural Economics, IADA, University of the Philippines at Los Baños, Laguna, Philippines.

MUBYARTO. 1965. The elasticity of the marketable surplus of rice in Indonesia. Ph.D. thesis, Iowa State University, USA.

NASOL, R. L. 1971. Demand analysis for rice in the Philippines. J. Agric. Econ. Dev. 1:1–13.

PAPADAKIS, J. 1966. Agricultural climates of the world. Buenos Aires. Published privately.

SCOBIE, G. T., and R. T. POSADA. 1976. The impact of high-yielding rice varieties in Latin America, with special emphasis on Colombia. Rice Program Centro Internacional de Agricultura Tropical, Cali, Colombia.

APPENDIX. **A model incorporating technology transfer and knowledge transfer**

Research is improved technology. The ultimate objective of research is fundamentally a systematic search process. A researcher bases the search for new technology on an existing structure of scientific knowledge and technology and builds on prior research findings. The process may be thought of as a "knowledge transfer." Knowledge transfer may be from one geographic area into another. (We include technology itself as part of knowledge. In particular, genetic material is treated as knowledge in this context.) Knowledge transfer may also take place across the categories of knowledge, i.e., between disciplines, such as plant breeding and genetics.

Once new technology is developed, two related processes take place. The first is that the technology, for a new variety for example, is transferred as a form of knowledge to other research institutions. It may be quickly incorporated into other breeding programs. The second is that as technology it is released to producers who test it and who engage in some further "subinvention" improvements. The diffusion process among producers requires time and economic activity from them. Each producer must, in some sense, experimentally test new technology under his own producing environment.

The diffusion of newly produced technology across production environments depends in part on the information-processing capabilities of producers, i.e., their ability to experiment and to interpret evidence. It also depends on the nature of existing technology and on the interactions between the environment and physical, biological, and economic properties of the technology. The diffusion pattern of a new rice variety, for example, is conditioned by genotype-environment interactions. The variety's true superiority over other existing ones will be limited by those interactions.

The following empirical specification crudely incorporates these considerations and allows an estimation of the contributions of indigenous national and international rice research.

$$Y_t/Y_{50} = C(L_t/L_{50})^{a_1} (F_t/F_{50})^{a_2} A_t^{(a_2 + a_4 S_t)}$$

$$RA_t^{(a_5 + a_6 ZS_t + a_7 (A_t + S_t) + a_8 (A_t + S_t)^2} \text{EXP}^{(a_9 MV_t + a_{10} MV_t^2 + a_{11} (MV_t A_t + a_{12} T)}$$

Y_t/Y_{50} is the ratio of production of rice in period t to mean production in the years 1949-51.

L_t/L_{50} is the ratio of harvested hectares of rice in period t to mean hectarage in 1949-51.

F_t/F_{50} is the ratio of fertilizer used on all crops per hectare of all crops (not available specifically for rice) in period t to the mean level in 1949-51.

A_t, S_t, RA_t, and ZS_t are knowledge stock variables. They are constructed ascumulated research investment with the following structure:

$$A_t = \sum_{1942}^{t-5} P_t + .8P_{t-4} + .6P_{t-3} + .4P_{t-2} + .2P_{t-1}$$

Note that research is not fully added to the stock until the fifth year after publication or about the seventh year after the research. The research measures are actually based on the number of publications (P_t), which have been screened for commodity relevance and for scientific significance by the international abstracting journals *Plant Breeding Abstracts* and *Biological Abstracts*.

A_t is a measure of the research undertaken in agronomy and plant breeding specifically to improve rice technology.

S_t is a measure of research activity in plant physiology, phytopathology, and soil science. This work is not commodity specific and represents agriculturally related scientific research activity.

RA_t measures agronomic and plant breeding research activity in countries other than the country in question, but which are in the same geoclimate region.

ZS_t measures agriculture-related scientific research in other countries located in the same geoclimate zone.

All research variables are expressed on a per subregion basis. The latter three variables are designed to incorporate geographic technology transfer specifically, if somewhat crudely, into the analysis. The geoclimate regions and zones are defined as modifications of the agricultural climate classification of Papadakis (1966) and are discussed extensively in Evenson (1976).

MV_t is the percent of hectarage planted to modern varieties in the country as defined by Dalrymple (1976).[1]

Although the model is limited by insufficient data, its usefulness can be judged partly by the statistical results and partly by the fact that it does provide an estimate of the supply function shifts due to the development of new varietal technology when data are insufficient for more direct estimates.

The model has three limitations. The first is that we do not have complete production data by country for rice. Several key inputs, notably labor and power inputs, are “left out” of the specification. One can take a statistical view of this problem by noting that in a linear regression model, the coefficient(s) of the included variable(s) will be biased by the product of the “true” coefficient of the left-out variable(s) and the regression coefficient, which would result from a regression of the left-out variable(s) on the included variable(s). If the left-out variables, labor and power, are highly correlated with the included land variable, the coefficient estimated for the land variable will be the sum of the true coefficients of land, labor, and power (in a Cobb-Douglas model). In this case the bias in the research stock coefficients will not be serious. Similarly, the fertilizer variable can serve as a proxy for other left-out biological inputs.

The second limitation is that the research stock variable cannot be measured precisely. This variable might be constructed using research input data on scientist man-years, but such data are not available. A measure of research sytem output is, in principle, a better variable. It is true that, for certain purposes, scientific publications are not good measures of real output. They vary in quality, and the work on which they are based varies in quality or in economic value. It is not obvious, however, that the mean economic value or quality of a sample of publications varies between countries or regions. If it does not, the total number of publications is a good index of the real economic value of the products of a research system. The publications measure we utilize should be an improved index of knowledge as a result of the screening process applied by the abstracting journals.

A third limitation is that we have only a crude categorization of high yielding varieties. Again, it is difficult to devise an ideal measure. In fact, the term itself has meaning only in a situation where a distinct new set of superior varieties has become available recently.

[1] Modern variety (MV) is synonymous with high yielding variety (HYV) as used by Dalrymple.

Table A1. Regression analysis: rice production data, 12 Asian countries, 1948–71.

Independent variable	Regression 1	Regression 2
LN (land) (a_1)	1.0217 (107.4)	1.0374 (345.8)
LN (fertilizer) (a_2)	.04087 (2.91)	.0477 (22.71)
LN (A) (a_3)	–.014 (2.54)	
LN (A)^a S (a_4)	.0002675 (2.00)	
LN (RA) (a_5)	–.01791 (2.08)	
LN (RA)^a ZS (a_6)	.0000894 (1.52)	
LN (RA)^a (A+S) (a_7)	.0000149 (.18)	
LN (RA)^a (A+S)^2 (A_8)	–.0000013 (6.00)	
MV (a_9)	–.00969 (1.96)	.0052 (5.20)
MV^2 (a_{10})	–.0000179 (27)	–.00005 (2.50)
MV^a A (a_{11})	.000039 (5.70)	
LN (Time) (a_{12})	–.0181 (3.63)	
Constant	1.22	–.22
R^2 (Adj)	.998	.996

^{a}Regression weighted by area and estimated utilizing Nerlove-Balaestra techniques. The "t" ratios are in parentheses.

Over a long period of time new varieties become available and high yielding varieties are replaced by higher yielding varieties.

Data from 12 tropical Asian countries for the period 1948–71 were utilized to estimate the parameters of this general model. The results are presented in Table Al, regression 1. Some judgments about the effects of data limitations can be made based on the estimated parameters and their standard errors.

First, we might note that the signs and magnitude of all estimated coefficients are as expected. The coefficient for land appears to be “picking up” the effects of left-out variables. The fertilizer coefficient is also as expected.

The knowledge stock variables are also plausible. The net contribution of the A and S variables to production is positive, and the interaction terms are also positive and provide evidence that knowledge transfer is occurring across both geoclimate regions and scientific disciplines. Indigenously produced technical knowledge (measured by A) has a positive interaction with related indigenously-produced science knowledge (S) and with the existence of MV material. It turns out to substitute for technical knowledge produced elsewhere in the region (RA).

Technical knowledge produced elsewhere in the region does contribute to indigenous production, however. The major effect is through interaction with zonal-related science knowledge. Interestingly, the effect of MV is strongly interactive with indigenously-produced technical knowledge. This reflects a form of knowledge transfer associated with the MV as measures of technical knowledge. The MV have made indigenous technical research more productive and vice versa.

Our model may be compared with the model that presumes that rice productivity gains in these Asian countries are associated only with MV (regression 2). That model shows a strongly diminishing impact of MV as the MV percentage is increased. That make sense because MV will be adopted first in producing environments where they are superior to existing varieties. The estimates indicate that the impact of MV declines to zero at around 50% adoption levels.

COMMENTS ON SOCIAL RETURNS TO RICE RESEARCH

G.M. SCOBIE

RATHER THAN ATTEMPT a critical summary of the Evenson and Flores paper I pose a series of questions. By drawing on other studies (Scobie and Posada, 1976a,b,c) and the Evenson and Flores paper, I offer some partial answers to alert both neophyte and practitioner to some gaps in our knowledge and in our ability to quantify the economic impact of technical change.

The work of Evenson and Flores and our own research (Scobie and Posada) have both some common features and some differences in emphasis. While both studies apply a relatively standard Marshallian model to estimate the shift in supply engendered by the presence of modern rice varieties, Evenson and Flores concentrate on the international dimensions of the generation and diffusion of new varieties. In contrast, the Scobie and Posada study has a national focus. The latter gives more attention to the political forces that underlie the initiation and funding of research programs, and to the impact of the new varieties on household income distributions.

A central question underlying any examination of either study is: As social scientists how good are we at understanding and measuring the costs and returns to rice research?

The term "social scientists" is deliberately chosen to emphasize my belief that sociologists, economic geographers, political scientists, and historians can contribute to our understanding of some of the forces that affect the generation, diffusion, and adoption of new technologies in developing agriculture.

I will concern myself mainly with the interrelated questions that follow. It should be stressed that I have endeavored to focus on some problems, rather than dwell on the "good news," such as the increased understanding of the process of technology transfer that Evenson and Flores have provided.

- What elements of the political economy are behind the generation of new technology?
- Who bears the cost of the generation of new technology?
- What can be said about the distributional impact of new technology on both functional and personal income distribution?

Economist, Department of Economics, School of Agriculture and Life Sciences, North Carolina State University, Raleigh, North Carolina, USA.

- To what extent does the set of economic policies, especially those apparently unrelated to the rice sector, influence the distributional impact?
- Should the "index number" or "production function" approach be used in measuring the physical impact of technological change?
- Can the total benefits of a varietal improvement program be attributed to the enhanced genetic potential as separate from the bundle of complementary inputs and practices?
- What role does the information processing ability of the users play in the adoption of new agricultural technology? Can it be measured? Should it be included in the costs?
- Should the measurement of the distribution of benefits include marketing intermediaries as well as the traditional factors, consumers and producers (the latter almost invariably taken as farmers)?
- Is the analytical apparatus adequate to deal with the differential impact of new technology arising from ecological heterogeneity?

THE COLOMBIAN EXPERIENCE

In 1957, the tall, US variety Bluebonnet-50 that was extensively grown in Colombia was attacked by a disease causing extensive losses. Rice imports rose drastically, and the real domestic retail price was higher in 1957 than in any other year since 1950 (and in fact up to 1974). That provided the stimulus to initiate a national rice research program whose primary objective was to select disease-resistant varieties. The establishment of that program in the Colombian Ministry of Agriculture[1] in 1957 marked a turning point in government policy,[2] reflecting an orientation toward policies favoring domestic consumers.

It would have been useful if Evenson and Flores had elaborated on their analysis of the background to Asian rice research. They note that historically, rice research programs were merely elements of colonial bureaucracy and insensible to the needs of producers and consumers. But even colonial bureaucracies had their *raison d'être* and would respond to perceived pressures, and the postwar resurgence of rice research must have reflected an institutional responsiveness to some interest groups.

By 1963, the Colombian program had selected the variety Napal for release. Napal's useful life was short, however, because it is susceptible to blast. Another local variety (ICA-10) and an imported variety from Surinam (Tapuripa) were subsequently released. In 1967 the newly formed Centro Internacional de Agricultura Tropical (CIAT) joined a collaborative effort with the Colombian program, and dwarf lines from the International Rice

---

[1] For a more detailed discussion of the origins and development of rice research in Colombia, see Rosero (1974).

[2] Leurquin (1967) provides useful background to the role of government intervention in the Colombian rice sector.

Table 1. Varieties, yields, and production of rice[a] in Coloombia, by sector for selected years.

Year	Upland sector		Irrigated sector		Percentage of the irrigated sector sown[b] to	
	Yield (t/ha)	Production (1000 t)	Yield (t/ha)	Production (1000 t)	Traditional variety (%)	Modern varieties (%)
1954	1.1	124	2.7	171	n.a.	0
1960	1.2	107	3.9	263	n.a.	0
1964	1.2	215	3.1	305	87	5
1966	1.4	339	3.0	341	90	0
1960	1.7	251	4.2	536	53	42
1970	1.6	198	4.9	554	36	55
1972	1.6	161	5.2	883	12	87
1974	1.6	150	5.2	1420	1	99
1975	1.6	152	5.4	1480	n.a.	n.a.

[a] Paddy rice. [b] The balance of the area was classified as "Other." n.a. = not available. Source: Federacion Nacional de Arroceros (1973, 1975). and unpublished data.

Research Institute (IRRI) were introduced. IR8 was released in 1968 followed by IR22 in 1970. In 1971, CICA-4, the first variety developed by the joint Colombian-CIAT program was released; it was more disease resistant and had better grain quality than IR8. To combat the continuing threat of rice blast and the short-lived disease resistance of the new varieties, CICA-6 was released in 1974, and CICA-7 and CICA-9 were released in 1976.

The adoption rate of those modem varieties (MV) has been spectacular. In 1966, 90% of the irrigated sector was sown to the traditional variety (Bluebonnet-50); by 1974 virtually all the irrigated-rice production came from modern varieties (Table 1).

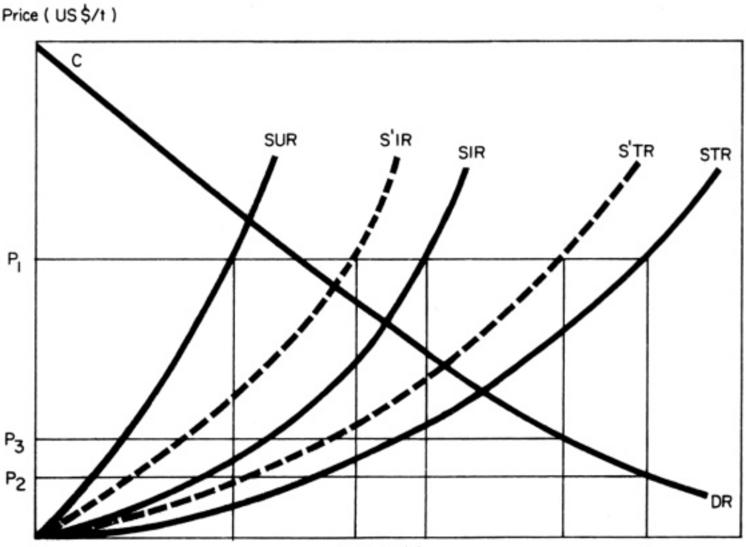
The Colombian research program, especially since 1967, has been oriented to the irrigated sector. Given the technological possibility of rapidly increasing rice output through the introduction of new varieties in irrigated culture, the choice was undoubtedly rational. The rate of progress achieved with the same research resources would surely have been less had attention been directed to the upland sector. A further explanation of the ecological orientation adopted lay in the close collaboration between the National Rice Grower's Federation (FEDEARROZ), which was founded and supported principally by the large irrigated rice growers, and the research program. Again, note the interplay in the generation of new technology; the ecological orientation was not an accident, and reflected the coincident interests of producers and researchers.

As a result of the emphasis on the irrigated sector and the rapid adoption of MV, yields and production in that sector rose dramatically (Table 1). In contrast, the comparatively disadvantaged upland sector experienced little or no technological change and its contribution declined from 50% of the national output in 1966 to 10% in 1974.

THE MODEL

In this section I outline a model for estimating the gross social benefits of the rice research program. The approach is based on the work of Griliches (1958) and Peterson (1967), and closely follows the formulation of Ayer and Schuh (1972) and Schuh (1968). The model estimates the total gross social benefits and their division between Colombian rice producers and consumers, and extends existing formulations by distinguishing between producers from the upland and the irrigated sectors because of the differential impact of the research program on the two sectors. It is suggested that the proposed formulation would have general applicability in analyzing the differential impact of new technology whose relevance is restricted (for whatever reason) to a subset of the producing firms. Bell (1972) presented a theoretical discussion built on the differential impact of technology for innovators and non-innovators. The present model is essentially an empirical application of his graphical analysis.

The model is represented graphically in Figure 1. The total supply curve (STR) is divided between the upland (SUR) and irrigated sectors (SIR). The impact of the varietal improvement program is shown by the supply curve denoted (S'IR), which is displaced *k* percent to the left of SIR in the absence of MV while the upland supply curve is unaffected. S'TR is the corresponding displacement of the total supply in the absence of MV. The demand curve (DR) is a declining function of the current farm price of rice, while the supply of rice is



1. Graphical representation of the model for estimating the distribution of gross benefits from the introduction of modern rice varieties.

determined by the previous year's price (implying a recursive cobweb model). The expected price P_1 calls forth OA units of production which clear the market at P_2 (the observed price), while P_3 is the price that would have prevailed in the absence of modern varieties.

Four implicit but important assumptions should be noted.

1. The rice economy of Colombia is closed, i.e. foreign trade (which was a small erratic fraction of output) is ignored. The importance of this assumption must be emphasized. It means that for rice (as for most of other basic food crops) an inelastic demand curve will be used, guaranteeing that the benefits of technical change will accrue to consumers. Much attention has been devoted to the measurement of output in the absence of MV but the problem of deciding what policies would have prevailed in their absence is treated rather superficially. At best, a free trade versus autarky comparison is made (e.g. Akino and Hayami, 1975). One saving grace is that gross social benefits are rather insensitive to differing elasticities (as Evenson and Flores note), but the distributional outcome turns critically on this assumption. As long as ex post analyses — which inherently require a comparison of the world with new varieties and the world as it would have been in their absence — persist, this difficulty will continue to be faced. Incidentally, I find that a Marshallian scissors diagram, which shows the actual ("with") supply curve and the hypothetical ("without") supply curve displaced to its left (as in Fig. 1), focuses attention more toward this problem than does the diagram used by Evenson and Flores.
2. Any influence of the state marketing agency during the introduction of MV in the rice market was small, and is ignored (see Gutierrez and Hertford, 1974; Scobie and Posada, 1976a).
3. Rice from both the upland and the irrigated sector is of the same quality.
4. The marketing margin for rice was constant, so that the derived farm level demand curve can be used instead of the retail level demand curve to measure consumer benefits.

Gross social benefits (GSB) in any one year are obtained by comparing the difference between total consumer utility and the real resource costs of rice production with and without the new varieties. Similarly, the use of a standard set of supply and demand equations and an estimate of the shift parameter lead to estimates of the annual benefits to producers and consumers. Ayer and Schuh's (1972) analysis is followed in these estimations, but their model is extended to incorporate the dual supply curve reflecting differing ecological zones. Details of the model are given in Scobie and Posada (1976a). The preferred set of price elasticities were:

		Supply		
	Demand	**Upland**	**Irrigated**	**Total**
1964–67	–0.449	0.118	0.32	0.235
1968–71	–0.449	0.116	0.279	0.235
1972–74	–0.449	0.115	0.253	0.235

The elasticities which were taken from other studies (see Scobie and Posada, 1976a) were applied "exogenously" to the model.

In estimating the shift parameter there are two alternatives, the ''index number" or the "production function'' approach (Peterson, 1967). Unlike Evenson and Flores, I adopted the former. Both invariably suffer from data limitations, but I believe that the misspecifications and multicollinearity problems inherent in the Evenson and Flores model may be more serious than they suggest. While the concept of regression to isolate varietal effects is intuitively appealing, the demand for the generally nonexistent data is substantial. Their use of aggregate fertilizer data as a proxy for rice-fertilizer seems particularly bothersome in the case (not unlikely) of differential growth rates in terms of the area of and technology for different fertilizer-using crops.

Given the continuing efforts of Dalrymple (1976) to provide estimates of the areas sown to modern varieties (by countries and over time), a minimum of assumptions is necessary to use the equation:

$$\frac{Q_{I,t}}{A_{I,t} + A_{T,t}} + \frac{Q_{T,t}}{A_{I,t} + A_{T,t}} = \frac{Q_t}{A_t}$$

and rearrange it as

$$Y_{I,t} = [Y_t - (1 - P_t)Y_{T,t}]/P_t,$$

where

$Q_{I,t}, Q_{T,t}$ and Q_t = the production from improved, traditional, and total rice in year t, respectively;
$A_{I,t}, A_{T,t}$ and A_t = the corresponding areas sown in year t;
$Y_{I,t}$, $Y_{T,t}$ *and* Y_t = the corresponding yields in year t, and
$P_t = A_{I,t}/A_t$ = the proportion of total area in modern varieties.

As the total yield is observable and P_t is given by Dalyrmple (1976) (for most of the major producing countries), then I only need to "invent" a value for the yield of traditional varieties. The average yield for a number of years before the introduction of improved varieties seems a reasonable basis.

This method makes no pretense at isolating the effect of the variety from other yield-increasing inputs and practices. The Evenson and Flores equation at least partially separates the varietal effect. However, I am inclined to the view that the question is academic. If there are, as widely agreed, complementary inputs associated with the use of improved varieties, then it is futile to discuss the appropriate element of the package to which we should attribute the increased yield. Furthermore, if the prices of inputs reflect their social opportunity costs, then the area under the supply curves will capture the resource costs of the added inputs and appropriately discount the gross social benefits.

Table 2. Gross benefits[a] to consumers and producers from new rice varieties in Colombia.

Year	Gains to consumers (million US$)	Forgone income to producers (million US$)			Gross social benefits (million US$)
		Upland	Irrigated	Total	
1964	0.1	0.0[b]	0.0[b]	–0.1	0.0[b]
1965	0.7	–0.3	–0.2	–0.5	0.2
1966	0.0	0.0	0.0	0.0	0.0
1967	2.2	–0.9	–0.5	–1.4	0.8
1968	28.7	–10.6	–7.2	–17.8	10.9
1969	17.3	–6.2	–4.9	–11.1	6.2
1970	28.1	–8.9	–8.6	–17.5	10.6
1971	42.8	–10.5	–15.8	–26.3	16.5
1972	81.6	–19.2	–29.8	–50.0	31.6
1973	33.4	–29.6	–48.0	–77.6	55.8
1974	325.5	–66.8	–123.2	–190.0	135.5

[a] Converted at US$1 = Colombian $28.69. [b] Less than US$0.1 million.

Gross benefits. Annual gross benefits to consumers and producers of both upland and irrigated rice are shown in Table 2.

Consumer benefits were positive, because in the absence of MV the volume of rice entering the domestic market was much lower, and hence the internal price (P_3 in Fig. 1) would have been much higher. However, precisely for the same reason, producers as a whole had forgone returns to fixed factors (land and entreprenurial skills). With the rapid expansion in output engendered by the MV, prices received by producers were much lower than they would have been in the absence of MV. Producers of both upland and irrigated rice had forgone income as a result of the introduction of MV.

Net benefits. This standard Marshallian division of gross benefits is a relatively blunt way of assessing the distributional impact of technological change. Two extensions are attempted. First, I considered the cost of the research and derived net benefits to producers and consumers. Subsequently, I examined the distribution of the gross benefits and research costs by income level within groups.

Costs incurred by IRRI in the development of IR8 and IR22, which occupied almost 60% of the area sown in Colombia, are not included. Hence for those varieties I overstate the net benefits by allowing their contribution to production without discounting their full costs. However, if net benefits are measured from Colombia's standpoint, it is valid to include only those costs Colombia incurred in testing, multiplying, and releasing the IRRI materials. Thus I was able to avoid the problems facing Evenson and Flores. Evenson (1974) stresses the importance of domestic research programs to receive, adapt, and diffuse internationally transferred technology. The inference is that without its internal research network, Colombia could not have so readily adopted the imported varieties.

The research program was funded by the National Rice Program of the

Table 3. Social benefits of rice research in Colombia and internal rates of return.

Period	Gross social benefits[a] (million US$)	Total research costs (million US$)	Net social benefits[b]		
			h = –0.300 e = 0.235	h = –0.449 e = 0.235	h = –0.754 e = 1.500
1957–59	0.0	0.0	0.0	0.0	0.0
1960–64	0.0	0.3	–0.3	–0.3	–0.3
1965–69	18.0	0.7	16.5	16.3	6.8
1970–74	254.4	1.3	507.2	253.2	111.2
	Internal rate of return (%)		101	94	79

[a]For the "preferred" elasticities of h = –0.449 and e = 0.235. US$1 = Colombian $28.69 [b] h and e are the price elasticities of demand and supply, respectively.

Instituto Colombiano Agropecuario (ICA), the contribution of growers by a research levy on each kilogram of output, and international contributions, originally from the Rockefeller Foundation and subsequently through CIAT.

The net social benefits (Table 3) were calculated by subtracting the total research costs from the gross social benefits shown in Table 2. The research program had a "gestation" period of about 8 years. However, regardless of which of three combinations of demand and supply elasticities is considered, the subsequent rise in gross social benefits relative to research costs was so marked that the internal rate of return is remarkably high. There appears to be little doubt that investment in rice research was a socially efficient activity.

The internal rates of return were calculated by projecting the 1974 net benefits to 1986. Because the rates of return are all high, the results are not sensitive to the assumptions made concerning future costs and benefits. These high returns are not uncommon in agricultural research. Reports cite return rates of 89% for cotton in São Paulo (Ayer and Schuh, 1972), 75% for rice in Japan (Akin, and Hayami, 1975), 20 to 30% for poultry in the USA (Peterson, 1967), 75% for wheat in Mexico (Barletta, 1971), 35% for corn in the USA (Griliches, 1958), 58 to 82% for rice in Colombia until 1971 (Ardila, 1973), and 76 to 96% for soybeans in Colombia (Montes, 1973).

The distribution of gross social benefits, research costs, and net benefits for producers and consumers is shown in Table 4. Computations used Harberger's (1972) estimate of 10% for the real rate of return on capital in Colombia.

It was assumed that the costs of the ICA program came from general tax revenue and were divided between consumers and producers on the basis of urban and rural proportions of total tax revenues in 1970 (Jallade, 1974). The 1970 producer contributions were further broken down between upland and irrigated producers. The contributions from FEDEARROZ were distributed between the upland and irrigated sector on the basis of their relative output; a 45% collection rate (FEDEARROZ, 1975) of 1 centavo/kilogram from all producers was assumed, but no contribution was assumed for upland producers with less than 10 ha. Expressed in 1970 values, US$2.84 million was devoted to

Table 4. Size and distribution of benefits and costs of modern rice varieties in Colombia, 1957–74.

Item	Benefits and costs (million US$)[a]					
	Producers			Consumers	Total Colombia	International cooperation[b]
	Upland	Irrigated	Total			
Gross benefits	–123.46	–184.49	–307.95	520.71	212.76	–
Costs of research						
FEDEARROZ[c]	0.29	1.04	1.33	–	1.33	–
ICA[d]	0.02	0.06	0.08	0.77	0.85	–
Total	0.31	1.10	1.41	0.77	2.18	0.66
Net benefits	–123.78	–185.59	–309.36	519.94	210.58	–

[a] US$1 = Colombian $28.69. [b] From Ardila (1973) and personal communication from the Centro Internacional de Agricultura Tropical (CIAT). [c] National Rice Growers Federation. [d] From Ardila (1973) and personal communication from the Instituto Colombiano Agropecuario (ICA).

Table 5. Distribution (%) of funding of the Colombian rice research program, 1957–74.

Selected year	Distribution of funding (%)			
	Consumers[a]	Producers[b]	International cooperation[c]	Total
1957	100	0	0	100
1960	55	0	45	100
1970	38	28	34	100
1974	22	37	41	100
1957–74 total	27	50	23	100

[a] From Ardila (1973) for 1957–70, and from unpublished data supplied by ICA for 1971–74. [b] Based on a constant collection rate of 45% of the research levy (FEDEARROZ, 1975) for the period of 1963–74. [c] From Ardila (1973) for 1958–71, and from unpublished data supplied by CIAT for 1972–74.

rice research between 1957 and 1974. The distribution among the three sources is shown in Table 5.

Because producers' incomes would have been higher in the absence of the rapid technological change, it is pertinent to inquire why 50% of the total research costs were borne by producers. Were they simply contributing to their own economic demise? By supporting FEDEARROZ, the rice growers had rapid access to the latest technical information regarding rice production. Hence financial support of FEDEARROZ is not an irrational decision for a rice producer, given the continual gains from the rapid adoption of both MV and the modern cultural practices. Growers who are not among the early adopters face lower prices and are forced to follow suit or withdraw.

Distribution of benefits and costs by income level. To evaluate the distributional impacts of technological change for 1970. the gross benefits, the costs of the research program, and the consequent net benefits were distributed among income groups for consumers, and between upland and irrigated producers.

Gross benefits to consumers were assumed to be directly proportional to the quantity of rice consumed. The tax-funded research costs borne by consumers

Table 6. Distribution of gross benefits, research costs, and net benefits to consumers by income level.[a]

Income categories (thousand Colombian $)	Percentage of total rice consumed[a]	Distribution of costs and benefits			
		Percentage of total taxes paid[b]	Gross benefits[c] (million Colombian $)	Research costs[c] (million Colombian $)	Net benefits[c] (million Colombian $)
0 – 4	7.6	0.1	103 (3.59)	0.001 (34)	103 (3.59)
4 – 12	42.6	1.6	579 (20.18)	0.019 (662)	579 (20.18)
12 – 24	26.9	8.9	366 (12.76)	0.109 (3,799)	366 (12.76)
24 – 48	15.6	16.7	212 (7.39)	0.205 (7,145)	212 (7.39)
48 and over	7.2	72.7	98 (3.42)	0.893 (31,126)	97 (3.38)
Total	100.0	100.0	1,358 (47.34)	1.227 (42,766)	1,357 (47.30)

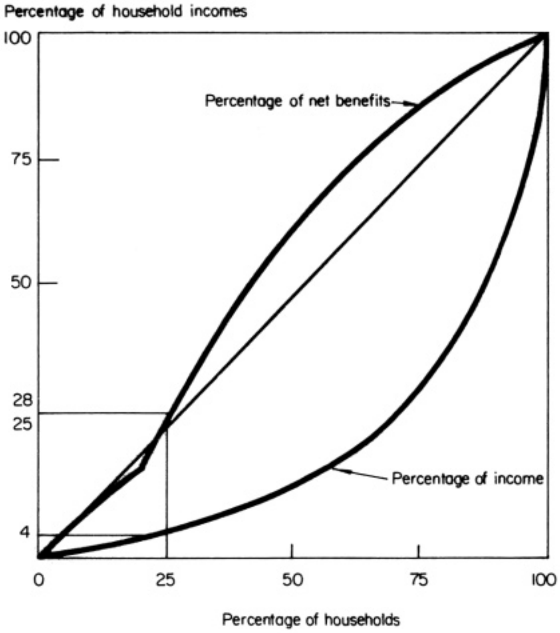
[a] From unpublished data supplied by the Departamento Administrativo de Estadisticas. [b] Estimated from Jallade (1974). [c] Amounts in parentheses areconversions at 1974 rate of US$1 = Colombian $28.69

were distributed on the basis of the proportion of total tax receipts from each income stratum in the urban and rural sectors. The results show the net benefit to consumers by income level (Table 6).

Rice is the major source of calories and the second major source of protein (after beef) in the Colombian diet (Departamento Nacional de Planeacion, 1974). Between 1969 and 1974 total domestic rice consumption doubled (US Department of Agriculture, 1976). Given the high percentage of consumption among the low income strata and their limited contributions through taxes to the research program, the net benefits of the research program were strongly biased toward them, when compared with the national distribution of household income. The comparison is illustrated in Figure 2. An arbitrarily selected point (marked on the graph) shows that while 25% of Colombian households received 4% of household incomes, they captured 28% of the net benefits of the research program.

In the case of producers, the forgone annual average income (Table 4) was distributed across farm sizes in proportion to estimates of the production based on census data. The research costs were also distributed by farm size, assuming that tax payments were proportional to production (in the case of the ICA costs), and by the method already discussed for the research levy of $0.35/t. The sum of the forgone income and the research costs was then expressed as a percentage of the estimated 1970 average net income by farm size for the entire rural sector (Table 7). Ideally, income distribution data are required for upland and irrigated rice producers by size of farm. As no such data are known to exist, a distribution of rural income by farm size for 1960 (Berry, 1974) was used. The income data were inflated to 1970 values using a consumer price index.

The positive benefits of the technological change all accrued to consumers, with the lowest income households receiving the largest absolute and relative gains. The forgone income to producers appeared to fall most heavily on the small upland-rice producers. Even if the average annual consumer benefits are included as benefits to upland producers, the small upland rice producers still



2. Distribution of income and net consumer benefits from modern rice varieties in Colombia.

appear as the most severely affected. That is not surprising, given the orientation of the research program toward the irrigated sector. It should be noted, however, that in 1970 only an estimated 12,000 upland rice producers had less than 5 ha. Hence, under any likely set of welfare weights, their losses would be more than offset by the gain to more than one million low-income, consuming households, implying an overall gain (albeit uncompensated) in social welfare.

Foreign trade, technological change, and income distribution. It is suggested that the net benefits of the rice research program were captured by Colombian

Table 7. Impact of rice research program on producers of upland rice and of irrigated rice.

Farm size (ha)	Forgone annual net income as a percentage of 1970 income	
	Producers of upland rice	Producers of irrigated rice
0–5	63	42
5–30	50	46
30–100	31	47
100–1000	22	67
1000 and over	15	43

consumers, with a disparate share going to low-income consumers. The net incomes of rice producers would have been higher in the absence of MV. It is of interest to inquire why this pattern of distribution occurred.

My basic premise is that the distributional outcome of the new rice technology in Colombia was principally a result of the set economic policies adopted at the national level, which were not directly related to the rice sector. Specifically, I suggest that through the use of tariffs against imported manufactured goods, Colombia's industrial protection policy allowed the price of foreign exchange to be maintained artificially low, making agricultural exports appear less attractive. This bias against the agricultural sector has been widely noted (Schuh, 1968), and it is believed that the Colombian case conforms to that general pattern. Virtually, no rice was exported during the period of rapid expansion of output (1968–74) that accompanied the introduction of MV.

The economic policies that prevail at any point in time are a product of continually evolving economic and political forces. These forces often oppose one another, reflecting the interests of different groups. Producer organizations are typically concerned with presenting cases for remunerative farm prices and promoting exports. On the other hand, manufacturing groups press for tariff protection and overvalued exchange rates, which have the additional side effect of fostering cheap domestic food supplies (in the presence of rapid technological change in agriculture), hence lowering the price of wage goods and indirectly subsidizing the price of labor to the manufacturing sector. As Barraclough (1970) notes, rapid urbanization, together with growth in the industrial and financial sectors, has increased the political weight of manufacturing relative to agricultural interests. The result was that while FEDEARROZ vigorously represented the interest of rice growers (Leurquin, 1967) and frequently won concessions favoring rice producers (e.g., a token export subsidy introduced in 1976), its influence tended to be overridden by national economy strategies promoted by an increasingly powerful entrepreneurial class whose political power base lies less and less with agricultural interests (Dix, 1967). As the net result of these forces, the benefits of the new rice varieties were captured by consumers because of the cheap-food policies consistent with, and complementary to, protection of the industrial sector.

Had a more attractive exchange rate prevailed, it is likely that Colombia would have been able to compete favorably in external markets with other Latin American exporters. Starting in 1975, however, the domestic price of rice reached a level that made exporting attractive, and it is probable that Colombia will now become a consistent rice exporter. Future direct benefits of new rice technology will be captured by producers and foreign consumers, rathern than by Colombian consumers as has been the case.

In this regard it is instructive to note the changing relative contributions of consumers and producers to the funding of rice research. Table 5 reveals that the relative contribution of consumers (through the tax-funded national rice research program) has been falling, while producer contributions (through the grower-administered research levy) have been rising. This pattern is consistent with the fact that as Colombia has become a rice exporter, producers, facing a more elastic demand, would capture a greater proportion of the social benefits of technological change; hence they would be expected to contribute relatively more to the generation of new rice technology. The reverse argument applies to consumers, whose share of future benefits is expected to decline.

CONCLUDING REMARKS

The economic impact of technological change in developing agriculture has been the subject of considerable debate. Criticism has been leveled at the agricultural sciences for the failure of the green revolution to attend to a broad spectrum of social ills. Technological change has been held responsible for increasing the wealth of the upper rural echelons and displacing rural labor. But few existing studies have examined the distributional consequences at a national level, considering consumers as well as producers. Where they have, a Marshallian division of the gross social benefit between producers and consumers has frequently been the limit of the distributional analysis.

I attempted some preliminary extensions.

1. A model that allows for differential impact of technological change on two classes of producers is introduced.
2. The incidence of research costs is considered in the distribution of the social benefit to different groups.
3. The distributional impact of the technology on consumer and producer households by income level is analyzed.

These extensions have only come at a price. I have ignored the consequences for the employment of resources released from the rice sector because of the differential impact of the new technology, and the lack of data to analyze the distributional consequences for household income leads me to a formidable number of assumptions.

Recognizing that technological change stems from conscious investment decisions governed in part by the private payoffs filtered through the sociopolitical system (de Janvry, 1977), I offer some tentative hypotheses to explain the particular distributional outcome encountered. Unlike Evenson and Flares who are concerned with the transfer of technology, I have focused on some of the political economy lying behind its generation. While much remains to be more rigorously tested, I believe that a clear (and perhaps obvious) conclusion emerges: considerations of the supply, demand, and distributional consequences of agricultural technology require a broad view encompassing the set of prevailing economic policies. Both the national and international economic order can have a marked influence on who benefits from technological change in developing agriculture.

REFERENCES CITED

Akino, M., and Y. Hayami. 1975. Efficiency and equity in public research: rice breeding in Japan's economic development. Am. J. Agric. Econ. 57(1):1–10.

Ardila V., J. 1973. Rentabilidad social de las inversiones en investigación de arroz en Colombia. M.S. thesis, ICA-Universidad Nacional de Colombia.

Ayer, H. W., and G. E. Schuh. 1972. Social rates of return and other aspects of agricultural research: the case of cotton research in São Paulo, Brazil. Am. J. Agric. Econ. 54(4):557–569.

Barletta, A. N. 1971. Costs and social benefits of agricultural research in Mexico. Ph.D. thesis, University of Chicago.

Barraclough, S. L. 1970. Agricultural policy and land reform. J. Pol. Econ. 78(3):906–947.

Bell, C. 1972. The acquisition of agricultural technology: its determinants and effects. J. Dev. Stud. 9(5):123–159.

Berry, R. A. 1974. Distribución de fincas por tamano, distribución del ingreso y efficiencia de la Producción Agrícola en Colombia. *In* H. Gomez O., and W. Wiesner D., ed. Lecturas sobre desarollo economico Colombiano. Fundación para la Educacion Superior y el Desarollo, Bogota.

Colombia, Departamento Nacional de Planeacion. 1974. Plan nacional de alimentación y nutrición. Documento DNP-UDS-DPN-011, Bogotá.

Dalrymple, D. G. 1976. Development and spread of high-yielding varieties of wheat and rice in the less developed nations. USDA, Foreign Agriculture Economics Report 95.

Dix, R. H. 1967. Colombia: the political dimensions of change. Yale University Press, New Haven.

Evenson, R. E. 1974. The "Green Revolution" in recent development experience. Am. J. Agric. Econ. 56(2):387–394.

FEDEARROZ (Federacion Nacional de Arroceros). 1973. Informe de gerencia. Bogota.

FEDEARROZ (Federacion Nacional de Arroceros). 1975. Informe de gerencia, Bogota.

Griliches, Z. 1958. Research costs and social returns: hybrid corn and related innovations. J. Pol. Econ. 66(4):419–431.

Gutierrez, A. N., and R. Hertford. 1974. Una evaluacion de la intervención del gobierno en el mercado de arroz en Colombia. Folieto Técnico No. 4, Centro Internacional de Agricultura Tropical, Cali.

Harberger, A. C. 1972. Project evaluation. MacMillan, London.

Hertford, R., J. Ardila V., A. Rocha, and C. Trujillo. 1977. Productivity of agricultural research in Colombia. Pages 86–123 *in* T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed. Resource allocation and productivity in national and international agricultural research. University of Minnesota Press, Minneapolis.

Jallade, J. P. 1974. Public expenditures on education and income distribution in Colombia. World Bank Staff Occasional Papers No. 18.

Janvry, A. de. 1977. Inducement of technological change and institutional innovations: an interpretative framework. Pages 551–566 *in* T. M. Arndt, D. G. Dalrymple, and V. W. Ruttan, ed. Resource allocation and productivity in national and international agricultural research. University Minnesota Press, Minneapolis.

Leurquin, P. P. 1967. Rice in Colombia: a case study in agricultural development. Food Research Institute Studies in Agricultural Economics, Trade and Development 7:217–303.

Montes, G. 1973. Evaluacion de un programa de investigación agricola: el case de la soya. M.S. thesis, Universidad de los Andes, Bogota.

O'MARA. G. Comment on J. R. Anderson and J. B. Hardaker. Economic models and small farmer technology: a review. *In* A. Valdes, G. M. Scobie. and J. L Dillon, ed. Economics and the design of small-farmer technology. Iowa State University Press. Ames. (forthcoming)

PETERSON, W. L. 1967. Returns to poultry research in the United States. J. Farm. Econ. 49(3):656–669.

ROSERO, J., M. 1974. El cultivo del arroz. ICA-FEDEARROZ Manual de asistencia. No. 9. Palmira, Colombia.

SCHUH, G. E. 1968. Effects of some general economic development policies on agricultural development. Am. J. Agric. Econ. 50(5):1283–1293.

SCOBIE G. M. and R. POSADA T. 1976a. The impact of high-yielding rice varieties in Latin America with special emphasis on Colombia. Centro Internacional de Agricultura Tropical. Cali.

SCOBIE, G. M.. and R. POSADA T. 1976b. The impact and political economy of technological change in agriculture: the case of rice in Colombia. Presented at a Seminar at the International Food Policy Research Institute. Washington. D. C.

SCOBIE, G. M.. and R. POSADA T. 197Ac. Margenes del mercado en la agricultura: el caso de Arroz en Colombia. Cuad. Econ. 13(30):59–72.

SCOBIE, G. M. and R. POSADA T. 1978. The impact of technical change on income distribution: the case of rice in Colombia. Am. J. Agric. Econ. 60(1):85–92.

US DEPARTMENT OF AGRICULTURE. 1976. Foreign agricultural circular, FR-1.

Market price effects of new rice technology on income distribution[1]

Y. HAYAMI AND R.W. HERDT

THE IMPACT OF MODERN TECHNOLOGY for staple cereal production in Asia on income distribution has caused major concern. Examination of such impact focuses on the issues that suggest that technological advances adversely affect income distribution. The reasons cited for such adverse effects include the faster rates of adoption by large farmers than by small farmers; the nonadaptability of the new technology to all geographic areas; and the incentives for consolidating small holdings into larger units, which promote a polarization of the rural population (Falcon, 1970; Johnston and Cownie, 1969; Staub and Blase, 1974; Wharton, 1961).

This paper examines a critical but heretofore neglected impact of technological change on income distribution — the impact on market price.

Technical progress implies a downward shift in the cost function or a rightward shift in the supply function, and normally results in an increase in consumption and lower cost. The distribution of economic welfare gains among consumers and producers depends on the price elasticities of demand and supply for the product for which technological advance occurs. In developed economies, consumers generally benefit from technological progress and farmers find themselves on a technological "treadmill" (Cochrane, 1958).

Such theory is based on a well-developed market economy and is not readily applicable to rice and wheat when grown as subsistence crops in the partially monetized economies of developing countries. A major fraction of a subsistence crop is consumed in the producers' households. Hence, producers' and consumers' gains or losses through market price changes apply to only a portion of the total produce. In that situation, the major portion of economic gain that is due to technical progress is internalized by producers, especially the small subsistence ones.

Agricultural economists. Department of Agricultural Economics, International Rice Research Institute, Los Baños, Philippines.

[1] An earlier version of this paper was Hayami and Herdt (1977).

We show that if demand is price inelastic and prices are permitted to adjust to market forces, the degree of consumers' surplus internalized by farm producers is inversely related to the proportion of output sold. If the international market fixes or determines the commodity's price, the technological change may not cause any price change and benefits will accrue to producers in direct proportion to their sales.

A model we developed incorporates the internal-consumption attribute of subsistence crops into an analysis of the relation between technical change and income distribution in a closed economy, both among and within sectors of the economy. The model is applied to data on the Philippine rice economy to illustrate the potential influences of current developments in rice production technology.

A MODEL OF INCOME DISTRIBUTION

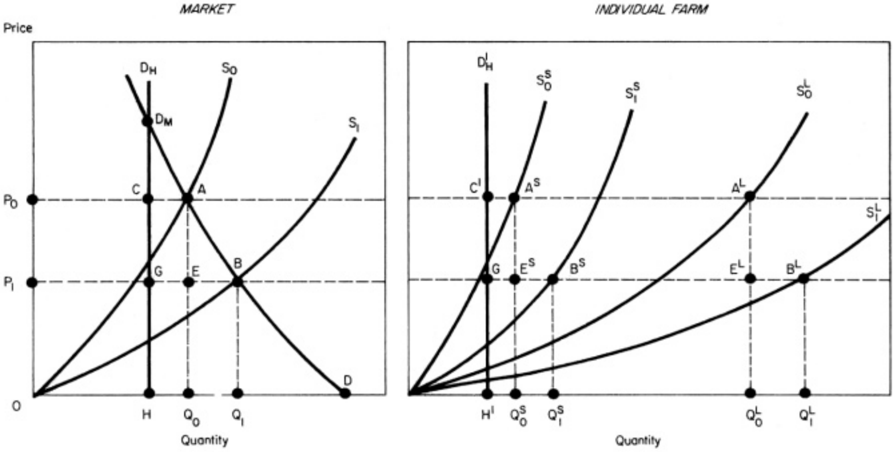
Critical considerations in our analysis of the distribution of gains from technical progress in the production of a subsistence crop are

- A mass of small producers produce the subsistence crop so that its market can be approximated by perfect competition.
- A subsistence crop, being a "necessity," is characterized by low price elasticity of demand.
- The producers consume a major portion of a subsistence crop and sell only a small portion.
- Demand and supply in the domestic market determine the price for the crop.

Intersectoral distribution. Farmers in developed countries consume only a small part of their staple food crop output. When technical progress occurs, a corresponding shift in the supply curve, when confronted by an inelastic market demand, causes a decline of output prices, and despite reduced production costs, producers' incomes decrease. In such a situation, technical progress implies a transfer of income from producers to consumers.

In subsistence agriculture, however, where only a minor portion of output is sold, the reduction in market prices due to the rightward shift in the supply curve has relatively little influence on producers' incomes. In fact, the smaller the ratio of sales to total output, the less likely it is that the reduction in cash revenue would exceed the reduction in production cost.

Such a relationship may be illustrated in the market diagram of Figure 1, which shows the market demand and supply schedules of a subsistence crop. The vertical line $D_H H$ is the demand curve of producers for home consumption. Considering the subsistence crop as a basic need that must be satisfied first, it is assumed that producers' households consume a given quantity and sell the rest in the market irrespective of price. (This restrictive assumption is relaxed in a later section.) $D_M D$ represents the market demand for the product, and the horizontal difference between $D_M D$ and $D_H D$ measures the quantity



1. The impact of technological change in a susbsistence crop.

purchased by nonfarmer households. The total demand for the crop is represented by D_HD_MD.

$S_0 0$ and $S_1 0$ are the supply curves before and after a technical change. Corresponding to the shift in the supply, the market equilibrium point moves from *A* to *B*. Consumers enjoy, the increased consumption (HQ_0 to HQ_1) at the reduced price ($0 P_0$ to $0 P_1$). Consumers' surplus increases by ACGB and producers' cash revenue changes from $ACHQ_0$ to $BGHQ_1$. while producers' home consumption stays the same. Production cost changes from $A0Q_0$ to $B0Q_1$.

Assuming that the "real income value" of home consumption is represented by the quantity consumed, changes in producers' income are reflected in cash income. Whether producers' cash income (revenue minus cost) is increased by the technical changed depends on the demand and supply functions. However, it should be clear that the higher the ratio of home consumption to output, the more likely it is that producers' incomes will increase. For example, with completely commercialized agriculture and zero home consumption ($D_H H$ coincides with the vertical axis). the reduction in cash revenue is AP_0P_1E – BEQ_0Q_1. which is clearly much larger than it is in subsistence agriculture (area $ACGE - BEQ_0Q_1$). In either case, the change in cost is measured by ($A0Q_0$— $B0Q_1$). On the other hand. the increase in consumers' surplus is clearly smaller in subsistence agriculture (area *ACGB*) than in commercialized agriculture (area AP_0P_1B).

The relevant range of the total demand schedule, D_HD_MD. is approximated by a typical constant elasticity demand function.

$$q = c\, p^{-\eta} \tag{1}$$

where p is the price and q is the quantity demanded of a subsistence crop, c includes income and other demand shifters, and η is the price elasticity of demand.

Assume a constant elasticity supply function as

$$q = b\, p^{\beta} \tag{2}$$

where p is the price and q is the quantity supplied, b includes supply shifters except technical change, and β is the price elasticity of supply.

Assuming a k-percent shift in the supply schedule due to technical progress, the new supply function, $S_1 0$, can be expressed as

$$q = b\,(1 + k)\, p^{\beta} \tag{3}$$

If we denote the equilibrium price and quantity before the technical progress as p_0 (= $0P_0$) and q_0 (= $0Q_0$) respectively, those after the technical change, p_1 (= $0P_1$) and q_1 (= $0Q_1$), can be approximated as

$$p_1 \cong p_0 \left(1 - \frac{k}{\beta + \eta}\right) \tag{4}$$

and

$$q_1 \cong q_0 \left(1 + \frac{\eta k}{\beta + \eta}\right) \tag{5}$$

provided that k is a relatively minor fraction.

Consumers' gain in terms of the increase in consumers' surplus is expressed as

$$\begin{aligned} \text{area } ACGB &= \text{area } AP_0P_1B - \text{area } CP_0P_1G \\ &= \int_{p_1}^{p_0} c\, p^{-\eta}\, dp - q_0\,(1 - r)\,(p_0 - p_1) \\ &\cong p_0 q_0 \frac{k\, r}{\beta + \eta} \end{aligned} \tag{6}$$

where r is the ratio of marketable surplus (total output minus home consumption) to total output ($r = HQ_0/0Q_0$). Equation 6 shows that consumers' gain from the technical progress is larger as r is larger or as the production of the crop is more commercialized.

Correspondingly, the cash revenue of producers will change by

$$\begin{aligned} &\text{area } BEQ_0Q_1 - \text{area } ACGE \\ &\quad = p_1\,(q_1 - q_0) - q_0\, r\,(p_0 - p_1) \\ &\quad \cong p_0 q_0\, k \frac{(\eta - r)}{\beta + \eta} \end{aligned} \tag{7}$$

which indicates that producers' cash revenue will increase if r is smaller than η. In other words, the less commercialized the production, the larger the gain in producers' cash revenue (or the smaller the loss).

Meanwhile, cost of production will change by

$$\frac{\text{area } B0Q_1}{p_1} - \frac{\text{area } A0Q_0}{p_0}$$

$$= \left[p_1q_0 - \int_0 (1+k)bp^\beta dp\right] - \left(p_0q_0 - \int_0 bp^\beta \, dp\right)$$

$$\cong p_0q_0 \frac{k^\beta (\eta - 1)}{(1 + \beta)(\beta + \eta)}$$

Because η is small for the basic staple cereals, certainly less than 1, cost or production will decline. (Cost here includes cash cost and payment in kind to local factors such as hired farm labor.)

Thus, corresponding to technological progress, producers' cash income (income accured to producers' owned factors) will change by change in cash revenue – change in cost

$$= p_0q_0k \frac{\eta - r + \beta(1 - r)}{(1 + \beta)(\beta + \eta)} \tag{9}$$

which indicates that the gains of producers will increase if r decreases, i.e. crop production is less commercialized.

The equations above clearly indicate that technological progress in subsistence crop production in a less commercialized economy would not only benefit consumers but also be likely to benefit producers.

Distribution among producers. The individual farm diagram of Figure 1 illustrates the changes in equilibrium points in individual farm producers corresponding to changes in market equilibrium point in the market diagram. $0'S^S_0$ and $0'S^L{}_0$ represent the supply curves of small and large farms, respectively, before technological advance, which correspond to $0S_0$ in the market diagram. $0'S_1^S$ and $0'S_1^L$ represent the supply schedules of the small and large producers after the technology change, which correspond to $0S_1$. Home consumption is assumed to be the same for both the small and the large farmers. The assumption seems reasonable considering the nature of subsistence crops.

Corresponding to the change in technology and in market prices, the equilibrium of the small producers moves from A^S to $B^{S,}$ corresponding changes in cash revenue (area $B^SE^SQ_0^SQ_1^S$ – area $A^SC'G'E^S$) and in cost (area $B^S0'Q_1^S$ – area $A^S0'Q_0^S$). Likewise, the big farmer's equilibrium moves from A^L to B^L, accompanied by the changes in cash revenue (area $B^LE^t,Q_0^LQ_1^L$ –area$A^LC'G'E^L$) and in cost (area $B^L0'Q_1{}^L$ – area $A^L0'Q_0{}^L$). The net effect on producers' income depends on the relative changes in revenue and cost, which in turn, depend on the price elasticities of individual producers' supply relative to the aggregate demand elasticity.

Aggregate price elasticity of supply (β), which determines market prices, is the weighted average of the price elasticities of supply of individual producers, $\beta = \sum_i w_i \beta_i$, where β_i is the price elasticity of supply of the i^{th} producer ($i = L$ for large producer and $i = S$ for small producer), and $w_i$is the share of the i^{th} producer in total output. Likewise, the rate of shift in the aggregate supply is an average of the rates of supply shift of individual producers, $k = \Sigma\ w_i k_i$.

Approximation formulas for analyzing the impacts of k-percent shift in the aggregate supply function on the i^{th} producer are derived by using the same procedures as those for the changes in intersectoral income distribution (equations 7–9).

$$\text{Change in cash revenue} \cong p_o q_{oi}\left(k_i - k\,\frac{\beta_i + r_i}{\beta + \eta}\right) \qquad (10)$$

$$\text{Change in production cost} \cong p_o q_{oi}\,\frac{\beta_i}{1 + \beta_i}\left(k_i - k\,\frac{1 + \beta_i}{\beta + \eta}\right) \qquad (11)$$

$$\text{Change in income} \cong p_o q_{oi}\left(k_i - \frac{k_i \beta_i}{1 + \beta_i} - \frac{k\, r_i}{\beta + \eta}\right) \qquad (12)$$

where q_{oi} and r_i represent, respectively, the output and the marketable surplus ratio of the i^{th} producer before the supply function shift. Note that equations 10–12 reduce to equations 7–9 if $k_i = k$ and $\beta_i = \beta$.

Whether technical progress in the subsistence crop has a positive effect on the income of the i^{th} producer (a positive value for equation 12) depends to a large extent, on the magnitudes of k_i and β_i relative to k and β. However, it is clear that as r_i becomes smaller, the increase in income becomes larger (or the decline is smaller). In other words, the income position of farmers who sell a small portion of their produce in the market will improve in relation to that of farmers who sell a large fraction, given a technical change.

This model also applies to technical change in the relative incomes of landlords and tenants. If rent is paid in kind as a fixed part of output, say 50%, the supply curve of a tenant is obtained by shifting the supply curve of an owner-operator to the left by 50%. However, if costs are shared in the same proportion by the landlord, the tenant's supply curve is the same as an owner-operator's. In this case, the changes in revenue, cost, and income of both landlords and tenants due to the technological change are all 50% of the changes in the case of the owner-operator, and can be expressed by multiplying equations 10–12 by 0.5. The major difference between the landlords and the tenants would be expressed by the values of r; the marketable surplus ratio of the small share tenant will be small, whereas the ratio of the large landlords will be nearly one.

In the case of leasehold tenure, with rent paid in kind in fixed quantity, the tenant's marketable surplus is reduced by the quantity of the rent (shown by a rightward shift of $D'_H H'$ in Fig. 1). Assuming that landlords sell the rice they collect as rent the aggregate market supply would be the same as for an owner operator. The change in income of the tenant due to the technical change can be expressed by equation 12 with a smaller value of r. The income of the landlords receiving a fixed quantity of rent in kind would be reduced by the rate of decline in the product market price, as expressed by equation 4.

Thus, technical progress in subsistence crop production narrows the income gap between large farms (or landlords) and smaller farms (or tenants) and contributes to more equal income distribution in the rural sector.

Distribution among consumers. Technical change in subsistence crop production represents a clear gain in the economic welfare of urban consumers, as shown in equation 6. The impact of a decline in price of staple foods on the income of individual urban households depends on the importance of the staple in the total consumption expenditure pattern. The poor classes normally spend a higher proportion of their income for such products than the wealthy, hence they benefit more.

Assume that total income (y) is spent either for the staple food (s) or for other commodities (x) as $y = p_s q_s + p_x q_x$, where p_s, p_x, q_s, and q_x represent respectively the prices and the quantities of the staple and the other commodities. Then, the rate of increase in real income due to a decline in the staple price can be approximated by

$$\frac{\Delta y}{y} - e \frac{\Delta p_s}{p_s} \tag{13}$$

where $e = p_s q_s / y$ is the ratio of expenditure for the staple to total household income.

According to equation 4, the percentage change in market price of the subsistence food crop corresponding to a k-% shift in the supply curve is k/ (ß + h). Therefore, the rate of increase in real income is approximated by

$$\frac{\Delta y}{y} \cong \frac{ek}{\beta + \eta} \tag{14}$$

Because e is inversely correlated with per capita income, the decline in the staple food price due to the technical progress in its production equalizes its income effect among urban consumers.

APPLYING THE MODEL TO PHILIPPINE RICE ECONOMY

The Philippines represents an especially relevant case for the application of our model. Rice is its most important subsistence crop (more than 30% of total crop area) and is a typical subsistence crop, in contrast with plantation-grown commercial crops, such as sugarcane and coconuts. Rice is also the most important food staple; more than 70% of the cereal food consumed nationally (as much as 90% in some regions) is rice.

In the Philippines, more than 65% of the lowland rice area now grows modern rice varieties, whose rapid development and diffusion began in the 1960's. The impact of the new rice technology on income distribution has become the subject of major concern. Ishikawa (1970) attributed the emergence of large commercial rice farms in Central Luzon, which coincided with the diffusion of modern varieties, to the high cash requirement of the new technology.

Intersectoral distribution. To empirically apply our model, the parameters of the demand and supply functions, the rate of technological change (supply shift), and the marketable surplus ratio must be specified. The first step is an analysis based on equations 4–9, of the distribution among producers and consumers of gains from the modern rice technology.

Estimates of the price elasticity of demand for rice by Nasol (1971), based on aggregate time-series data, ranged from –0.23 to –0.47, with a mode of –0.3. Our analysis uses 0.2, 0.3, and 0.4 for h to assess the impacts of different price elasticities on our results. Mangahas et al. (1966) analyze the price elasticity of rice supply. Their estimates of short-run and long-run elasticities are distributed around mean values of 0.3 and 0.5, respectively. Our analysis adopts 0.3 and 0.5 as boundary estimates for *ß*.

We assume 10% for *k,* the ratio of shift in the aggregate supply function. Average national yields of new rice varieties grown with irrigation are about 13% higher than those of traditional varieties. Without irrigation new rices yield 5 to 15% higher (Atkinson and Kunkel, 1973; Herdt and Wickham, 1974).

National aggregate data on the quantity of marketable surplus of rice are not available. A sample survey in Central Luzon, often called the rice bowl of the Philippines, by IRRI's Department of Agricultural Engineering provides an initial approximation (Table 1). About 40% of production was sold by farmers.

Table 1. Average rice production and amounts disposed per farm in Central Luzon, 1972/73 crop year.

	Quantity	
	Kg	%
Total output	10,376	100
Production expenses in kind[a]	1,804	17
Rent in kind	1,848	17
Home consumption[b]	2,860	27
Sale	4,224	39

[a] Includes hired labor wages, seed, and feed uses. [b] Includes donation. Source: Sample survey of 58 farms conducted by the Department of Agricultural Engineering, International Rice Research Institute.

Table 2. Estimates of the percentage of change in consumers' surplus and producers' income due to technical progress in rice production in the Philippines.

Changes in		Estimates of change at k =10%, r=0.4					
		η=0.2		η=0.3		η=0.4	
		β = 0.3	β = 0.5	β = 0.3	β = 0.5	β = 0.3	β = 0.5
Price	$-\frac{k}{\beta+\eta}$	–20.0	–14.3	–16.7	–12.5	–14.3	–11.1
Quantity	$\frac{k\eta}{\beta+\eta}$	4.0	2.9	5.0	3.8	5.7	4.4
Consumers' surplus	$\frac{kr}{\beta+\eta}$	8.0	5.7	6.7	5.0	5.7	4.4
Producers' cash revenue	$k\frac{(\eta-r)}{\beta+\eta}$	–4.0	–2.8	–1.7	–1.2	0	0
Production cost	$\frac{k^{\beta}(\eta-1)}{(1+\beta)(\beta+\eta)}$	–3.7	–3.8	–2.7	–2.9	–2.0	–2.2
Producers' cash income (producers' surplus)	$k\frac{\eta-r+\beta(1-r)}{(1+\beta)(\beta+\eta)}$	–0.3	1.0	1.0	1.7	2.0	2.2

In addition, a major portion of rent in kind was also likely to be sold in the market by landlords. Central Luzon farmers, however, sell more in the market than do other Philippine farmers. Therefore, it seems reasonable to assume that the aggregate marketable surplus ratio (r) is 0.4.

Applications of the specified parameters into equations 4–9 are summarized in Table 2. A 10% rightward shift in the supply function due to technical progress results in a price decline of 10 to 20% and an increase in quantity of 3 to 6%. Consumers’ surplus rises by 4 to 8% as a result of an increase in consumption at reduced prices. On the other hand, producers' cash revenue declines slightly. However, the reduction in production cost more than compensates for reduction in revenue, resulting in 1–2% increase in the cash income of producers (except in the case of $\eta = 0.2$ and $\beta = 0.3$).

In a fully commercial economy, such as that of the United States, technological progress in basic staple foods results in a transfer of income from farm producers to urban consumers. In a semisubsistence economy such as that of the Philippines, however, technological progress does not exert such an unfavorable distributional impact on producers. Although the major gain from

Table 3. Distribution among producers and consumers of economic welfare gains resulting from progress in rice production in the Philippines for different assumptions on the marketable surplus ratio. 1969/70-1971/72 averages.[a]

		k = 10%. ß = 0.4 h = 0.3	
		r = 0.4	*r* = 1.0
		Million US$	
Welfare gains			
Total		21.8	22.3
Consumers	$P_0q_0\dfrac{kr}{\beta+\eta}$	17.7	44.4
Producers	$P_0q_0\,k\dfrac{\eta-r+(1-r)}{(1+\beta)\,(\beta+\eta)}$	4.1	-22.1
Welfare gains		%	
Total		100	100
Consumers		81	199
Producers		19	–99

[a] p_0q_0 = US\$311 million assuming P_0 = US\$0.0595/kg of ordinary paddy and q_0 = 5,225,440 t, the price and output values for 1969/70–1971/72, assumming 44 kg/cavan, based on Anden (1974).

technical progress in rice production goes to urban consumers in the form of lower prices, the aggregate income of rice producers does not decline but rather is likely to improve.

The economic benefits from progress in rice production technology and their distribution among consumers and producers in a semisubsistence economy may be more clearly visualized from Table 3, which compares the distribution of economic welfare gains in a semisubsistence economy (*r* = 0.4) and that in a fully commercial economy (*r* = 1.0) for the most probable values of *ß* = 0.4 and h = 0.3.

In both cases, the benefit of the new technology is an annual economic gain worth about US\$22 million. However, the effects on the income distribution are totally different for the different *r*-values. In the semisubsistence economy, about 80% of the new income goes to consumers and 20% to producers. In contrast, in the fully commercial economy, consumers gain twice the value of new income—half as a benefit of the lower cost technology and half as a transfer from producers whose losses equal the benefits of the technology.

Distribution within the rural sector. We use equations 10–12 to analyze the impact of the new rice technology on income distribution among rice producers. The problem is reduced to a comparison of changes in revenue, cost, and income of farmers in response to the price decline that results from the shift in the aggegate supply function.

Table 4 shows the distribution of farms in the IRRI survey grouped in terms

Table 4. Distribution of farms in Central Luzon among the classes divided in terms of the marketable surplus ratio, 1972/73 crop year.

r-classes	Average sale ratio	Farm distribution	
		no.	%
Total	0.39	58	100
0 to 0.25	0.13	31	53
0.26 to 0.50	0.40	17	29
0.51 to 0.75	0.61	8	15
0.76 to 1.00	0.79	2	3

Source: Sample survey conducted by the Department of Agricultural Engineering, International Rice Research Institute.

of the marketable surplus ratio (*r*-classes). It indicates that more than 50% of farmers in Central Luzon sold less than 25% of their produce, and less than 5% sold more than 75%. For illustration, $r = 0.2$ for small farms and $r = 0.8$ for the large farms.

There is no empirical evidence that small and large farmers in the Philippines differ in rate of technical progress in rice production (k) and in price elasticity of rice supply (β). Rather, available evidence supports the hypothesis that there is no significant difference between the rate of diffusion of the modern varieties and the resulting increase in yield between the small and the large producers (Atkinson and Kunkel, 1973).

Considering the highly divisible nature of modern seed technology, it seems reasonable to expect that technical progress has been neutral with respect to farm scale. However, to test the effect of differential rates of technical progress, we made an analysis based on two alternative assumptions: 1) the same rate of technical progress for different size classes ($k_s = k_L = K = 10\%$), and 2) a rate of technical progress of the larger farmers twice that of the small farmers ($k_s = 7$, $k_L = 14$, $k = 10\%$).

It is possible that larger farmers with a greater capacity for investment financing find it easier to adjust their production to the long-run equilibrium point. Considering such a possibility, we made two further, alternative assumptions: 1) large and small farmers have the same price elasticity of supply ($\beta_s = \beta_L = \beta = 0.4$), and 2) the price elasticity of the large farmers reaches the long-run level, while the elasticity of the small farmers remains at the short-run level ($\beta_s = 0.3$, $\beta_L = 0.5$, $\beta = 0.4$).

Accordingly, there are four cases in the estimation of differential impacts of the new technology on small and large farmers. Case 1 assumes the same price elasticity of supply and the same rate of technical progress; Case 2 assumes a larger supply elasticity for the large farmers than for small farmers but the same rate of technical progress; Case 3 assumes the same supply elasticity for both sizes but a higher rate of technical progress for the large farms; and Case 4 assumes a larger supply elasticity and a higher rate of technical progress for the larger farms.

Table 5. Estimates of the differential impacts of technical progress in rice production on small and large fanners in the Philippines. [a]

Farm type	Specified (%)			Changes (%) in		
	$k = 10$,	$\eta = 0.3$	$\beta = 0.4$	Cash revenue	Production cost	Cash income [b]
	r_i	β_i	k_i	$k_i - k \quad \frac{\beta_i - r_i}{\beta + \eta}$	$\frac{\beta_i}{1+\beta_i}(k_j - k)\frac{1 + \beta_i}{\beta + \eta}$	
			Case 1			
Small farm	0.2	0.4	10	1.4	–2.9	4.3
Large farm	0.8	0.4	10	–7.1	–2.9	–4.2
			Case 2			
Small farm	0.2	0.3	10	2.9	–2.0	4.9
Large farm	0.8	0.5	10	–8.6	–3.8	–4.8
			Case 3			
Small farm	0.2	0.4	7	–1.4	–3.7	2.3
Large farm	0.8	0.4	14	–3.1	–1.7	–1.4
			Case 4			
Small farm	0.2	0.3	7	–0.1	–2.7	1.6
Large farm	0.8	0.5	14	–4.6	–2.5	–2.1

[a] k = shift in supply function; η = price elasticity of demand; β = price elasticity of supply; r_i = aggregate marketable surplus ratio; i = producer (large or small). [b] Cash revenue minus production cost.

The results for those four cases are summarized in Table 5. In all cases, technical progress improves the income position of small farms while it impairs that of the large producers. In Case 1, which may have realistic assumptions for the Philippines, the 10% shift in the suply function due to the new technology increases the incomes of small farms and reduces those of large farms by more than 4%. However, even when the rate of technical progress of large farms is twice as fast as that of small farms (cases 3 and 4), the income of the small farms improves and that of the large farms declines by about 2%. Thus, improved technology tends to equalize incomes among rice producers.

Table 5 also provides insight into the relative changes in income position among tenants and landlords. In a typical Philippine share tenancy, tenants and landlords share output and cost more or less equally. As discussed earlier, the only difference in the impact of technical change on their incomes arises from the difference in the marketable surplus ratio. Therefore, in Case 1, “small farm” may be regarded as “tenants” and “large farm” as “landlords.” However, the income-equalizing effect of the new technology between tenants and landlords could be greater than shown because r_i for most share-tenants is smaller than 0.2, and r_i for large landlords must be close to 1.0.

Distribution in urban sector. As shown in Tables 2 and 3, the major gains in economic welfare from the development of new rice technology go to consumers.

By applying data on the share of rice in the total expenditures of urban households to equation 14, with the most probable parameters of demand and supply ($\beta = 0.4$, $\eta = 0.3$), we show that percentage increase in real income varies inversely with household income. While the 10% shift in the rice supply function increases real income by about 4% for households with less than US$250 income, it increases the real income of the highest income classes (US$2500) by only 1%.

Thus, the relative gain in real income is largest for the households of low-income urban families. Note also that large benefits of new rice technology go not only to urban workers but also to landless farm workers for whom rice is a major item of household expenditures.

BIAS DUE TO THE ASSUMPTION OF FIXED HOME CONSUMPTION

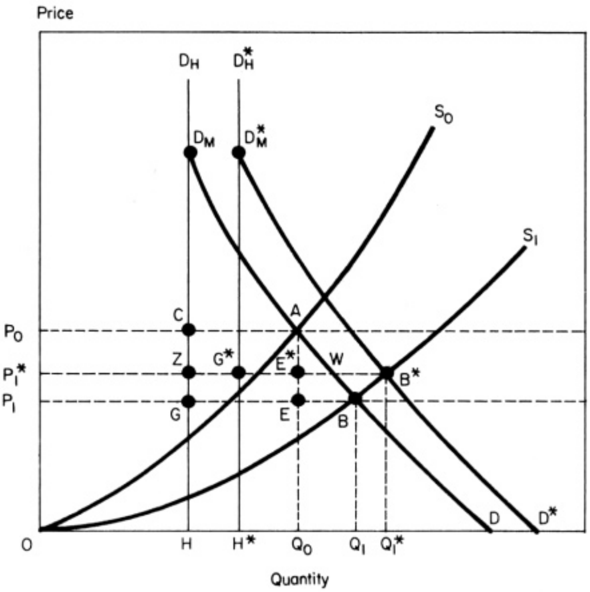
The most restrictive assumption in the preceding analysis is that of a fixed consumption by farmers' households of the subsistence produce. The assumption seems reasonable considering the nature of the subsistence crop and the substantial transaction cost usually involved in the substitution of purchased goods for home-produced goods.

The attempts to estimate the price response of home consumption have been few. A recent study in the Philippines based on a sample survey of the same farmers for 3 consecutive years shows that 1) the effect of price changes on home consumption of rice is not statistically significant, and 2) home consumption rises significantly in response to increases in output, although it tends to level off at high outputs. The results of the regression analysis were confirmed by a motivation survey on the disposition of rice output (Toquero et al, 1975).

In the case of rice in the Philippines, it is reasonable to assume that home consumption is not price responsive and can be approximated by a vertical line such as D_HH in Figure 1. However, D_HH does not stay stable, but shifts to the right as output increases $0Q_0$ to $0Q_1$. The rightward shift in the home consumption schedule implies a similar shift to the right in the total demand schedule, as represented by the shifts from D_HH to $D_H{}^*H^*$ and from D_HD_MD to $D_H{}^*D_M{}^*D^*$ in Figure 2. Corresponding to this shift, the market equilibrium after the introduction of new technology will be at B^* instead of at B.

The nonproducer consumers' surplus, with assumed increase in home consumption in response to output increase, is represented by area $B^*D_M{}^*G^*$. Since $D_H{}^*D_M{}^*D^*$ is parallel with D_HD_MD, area $B^*D_M{}^*G^*$ is equal to area WD_MZ. Therefore, under the assumption of fixed home consumption by producers households, the increase in consumers' surplus due to technical change is larger than when home consumption increases in response to output increases by area $BWZG$.

Correspondingly, the assumption of the fixed home consumption is likely to produce an overestimation of producers' cash revenue by the difference between (*area* $B^*G^*Q_1{}^*$ = area $ACHQ_0$) and (*area* BEQ_0Q_1 − area $ACGE$), and to produce an underestimation of the cost of production by area $BQ_1Q_1{}^*B^*$.



2. The impact of technological change on a subsistence crop under the assumption of variable home consumption.

Define m as the rate of shift in the total demand function corresponding to the increase in home consumption (Δh)

$$m = \frac{H\,H^*}{0Q_0} = \frac{\Delta h}{q_0} \tag{15}$$

$$\cong \frac{\Delta q}{q_0}\,\delta\,(1 - r)$$

where $\delta = \left(\frac{\Delta h}{\Delta q} \cdot \frac{q}{h}\right)$ and is the elasticity of home consumption with respect to output. Assuming that m is nearly constant for the relevant range of analysis, the total demand schedule $D_H D_M^* D^*$ can be approximated by

$$q = c\,(1 + m)\,p^{-\eta} \tag{16}$$

The equilibrium price and quantity after the change in technology, including the adjustment in home consumption resulting from the output increase, can be obtained by solving the simultaneous system consisting of equations 3 and 16 as follows:

$$p_1^* \cong p_0\left(1 - \frac{k}{\beta + \eta} + \frac{m}{\beta + \eta}\right) \tag{17}$$

$$q_1^* \cong q_0\left(1 - \frac{\eta k}{\beta + \eta} + \frac{\beta m}{\beta + \eta}\right) \tag{18}$$

Correspondingly, the changes in consumers' surplus, producers' cash revenue, and production cost due to the change in technology are recalculated for the case of variable home consumption as

Change in consumers' surplus

$$= \text{area } WD_MZ - \text{area } AD_MC$$

$$\cong p_0q_0\left(\frac{kr}{\beta + \eta} - \frac{mr}{\beta + \eta}\right) \tag{19}$$

Change in producers' cash revenue

$$= \text{area } B^*G^*H^*Q_1^* - \text{area } ACHQ_0$$

$$\cong p_0q_0 \frac{k\,(\eta - r)}{\beta + \eta} - \frac{m(\eta - r) - m(k - m)}{\beta + \eta} \tag{20}$$

Change in production cost

$$= \text{area } B^*0Q^*_1 - \text{area } A0Q_0$$

$$\cong p_0q_0 \frac{k\beta\,(\eta - 1)}{(1 + \beta)\,(\beta + \eta)} + \frac{\beta m}{\beta + \eta} \tag{21}$$

The second term of each expression represents the possible bias due to the assumption of fixed home consumption. To evaluate the biases, the value of *m* is required.

Equation 18 implies

$$\frac{\Delta q}{q_0} = \frac{\eta k + \beta m}{\beta + \eta} \tag{22}$$

Substituting the above expression in equation 15, we obtain

$$m \cong \frac{k\eta\delta\,(1 - r)}{\beta + \eta - \beta\delta\,(1 - r)} \tag{23}$$

which is calculated as 1.2% for the probable values of parameters ($\eta = 0.3$ $\beta = 0.4$, $k = 10\%$, $r = 0.4$, $\delta = 0.4$, δ is based on Toquero et al., 1975).

Estimates of the changes in producers' surplus and consumers' cash income for the two assumptions about producers' home consumption are in Table 6.

Table 6. Estimates d the changes in consumers' surplus and producers' income due to technical progress in rice production for two assumptions on producers' home consumption.

	Estimated changes[a] in		
	Fixed home consumption	Variable home consumption	Difference[b]
Price	–14.3	–13.6	1.7
Quantity	4.3	5.0	0.7
Consumers' surplus	5.7	5.0	–0.7
Producers' cash revenue	–1.4	–1.1	0.3
Production cost	–2.8	–2.3	0.5
Producers' cash income	1.4	1.2	–0.2
Producers' home consumption	0	2.0	2.0

[a] Assuming h (price elasticity of demand) = 0.3, β = 0.4, *k* (shift in supply schedule) = 10%. *r* (ratio of marketable surplus to total output) = 0.4, d (elasticity of home consumption) = 0.4. [b] Fixed home consumption – variable home consumption.

The assumption of fixed home consumption may contribute to a slight overestimation of both consumers' and producers' gains. The loss of producers from the reduction in cash income seems more than compensated for by increased home consumption. The possible biases in consumers' welfare and in producers' cash income are too small to affect the basic conclusion on intersectoral income distribution. Also, because the bias in the estimate of price change is small, the conclusion on income distribution within the urban sector remains unaltered.

Consider the implications of assuming fixed home consumption on the income distribution among large and small farmers. Individual farmers will try to maximize their profit for the market price determined by equation 17. Because the elasticity of home consumption of rice with respect to output declines as output rises, the rate of increase in home consumption corresponding to the increase in output due to technical progress differs among large and small farmers. It may be smaller for larger farmers than for smaller farmers. The rate of increase in aggregate home consumption in response to the increase in aggregate rice output is the weighted average of the rates for the large and small producers.

$$m = \Sigma w_i m_i \tag{24}$$

Applying the same procedure as that for fixed home consumption, the formula for analyzing the impacts of change in technology on the i^{th} producer for the assumption of variable home consumption is:

Change in cash revenue

$$\cong p_0 q_0 k_i - \frac{k(\beta_i + r_i)}{\beta + \eta} - m_i + \frac{m(\beta_i + r_i)}{\beta + \eta} \tag{25}$$

Change in production cost

$$\cong p_0 q_0 \frac{\beta_i}{1+\beta_i}\left(k_i - k\frac{1+\beta_i}{\beta+\eta} + m\frac{1+\beta_i}{\beta+\eta}\right) \tag{26}$$

where m_i is defined as

$$m_i = \frac{\Delta h_i}{q_{oi}} = \frac{\Delta q_i}{q_{oi}}\,\delta_i\,(1-r_i) \tag{27}$$

where q_{oi} and r_i are the quantity of total output (= consumption) and the marketable surplus ratio before the introduction of new technology respectively; Δq_i and Δh_i are the changes in the quantities of total output and home consumption due to the introduction of the technology, and δ_i is the output elasticity of home consumption of the i^{th} producer ($i = S$ for small producer and $i = L$ for large produce;).

Because individual producers increase output along their supply schedules in response to the change in market price from p_0 to p_1*, which is given by equation 17, the rate of increase in output can be approximated by

$$\frac{\Delta q_i}{q_{oi}} \cong k_i + \frac{\beta_i\,(m-k)}{\beta+\eta} \tag{28}$$

m_i is given as

$$m_i = k_i + \frac{\beta_i\,(m-k)}{\beta+\eta}\quad\delta(1-r_i) \tag{29}$$

The estimates of the impacts of technical progress on large and small farmers for different assumptions on producers' home consumption behavior are compared in Table 7. For variable home consumption, it is assumed that the home consumption of small producers is highly responsive to output increases with $\delta_S = 0.6$, whereas the home consumption of large producers is in saturation, i.e. $\delta_L = 0$.

Compared with the case of fixed home consumption, the favorable impact of the technical change in promoting a more equal distribution of cash income is less dramatic if we allow changes in home consumption for small producers. However, even in case 4 with the higher rate of technical progress and the larger capacity for supply adjustment of larger farmers, the impact of technical progress on the distribution of cash income is in the direction of promoting equality. While small farmers' cash income position stays fairly stable, larger farmers incur substantial losses. The economic welfare of small farmers clearly increases as their consumption of rice increases, and their cash income remains nearly constant.

Table 7. Comparison of the differential impact of technical progress in rice production on small and large farmers for different assumptions on producers' home consumption.

	Change (%)						
	Fixed home consumption case[a]			Variable home consumption case[b]			
	Cash revenue	Production cost	Cash income	Cash revenue	Production cost	Cash income	Home consumption
Case 1[c]							
Small farm	1.4	–2.9	4.3	0	–0.5	0.5	3.0
Large farm	–7.1	–2.9	–4.2	–5.1	–0.5	–4.6	0
Case 4[c]							
Small farm	–0.1	–2.7	1.6	–0.7	–0.2	–0.5	1.9
Large farm	–4.6	–2.5	–2.1	–3.4	–0.2	–1.4	0

[a] Assuming δ (elasticity of home consumption) = δ_S (small producer) = δ_L (large producer) =0. [b] Assuming δ = 0.4, δ_S =0.6, δ_L = 0. [c] Parameter specifications are same as those for Table 6.

Table 7 clearly shows that, if the specification of the model and parameters are correct, technical progress in rice production will 1) contribute to the welfare of small producers by increasing their rice consumption, and 2) result in a reduction of income to large commercial farmers or landlords. The reduction in their income will be transferred to the urban poor and the landless rural workers in the form of a lower price of rice.

Thus, the conclusion that technical progress in the production of subsistence crops in a semimonetized economy promotes a more equal distribution of income and welfare remains unchanged — even if we remove the restrictive assumption of fixed home consumption by producers' households.

CONCLUSION AND IMPLICATIONS

Our model, when applied to the Philippine rice economy, indicates that the introduction of modern technology in the production of subsistence crops in semisubsistence economies, such as the modern rice varieties in tropical Asia, benefits both consumers and producers. It promotes more equal income distribution through downward pressure exerted on prices and hence on the incomes of those farmers with a large proportion of marketed surplus. It tends to transfer income from large commercial farmers and landlords to the urban poor and the rural landless classes.

The argument that the new technology increases the income disparity between large commercial units and small subsistence units, or increases the polarization of the rural population into large commercial farms and landless workers, seems to have been based on the observation that the emergence of the new rice technology coincided with growing income disparities and increase in landless laborers.

Such an argument, based simply on coincidences, misses the real cause of the growing disparity and the increasing landless population. In terms of our model, the real cause is a rapid (population-induced) shift in the demand function for the major subsistence crops that has exceeded the speed of the supply function shift. The resulting rise in price of major food staples has an especially adverse impact on the low-income working classes. The rising prices also provide large gains to the large producers who sell a major portion of their produce, while providing little benefit to small, near-subsistence farmers.

These phenomena represent the reverse of the results obtained in Table 4 through 7 under the assumption of a rightward shift in the supply function with a stable demand function. In recent years technology has not shifted the supply curve fast enough. But without the supply shift from earlier developments in technology, the increase in prices would have been greater and might have occurred sooner, and the adverse effects of rising prices on income distribution would have been much greater.

We suggest that a critical factor for attaining a more equal income distribution in the developing economies is intensification of efforts for developing improved technology for the subsistence crop sector. That will enable the supply function of major food staples to shift more rapidly than the demand function.

This analysis, however, does not imply that technological advances can solve the whole problem. On the contrary, Tables 4 and 7 show that if technical progress is slower for the small farmers than it is for the large farmers, the relative income gains for small farmers are reduced. In fact, a real danger will arise if new technology is monopolized by a small number of large commercial farms, with no significant shift in the aggregate supply schedule. In such a case, the large farms could capture the whole gain of technical progress by increasing output without a resulting decline in prices.

Likewise, if the commercial farmers in a subsistence country can exert political power to gain price support at the pre-innovation level, the large farmers will capture the benefits — with a large marketed surplus — at taxpayers' expense. (This does not occur with price stabilization programs designed to smooth out fluctuations within a year.)

To avoid that possibility, the rate of shift in supply of the major subsistence crops must exceed the rate of shift in demand. That means:

— strengthening research and development work for rice, to provide a continuous flow of new technology,

— improving extension, credit and marketing services, which will encourage adoption of the technology by small farmers, and

— providing indivisible factors, such as irrigation, which are beyond the means of individual small farmers.

REFERENCES CITED

ANDEN, T. L. 1974. Data series on rice statistics: Philippines. Department of Agricultural Economics, International Rice Research Institute, Los Baños, Philippines.

ATKINSON, L. J., and D. E. KUNKEL. 1973. HYV in the Philippines: progress of the seed-fertilizer revolution. Econ. Res. Serv. U.S. Dep. Agric.

COCHRANE, W. W. 1958. Farm prices: myth and reality. University of Minnesota Press.

FALCON, W. P. 1970. The green revolution: generations of problems. Am. J. Agric. Econ. 52:698–710.

HAYAMI, Y., and R. W. HERDT. 1977. Market price effects of technological change on income distribution in semisubsistence agriculture. Am. J. Agric. Econ. 59(2):245–256.

HERDT, R. W., and T. H. WICKHAM, 1974. Major constraints to rice production with emphasis on yields in the Philippines. Paper presented to the International Rice Research Conference, April 22, 1974, International Rice Research Institute, Los Baños, Philippines.

ISHIKAWA, S. 1970. Agricultural development strategy in Asia. Asian Development Bank, Manila.

JOHNSTON, B. F., and J. COWNIE. 1969. The seed-fertilizer revolution and labor force absorption. Am. Econ. Rev., 59:569–582.

MANGAHAS, M., A. RECTO, and V. W. RUTTAN. 1966. Price and market relations for rice and corn in the Philippines. J. Farm Econ. 48:685–703.

NASOL, R. L. 1971. Demand analysis for rice in the Philippines. J. Agric. Econ. Dev. 1:1–13.

STAUB, W. J., and M. G. BLASE. 1974. Induced technological change in developing agricultures: implications for income distribution and agricultural development. J. Dev. Areas 8:581–596.

TOQUERO, Z., J. B. DUFF, T. L. ANDEN, and Y. HAYAMI. 1975. Marketable surplus functions for a subsistence crop: rice in the Philippines. Am. J. Agric. Econ. 57:705–709.

WHARTON, C. R., JR. 1961. The green revolution: cornucopia or Pandora's box? Foreign Affairs 47:464–476.

COMMENTS ON
MARKET PRICE EFFECTS OF NEW RICE TECHNOLOGY ON INCOME DISTRIBUTION

P. PINSTRUP-ANDERSEN

THE ANALYSIS by Hayami and Herdt covers a much discussed question: has the new rice production technology had adverse effects on the distribution of wealth and income?

Refuting many adverse claims, Hayami and Herdt argue that the effect of new rice technology on market price has in fact promoted a more equal income distribution among rice producers and consumers in the Philippines.

My discussion focuses on two issues.

1. The appropriateness and validity of the model used, the assumptions made, and the conclusions from the empirical analysis.
2. The findings from similar research in Colombia.

INTERSECTORAL DISTRIBUTION

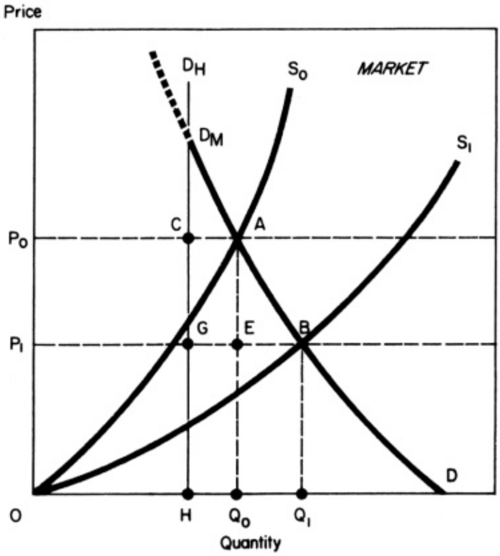
The intersectoral distribution is estimated by a straightforward consumer-and-producer-surplus model with two separate markets. On the basis of this model and by using data from the Philippines, Hayami and Herdt conclude that the aggregate income of the rice producers studied did not decline as a result of the introduction of new technology and the corresponding shift in the supply curve.

Because the price elasticity of demand for rice is between 0 and – 1, general equilibrium conditions suggest that a shift in the supply curve while the demand curve remains constant would result in a decline in aggregate producer revenues. That does not occur in the Hayami and Herdt analysis because basically,

1. A large proportion of the production is consumed by the producers themselves.
2. It is assumed that the "real income value" of home consumption is represented by the quantity consumed irrespective of price.

Therefore, while a shift in the supply curve reduces production costs for the total production, the price is reduced on the marketed surplus only. As the

Director, Agroeconomic Division, International Fertilizer Development Center, Florence, Alabama, USA.



1. Impact of technological change on a subsistence crop.

marketed surplus becomes smaller relative to total production, the reduction in cash revenues likewise becomes smaller relative to total cost savings and to producer surplus increases.

Under the assumption made, the conclusion is correct. I find it difficult, however, to justify an assumption that maintains that the real income value is independent of price for one group of consumers but not for another. I believe that the real income value to the consumer must take into account the price, whether the consumer is also a producer or not. I believe there is ample evidence—both theoretical and empirical—that this is more realistic than the assumption made.

If my postulate is accepted the analysis proceeds along somewhat different lines than those suggested by Hayami and Herdt. Figure 1 represents an exact copy of the market curves of Hayami and Herdt's Figure 1. The consumer surplus, indicated by the area P_1BAP_0, consists of the consumer surplus obtained by the producers in their capacity as consumers of home produce (P_1GCP_0) and the consumer surplus obtained by the nonproducing consumer ($GBAC$). The distribution of the total consumer surplus between the two markets obviously depends on the proportion of the total production consumed in each market. The higher the proportion used for home consumption, the larger is the proportion of the total consumer surplus obtained by the producers. The total producer surplus, on the other hand, does not depend on the relative distribution between home consumption and sale. But, as Hayami and Herdt stated, the part of the producer surplus that constitutes marketable surplus depends on the proportion sold.

Hence, the conclusion that the effect of new technology on intersectoral income distribution is more favorable to the producers in cases where a large proportion of the production is consumed by the producers is merely a matter of the producers capturing consumer surpluses.

Assuming a price-independent real income value of home consumption, the analysis fails to recognize the gains in consumer surplus obtained by producers and overestimates producer surpluses. Although farmers who use a large proportion of total production at home obtain a net gain from new technology, it is important for policy prescription to emphasize that the gain is obtained only because the increase in the consumer surplus obtained by the producers more than offsets the loss in producer surplus.

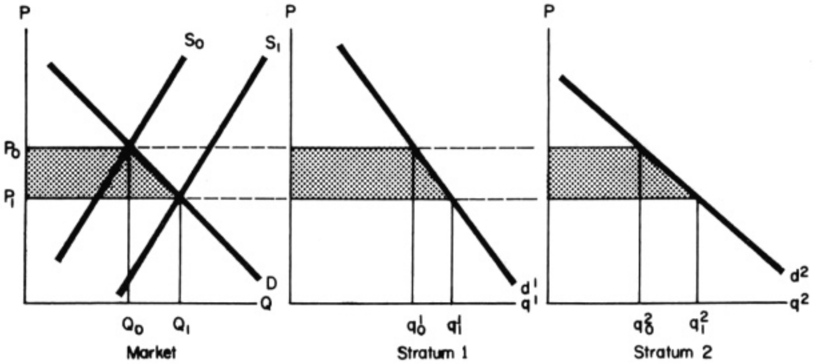
I have serious reservations regarding the validity of the assumption of fixed home consumption by producers. While Toquero et al. (1975) found that the price coefficient in a supply function for rice in the Philippines was not statistically different from zero, they also found that producers would expand home consumption if new production-increasing technology was introduced. Toquero considered reasonable the completely inelastic demand for home produce because rice is a "commodity filling a basic subsistence need."

But if, in fact, producers fill such a basic need no matter what the market price is, why do they increase home consumption when the supply curve is shifted? One would expect that if producers do not adjust home consumption to prices because their demand is saturated, neither would they adjust it to output expansions.

The nonsignificant coefficient of price found by Toquero et al. (1975) is probably best explained as a cancelling by opposing income and substitution effects. Such cancelling would not occur when the supply curve is shifted among farmers who retain a large proportion of the production for home consumption because, as Hayami and Herdt show, cash incomes will increase for decreasing prices. Hence, the income and the substitution effects will operate in the same direction rather than oppose each other. This may explain why producers adjust home consumption to shifts in the supply curve, but not to externally caused price changes. This does not mean, however, that the demand is completely price inelastic.

Distribution within the producer sector. Hayami and Herdt conclude that the new rice technology may benefit smaller farmers more than larger ones because the former consume a larger proportion of the total production than the latter do. Assuming that the rate of adoption of new technology and production costs are not functions of farm size, this conclusion is probably valid. However, as previously mentioned, the benefits obtained by the smaller farmers refer to consumer surpluses.

Assuming an inelastic market demand for rice, the decrease in the producer surplus per unit of additional production will be the same for all farmers irrespective of the proportion marketed. But as home consumption increases, more of the loss in producer surplus is recaptured by the farmer as consumer



2. The change in consumer surplus and its distribution among consumer strata. P = price; Q, q = quantity in the market and the strata, respectively; D, d = demand in the market and the strata, respectively; S = supply. Subscript 0, 1 indicate before and after the shift in the market supply curve. Superscript 1, 2 indicate strata 1 and 2, respectively.

surplus. Unless a large portion of the aggregate production is consumed by producers, cash incomes would fall. Hence, separating the consumer and producer surpluses obtained by the producers greatly clarifies the analysis.

Distribution within the consumer sector. Hayami and Herdt estimate the distribution of benefits from new technology as the relative price decrease multiplied by the budget proportion spent on rice. Because all consumers are faced with the same market and, therefore, the same decline in rice prices, the distribution of benefits or "rate of increase in real income" is proportional to the budget proportion spent by each income stratum. The budget proportion spent on rice is inversely correlated with per capita incomes. Hence, no further analysis is needed to reach the conclusion that a decline in rice prices will result in a percentage increase in real incomes that is inversely correlated with income level. That of course, does not imply anything about the distribution of absolute gains.

I suggest an alternative procedure for estimating the distribution of benefits from new technology among consumer income strata.[1]

The consumer surplus obtained from a price decline may be divided into that obtained from a price decline on the quantity consumed prior to the price change, and that obtained from the consumption of additional quantities at a lower price. Hence, the proportion of the total consumer surplus obtained by any income stratum is determined by the relative quantity consumed prior to the price change and the relative price elasticity of demand for the particular income stratum. Figure 2 illustrates the distribution of the total

---

[1] The following analysis draws on Pinstrup-Andersen (1977).

consumer surplus between two income strata with different price elasticities of demand.

The change in consumer surplus caused by a price change is measured as the area to the left of the demand curve, between the old and the new price levels. If the consumer sector is divided into income strata, the total change in consumer surplus may be viewed as the sum of the changes in the consumer surplus for each stratum. What is of interest here is to estimate the distribution of the total consumer surplus among such income strata.

Suppose that a new production technology causes the supply curve to shift from S_0 to S_1 and the demand curves for the market (D) and for strata 1 and 2 (d^1 and d^2) remain constant. The price of the commodity considered decreases from P_0 to P_1, and the quantities sold increase from Q_0 to Q_1, after adjustments leading to a new market equilibrium. Assume a closed economy in which all consumers face the same market, and that only one market price exists for each commodity. The market demand curve is then merely the sum of the strata demand curves. The total consumer's surplus is then estimated as:

$$(P_0 - P_1)\, Q_0 + \tfrac{1}{2}\,(Q_1 - Q_0)\,(P_0 - P_1) = \tfrac{1}{2}\,(P_0 - P_1)\,(Q_0 + Q_1)$$

and equals the sum of the strata surpluses:

$$(P_0 - P_1)\,\tfrac{1}{2}\sum_{i=1}^{m}(q_1^i + q_0^i)$$

where m is the number of income strata and q^i is the quantity for stratum 1[2]. All other terms are explained above.

The new market equilibrium price (P_1) and the quantity (Q_1), are estimated as follows:

$$P_1 = P_0\left(1 - \frac{B}{\varepsilon - \eta}\right)$$

$$Q_1 = Q_0\left(1 + \frac{P_1 - P_0}{P_0}\,\eta\right)$$

and the new quantity for stratum i is estimated as:

$$Q_1 = Q_0\left(1 + \frac{P_1 - P_0}{P_0}\,\eta_i\right)$$

---

[2] A price change in one commodity causes adjustments in the purchase of other commodities, which in turn changes the consumer surplus obtained from those other commodities. Such changes are likely to be amall and are ignored in this analysis.

where

e = price elasticity of supply
h = market price elasticity of demand
h_i = price elasticity of demand in stratum 1
B = the horizontal shift in the supply curve as a proportion of initial quantity

The formula was used to estimate the distribution of benefits from new technology in 17 commodities among five consumer income strata of the population of Cali, Colombia. Table 1 shows price elasticities and estimated absolute value per capita consumer surplus — average and by stratum — brought about by a horizontal shift to the right in the supply curve for rice equal to 10% of the initial quantity. Because no acceptable estimates of the supply elasticity were available, estimates of 0 and 1 were made for supply elasticities. The estimates are expected to provide the lower and upper limits of the true estimate.

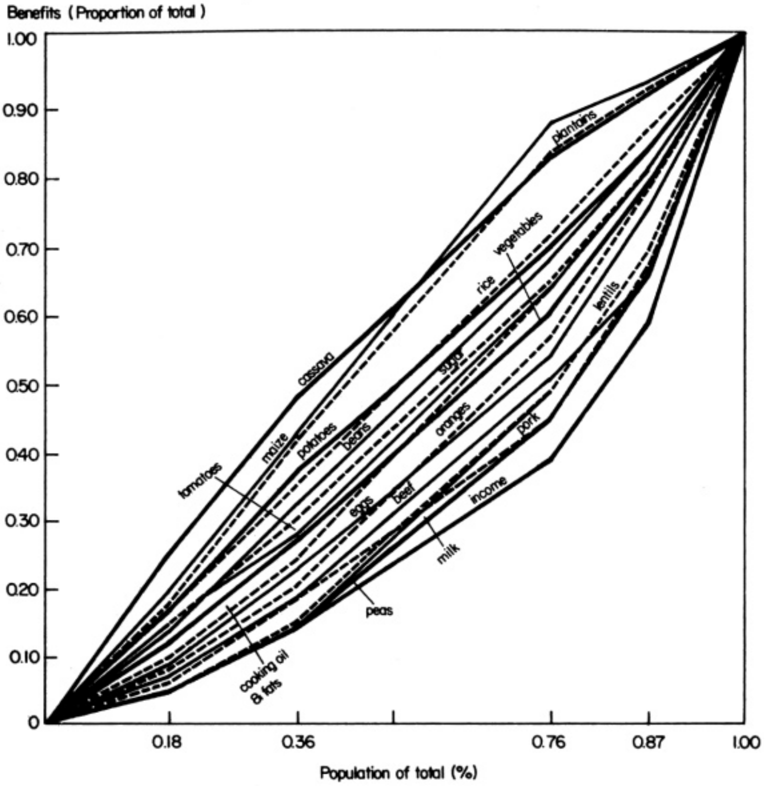
Each value shown in Table 1 may be interpreted as the benefit accruing to each consumer during a year following a shift in the supply curve and the subsequent instantaneous adjustment to the new market equilibrium, where the benefit is expressed in terms of consumer real income. A horizontal shift in the supply curve for rice equal to an additional 10% of the initial quantity of rice supplied would thus add US$1.71 to the annual real per capita income on the average if the supply elasticity is 0, and US$0.44 if the supply elasticity is 1. Each consumer in stratum 1 would receive $1.82 and $0.46, respectively, while that in the highest income stratum would receive $2.14 and $0.53 under each of the two supply elasticities.

Although the consumer surplus is sensitive to the magnitude of the supply elasticity, the distribution of any given consumer surplus among income strata does not depend on the supply elasticity. To compare the distribution among

Table 1. Estimated price elasticity of demand and consumer surplus for rice by income stratum, Cali, Colombia, 1976.

Income stratum[a]	Estimated price elasticity of demand	Value of per capita consumer surplus[b] at	
		e = 0 (US$)	e = 1 (US$)
I	–0.426	1.82	0.46
II	–0.399	1.69	0.42
III	–0.397	1.82	0.46
IV	–0.262	1.83	0.46
V	–0.187	2.14	0.53
Market av.	0.354	1.71	0.44

[a] I and V indicate lowest and highest income strata. [b] Exchange rate at time of study: US$1 = Colombian P20.



3. Relationship between cumulative distribution of benefits (income) and cumulative population distribution.

consumer income strata of benefits from shifting the supply curve of alternative commodities, some measure is needed to rank the commodities according to distributional bias. In the development of such a measure, the cumulative proportion of total benefits is related to the cumulative proportion of the population of consumers, with the latter ranked from lowest to highest per capita income.

That relationship may be illustrated by curves similar to Lorenz curves (Fig. 3). The ratio of the area above any such curve to that below provides a measure for distributional bias. An alternative measure is provided by the gini equivalent coefficient, which is the area between the curve and the diagonal divided by one-half.

The coefficient of distribution for rice Cas estimated at 1.03, and the gini equivalent coefficient at 0.01. The actual gini coefficient for the population studied was 0.42. Hence, new technology resulting in expanded rice production would tend to improve income distribution among consumers. In rice, the distribution of benefits among income strata is essentially unbiased (the dis-

Table 2. Estimated coefficients of distribution (α') and "gini equivalent" coefficients (G') of selected commodities, 1976.

Commodity	α'	G'^a
Cassava	0.74	n.a.
Maize	0.76	n.a.
Plantain	0.82	n.a.
Rice	1.03	0.01
Potatoes	1.04	0.02
Beans	1.14	0.06
Sugar	1.22	0.10
Tomatoes	1.26	0.12
Cooking oils and fats	1.37	0.16
Vegetables	1.37	0.16
Eggs	1.58	0.23
Oranges	1.59	0.23
Beef	1.88	0.31
Lentils	1.99	0.33
Pork	2.02	0.34
Peas	2.03	0.34
Milk	2.15	0.36
Income	–	0.42

[a] n.a. = not applicable.

tribution coefficient is nearly equal to 1). In three commodities (cassava, maize, and plantain), benefit distribution favored the lower income consumers, while in the remaining 13 commodities consumer benefits were biased in favor of higher income consumers (Table 2).

CONCLUSIONS

Hayami and Herdt have discussed an important topic for which solid analytical information was urgently needed. Much of the available information on the distribution of benefits from new agricultural production technology is based on incomplete analyses and casual observations. Often the effects of new technology have been confused with effects of other changes occurring simultaneously, and causal effects are frequently not fully understood.

As the authors pointed out, the analysis deals only with the market price effects. For that purpose, the consumer and producer surplus model seems to be an adequate tool.

The analysis illustrates how small food producers may obtain a large proportion of the additional consumer surplus brought about by new technology. Given certain market demand and supply elasticities, the additional consumer surplus obtained by producers who consume a large proportion of their total production may more than offset the negative producer surplus, thus resulting in a positive net surplus to such producers in spite of an inelastic market demand curve. Also, net cash incomes of those farmers may increase as the supply curve shifts because the cost savings exceed the loss in gross revenues.

The extent to which savings occur in cash versus noncash costs is thus an important consideration.

The distribution of benefits among consumer groups depends on the relative consumption by each of these group; before the introduction of new technology and the relative price elasticities of demand. Hayami and Herdt consider only the former. My suggested alternative approach considers both factors. Although empirical evidence on this issue is limited, it is probably correct to conclude that, in general, the distribution of benefits from new technology would be biased in favor of higher income consumers but less so than current income distribution is. Hence, new technology would tend to improve existing income distribution among consumers. In the case of basic staples, the benefit distribution may actually be biased in favor of lower income consumers.

REFERENCES CITED

PINSTRUP-ANDERSEN, P. 1977. Decision-making on food and agricultural research policy: distribution of benefits from new agricultural technology among consumer income strata. Agric. Adm. 4:13–28.

TOQUERO, Z., B. DUFF, T. ANDEN, and Y. HAYAMI. 1975. Marketable surplus functions for a subsistence crop: rice in the Philippines. Am. J. Agric. Econ. 57:705–709.

POLICY

New rice technology and national irrigation development policy

M. KIKUCHI AND Y. HAYAMI

IRRIGATION IS A CRITICAL part of the infrastructure for agricultural development in rice-growing regions in Asia. It contributes to increased and stabilized rice yields for a given technology. It also facilitates the development and diffusion of modern rice varieties, which require higher levels of fertilizers and related inputs to fulfill their yield potential.

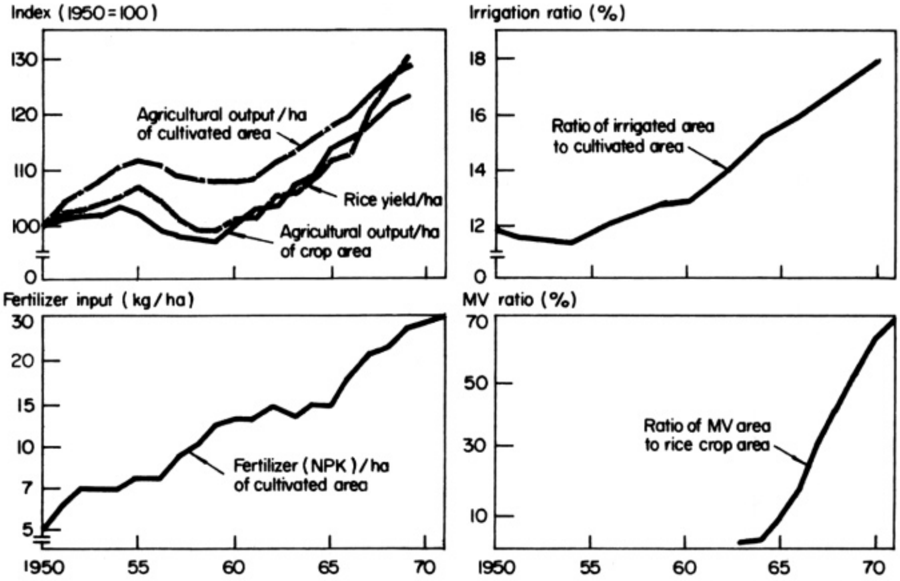
Inadequate irrigation facilities have been identified as a major constraint to the realization of the potential productivity of the new rice technology at the farm level. But it has not been clearly recognized that the new rice technology has a latent power that can remove that constraint. Because of the high complementarity between the new rice technology and good water control, the modern varieties (MV) increase the rates of return to irrigation investments. Those higher rates of return should have the effect of inducing the allocation of more funds to irrigation.

Irrigation systems, especially the gravity type, are endowed with the attributes of public infrastructure, such as indivisibility and externality. Asian peasant farmers cannot be expected to procure such systems individually. The construction and maintenance of irrigation systems have traditionally been a major responsibility of government in monsoon Asia. Thus, the decisions on irrigation investments involve the political process. But is there any mechanism in the political process to guarantee a rational response to the opportunity created by the new rice technology? That is the major question we address in this paper.

We approach the question with a case study of irrigation investments in the Philippines. First we review the trends in irrigation development, and identify

Postdoctoral fellow and agricultural economist, Department of Agricultural Economics, International Rice Research Institute, Los Baños, Philippines.

[1] Earlier results of this study were reported in Hayami et al. (1976) and Hayami and Kikuchi (forthcoming).



1. Growth in land productivity and development of irrigation infrastructure and seed-fertilizer technology in the Philippines. Sources: Anden (1974), Crisostomo and Barker (1973), Republic of the Philippines Department of Agriculture and Bureau of Agricultural Economics.

population pressure and the increasing scarcity of land for cultivation as the basic cause for the trend of accelerated government irrigation investment. Then, we associate short-run fluctuations in government irrigation investment with the changes in the rates of return to irrigation investments that resulted from fluctuations in rice prices. Based on the results of multiple regression analysis of the total variation in government investment in terms of the two major factors identified, we try to estimate the effects of the new rice technology on government investments in irrigation systems.

PROCESS OF AGRICULTURAL DEVELOPMENT IN THE PHILIPPINES

During the 1950's, agriculture in the Philippines experienced a major change in its growth momentum. Until the end of the decade, Philippine agriculture followed the traditional growth pattern prevalent in Southeast Asia. In this pattern, growth in output resulted primarily from the expansion of the cultivated area. The area expansion was a response to world demand for export crops, such as sugar and coconuts. That demand caused an increase in area planted to food staples, such as rice and corn, to meet the increase in domestic demand brought about by growth in aggregate export demand and population increase. Meanwhile, there was a little gain in the productivity of land.

Toward the end of the 1950's, area expansion of agriculture in the Philip-

Table 1. Contribution of area and land productivity to the growth in output and labor productivity in Philippine agriculture, 1948–72 (Crisostomo and Barker, 1973).

	1948–52 to 1958–62		1958–62 to 1968–72	
	Annual growth rate (%)	Relative contribution (%)	Annual growth rate (%)	Relative contribution (%)
Total agricultural output	4.1	100	3.6	100
Cultivated land area	3.4	83	1.8	50
Output per hectare of cultivated land area	0.7	17	1.8	50
Agricultural output per farm worker	1.5	100	1.5	100
Cultivated land area per farm worker	0.7	50	–0.3	–20
Output per hectare of cultivated land area	0.7	50	1.8	120

pines began to slow, and an increase in land productivity emerged as a major factor in the growth of agricultural output. During the 1950's total agricultural output increased at an annual compound rate of 4.1%, of which more than 80% was from area expansion. In contrast, during the 1960's only 50% of the output growth (at the rate of 3.6%/year) resulted from the increase in cultivated land area, with the remaining 50% from an increase in yield per hectare (Table 1). If there had been no acceleration in the rate of growth in land productivity (from 0.7 to 1.8% per year), the growth in agricultural output would have sharply declined (from 4.1 to 2.5% per year).

Investment in irrigation played a key role in the acceleration of land productivity. As Figure 1 shows, development of the irrigation infrastructure, as measured by the ratio of irrigable area to cultivated area, began to accelerate in the late 1950's when area expansion began to stagnate. In the Philippines the irrigation systems were built primarily to supply water for rice production. With the expansion and improvement in irrigation systems followed by the diffusion of MV and the increased application of fertilizer, land productivity began to rise in the mid-1960's.

The improved irrigation system was a key to the development and diffusion of the seed-fertilizer technology. The high yield potential of the short-statured MV cannot be realized without adequate controlled water. By reducing the risk of crop failure, the assured water supply not only increased the response of rice plants to fertilizer but also increased farmers' application of fertilizer. Thus, the development of irrigation systems was a prerequisite for the introduction and the application of modern rice technology and the increase in land productivity during the 1960's.

The government has played a major role in irrigation development. Table 2

Table 2. Irrigable areas in the Philippines by type of systems, selected years.

Type of system	1952		1955		1960	
	Thousand ha	%	Thousand ha	%	Thousand ha	%
National gravity system (NIA[a])	110.8	22.9	137.9	24.9	260.9	35.3
Communal system						
Government assisted	—	—	36.9	6.7	83.5	11.3
Private	333.6	69.0	333.6	60.2	333.6	45.1
Pump irrigation system	12.2	2.5	17.6	3.2	32.5	4.4
Others[b]	27.2	5.6	27.7	5.0	28.4	3.8
Total	483.8	100.0	553.7	100.0	738.9	100.0

Type of system	1965		1970		1975	
	Thousand ha	%	Thousand ha	%	Thousand ha	%
National gravity system (NIA[a])	318.7	34.1	420.4	36.3	561.3	34.9
Communal system						
Government assisted	153.7	16.4	199.6	17.2	320.9	20.0
Private	373.6	40.0	418.4	36.1	486.6	29.2
Pump irrigation system	60.0	6.4	89.2	7.7	225.6	14.0
Others[b]	29.2	3.1	30.0	2.6	30.9	1.9
Total	935.3	100.0	1157.6	100.0	1607.2	100.0

[a]National Irrigation Administration. [b]Includes friar land irrigation systems and municipal systems. Source: See Appendix A–B.

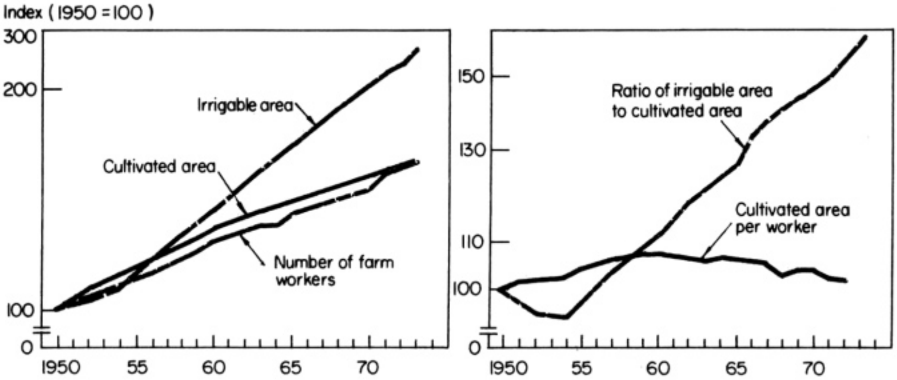
shows that the irrigable area commanded by national gravity systems (“systems-command area”) under the National Irrigation Administration (NIA) increased rapidly.

DETERMINANTS OF IRRIGATION INVESTMENT

From our review of the growth experience of Philippine agriculture in the previous section, it is clear that development in the irrigation infrastructure was the key to growth in land productivity and that government investment was primarily responsible for irrigation development.

Long-term trends. A prime question is why the government irrigation investment accelerated in the late 1950’s as if to compensate for the deceleration in expansion of cultivated land area.

The relations illustrated in Figure 2 indicate that the land for agricultural production had increasingly become scarce and the marginal cost of bringing an additional unit of land into cultivation had risen sharply. By the late 1950’s it became cheaper or more profitable to increase agricultural output by improv-



2. Comparisons in the trends of cultivated and irrigated land areas and of number of farm workers in the Philippines, 3-year moving averages, semi-log scale (Crisostomo and Barker, 1973; see also Appendix A of this paper.).

ing the quality of land than by expanding the cultivated area. It is hypothesized that the acceleration in government investment in irrigation was induced by the increased rate of return to investment in the improvement of land quality relative to that in the opening of new land for cultivation.[2] The diffusion of MV, which perform best with good irrigation, should have increased the relative advantage of improving the irrigation infrastructure over opening new land.

As a partial test of the above hypothesis we estimated both the benefit:cost (B:C) ratios and the internal rates of return for investments in irrigation construction and land opening (Table 3). In these calculations benefits are measured in terms of increases in value added in agricultural production due to irrigation construction, by subtracting the increases in the cost of current production inputs, such as fertilizer, from the increases in rice output. Both capital investments and operation-maintenance expenditures are included on the cost side. The capital costs of irrigation are those of building the NIA gravity systems. The costs of opening new land are those of land resettlement projects of the Department of Agrarian Reform. Both the B:C ratios and the internal rates of return are estimated in terms of 1970 constant prices. (For more details see Appendix A.)

The B:C ratios and the internal rates of return for irrigation are estimated for traditional varieties versus MV and for nitrogen inputs of 0, 15, 20, and 60 kg/ha. In both the B:C ratios and the rates of return, we observe the trends of decreasing profitability of investment in irrigation over time for a fixed technology. Such trends reflect the fact that irrigation projects have moved from accessible, less costly sites to less accessible, more costly ones. However, increasing-cost or decreasing-profitability trends, which result from a gradual

---

[2] The construction of irrigation systems sometimes contributes to the expansion of cultivated area. Such contributions are especially significant in and regions, but not so important in a monsoon climate as in the Philippines.

Table 3. Estimates of benefit:cost ratios and internal rates of returns to investments in irrigation construction and to land opening. in terms of 1970 constant prices. Philippines, 1976.

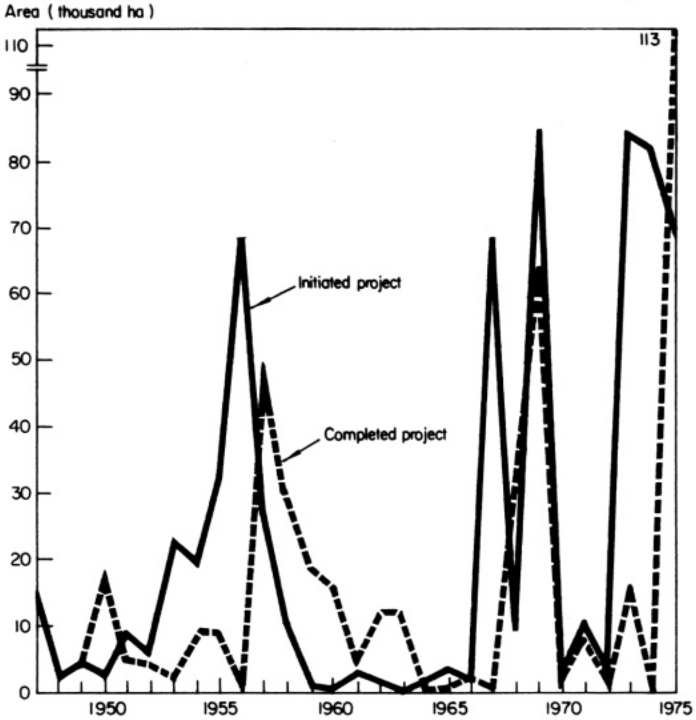
Benefit:cost ratios and returns in selected years	Irrigation project[a]					
	Traditional varieties		Modern varieties		Land openings[b]	
	0 kg a.i. N/ha	15 kg a.i. N/ha	20 kg a.i. N/ha	60 kg a.i. N/ha	Rice case	Corn case
Benefit:cost ratio						
1949–53	2.88	2.98				
1953–57	2.68	2.77				
1958–62	2.12	2.20				
1963–67	2.15	2.23				
1968–72	2.01	2.07	2.35	2.65		
1970–74	1.67	1.73	1.96	2.21	0.68	1.01
internal rate of return (%)						
1949–53	31	31				
1953–57	29	30				
1958–62	22	22				
1963–61	23	24				
1968–72	21	21	24	25		
1970–74	19	20	23	24	9	13

[a] NIA projects completed during a 5-year period. [b] Government land resettlement projects completed in 1973. The rice case assumes one crop of upland rice pianted in newly settled areas. The corn case assumes two crops of corn planted in newly settled areas. See Appendix E.

exhaustion of less costly projects, have been more than compensated for by the development and diffusion of modem seed-fertilizer technology since the late 1960’s.

Unfortunately, there are no time-series data available to analyze the changes in costs and returns to investments in opening new land over time. Table 3, however, provides clear evidence that investments in irrigation have become much more profitable than land opening, at least in the 1970’s. Considering the deceleration in the expansion of cultivated area and the declining 1and:labor ratio (Fig. 2), it seems reasonable to infer that the costs of land opening have risen more rapidly than those of irrigation construction; that produced a cumulative divergence in the rates of return to investment in irrigation and land opening.

Thus, although the evidence is not conclusive, the data in Figure 2 and Table 3 are consistent with the hypothesis that for the past two decades investment in irrigation as a means to improve land quality has become increasingly more profitable than investment in expansion of cultivated area by opening new land. We identify the increase in the relative profitability of irrigation investment as the basic factor that induced the intensification of government efforts to develop irrigation systems. The development of irrigation in the Philippines accelerated at a sufficiently rapid rate to sustain growth in agricultural output from the 1950’s to the 1960’s, despite a deceleration in the expansion of cultivated land area.



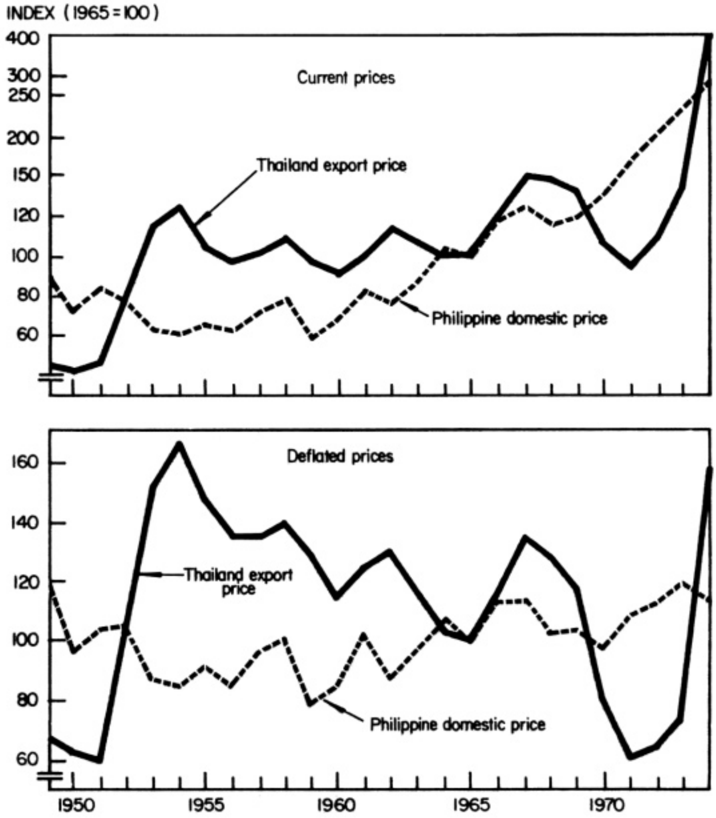
3. Areas for which new National Irrigation Administration irrigation systems were initiated and completed. See Appendix B.

Short-term fluctuations. So far, we have identified the increased profitability of investment in improving land quality relative to investment in area expansion as the factor underlying accelerated government investment in irrigation. That factor explains acceleration in the long-term trend, but it is not sufficient to explain shot-run fluctuations.

Annual fluctuations in government irrigation investment have been extensive (Fig. 3). There is about a 2-year lag between initiation and completion. The fluctuations may seem totally *ad hoc.* However, careful observation reveals that the initiation of new construction tends to concentrate in the years when the world price of rice was rising. The indices of Thai export prices are plotted in Figure 4 to represent the movements in the international price of rice (solid line),

The positive association of irrigation and world rice price suggests the hypothesis that the fluctuations in the investment in NIA irrigation systems represent the efforts of the Philippine government to stimulate domestic production and counteract the rising cost of rice imports in the years of high rice prices.

It is interesting that government irrigation investments in the Philippines



4. Indices of Thai export price and Philippine domestic price of rice. Thai price = FOB Bangkok, 5% broken. Philippine price = wholesale, Macan-first class, at Manila. Deflated prices = current prices deflated by the consumers' price index of Manila, excluding rice, 1965 = 100 (Anden, 1974; Central Bank of the Philippines, 1975; Rice Committee Board of Thailand).

have had no significant association with domestic rice prices (Fig. 4). That lack may be explained in terms of the goals and means of the Philippine rice policy. An overriding motive of the government policy has been to supply a sufficient amount of rice — a basic-wage good — to urban consumers at relatively low and stable prices. Given the very high share of rice in household expenditure, an increase in rice prices has an immediate impact on low-income classes, often resulting in social unrest. Moreover, high rice prices adversely affect capital formation and economic growth by raising money wage rates. High money wage rates cause a decline in both the rates of return to capital and the international competitive positions of domestic industry, mining, and plantation crops.

As a secular importer of rice, the Philippines has achieved the policy goal of supplying rice to domestic consumers at stable prices primarily by controlling imports. In years of low world prices the government imported rice at a profit, but in years of high world prices the government incurred losses from the imports as well as serious drains on foreign exchange (Barker et al., 1978). As a result, the domestic price of rice in the Philippines has been more stable than the world price relative to the consumers' price index (Fig. 4).

Considering the high premium on government funds and foreign exchange in developing economies such as the Philippines, it is reasonable to expect that government efforts to increase domestic rice output will be strengthened to counteract rising costs of imports in the years of rising rice prices. Increases in the import cost imply increases in the profitability of investment in irrigation as a means of raising the self-sufficiency rate. Thus, the hypothesis may be restated: short-run fluctuations in government irrigation investments were induced by changes in the social rates of returns to such investments, that, in turn, resulted from the fluctuations in world rice prices.

Decision processes. The response of irrigation investment to rice prices is evidence of rational decision making in the allocation of government funds. However, it does not imply that government administrators and legislators are rational and solely motivated to promote the welfare of society. It seems reasonable to assume that, as is the case in any other country, they are more interested in preserving their vested interests than in promoting social welfare.

Actual decisions on government resource allocations are made through the political process, which involves compromises among vested interests.

Such decision processes are not, however, necessarily inconsistent with the rational allocations of government resources. The behavior of government administrators and legislators to promote their own interest could guide resource allocations toward a socially optimum direction. If the government fails to assure a sufficient supply of rice to urban consumers at reasonably low prices, social unrest would undermine the political basis of the regime.

The policy objective of supplying sufficient food at low and stable prices must be achieved within the stringent constraints of government budget and foreign exchange, on which various vested-interest groups have their claims. Government planners have to carefully calculate the cost of achieving the goal of a sufficient food supply. Thus, the government is compelled to respond to changes in world rice prices.

Such government response to price fluctuations, though rational in the short run, seems highly inefficient in the long run. If the government based its investment decisions on the long-run need of irrigation as a critical condition for increasing food output in order to meet the long-term growth in food demand, the government irrigation investments in the Philippines would not have been subject to the large short-run fluctuations seen in Figure 3. Were that the case, the recurrent "rice crises" could have been avoided or greatly mitigated. Very likely, not only national governments but also international lending agencies such as the World Bank would be responsible for such short-sighted response.

INVESTMENT-INDUCEMENT EFFECT OF MODERN VARIETIES

From the observations in the previous section, we hypothesized:

- The trend of accelerated government investment in irrigation in the Philippines since the late 1950's was induced by an increasing scarcity of land or by the increasing cost of the expansion of cultivated land area, which increased the relative profitability of irrigation construction as compared to land opening.
- Short-run fluctuations in government irrigation investment resulted from the changes in the profitability of irrigation construction, which, in turn, was largely affected by the fluctuations in the world price of rice.

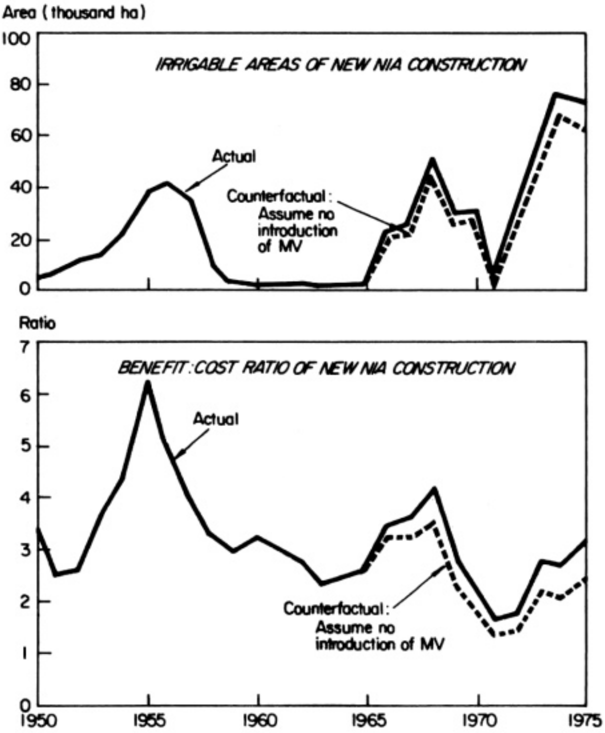
However, the price of rice is not the sole determinant of the profitability of irrigation investment. The rice-growing technology is also an important determinant. To assess the effect of new rice technology, we estimated the B:C ratios for the construction of NIA systems by evaluating gains in rice yields by current Thai export prices, while incorporating the effects of improvements in rice varieties and fertilizer applications. Such estimates are compared with increments in the irrigable area commanded by the newly constructed NIA systems (Fig. 5).

The top part of Figure 5 replots the areas for which the new NIA construction was initiated after reducing *ad hoc* variations by taking 3-year moving averages. The lower figure plots the 3-year moving averages of the B:C ratios that evaluate benefits and costs for the projects completed in the given years, in terms of current prices. (Note the difference from the B:Cratios in Table 3 that are in terms of 1970 constant prices.)

The calculations of B:C ratios before 1964 assumed that whole irrigation-system command areas were planted with traditional rice varieties. For later years the B:C ratios were calculated separately for the cases of traditional varieties and MV. The values were averaged into a single series (solid line), using areas planted to the respective varieties as weights. The dotted line shows the counterfactual calculations which assumed that the MV had not been developed.

There is a close association between movements in the area where irrigation construction has been initiated, and the B:C ratio in Figure 5. Such association strongly supports the hypothesis that short-run fluctuations in government investments in irrigation infrastructure were induced by changes in the "nominal" rates of return to the irrigation investment due to price fluctuations.

However, it is important to observe that, despite the positive correlation in cyclical fluctuations between the areas of the new NIA construction and the B:C ratios, they move in opposite directions as secular trends — while an increase in the designed irrigable area tends to accelerate over time, the B:C ratio declines slightly. Therefore, the trend of accelerated government irrigation investment cannot be explained by changes in current profitability. The explanation should be sought in the long-term increase in the marginal cost of



5. Comparison of the areas for which the new construction of the National Irrigation Administration (NIA) system was initiated and the benefit:cost ratios of the construction evaluated at current prices, 3-year moving averages. See Appendix A, B, C.

opening new land that has made irrigation investments relatively more profitable.

As an econometric test of our hypothesis a regression analysis was made by relating government investment in irrigation infrastructure to the index of land scarcity and the current rates of return to the irrigation investments. The data used to represent the levels of government irrigation investment and their rates of returns are, respectively, the areas for which the construction of new NIA systems was initiated (Z) and the corresponding B:C ratios evaluated in current prices. The index of scarcity of land for cultivation (S) was calculated by

$$S_t = \frac{M}{M - A_t}$$

where A_t is actual cultivated area in year *t,* and M is the maximum potential area that can be brought into cultivation. The formula assumes that the marginal cost of increasing a unit of cultivated area, which reflects the scarcity of land, rises exponentially as actual cultivated area increases, and finally

Table 4. Results of regression analysis.[a]

Regression number	Regression coefficients of					Intercept	R^2	Durbin-Watson statistics
	(*B:C*)*t*	(*B:C*)*t*	(*B:C*)*t*–1	*St*	*Zt*–1			
1	14.5** (4.27)			92.1** (5.27)		–179	0.550	0.66
2		12.6* (2.47)		55.7** (2.98)		–100	0.362	0.60
3			11.1* (2.61)	89.5** (4.09)		–164	0.395	0.74
4	9.48** (3.12)			55.7** (3.09)	0.569** (3.84)	–113	0.718	1.58

[a] Figures in parentheses are *t*-values. *significant at 5%; **significant at 1%.

becomes infinite as the maximum limit of cultivable area is reached. *M* is assumed to be 14 million ha, about twice the area presently cultivated.

The results of regression analysis, using the ordinary least-square method applied to the 1950–74 time-series data, are summarized in Table 4. A simple linear regression model was estimated for three different specifications of the B:C ratio: regression 1 relates the B:C ratio in year *t* to the area of irrigation construction initiated in the same year, and the benefit (B) from the irrigation construction was evaluated in Thai rice export prices; regression 2 uses the benefit (B') evaluated in Philippine domestic prices; and regression 3 uses the B:C ratio of Thai-price evaluation lagging by 1 year.

In all three cases, both the B:C ratio and the land scarcity index are statistically significant at a conventional level. However, judged from the *t*-values and R^2, regression 1 isclearly superior in terms of both the goodness of fit to data and the statistical significance or regression coefficients, although it is subject to the serial correlation among residuals. The results support the hypothesis that the government irrigation investments were, to a large extent, induced by the growing scarcity of land and the fluctuations In the world price of rice. Also, the comparison of regressions 1 and 3 suggests that the government response to the short-run changes in the rate of return due to price fluctuations was quite fast, exhibiting almost no time lag.

To consider possible distributed lag effects, a Koyck-Nerlove model was estimated as regression 4. The distributed-lag specification improved the gooddess of fit and reduced the residual serial correlation. The results show that, although the government may be more sensitive to current prices than tu lagged prices, the distributed lag effects are significant.

To estimate the effects of the introduction of MV on irrigation investment, we made counterfactual calculations by using the regression results. Reductions in the average B:C ratio due to the counterfactual assumption of no introduction of MV (Fig. 5) are multiplied by the coefficient of B:C in regression 1 to produce the estimates of reductions in the area for which the NIA construction was initiated (*Z*). The results are shown by the dotted line in the upper part of Figure 5. If there had been no development in MV technology, the area for which construction was initiated during 1965-74 would have been smaller by 61,000 ha, which is about 11% of the total irrigable area commanded by NIA systems in 1975. Such calculations would represent the lower boundary estimates of the impact of MV on ittigation development because the long-run coefficient of B:C implied in regression 4 is 22.0, higher than the coefficient in regression 1. That implies that the impacts will continue to increase in the future as adjustments progress

CONCLUSION

Both the historical observations and the statistical tests are consistent with the hypothesis that the efforts of the government to develop irrigation in the Philippines during the past two decades were induced by the increases in the social rates of return to investment in irrigation systems. Increases in the social profitability of irrigation investment resulted largely from the relative rise in the cost of opening new land for cultivation, the development and diffusion of MV, and the changes in the world price of rice.

The results of counterfactual calculations show the critical role of complementarity between irrigation and new rice technology. While irrigation investment prepares the conditions for the diffusion of MV, the development of MV has the power of inducing public investment in irrigation.

Our analysis also suggests the danger of the investment inducement mechanism being misguided by cyclical price changes due to weather fluctuations, resulting in the long-run inefficiency in the social resource allocations. The phenomenon of government-induced, cobweb cycles in the supply and demand of food does not seem unique to the Philippines, but is pervasive among developing and developed countries. Should both national governments and international agencies try to avoid the recurrent “world food crises,” they should base their investment decisions on the long-run need for food.

REFERENCES CITED

ANDEN, T. L. 1974. Data series on rice statistics, Philippines. Department of Agricultural Economics, International Rice Research Institute, Los, Baños, Philippines.

BARKER, R., E. BENNAGEN, and Y. HAYAMI. 1978. New rice technology and policy alternatives for food self-sufficiency. Pages 337–361 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

CENTRAL BANK of the PHILIPPINES. 1975. Consumer price index in Manila, 1949–75. Manila.

CRISOSTOMO, C. M., and R. BARKER. 1973. Growth rates of Philippine agriculture, 1948–71. Paper presented at the conference on Agricultural growth in Japan, Korea, Taiwan, and the Philippines, February 1973. East-West Center, Honolulu, Hawaii.

DAVID C. C., and R. BARKER. 1978. Modern varieties and fertilizer consumption. Pages 175–211 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

HAYAMI, Y., C. C. DAVID, P. FLORES, and M. KIKUCHI. 1976. Agricultural growth against a land resource constraint: the Philippine experience. Aust. J. Agric. Econ. 20:144–159.

HAYAMI, Y., and M. KIKUCHI. 1978. Investment inducement to public infrastructure; irrigation in the Philippines. Rev. Econ. Stat. 60:70–77.

IENAGA, Y. 1970. Ineseisanno kisojoken (Basic condition of rice production). *In* Y. Miyahara, ed. Philippine no nogyo (Agriculture in the Philippines), Institute of Developing Economies, Tokyo.

RICE COMMITTEE BOARD of THAILAND. 1949–75. Report on rice prices, a weekly report. Bangkok. (mimeo.)

REPUBLIC of the PHILIPPINES, DEPARTMENT of AGRICULTURE. 1950–71. Philippine agricultural statistics. Quezon City, Philippines. (mimeo.)

REPUBLIC of the PHILIPPINES, DEPARTMENT of AGRICULTURE. Bureau of Agricultural Economics. 1950–71. Crops and livestocks statistics. Quezon City, Philippines. (mimeo.)

REPUBLIC of the PHILIPPINES, DEPARTMENT of COMMERCE and INDUSTRY, BUREAU of CENSUS and STATISTICS. 1965. Census of the Philippines, 1960, Vol. 11. Summary report, Manila.

REPUBLIC of the PHILIPPINES, NATIONAL IRRIGATION ADMINISTRATION. 1974a. Annual report 1973–74. Quezon City.

REPUBLIC of the PHILIPPINES, NATIONAL IRRIGATION ADMINISTRATION. 1974b. Communal irrigation systems as of June 30, 1974. Quezon City, Philippines. (mimeo.)

REPUBLIC of the PHILIPPINES, NATIONAL IRRIGATION ADMINISTRATION. 1974c. Revised listing of national irrigation systems operated and maintained by the National Irrigation Administration, as of June 30, 1974. Quezon City, Philippines. (mimeo.)

APPENDIX A
ESTIMATION OF IRRIGABLE AREAS

Data on irrigable areas in the Philippines are available only for scattered years. Those are 1952, 1960, and 1965, for which data on irrigable areas by type of irrigation system are available; and 1948 and 1960 for which only total irrigable areas are recorded. The 1952, 1960, and 1965 data are from Ienaga (1970). The original sources are F. H. Lurson, *Irrigation Problems in the Philippines,* 1952, and Republic of the Philippines, *The irrigation program of the Philippines,* 1965; and the 1948 and 1960 data are from *Census — Bureau of Census and Statistics* (1965).

Annual time series of irrigable areas are estimated by using these scattered data as bench marks. The estimation procedures follow:

NIA systems. Areas served by the National Irrigation Administration (NIA) gravity systems are estimated by adding to or subtracting annual increments in NIA-command areas from the 1952, 1960, and 1965 benchmark data. Data on the annual increments are given by NIA (1974c). When this procedure produces estimates for bench-mark years that are different from the original bench-mark data, the annual increments are adjusted proportionally so as to achieve consistency.

Communal systems. The procedures for estimating the government-assisted communal systems are the same as those for the NIA systems (NIA, 1974b), except that no benchmark figure exists for 1952.

The irrigable areas served by private (nongovernment-assisted) communal systems for 1961–64 and 1966–75 are extrapolated from the 1960 and 1965 bench marks by the average rate of increase for 1960–65. The benchmark data indicate that the irrigable area declined from 1952 to 1960, which is highly unlikely. Therefore we assumed a constancy in the area under private communal systems before 1960.

Pump irrigation systems. Data on pump systems for 1973–75 are from NIA (1974b). Estimates for other years are made by interpolating the bench-mark data for 1952, 1965, and 1973 and by assuming constant growth rates among the benchmark years.

Other systems. Areas under the commands of Friar Land and municipal irrigation systems are extrapolated or interpolated from the 1952 and 1965 bench-marks by using the average growth rate for 1952–65.

Total irrigable areas. For 1952–75 the estimates for different systems are added up to total irrigable areas. For 1947–51 the total irrigable areas are estimated on the basis of the Census bench marks for 1948 and 1960. The bench-mark for 1960 is 19% lower than the Ienaga bench mark. Therefore, we inflated the 1948 bench mark (400,000 ha) by 19%. The 1947–51 data are estimated from the adjusted *Census* bench marks by extrapolations and interpolations.

ESTIMATION OF THE BENEFIT:COST RATIOS AND THE INTERNAL RATES OF RETURNS

The benefit:cost (B:C) ratios for building irrigation systems and opening new land for cultivation are calculated as the ratios of the capitalized values of benefit flows to the capital costs. The formula is:

$$\frac{B}{C} = \frac{R[(1+i)^n - 1]}{iK\,(1+i)^{m+n} + O\,[(1+i)^n - 1]}$$

where:

R = annual benefit flow per hectare,
K = capital cost per hectare,
O = annual operation and maintenance cost per hectare (assume to be 5% of capital cost),
i = interest rate (assume to be 12%),
m = average gestation period of investments, and
n = period of usable life (assume to be 50 years for irrigation and infinite for land opening).

The internal rates of return (r) are calculated as the rates that satisfy

$$K = \frac{(R - O)\,[(1+r)^n - 1]}{r\,(1+r)^{m+n}}$$

Irrigation case. The capital costs of irrigation (K) are those of constructing the NIA national gravity systems. Data on the total capital costs of the newly constructed systems, the periods of construction, and the areas to be irrigated by the systems are provided by NIA. The average gestation period (m) is assumed as a median of a construction period. For the calculations of B:C ratios in real terms, the capital costs are deflated by the Gross National Product implicit deflator for investments in construction, with 1970 = 100.

Operation and maintenance costs of irrigation systems (O) are assumed to be US$8.57 (US$ = ₱7) per hectare, based on the irrigation fee, in the calculations in the real terms of 1970 constant prices, and are assumed to be 5% of capital costs in the calculations in terms of current price, which is the ratio of the operation and maintenance cost to the capital cost per hectare in 1968–72.

Benefit flows (R) are defined here as increase in gross value added per hectare due to the construction of irrigation systems. They are calculated by subtracting increases in the cost of intermediate inputs for rice production from increases in the value of rice output. Irrigation would result in larger rice output and inputs partly because it raises the productivity of the wet-season crop and partly because it increases crop areas in the dry season. Estimation of the rice yields per hectare, for alternative varieties and fertilizer input levels is based on the representative nitrogen response functions specified by David and Barker (1978).

Land opening case. Data on opening new land are those of land resettlement projects of the Department of Agrarian Reform, completed in 1973. The capital costs (K) include those of land survey, land clearing, transportation and housing infrastructure, subsistence rations for one year, and medical assistance. The data are provided by the Census anti Statistics Division, Bureau of Land Resettlement, Department of Agrarian Reform. The costs in 1973 prices are converted into those of 1970 pirces by the GNP implicit deflator for investment in construction.

Benefits from opening land (R) are estimated as 95% of total output values produced in the opened land, assuming a value-added ratio of 95%. Outputs are valued at 1970 prices. Two cases are assumed for crops planted in the new land: planting one crop of upland rice, and planting two crops of corn. Average yields of rice and corn per hectare are assumed as 897 kg and 819 kg, respectively, based on the national average in upland fields for 1969–73.

Opportunity costs of labor. In the above calculations we did not subtract from benefit streams the increases in labor costs for crop production due to irrigation and land opening. This assumes that the increments in labor ate available at zero opportunity cost. In fact, there is little change in labor input for the wet-season crop due to irrigation. Labor use in the dry season increases. However, it is reasonable to assume that farm labor in the dry season, which remains primarily idle without irrigation, has a low opportunity cost. Also, it is reasonable to assume that the workers who are resettled by the government land-opening projects are those who had difficulty in finding productive employment in their original locations.

Yet, there is no denying that our assumption of zero opportunity cost of labor results in overestimation of benefits to some extent. However, the calculations that impute the increases in labor inputs by market wage rates reduce the B:C ratios of irrigation construction by only 20 to 30%. More importantly, such procedures do not alter the pattern of changes in the B:C ratio over time. Reductions in the B:C ratio for land opening are much larger if we impute farm labor by market wage rates, because labor is a more dominant component of the total cost of crop production under upland conditions. Therefore, our calculations tend to overestimate the benefits of land opening relative to irrigation construction. Thus, the conclusion of our analysis on the relative advantage of irrigation construction over land opening will not be changed by a modification of the assumption on labor's opportunity costs.

APPENDIX B. **Irrigable areas and the areas for which construction of National Irrigation Administration (NIA) systems was initiated and completed in the Philippines, 1947–75.**

Year	Irrigable area (thousand ha)		Areas of new NIA construction (thousand ha)	
	Total	NIA system	Initiated	Completed
1947	474.1	81.0	15.6	–
1948	476.0	81.0	2.2	–
1949	477.9	84.9	4.6	3.9
1950	479.9	102.1	2.7	17.2
1951	481.8	100.8	9.3	4.7
1952	483.8	110.8	6.0	4.0
1953	496.9	115.1	22.5	2.0
1954	519.2	126.7	19.2	9.4
1955	553.7	137.9	31.7	9.0
1956	571.9	140.9	66.5	0.8
1957	637.0	189.6	26.1	46.4
1958	679.0	222.2	10.6	30.4
1959	709.7	242.8	0.3	18.4
1960	730.9	260.9	–	15.8
1961	772.7	270.8	2.6	3.9
1962	821.0	288.8	1.2	11.7
1963	873.0	308.1	–	11.6
1964	879.1	312.3	1.8	0.2
1965	935.3	318.7	3.2	0.5

(continued on next page)

Appendix B **continued**

Year	Irrigable area (thousand ha)		Areas of new NIA construction (thousand ha)	
	Total	NIA system	Initiated	Completed
1966	954.3	320.4	1.5	1.7
1967	981.0	320.9	68.7	0.5
1968	1044.0	355.8	9.2	34.9
1969	1129.7	419.5	83.8	63.7
1970	1157.6	420.4	1.0	0.9
1971	1188.2	428.6	10.2	8.2
1972	1223.0	429.4	3.2	0.8
1973	1278.1	450.4	83.2	21.1
1974	1353.3	450.4	79.2	–
1975	1607.2	561.3	68.5[a]	110.9[b]

[a] Preliminary. [b] Double the January 1-June 30 total.

Appendix C. **Estimates of B:C ratios for the construction of National Irrigation Administration irrigation systems, in terms of current prices. Philippines.**

Year	Current capital cost[a] (US$/ha)	Thai rice export price 1969-71=100	Nitrogen price (US$/kg)	MV ratio (%)	B:C ratio (3-year moving average)		
					Traditional varieties	Modern varieties	Average
1949	23.4	42.5	0.094	–			
1950	57.2	41.2	0.096	–	3.34	–	3.34
1951	65.9	43.1	0.098	–	2.48	–	2.48
1952	107.1	61.4	0.100	–	2.63	–	2.63
1953	118.2	100.0	0.101	–	3.58	–	3.58
1954	60.7	112.4	0.103	–	4.36	–	4.36
1955	84.5	92.2	0.105	–	6.35	–	6.35
1956	46.4	88.2	0.105	–	4.93	–	4.93
1957	92.4	89.5	0.105	–	3.98	–	3.98
1958	121.2	94.8	0.105	–	3.19	–	3.19
1959	104.6	87.6	0.106	–	2.95	–	2.95
1960	100.8	81.0	0.115	–	3.21	–	3.21
1961	88.6	89.5	0.129	–	3.03	–	3.03
1962	120.6	100.0	0.146	–	2.86	–	2.86
1963	130.5	93.5	0.158	–	2.28	–	2.28
1964	190.5	90.2	0.172	–	2.43	–	2.43
1965	95.2	89.5	0.195	–	2.55	3.37	2.58
1966	138.5	105.9	0.200	11.3	3.35	4.49	3.48
1967	122.2[b]	134.6	0.199	22.7	3.35	4.55	3.62
1968	105.9	131.4	0.193	34.0	3.61	4.94	4.13
1969	114.4	122.2	0.185	61.6	2.29	3.07	2.70
1970	305.6	93.5	0.241	61.4	1.84	2.39	2.19
1971	163.6	84.3	0.246	67.0	1.41	1.77	1.65
1972	241.1	96.7	0.250	73.4	1.49	1.90	1.78
1973	343.5	126.8	0.275	70.3	2.20	3.02	2.81
1974	378.3[b]	354.2	0.297	80.0	2.09	2.89	2.69
1975	413.2	196.9	–	–	2.39[c]	3.35[c]	3.14[c]

[a] For projects completed in given year. [b] Estimated by interpolation. [c] 2-year averages.

COMMENTS ON
NEW RICE TECHNOLOGY AND NATIONAL IRRIGATION DEVELOPMENT POLICY

A. SIAMWALLA

THE KIKUCHI-HAYAMI PAPER attempts to prove the basic Hayami-Ruttan thesis that shifts in both production and productive technology are dictated by the price mechanism, which occasionally actually reflects the scarcity factor.

One of the most controversial aspects of the Hayami-Ruttan thesis is their notion of public-sector behavior, which may be characterized as macroirrationality and microrationality. In more expressive, less accurate terms, the public sector is supposed to be penny-wise and pound-foolish. Thus, there is an extensive discussion of the distortions introduced by various government price policies. But, nonetheless, the scientists hired by those governments do adopt, according to Hayami and Ruttan, research policies that are *economically rational.* The evidence compiled by Hayami and Ruttan, particularly on the tenet that government research programs are *rational,* cannot, however, be regarded as conclusive, not even for the US and Japan, the main foci of their work.

The Kikuchi-Hayami paper addresses the same set of problems. Instead of looking at research activities of the public sector, Kikuchi and Hayami look at public irrigation policies. Instead of discussing US or Japanese government behavior, they look at the Philippines. They achieve the heartening result that the Philippine government has indeed been moved by economic considerations, as far as investment in irrigation is concerned. But they are quick to point out that that observation in no way implies that the Philippine government has consistently used economic criteria in other aspects of rice policy.

To what extent is this conclusion justified as far as the Philippines is concerned? The heart of the paper is in the sections that examine the short-term movements in irrigation expansion. They claim that the main variable explaining the movements is in the benefit:cost (B:C) ratio. This ratio can be regarded as affected by

1. The purely technological factors, changes in which can be detected by looking at B:C ratio at constant prices, and
2. Changes in the relative prices of inputs and outputs. Fertilizer and construction costs for dams are large among the inputs and rice cost looms large among the outputs.

Economist, Faculty of Economics, Thammasat University, Bangkok, Thailand.

As far as the technological factors are concerned, the evidence that Kikuchi and Hayami present in Table 3 suggests that the irrigation authority seems to have moved quite rationally from easier to harder projects, in terms of irrigation technology. The downward secular tendency of the benefit:cost ratio due to the diminishing returns to irrigation is, however, counterbalanced by the appearance of modern rice varieties as well as by the growing shortage of alternative land-augmenting technologies, e.g. land clearance. Thus, the overall impact is probably neutral, although Kikuchi and Hayami suggest that the situation is indeed becoming more favorable to irrigation.

As it turns out, the secular factors are not as important as the short-term fluctuations in prices, particularly those of rice. This has been truer since 1960 than it was before then. Thus in the high-price years of 1967–68 and 1972–75 the area of new NIA construction was 395,800 ha, which is about 95% of the area covered by the NIA during the period 1960–75.

Admittedly, the bunching together of the projects during the two periods is due not entirely to high rice prices, but partly to introduction of modern varieties starting in 1964. Even if the counterfactual case of nonintroduction (Kikuchi-Hayami, Fig. 5) is taken into account, the proportion of construction initiated during those high-price years would still be quite large.

An interesting question then arises. In what sense can it be said that a long-term policy such as irrigation is *rational* when its primary task is to cope with short-term changes in rice prices? A full answer can be given only by a study that covers not only irrigation policy, but also the Philippines' trade and inventory policies — importation and inventory holding being regarded as alternative *technologies* to cope with the rice supply problem. Until that study is done, any conclusion on the behavior of governments in general, or even of the Philippines in particular, must of necessity be ambiguous, as indeed is the conclusion of Kikuchi and Hayami.

If the broader questions of welfare economics are put aside there is a narrower, behavioral question. Have Kikuchi and Hayami proven that the NIA follows the fluctuations in B:C ratio in its decision to initiate new irrigation construction? I believe the answer depends crucially on the assumption of divisibility, i.e. the projects initiated are in fact many small-scale independent ones. If the projects are, in fact, lumpy and the B:C ratios at the same time exhibit a few high peaks, as in the lower panel of the Kikuchi-Hayami Figure 5, then it is possible to obtain strong correlations. In that case, if the B:C ratios fluctuate less, the government may not behave as predicted by the estimated equation, because it would find it impossible to engage at a lower level of activity.

I am not familiar enough with the Philippine irrigation system to question the validity of this assumption in this particular case, but I would suggest that any attempt to extend the methods and findings of this paper to other countries, particularly to countries with large deltaic areas, should begin with a careful look into this question, A problem that may also arise is one of measurement. It is implicitly assumed by Kikuchi and Hayami that a particular plot of land can be pronounced irrigated or nonirrigated at a particular point in time. It is possible for a government to expend a great deal of effort in improving the efficiency of an existing irrigation system without expanding the area irrigated at all.

While the major argument of Kikuchi and Hayami is striking, their case cannot be regarded as proven.

New rice technology and policy alternatives for food self-sufficiency

R. BARKER, E. BENNAGEN, AND Y. HAYAMI

SELF-SUFFICIENCY IN FOOD staples is a national goal of most major rice-producing countries of South and Southeast Asia. It was thought that the introduction of modern rice varieties (MV) might make it possible to achieve the goal, but importation levels generally have not declined.

In two other studies, using rice in the Philippines as a case, we attempted to evaluate output price support, input subsidy, and irrigation investment as policy alternatives to achieve food self-sufficiency in developing countries (Barker and Hayami, 1976; Hayami et al., 1976). We concluded that in terms of the social benefit:cost ratio, fertilizer subsidy is clearly more efficient than rice price support. Our analysis also showed that irrigation development is normally more efficient than manipulating price incentives, such as price support and subsidy, but it becomes inferior to a fertilizer subsidy if a high discount rate is applied to a large-scale, high cost project.

In this paper, we expand our earlier analysis by assessing the impact on the social benefit:cost ratios of the alternative policies of

- the introduction of MV, and
- the changing relationships in prices of rice (both domestic and imported), fertilizer, and the cost of irrigation construction.

The analysis in our previous studies was based on normal relationships between rice and fertilizer prices—assuming the domestic and import price of rice to be equal—and on the modern rice technology existing in 1975. However, it seems reasonable to hypothesize that policy makers take into account the potential of existing technology and the prevailing price relationships in specific years rather than the normal relations. Even with respect to irrigation

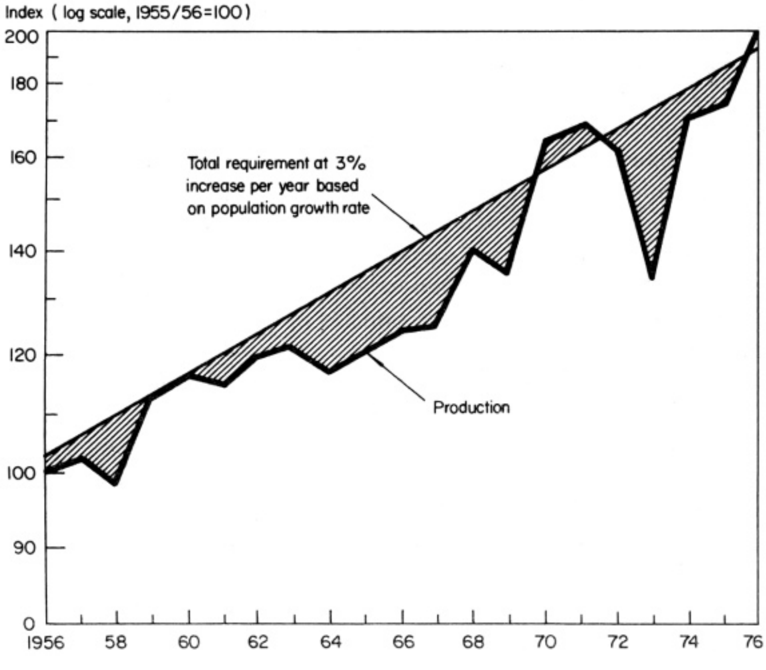
Agricultural economist, research assistant, and visiting agricultural economist, Department of Agricultural Economics, International Rice Research Institute, Los Baños, Philippines.

investment it has been shown that decisions are influenced by the benefit:cost relationships existing in the short run (Hayami and Kikuchi, 1975).

In this paper we attempt to determine how the shifts in technology and price relationships affect the relative advantages of the different policy alternatives. By associating the changes in the rankings of policy alternatives in terms of social efficiency criteria with actual policy choices in the Philippines, we try to draw inferences of the effects of new rice technology on the policy decisions by government.

RICE POLICY GOALS IN A CHANGING ENVIRONMENT

Despite the publicized goal of national self-sufficiency in rice, the Philippines has for the past two decades been the second largest importer of rice in Southeast Asia (second only to Indonesia). However, there were three periods in which at least temporary self-sufficiency was achieved (Fig. 1). The upward trend in production has kept pace with the growth in demand, but on the average has remained about 5% below the level required for self-sufficiency. In short, the Philippines at present appears to have a strategy that results in rice self-sufficiency in 2 years out of 10. The question is whether the Philippines



1. Philippine rice production and requirements, 1955–56 to 1975–76.

failed to achieve its self-sufficiency goal despite the national efforts or because other goals were more paramount.

Mangahas and Librero (1973) stated that it should be apparent to anyone familiar with the rice crisis of the post-war period, *that a prior objective (to self-sufficiency) is to attain a level of security and contentment, somehow defined for rice consumers, specifically the urban consumers.* (The emphasis is theirs.) Government control of the level of rice imports has been the major instrument for achieving that objective. The rice price policy program was designed to support a *floor* price for producers and maintain a ceiling price for consumers. Although a major justification for such a program was the protection of the income of small farmers, the policy was biased more in favor of consumers than producers. The Philippine government until 1976 had never purchased more than 5% of the rice crop, and as a result could not maintain a margin between the floor price for producers and the ceiling price for consumers much in excess of the normal marketing margin. Given the limitations of the government budget, and the desire to supply cheap rice to consumers, it has been difficult to raise the producer price support to the level required to achieve self-sufficiency. Thus, the necessity of supplying rice to urban consumers at relatively low prices can be viewed as an overriding restraint faced by the government in designing a price policy to achieve self-sufficiency.

The government has used a number of other policy instruments, not only to encourage rice self-sufficiency but also to achieve a higher return and greater measure of equity for the producer. It has programs designed to increase rice production and programs related to agrarian reform. The support given to various government programs has been highly variable over time.

Until 1960, growth in rice production was achieved mainly by expansion in land area. By the late 1950's few new lands were suitable for rice production. The rising level of rice imports led to an increase in government irrigation investment and an unsuccessful attempt to raise farm production by means of a subsidized credit program operated through the government cooperatives. Fertilizer was also subsidized, but the annual volume of fertilizer distributed to rice producers over a 7-year period (1957–58 to 1963–64) averaged only 28,000 t, less than 10% of the volume currently handled in the Masagana 99 programs.

After the comparatively good harvest years from 1952 to 1962, emphasis on irrigation investment and other government production programs generally slackened. The period 1963 to 1965 saw a sharp rise in government imports, much of them motivated by political considerations (Sumalee, 1976). In this period the first steps toward the adoption of a workable land reform code were taken.

From 1966 to 1970 the government adopted a strategy to promote self-sufficiency centered on the introduction of the MV. That campaign was administered by the Rice and Corn Production Coordinating Council (RCPCC) under the direction of the executive secretary of the President.

Although land reform received some attention, the emphasis was on production. Imports were negligible in 1968–70 and by 1970 it was widely believed that self-sufficiency had at last been attained. Government efforts to encourage rice production again slackened, and irrigation development declined almost to zero (Hayami and Kikuchi, 1975).

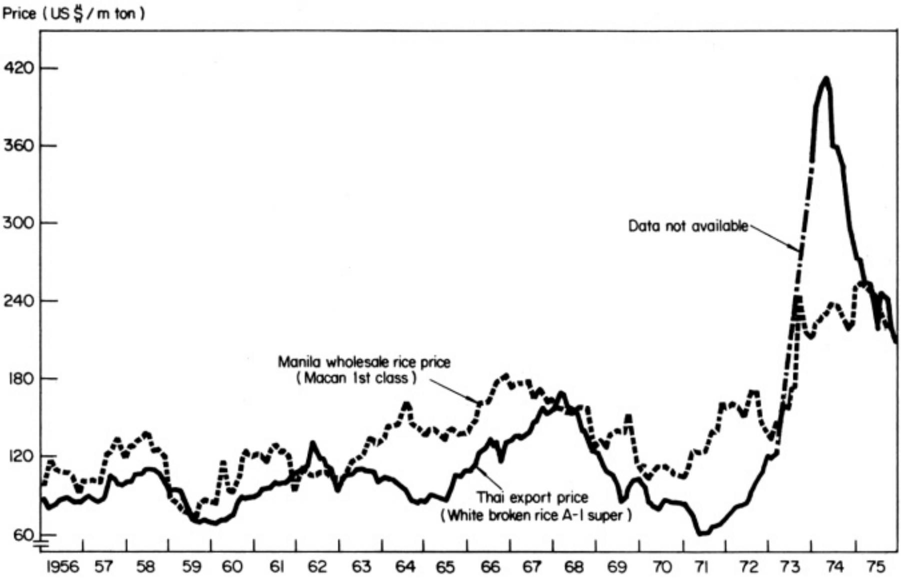
Between 1970–71 and 1972–73, unfavorable weather caused national rice production to decline by almost 20%. Martial law was declared in September 1972, and one of the first steps of the martial law government was to revitalize rice production and land reform programs. The Masagana 99 program was organized to provide subsidized inputs and credit to farmers. New irrigation investments increased sharply. Production increased and by 1976 the country was again enjoying self-sufficiency. How much of the production gain was due to good programs, and how much to good weather is still being debated. But if history repeats itself, government support will once again slacken.

It is our contention that the highly cyclical nature of government efforts for the support of rice production has reflected the government's response to changes in the benefits and costs of various policy alternatives. The social benefit:cost ratios have shifted in part as a result of long-run changes, such as the introduction of new rice technology, and in part because of short-run changes in price and cost relationships, such as the price of imported and domestic rice.

The relationship between the domestic and foreign supply situation, as reflected in the domestic and import prices of rice, dictates the magnitudes of the benefits of specific government policies. In the period prior to the introduction of MV, the margin between the import and domestic price of rice fluctuated, but the size of the difference has been much more pronounced in the past decade. That can be seen by comparing the movements of Manila wholesale rice price with the Thai export price (Fig. 2). The recent increased fluctuation of both domestic and import prices is not related directly to the shift toward the use of modern technology, but rather to other factors that cause a rapid change in world supplies of rice and other food grains. However, because increases in food grain production are becoming more dependent on modern inputs such as fertilizer and irrigation, fluctuations in supply can be more readily influenced by government policy. Faulty policies will aggravate those cyclical fluctuations.

Table 1 shows the actual difference in the retail cost of imported rice and the government sales price for years in which the Philippines imported rice. If we adjust for the abnormally low government sale price and high market costs in the political election years (1963 and 1965), the average annual loss from 1963 to 1967 was only about US$14.29/t or 5% of government sale price. Thus, domestic prices and import costs were fairly comparable in that period. The differences were more pronounced in more recent years than in the period up to 1967.

In 1971 the government made substantial profit from the sale of imported



2. Comparison of Thai export rice price, white broken rice A-1 super (FOB Bangkok), and Manila wholesale rice price (Macan 1st class), 1956–75. Sources: Thai export rice prices — Rice Committee Board of Trade of Thailand. Manila wholesale prices — Central Bank of the Philippines (adjusted to US dollars per metric ton).

rice. In 1972–73, on the other hand, the government loss was high. The higher the import prices, the larger are the benefits from the investments to achieve rice self-sufficiency.

Table 1. Statement of profit (loss) on imported rice,[a] Philippines, 1963–74,

Year	Profit or loss (US$/t)					
	Cost and freight cost (1)	Marketing[b] cost (2)	Retail[c] cost (3)=(1)+(2)	Government sales price (4)	Government profit (5)=(4)–(3)	Government profit as % of sales price (5)÷(4)
1963	67.14	35.71	102.85	48.57	–54.28	–111.8
1964	71.42	20.00	91.42	78.57	–12.85	–16.4
1965	80.00	38.57	118.57	68.57	–50.00	–72.9
1966	74.28	15.71	89.99	84.29	–5.70	–6.8
1967	77.14	15.71	92.85	95.71	2.86	3.0
1971	78.57	20.00	98.57	131.43	32.86	25.0
1971–72	85.71	22.85	108.56	127.14	18.58	14.6
1972–73	291.43	81.43	372.86	142.86	–230.00	–161.0
1973–74	245.71	61.43	307.14	181.43	–125.71	–69.3

[a] Converted at 1 ganta = 2.382 kg and ₱7.00 = US$1.00. Sources: 1963–71 RCA, Accounting Dep., as reported in Mearsand Lacsina, 1974, p. 251,1972–74 NGA, Accounting Dep. [b] 1963–66,1972-74 retail cost per kilogram less cost and freight. 1967–71 retail cost per kilogram less cost, insurance, and freight cost. [c] Administration overhead not included in cost.

Rice technology also affects the benefit:cost ratios of rice self-sufficiency policies. The first of the modern IRRI varieties (MV) was released in the Philippines in 1966. Their effect was to increase the marginal productivity of fertilizer with respect to rice. Although farmers responded by applying more fertilizer per hectare, ample evidence is available that the actual level of fertilizer input lagged behind its new optimum due to inertia, insufficient information, risk aversion, and other problems related to fertilizer and credit distribution. Recent research on the constraints to increased rice production in the Philippines supports our general assumption that despite the rapid spread of MV, fertilizer use in many regions of the Philippines is still well below optimum (De Datta et al., 1976; International Rice Research Institute, 1975). Such disequilibria in the levels of modern inputs in agriculture have been found even in developed economies such as the United States (Griliches, 1964) and Japan (Hayami et al., 1975).

Another effect of MV was the increase in the rates of return to irrigation investments because MV show a high complementarity with better water control facilities.

Other factors that have affected the benefit:cost picture are the changes in the price of fertilizer and in the real cost of irrigation investment. The decline in the import cost of fertilizer has been accompanied by a gradual decline in the fertilizer:rice price ratio in the Philippines until 1973 (Table 2). Now after a sudden rise in the world price of fertilizer due to scare buying, the price has

Table 2. Export price of nitrogen and Philippine domestic nitrogen:rough rice price ratios, 1960-75. [a]

Year	Export nitrogen (US$/t)	Domestic price of		Nitrogen:rough rice price ratio
		Nitrogen (US$/kg)	Rough rice (US$/kg)	
1960	—	.121	.029	4.2
1961	—	.129	.033	3.9
1962	—	.144	.031	4.6
1963	180	.150	.039	3.9
1964	200	.159	.044	3.6
1965	225	.184	.046	4.0
1966	180	.169	.049	3.5
1967	165	.164	.050	3.3
1968	150	.154	.047	3.3
1969	135	.140	.049	2.9
1970	120	.196	.051	3.8
1971	110	.183	.079	2.3
1972	135	.203	.087	2.3
1973 Phase I [b]	330	.176	.113	1.6
1974 Phase II [c]	390	.176	.106	1.7
1974 Phase III [b]	775	.443	.143	3.1
1975 Phase IV [c]	755	.709	.126	5.6
1975 Phase V [b]	330	.571	.143	4.0

[a] Source of nitrogen price 1960–72, Central Bank and 1973–75, Fertilizer Industry Authority; rough rice price, BAEcon. Converted at ₱7.00 = US$1.00. Export nitrogen price, FOB point of export, provided by H.R. von Uexkull, Potash Research Associate, 1963–72. World Bank Fertilizer Unit 1973—75,1963–65, based on ammonium sulfate; 1966–75, based on urea. [b] Average price from June to July 1973, 1974, and 1975. [c] Average price for December 1973–74 and January 1974–75.

settled back to its 1973 level. The fertilizer:rice price ratio is about at the level that prevailed in the early 1960's. The real cost of irrigation appears to have risen slightly over time as a result of a shift from easy-to-irrigate to more-difficult-to-irrigate project areas.

Our objective in the remainder of this paper is first to determine how the benefits and costs of price support, fertilizer, and irrigation investment policies have changed over time. Secondly, we will determine to what degree changes in the social benefit:cost ratios are associated with changes in government policy.

MODEL FOR POLICY EVALUATION

In this section a model is developed for estimating the benefits and costs associated with three policy alternatives to achieve self-sufficiency in rice production. Simplifiying assumptions adopted for the analysis are as follows:

- We assume that no producer and consumer is large enough to influence market prices; thus unique schedules can be specified for domestic supply and demand.
- We assume that a change in fertilizer prices does not significantly affect the use of factors such as land, labor, and fixed capital. This assumption implies zero cross elasticity in input demand functions. To the extent that fertilizer is a substitute for, or complementary with, other inputs, especially land, the results of our analysis are biased. Fertilizer is a substitute for land itself, but it has a strong complementarity with irrigation systems that improve land quality. These competitive and complementary relations are highly complex and so it is difficult to identify the direction of the possible bias.
- Other current inputs such as chemicals are applied proportionally to the inputs of fertilizers.
- We abstract from the analysis the changes in marketing costs corresponding to the choice of alternative policies. This is partly because of data limitation and partly because there are many options in administering the same program. For example, price support in buying rice from producers at higher prices and selling to consumers at lower prices can be administered either through the establishment of a government marketing agency or through subsidizing private marketing firms. Distribution of benefits and costs between the government and the private sector differs for different administrative designs.

A simple model of policy evaluation in the Philippines is in Figure 3. *SS* represents the domestic supply curve for rice. The supply response in the Philippines has been primarily based on the response to the use of traditional inputs such land and labor. Previous studies of rice supply (Mangahas et al., 1966) indicate that the price response of supply is largely an area response effect. It is reasonable to assume that area response accompanies a more or less parallel change in labor. Thus, in the case of the Philippines, the production cost represented by an area below *SS* consists primarily of the opportunity costs of land and labor.

The vertical line D_hH represents the demand curve of producers for home consumption. Here it is assumed that producers' households consume the same quantity of their produce irrespective of prices and sell the rest in the market. For the support of this assumption see 1975 study by Toquero et al.

D_mD represents the market demand for the product — the horizontal distance between D_mD and D_hH measures the quantity purchased by urban (nonfarmer) households. The total demand for rice is represented by D_hD_mD.

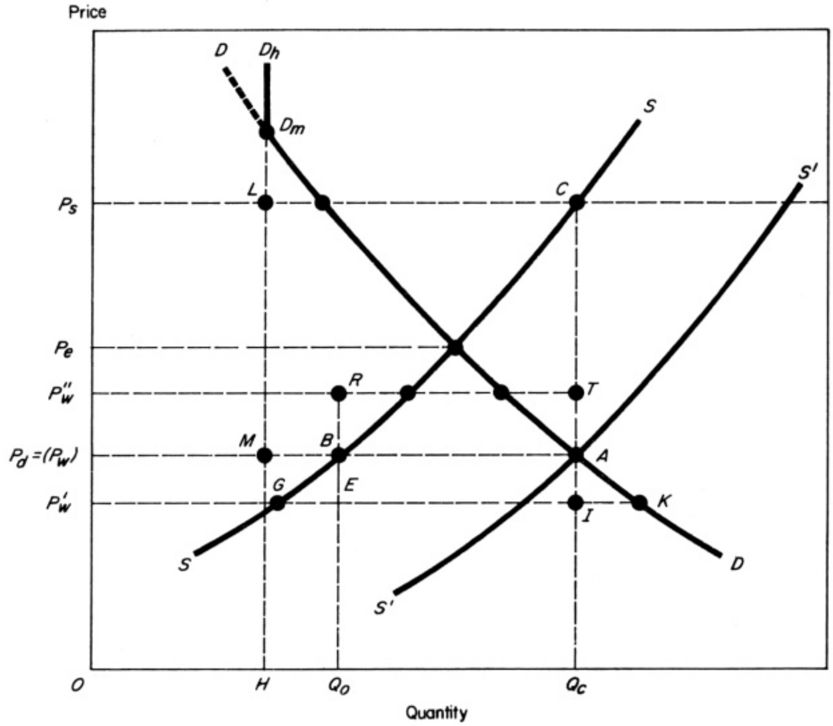
Normally, the world price of rice (OP_w) has been below the domestic equilibrium price (OP_e) that would have been established at the intersection of D_mD and *SS*. Without government intervention the Philippines would import AB. Let us assume first that the price for imported rice is exactly equal to a target price (OP_d) for domestic consumers that the government intends to maintain. If OP_d is that domestic target price, then it is necessary to have OQ_c available to consumers. There are four possible alternatives:

- Import *AB,*
- Support the rice price received by producers at OP_s,
- Subsidize fertilizer prices sufficiently to shift the supply function from S to S', and
- Invest in irrigation systems so as to shift the supply function from S to S'.

The first alternative, which has been the traditional policy of the Philippine government, serves as a standard for comparing the three alternative self-sufficiency policies. It is important to note that our standard of comparison is different from the free market equilibrium that is usually used as a bench mark of price policy evaluation, e.g., Johnson (1965) and Wallace (1962). Our bench mark assumes government intervention in the control of rice imports to ensure a target rice price for consumers. Our bench mark coincides with the free market equilibrium when the target price is the same as the world price.

A slight variation of the initial assumption is also in Figure 3. The world price may be either below the target retail price ($OP'_w < OP_d$) or above the domestic target retail price ($OP''_w > OP_d$). If the government maintains imports at AB, it will incur a profit in the former case by restricting imports and selling above the purchase price (OP'_w). This policy will protect domestic producers and earn revenue for the government at a cost to the consumer. However, when in the latter case the world price is above the domestic sale price, the import required by the government to maintain the domestic price at OP_d is greater than would occur in free trade. Selling below the purchase or import price benefits the consumers at a cost to the government and the producers. Due to the fluctuation in the world price relative to the domestic target (OP_d), the Philippines in the recent past has profited in some years and lost money in others from its import transactions. On balance, the domestic Philippine price has remained fairly much in line with world rice prices.

The three alternative self-sufficiency policies are described in the subsections that follow. The mathematical formulation for the estimation of benefits and costs of alternative policies is shown in Appendix A.



3. Model of price support and fertilizer subsidy for rice.

Price support. Assuming a domestic supply schedule *SS* as fixed, self-sufficiency in rice can be achieved by supporting the producer price at OP_s. Because the government has to maintain the consumer price at OP_d, self-sufficiency in rice by means of price support would involve a cost to the government represented by area *ACLM* as a difference between the procurement cost and the sale. If the gap between the producer price and the consumer price is not so large as to cover the marketing cost, producers may retain *OH* for home consumption. However, as the difference becomes larger, producers would sell all of this product and buy back a part for their own consumption. In this case, the government cost will exceed area *ACLM* and may even approach area ACP_sP_d.

In addition, compared with the check case of importing *AB,* the policy to achieve self-sufficiency by supporting the producer price at *OP* would result in an increase in government cost by area *ABEI* representing a forgone revenue if the world price is OP'_w (a decreased area *ABRT* if the world price is OP''_w).

Now, with the support price at *OPs,* producers' revenue from the sale of rice would increase by area *ACLM,* but the cost of the rice to the producers would also increase by area *ABC.* The difference, area *BCLM,* represents an increase in the income of the rice producers at a cost to the government. The net loss of economic welfare to society is represented by the area ABC (aside from the consideration of possible benefit from foreign exchange savings discussed below).

A net saving of foreign exchange is area ABQ_0Q_c (IEQ_0Q_c if world price is lower than domestic price and TRQ_0Q_c if vice versa) minus the increase in fertilizer input due to increased fertilizer application stimulated by a more favorable ratio of fertilizer price to rice price. It is likely that this formula overestimates the contribution of price support to foreign exchange savings, because not only fertilizer import but also the import of other inputs such as farm machineries that have foreign exchange components may be increased as a result of higher rice prices. Also, the export of cash crops such as sugar may be reduced because higher price may result in a diversion of land area from the cash crops to rice.

Fertilizer subsidy. Self-sufficiency in rice can be achieved, without supporting the producer price, by shifting the supply curve from S to S' in Figure 3. Because the supply curve represents a marginal-cost curve, it can be shifted to the right by lowering the price of the input.

Given the production elasticity of fertilizer in the rice sector and the price elasticity of demand for fertilizer used for rice production, we can determine

- the quantity of fertilizer required to obtain the increased output needed for self-sufficiency, and
- the decline in price required to induce this additional fertilizer consumption needed.

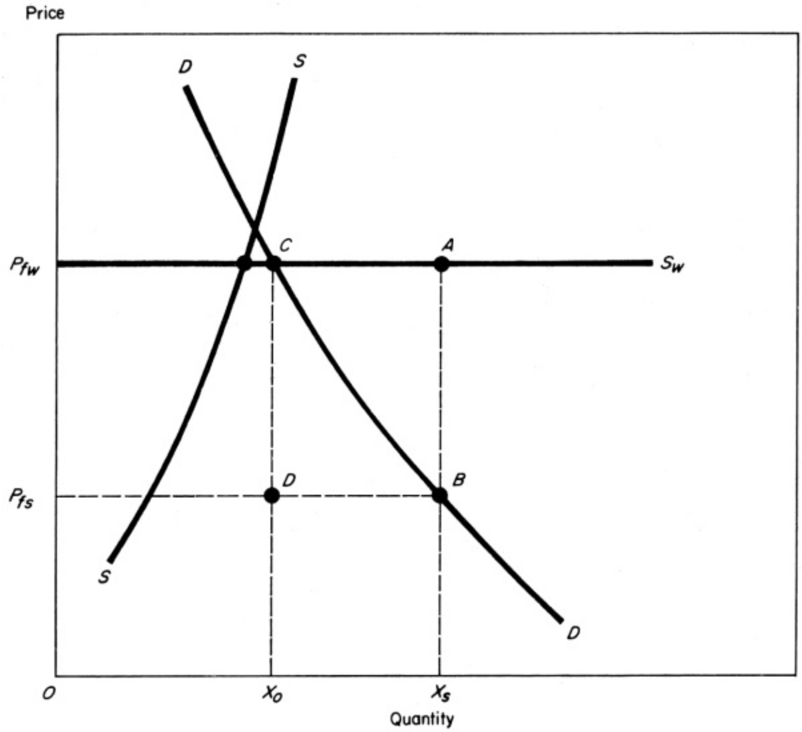
A model of the fertilizer market is in Figure 4. The demand curve is represented by DD. The domestic supply curve is SS and the world supply curve (S_w) is assumed to be completely elastic.

If the price of fertilizer applied to rice must be subsidized at OP_{fs} to achieve self-sufficiency, the government cost of fertilizer subsidy to rice is represented by the area $ABP_{fs}P_{fw}$. The reduction (increase)in government revenue due to a decrease in rice imports as a result of the achievement of self-sufficiency is, as in the case of rice price support, represented by the area $ABEI$ (or area $ABRT$) in Figure 3.

The rice producers would receive a dual benefit from

- being able to buy all their fertilizer at a lower cost as represented by the area $CDP_{fs}P_{fw}$ in Figure 4, and
- the increased output value, area ABQ_0Q_c less the fertilizer cost from using additional amounts of fertilizer because of the more favorable price relationship, area BDX_0X_s in Figure 4.

Net savings in foreign exchange can be shown as the net reduction in foreign exchange expenditures for rice imports, area ABQ_0Q_c, in Figure 3 less the increase in foreign exchange requirement for increased fertilizer import, area ACX_0X_s in Figure 4. As in the case of rice price support, the welfare of rice



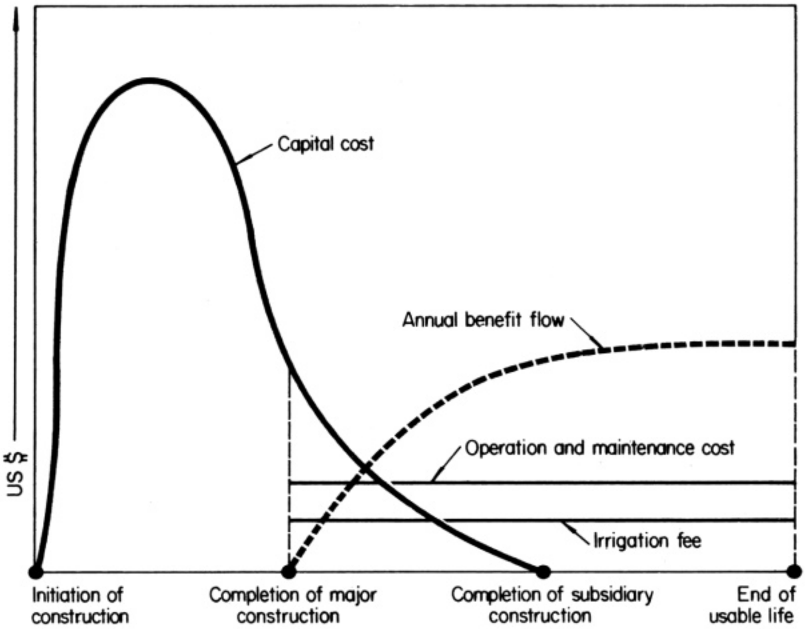
4. Model of fertilizer demand in relation to subsidy.

consumers does not change because they consume the same quantity of rice at the same price irrespective of the support, or subsidy programs.

Irrigation development. Rice self-sufficiency can be achieved by investing in irrigation systems instead of creating artificial price incentives. Improvement in irrigation infrastructure has the effect of lowering the cost curve, thereby shifting the supply curve to the right as represented by the shift from S to S' in Figure 3.

A major problem in comparing price policy and infrastructure development policy is the difference in the distribution of benefits and costs over time. A constant flow of annual government expenditure is required for supporting product prices or subsidizing input prices if a level of output increased by the price incentives is to be maintained. Resulting benefits to producers and savings of foreign exchange also flow in constant streams.

In contrast, if the same amount of output is to be increased by government investments in irrigation systems, a large initial capital cost (with a certain foreign exchange component) is involved during the construction period. The benefit will increase gradually as the major structure is built and subsidiary lat-



5. Distribution of benefits and costs over time associated with investment in irrigation systems.

erals and ditches are constructed. The full benefit will emerge when a farming system in the command area is completely adjusted to the irrigation system. The benefit stream can be maintained with a flow of operation and maintenance expenses until the end of a usable life. The government can plow back a part of benefit by charging irrigation fees for the service rendered to farmers in the command area (Fig. 5).

To compare price policy and irrigation development policy as alternatives to achieve food self-sufficiency, it is necessary to convert their benefits and costs into the same time dimension. The methodology adopted here is to capitalize all benefits and costs associated with an irrigation development project, from its initiation to the end of its usable life, into present values at the time of initiation. Then, using a real discount interest, we convert the present values of benefits and costs into infinite annual streams, which we compare with the annual benefits and costs associated with the product price support and the input price subsidy.

PARAMETERS AND DATA

The time framework of the analysis is as follows: First, we consider two time regimes: before the introduction of modern varieties (TV regime) and after the introduction of modern varieties (MV regime). The TV regime is from 1960 to

1967, and the MV regime, from 1968 to 1975. Analysis is conducted first on the basis of normal conditions for each time period. The MV regime is then further divided into two subperiods, one representing the period of low international prices of rice and fertilizer (1970–71), and the other reflecting the period of high world rice and fertilizer prices (1973–74) (Table 3).

It should be emphasized that in comparing the benefits and costs of alternative policies for achieving self-sufficiency between the TV and MV regimes in the normal years, we have assumed that the rice consumption and fertilizer input are at levels that existed in 1975. The gap between production and consumption is taken as an average 5% of consumption, or 220,000 t. In short, we compare the benefits and costs of producing an additional 220,000 t domestically under each of three alternative policies, hypothesizing that the relative advantage of using price support, fertilizer subsidy, or irrigation investment would change with a change in technology under the same price relationships. The decision was made to hold the quantity relationships at the 1975 level and to vary technology relationships, because our main interest is in the relative rather than the absolute level of alternative benefits and costs. In these calculations, the quantity of producer's home consumption was allowed to vary, declining from 50% in the TV regime to 40% in the MV regime (Mears and Lacsina, 1974).

However, to compare the three periods within the MV regime, both rice output and fertilizer input were adjusted for farmer's production responses to different price relations by using the fertilizer demand and rice production

Table 3. Data assumptions for the evaluation of policy alternatives to achieve rice self-sufficiency in the Philippines.

	TV regime	MV regime		
	$P_d = P_w$	$P_d = P_w$ (normal year)	$P_d > P_w$ (1970-71)	$P_d < P_w$ (1973-74)
Parameters				
Price elasticity of rice supply β	0.3 & 0.1	0.3 & 0.1	0.3 & 0.1	0.3 & 0.1
Production elasticity of fertilizer a	0.05	0.1	0.1	0.1
Price elasticity of fertilizer demand (-y)	–0.75	–0.5	–0.5	–0.5
Prices (US$/mt)				
Domestic producer price of rice (P_d)	200	200	200	200
Domestic consumer price of rice (P'_d)	260	260	260	260
Import price of rice (P_w)	200	200	160	360
Retail cost of imported rice (P'_w)	260	260	220	420
Import price of nitrogen (P_{fw})	400	400	250	600
Farm price of nitrogen (P_{f0})	460	460	310	660
Farm wage rate (P_z) ($/man-day)	1.2	0.8	0.8	0.8
Quantities (1000 mt)				
Domestic rice consumption (q_c)	4400	4400	4400	4400
Domestic rice output (q_0)	4180	4180	4261	4107
Producers' home consumption of rice (h)	2090	1670	1670	1670
Nitrogen input in rice production ($x_0/1.5$)[a]	80	80	97	67

[a] x_0 is the total input of fertilizers and chemicals measured in nitrogen equivalents,

parameters specified below. The comparison aims to evaluate the relative advantages of three alternative policies between the different price relations under the same technology.

The introduction of MV has changed the elasticity of fertilizer production with respect to rice (a) and the elasticity of fertilizer demand (g). The elasticity estimates for the MV regime are based on an analysis by David (1975). The elasticity estimates for the TV regime are computed by deriving a set of typical response functions for MV and TV under irrigated and rainfed conditions. The procedure for deriving the typical response functions is described by David and Barker (1976). We then derive the MV and TV estimates of elasticities for these functions, and apply the percentage difference to the David estimates (Appendix B).

A study conducted by Mangahas et al. (1966) shows that the estimates of the short-run elasticity of supply (b) are distributed around 0.3 using pre-MV time series data. This analysis is currently being updated, and preliminary estimates suggest that the elasticity may have declined from 0.3 to 0.1. In this analysis, we used 0.3 and 0.1 as alternative assumptions b.

The domestic producer price of rice is taken at its 1975 level at $200/t in milled rice, which is equivalent to a farm price of 1 Philippine peso/kg of paddy. The domestic consumer price is specified as $260/t, assuming that the marketing and processing cost is $60/t or 30% of the producer price in the normal years (Mears and Lacsina, 1974).

All other prices are deflated by the domestic rice price accordingly. The import price of rice, increased by 30% for marketing charges, is equivalent to the domestic consumer price in both the TV- and MV-regime normal years. But the import price was well below the domestic price in 1970-71 and well above it in 1973–74. The nitrogen import price declined to its lowest level in 1970–71, but increased sharply as a result of the shortage and scare buying in 1973–74. However, the effect of the oil crisis appears to have raised the cost of imported fertilizer to about the level that prevailed during the TV regime. The marketing cost for nitrogen was $60/t, or 15% of the import price in the normal years. The cost of nitrogen is multiplied by 1.5 to make allowance for the cost of other nutrients and chemicals highly complementary to fertilizer input.

The only price assumed to have changed between the TV-regime and the MV-regime normal years is the wage rate. Real wages measured in the purchasing power of rice fell substantially between the early 1960’s and the early 1970’s.

Costs and benefits associated with the construction of new irrigation are summarized in Table 4. The budget shown is for a typical diversion system of the National Irrigation Administration. The real cost of constructing irrigation systems is assumed to have risen by 20% as a result of the shift toward areas more difficult to irrigate.

We computed the increase in yield achieved by shifting from rainfed to irrigated conditions, using generalized production functions (Appendix B). The shift with TV assumes 5 to 25 kg increase in nitrogen input per hectare. The shift with MV assumes an increase of 30 to 60 kg.

It is assumed that the nitrogen cost is 50% of the cost of current inputs, capital interest, and depreciation for rice production, about 80% of which is supplied from abroad (k = 2 and k' = 1.6). Further, it is assumed that labor input per hectare of crop area corresponding to the shift from the rainfed to the irrigated conditions increases from 65 to 90 man-days. Information on labor, current input, and capital cost for rice production is based on IRRI farm surveys in Central Luzon and Laguna Provinces conducted in 1966 and 1975.

These increases in inputs, and the corresponding increases in output derived from the generalized production functions are aggregated for wet and dry seasons by multiplying the rates of actual irrigation to produce the average increases in input and output per hectare of irrigation-system command area as shown in Table 4. (It is assumed that there is no farm production in the dry season in the rainfed area.)

Another critical variable in the benefit-cost analysis of irrigation investment is the interest rate, which is assumed to reflect a social discount rate. The 15% rate used in this analysis is commonly used in the project evaluation of the National Economic Development Authority in the Philippines.

BENEFITS AND COSTS OF ALTERNATIVE POLICIES

The estimated benefits and costs associated with three policy alternatives to achieve rice self-sufficiency in the Philippines for different technology and price regimes are presented in Tables 5 and 6. Major findings can be summarized as follows:

1. For all the technology and price regimes, the rice price-support program produces both the highest benefits to producers even for the lower estimates

Table 4. Data assumptions on the costs and benefits associated with an increase by one hectare of irrigation-system command area in the Philippines.

	Costs and benefits	
	TV regime	MV regime
Capital cost: Total (US$)	500	600
Foreign exchange component (US$)	200	240
Irrigation rates: Wet season	0.75	0.75
Dry season	0.33	0.33
Increase in rice output per year (ton of milled rice)	1.5	1.8
Increase in nitrogen input per year (kg)	30	45
Increase in labor input per year (man-days)	40	50
Operation and maintenance cost per year (US$)	20	20
Collection of water fee per year (US$)	15	15
Period of usable life (years)	50	50
Construction period (years)	3	3
Discount rate (%)	15	15

Table 5. Estimates of social benefits associated with alternative policies to achieve rice self-sufficientcy in the Philippines (million US$ in 1975 prices).

	Annual benefit flow (million US$)			
	Increase in producers' income (1)	Change in government cost of rice import (2)	Foreign exchange savings (3)	Total (1)+(2)+ 0.05 (3)
TV regime ($P_d = P_w$):				
Price support: $\beta = 0.3$	82	0	37	84
$\beta = 0.1$	296	0	22	297
Fertilizer subsidy	61	0	–42	59
Irrigation development	20	0	24	21
MV regime: $P_d = P_w$ (normal year)				
Price support: $\beta = 0.3$	97	0	40	99
$\beta = 0.1$	352	0	30	354
Fertilizer subsidy	66	0	12	67
Irrigation development	21	0	23	22
$P_d > P_w$ (1970–71)				
Price support: $\beta = 0.3$	61	–6	20	56
$\beta = 0.1$	202	–6	16	198
Fertilizer subsidy	40	–6	8	35
Irrigation development	14	–6	11	9
$P_d < P_w$ (1973–74)				
Price support: $\beta = 0.3$	134	47	98	186
$\beta = 0.1$	515	47	80	566
Fertilizer subsidy	92	47	46	141
Irrigation development	26	47	60	76

based on the assumption that *ß* = 0.3 and, in most cases, the largest savings of foreign exchange. Consequently, the total social benefit produced by such programs is the highest among the three policy alternatives. However, because the direct costs to the government are even larger, the social net benefits are negative, and the social benefit:cost ratios (B:C) are less than one except for years, such as 1973–74, when the import cost of rice exceeds the domestic price and the government incurs the large deficit from the rice-import operations.

2. By lowering the assumed value of *ß* from 0.3 to 0.1, the cost of government price-support program for self-sufficiency rises to an almost prohibitive level even though the efficiency of the program, as measured by the B:C ratios, does not decline as much.

3. Producers' benefits produced by the fertilizer-subsidy program are the second largest among those of the policy alternatives. The foreign exchange savings are the smallest (negative for the TV regime), because the subsidy program has the effect of increasing the consumption of fertilizer imported from abroad relative to the use of domestic factors such as labor and land.

Table 6. Evaluation of alternative policies to achieve rice self-sufficiency in the Philippines in terms of social benefit and cost criteria.

	Annual flow (million US$)			
	Total social benefit (1)	Government cost (2)	Benefit:cost ratio (1)÷(2)	Internal rate of return (%)
TV regime $(P_d = P_w)$:				
Price support: b = 0.3	84	85	0.99	—
b = 0.1	297	310	0.96	—
Fertilizer subsidy	59	115	0.51	—
Irrigation development	21	8.8 (56)[a]	2.39	31
MV regime: $P_d = P_w$ (normal year)				
Price support: $\beta = 0.3$	99	101	0.98	—
$\beta = 0.1$	354	366	0.97	—
Fertilizer subsidy	67	59	1.13	
Irrigation development	22	8.7 (55)	2.53	32
$P_d > P_w$ (1970–71):				
Price support: $\beta = 0.3$	56	63	0.90	—
$\beta = 0.1$	198	207	0.95	—
Fertilizer subsidy	35	30	1.18	—
Irrigation development	9	5.5 (55)	1.64	32
$P_d < P_w$ (1973–74):				
Price support: $\beta = 0.3$	186	142	1.31	—
$\beta = 0.1$	566	541	1.05	—
Fertilizer subsidy	141	99	1.43	—
Irrigation development	76	11.6 (55)	6.55	36

[a] Figures in parentheses are initial capital costs.

4. For the TV regime, the total social benefit produced by the fertilizer subsidy is exceeded by the subsidy cost to the government, resulting in a B:C ratio smaller than one. For the MV regime, the government subsidy cost is smaller than the benefit and the B:C ratio becomes greater than one. Such an improvement in the efficiency of the fertilizer-subsidy program is primarily due to increase in the rice-output response to fertilizer as reflected in the increase in the production elasticity of fertilizer ($\beta = .05$ to $\beta = .1$).

5. The irrigation investment produces relatively small annual benefit flows to producers compared with the rice price-support and fertilizer-subsidy programs. But because the government costs are even smaller (in annual flow terms), the B:C ratios are usually the highest among the three alternatives. An increase in the real cost of irrigation construction due to the gradual exhaustion of easier construction sites seems to be largely compensated for by the introduction of new rice technology, resulting in a more or less constant efficiency in the government irrigation investments for the TV and the MV regimes in terms of the B:C ratio criterion.

6. Changes in the import price relative to the domestic price of rice have large effects on the efficiencies of government programs to achieve rice self-sufficiency. The B:C ratios for the three policy alternatives are all low for the price relationship that prevailed during 1970–71 when the world rice prices declined sharply and the government could import rice with profit. The B:C ratios increase dramatically as the price relationships change to those which prevailed during 1973–74. when the government had to import at a large deficit to prevent domestic rice prices from rising despite the world food shortage and high prices.

The changes in the benefits and costs associated with the three alternative programs to achieve rice self-sufficiency over the different technology and price regimes seem largely consistent with the actual policy choice of the Philippine government.

Despite frequent appeals and government gestures. the rice price support has never been contemplated seriously as a major policy instrument to increase output to a self-sufficiency level. This poses no anomaly considering the large government costs and the low B:C ratios as estimated by our analysis.

The fertilizer subsidy had also not been exercised to any significant extent during the TV regime. But government adopted it as one major instrument to achieve rice self-sufficiency within the Masagana 99 Program. The fertilizer subsidy is characterized by an increase in the B:C ratios. partly because of the introduction of MV and partly because of the sharp increase in the world price of rice.

For both the TV and the MV regimes, investment in irrigation systems has been the government's major means for increasing rice production. It has also proved the most effective policy for raising national output and productivity. The high B:C ratios of the irrigation development program estimated in our study clearly suggest the basis of the government choice of irrigation investment as the major means to achieve rice self-sufficiency.

Changes in the price relations seem a strong force governing the government efforts for rice self-sufficiency. Slackening of the efforts during the period of the *green revolution euphoria* (1970–71) corresponds to the sharp declines in the B:C ratios of all the three policy alternatives. In contrast, the increases in the B:C ratios during the world food crisis (1973–74) were accompanied by the dramatic increases in irrigation investments and the initiation of large crash programs such as the Masagana 99.

CONCLUSION

We have developed a highly simplified model to compare the benefits and costs associated with the three policy alternatives to achieve rice self-sufficiency and applied it to the case of the Philippines for the various regimes of technology and price relations. Our model is used to budget the benefits and costs of increasing rice production to achieve rice self-sufficiency, using 1975 as the base year for quantities and prices. Our analysis abstract, many factors that might have influenced actual government decisions. Yet, the results show rather clearly that the government policy choice has been rational in terms of short-run changes in social benefit-cost criteria. Changes in rice production technology and price relations that affect the magnitudes and the rankings of social payoffs among policy alternatives seem to have potent effects on government decisions.

Such apparent rationality in the government policy choice does not necessarily imply that government administrators and legislators are so rational and perceptive as to base their decisions on the explicit calculations of the social benefit:cost ratios. It seems more reasonable to hypothesize that the apparently rational short-run policy choice has resulted as a compromise in struggles among vested interests, the force of whose arguments is to a large degree governed by the food-grain situation existing at any particular point in time.

This government response to changes in technology and prices does not ensure the optimum resource allocation in society. The slackening of the efforts to increase domestic rice production during the *green revolution euphoria* period seems at least partially responsible for the rice crisis in the Philippines in 1973, which compelled the introduction of high cost crash programs during the period of world food crisis.

We have developed a model of policy evaluation in a fairly limited context. It should not be implied from this analysis that achieving self-sufficiency through any of the alternatives discussed is a desirable policy goal. There are not only alternative ways of achieving self-sufficiency, but also alternative goals to self-sufficiency that may be more desirable.

What we do argue, however, is that in a condition of highly volatile food-grain and fertilizer prices, such as we have experienced recently, food-staple self-sufficiency has become a matter of major concern to many developing countries, and the policy alternatives included in our analysis have, in fact, been among the major alternatives actually contemplated and exercised.

Our Philippine case study shows the rational policy choice by the government, even though such choice was not based on explicit rational calculations. Our analysis also shows that the rational policy choice may accentuate rather than stabilize price fluctuations because the decision was often proved unwise by short-run fluctuations in supply due to weather.

REFERENCES CITED

BARKER, R., and Y. HAYAMI. 1976. Price support versus input subsidy for food self-sufficiency in developing countries. Am. J. Agric. Econ. 58:617–628.

DAVID, C. C. 1975. A model of fertilizer demand among Asian rice farms: a macro-micro analysis. Ph. D. thesis, Stanford University Food Research Institute.

DAVID, C. C., and R. BARKER. 1978. Modern rice varieties and fertilizer consumption. Pages 175–211 *in* International Rice Research Institute. Economic consequences of the new rice technology. Los Baños, Philippines.

DE DATTA, S., K. A. GOMEZ, R. W. HERDT, and R. BARKER. 1976. Farm yield constraints in Laguna, Nueva Ecija, Camarines Sur, and Iloilo province sites, Philippines, 1975. 4th International Rice Agro-Economic Network Working Paper No. 5. 48 p.

GRILICHES, ZVI. 1964. Research expenditures, education and the aggregate agricultural production function. Econ. Rev. 54:961–974.

HAYAMI, Y., R. BARKER, and E. BENNAGEN. 1977. Price incentive versus irrigation investment to achieve food self-sufficiency in the Philippines. Am. J. Agric. Econ. 59:717–721.

HAYAMI, Y., and M. KIKUCHI. 1975. Investment inducements to public infrastructure: irrigation in the Philippines. IRRI Agric. Econ. Dep. Paper No. 75–15.

INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI). 1975, Changes in rice farming in selected areas of Asia. Los Baños, Philippines. 377 p.

JOHNSON, P. R. 1965. The social cost of the tobacco program. J. Farm Econ. 47:42–255.

MANGAHAS, M., A. RECTO, and V. W. RUTTAN. 1966. Price and market relationships for rice and corn in the Philippines. J. Farm Econ. 48:685–703.

MEARS, LEON A. and T. A. LACSINA. 1974. Rice economy of the Philippines. University of the Philippines Press, Quezon City, Philippines.

SUMALEE, APIRAKSIRIKUL. 1976. Rice trade policy as it relates to national objectives in the Philippines. M.S. thesis, School of Economics, University of the Philippines.

TOQUERO, Z., B. DUFF., T. LACSINA, and Y. HAYAMI. 1975. Marketable surplus functions for a subsistence crop: rice in the Philippines. Am. J. Agric. Econ. 57:705–709.

WALLACE, T. D. 1962. Measures of social costs of agricultural programs. J. Farm Econ. 44:580–594.

APPENDICES

APPENDIX A. **Formula to estimate benefits and costs associated with alternative policies.**

PRICE SUPPORT. The cost to the government or difference between procurement cost and sales revenue is

$$\text{area } ACLM \text{ (Fig. 3)} = (p_s - p_d)(q_c - h) \tag{1}$$

Reduced revenue from government imports is

$$\text{area } ABEI \text{ (Fig. 3)} = (p_d - p_w)(q_c - q_o) \tag{2}$$

where p_d and p_s are unsupported and supported rice prices for domestic producers;

q_o and q_c = domestic output and consumption of rice;
h = producers' home consumption;
p'_d = consumer price of rice;
p'_w = the retail cost of imported rice, which is equal to the import price (p_w) plus the marketing cost.

The relation between p_d and p_s can be established as

$$p_s = p_d\,(1 + k)^{\frac{1}{\beta}}$$

where:

$$k = \frac{q_c - q_o}{q_o}$$

and β is the price elasticity of rice supply.

Because we assume constant-elasticity supply function, $q = fP\beta$ where f is a scalar including supply shifters, an increase in rice producers' income due to government support is calculated as

area $BCLM$ (Fig. 3) = area BCP_sP_d (Fig. 3) − area MLP_sP_d (Fig. 3)

$$\begin{aligned} &\quad P_s - \beta \\ &= \phi p \quad dp - h\,(p_s - p_d) \qquad (3) \\ &\quad p_d \\ &= \frac{1}{1+\beta}(p_s q_c - p_d q_o) - h\,(p_s - p_d) \end{aligned}$$

The net saving in foreign exchange is

area ABQ_oQ_c (Fig. 3) – increase in fertilizer import

$$= p_w \, (p_c - q_o) - p_{fw} \, (x_c - x_o) \tag{4}$$

where p_{fw} is the import price of fertilizer, and x_o and x_c are the fertilizer inputs corresponding to p_d and p_s, respectively. The relation between x_o and x_c is established as

$$x_c = x_o \left(\frac{p_s}{p_d}\right)^{\gamma}$$

where γ is the price elasticity of demand for fertilizer.

FERTILIZER SUBSIDY. The fertilizer input required to produce a self-sufficiency level of rice output, q_c, while other factors remains constant, is

$$x_s = x_o \left(\frac{q_c}{q_o}\right)^{\frac{1}{\alpha}} \qquad = x_o \, (1 + k)^{\frac{1}{\alpha}}$$

where α is the production elasticity of fertilizer for rice.

The subsidized price of fertilizer that would induce farmers to apply more fertilizer at the level x_s is

$$p_{fs} = p_{fo} \left(\frac{x_s}{x_o}\right)^{-\frac{1}{\gamma}} \qquad = p_{fo} \, (1 + k)^{-\frac{1}{\alpha\gamma}}$$

where p_{fo} and p_{fs} are unsubsidized and subsidized prices of fertilizer for farm producers, respectively.

The government cost of fertilizer subsidy for rice to achieve self-sufficiency is

$$\text{area } ABP_{fs} \; P_{fw} \quad \text{(Fig. 4)} = x_s \; (p_{fo} - p_{fs}) \tag{5}$$

A reduction (or increase) in government revenue due to a decrease in rice import as a result of achieving self-sufficiency is the same as for rice price support (see equation 2).

The rice producers' benefit is

area $CDP_{fs} P_{fw}$ (Fig. 4) ± area ABQ_oQ_c (Fig. 3) – area BDX_oX_s (Fig. 4)

$$= \quad (p_{fo} - p_{fs})x_o + p_d \, (q_c - q_o) - pfs \, (x_s - x_o) \tag{6}$$

The net saving in foreign exchange is

area ABQ_oQ_c (Fig. 3) – area ACX_oX_s (Fig. 4)

$$= p_w \, (\, q_c - q_o) - p_{fw} \, (\, x_s - x_o) \tag{7}$$

IRRIGATION DEVELOPMENT. Simplifying assumptions for the capitalization of irrigation costs and benefits, adopted primarily for the limitation of data. are as follows:

1. The whole capital cost is spent in the median year of the construction period.
2. No benefit is produced until the construction of the irrigation systems is completed. However, the full benefit of the systems in the form of increases in farm output (rice) with corresponding increases in inputs (fertilizers) emerges in the year after the completion of government construction project and is maintained until the end of its usable life.
3. Both the cost of operation and maintenance and the collection of irrigation fee per hectare of command area per year are fixed throughout the period of usable life.
4. Government policy is such that an increase in domestic rice output substitutes for an equal reduction in imports, thereby resulting in no change in domestic rice supply and prices. An additional amount of fertilizer required to increase domestic output in the expanded area under irrigation is procured from overseas and is made available to rice producers at constant import prices.

The capitalized present values of government costs, farm producers' benefits. and net foreign exchange savings associated with the policy of developing irrigation Infrastructure to achieve food self-sufficiency, can be calculated as follows:

$$\text{Government cost} = \frac{c}{(1+i)^m} + (O - w)\frac{[(1+i)^n - 1]}{i\,(1+i)^{t+n}}$$

$$\text{Producers' benefit} = (\Delta q\, p_d - k\,\Delta x\, p_{fo} - \Delta z\, p_z - w)\frac{[(1+i)^n - 1]}{i\,(1+i)^{t+n}}$$

Net foreign exchange saving

$$= \frac{e}{(1+i)^m} + (\Delta q\, p_w - k\,\Delta x\, p_{fw})\frac{[(1+i)^n - 1]}{i(1+i)^{t+n}}$$

Where

Δq $(=q_c - q_o)$ = increase in rice output required to achieve self-sufficiency:
c = capital cost of building irrigation systems to increase output by Δq;
e = foreign exchange compodent in c;
o = operation and maintenance cost;
w = irrigation fee;
Δx $(= x_s - x_o)$ = increase in nitrogen input to produce
Δz = increase in labor input to produce Δq;
P_d = domestic producer price of rice;
P_w = import price of rice;
P_{fo} = nitrogen price paid by rice producers:
P_{fw} = import rice (=farm price) of nitrogen;
P_z = farm wage rate;
k = ratio of the total cost of current inputs, capital interest and depreciation to the cost of nitrogen input for rice production.

(continued on next page)

APPENDIX A **continued**

k' = ratio of the foreign exchange cost of current inputs, capital interest and depreciation to the cost of nitrogen input for rice production;
t = period of irrigation construction;
m = median of the construction period;
n = period of usable life of irrigation systems, and
i = interest rate.

The capital values are multiplied by i to be converted into annual flows so that they are comparable with the annual benefits and costs of price support and fertilizer subsidy programs.

APPENDIX B. **Procedures for estimating production and price elasticities for fertilizer.**

From the research of David (1975), we use the direct estimates for production and price elasticity for the MV regime in the Philippines. The production elasticity of fertilizer for rice $a_m = 0.1$, and the price elasticity of demand for fertilizer is $g_m = 0.5$. Taking those values as appropriate for MV, we estimate the corresponding elasticities for traditional varieties as follows:

We start with four basic equations for irrigated and rainfed conditions, the first two for MV, the latter two for TV (David and Barker, 1976).

MV in irrigated fields:

$$Y = 2100 + 18N - 0.09N^2 \tag{1}$$

MV in rainfed fields:

$$Y = 1400 + 15N - 0.11N^2 \tag{2}$$

TV in irrigated fields:

$$Y = 2100 + 11N - 0.13N^2 \tag{3}$$

TV in rainfed fields:

$$Y = 1400 + 9N - 0.16N^2 \tag{4}$$

The estimate of the production elasticity a^* for each function is as follows:

$$Y = a + bN + cN^2 \tag{5}$$

$$a^* = \frac{d\bar{Y}}{d\bar{N}} \frac{\bar{N}}{\bar{Y}} = (b + 2cN) \frac{\bar{N}}{\bar{Y}} \tag{6}$$

The production elasticity is estimated with Y and N calculated for the nitrogen-paddy price ratio, 4:l. A weighted elasticity is determined for MV(a^*_m) and TV

(continued on opposite page)

APPENDIX B **continued**

(a^*_t), based on the proportion of the area in irrigated and rainfed rice. The results are shown in Appendix C. The production elasticity for TV corresponding to the value a_m = 0.1 (that for MV) is estimated by the following formula:

$$\hat{\alpha}_t = \alpha_m \frac{\alpha^*_t}{\alpha_m^* \; W_m + \alpha \; {}^*t W_t} \qquad (7)$$

where W_m and $W_t$are percent area sown to MV and TV for the period 1972–74.

Estimates of the price elasticity are based on the equilibrium condition:

$$\frac{dY}{dN} = p = b + 2\,cN \qquad (8)$$

where $p = p_n / p_y$, the nitrogen:paddy price ratio, which is assumed at 4/1.

Transposing, the demand function is:

$$N = \frac{P}{2c} \; \frac{b}{2c} \qquad (9)$$

The price elasticity of demand for fertilizer is:

$$\gamma^* = \frac{d\overline{N}}{dp} \; \frac{\overline{P}}{\overline{N}} \; \frac{1}{2c} \; \frac{\overline{P}}{\overline{N}} \qquad (10)$$

The values of the production elasticities, a*, derived from the equations are shown in Appendix C. The y_t corresponding to y_m = -0.5 is estimated using the same weighting procedure as that used for the production elasticity estimate in equation 10.

The resulting estimates are: y_t = 0.05, $\hat{y}$ = -0.75.

APPENDIX C. Estimates of production and price elasticities for traditional and modern varieties using farm level response functions.

Water control, variety	Percent of area	$\overline{N}$ (kg/ha)	Y (kg/ha)	a	g
Modern varieties					
Irrigated	31	78	2956	0.104	-.28
Rainfed	28	50	1815	0.107	-.36
Traditional varieties					
Irrigated	10	27	2302	0.047	–.57
Rainfed	31	16	1503	0.041	–.78
Weighted elasticities					
Modern (a_n^*, g_n^*)	59			0.105	-.32
Traditional (a_t^*, g_t^*)	41			0.043	-.73
Traditional ($\hat{a}_t$, $\hat{g}_t$)				0.054	–.75

COMMENTS ON
NEW RICE TECHNOLOGY AND POLICY ALTERNATIVES FOR FOOD SELF-SUFFICIENCY

D. D. HEDLEY

THE PURPOSE OF THE PAPER is described by the authors *to determine. . . how the shift in technology and price relationships affects the relative advantages of the differentpolicy alternatives* in the Philippines. The authors use a series of equations representing demand and supply to create a static partial-equilibrium model of the Philippine rice economy. The criteria for distinguishing the effects of alternative policies are increases in producers' income, changes in government rice-import costs, and foreign exchange savings. The core of the analysis is that the goal of policy makers is the achievement of self-sufficiency in rice production.

Four situations are characterized in the study: modern (MV) and traditional variety (TV) situations are examined in conjunction with high and low domestic prices in relation to world rice prices. In examining this paper, I explore a few avenues of constructive criticism. The simplicity of the model needs comment, as does the way in which the results are interpreted and presented. Additionally, the concept of self-sufficiency as applied in the Barker et al. paper is discussed.

At the outset it is important to recognize the contribution of the Barker et al. paper to the conference. The authors have clearly focused on a topic of considerable importance, and have developed a rigorous methodology to examine it. Yet the methodology has not required the vast amounts of data normally associated with efforts of this kind. By careful selection of information from previous studies, and by building up a theoretical structure consistent with the sound information available, the authors have avoided the usual handicap of poor data quality and availability for the major policy evaluation of the model. Equally important is that many assumptions made in the construction of the model, while reasonable, are indeed testable hypotheses once the data become available. As a result, construction of a model of this type can pinpoint exactly the data requirements for further research and expansion of the model. Without going through the modeling process several important areas of research and data development could be missed.

Agricultural economist, the Rockefeller Foundation, Indonesia.

The development of the responses for MV and TV under rainfed and irrigated conditions is to some extent artificial (Barker et al., Appendix B). The regression coefficients in the quadratic production function are assumed to be linearly related to number of water stress days for the 30-60 days before rice harvest. To some extent, this assumption builds on the subsequently determined returns to irrigation and nitrogen.

The procedure of comparative statics used by the authors is a common method. The supply and demand curves suggested are constant elasticity functions, deterministic in nature and not stochastic. The elasticities of supply and demand are drawn from other studies, and assumed constant within the function.

Although stochastic supply and demand functions developed in the past would have been more satisfying, the assumptions of constant elasticities will likely have little impact on the results. The ordering of the social benefits for each alternative is unlikely to change if stochastic functions are used, even without the assumption of constant elasticities. The results from this perspective appear quite robust. To comment on or debate the choice of elasticities is not really a productive exercise here. However, an exploration of the sensitivity of many of the assumptions and parameter values used would have been interesting to the reader.

The approach used by Barker et al. is examination of one *year,* or one time period, assuming full adjustment to confirm or deny the rationality of public policy choice — on an ex post basis. But this comparative-statics approach does not permit any examination of the adjustment process.

The comparative-statics approach suffers, I believe, by providing only a snapshot view and not some idea of the *path of events* over time. My own approach would have been to use stochastic demand and supply schedules for rice validated over a certain period of time. In turn, policy actions could be imposed on the model with account taken, from a theoretical point of view, of alterations in structure. Clearly the *lags* in policy consequences, the impacts of midcourse corrections, or policy reversals can be more completely examined.

As an example of this, with a price support program — effectively a price guarantee — it is clear that because of both declining risk and rising returns to farmers, the supply curve will become considerably more elastic. If this modification is made, the social benefits will probably be altered considerably, as Barker et al. show. One may also argue that farmers do not really believe the government will follow through on its commitment to a price support. Thus the supply elasticity could remain unchanged. If the government *does* carry out the policy, any subsequent year with this policy in effect will show the increasing supply elasticity.

A second example of the need for exploration of adjustment processes is contained in the Barker et al. assumption that the increasing difficulty of providing irrigation is *perfectly* offset by the technological improvements in rice production. While it simplifies the analysis, it does not illuminate either the adjustment process or the distribution of benefits.

My comment is not intended to be critical of the paper; rather I ask for a considerably more sophisticated model or simulator to provide assurances that public policy has indeed been rational. The snapshot provided by the authors leaves one unconvinced of the rationality of public policy.

Another whole area of concern in this work is the distribution of benefits geographically (or regionally), by income class, by tenure class and, finally, in terms of altered factor shares, particularly for the price support (factor and product) programs. Again, I recognize I am asking the authors for considerably more work than they present. However, without knowledge of the distribution of benefits and an evaluation of the institutional, political, and social (or group) pressures facing policy makers, the authors again leave one unconvinced that the public policy choice is indeed the obviously rational one. Their conclusion may indeed be coincidence. Examination of historical events, with knowledge of only the beginning and ending environment and without analytically incorporating the flow of intervening events, can lead to substantial error. Yet this method is the paradigm of static analysis.

Going farther, the analysis by Barker et al. is in fact an *ex post* explanation of past public policy choice. Through their approach, capability to describe and reflect past public policy choices can be built up. The usefulness of this work increases immensely when that capability is such that we can confidently describe and reflect an evaluation of alternative public policy choices from an *ex ante* point of view. I cannot overemphasize the point — although I recognize that policy makers must be listening — if *ex ante* policy analysis is to be fully productive. Clearly, I see the Barker et al. work as the precursor to such *ex ante* policy analysis.

Another consideration in government policy examination that I feel is of major importance is the determination of *policy risk* associated with any course of action. By policy risk, I refer to the possible consequences of adjustment for government expenditures and social benefits that may come about by adjustment within the economy to a governmental action. In my own experience in Canada, this aspect is as important as the mean estimates of expenditure and cost. Barker et al. ignore this aspect completely in their safe world of static analysis.

A last comment on the Barker et al. methodology: the analysis, to me, suffers from the narrow focus of the paper on rice self-sufficiency. Admittedly this is an avowed objective of government, but other objectives also prevail. It would have been instructive to examine as well a range of alternatives in closing the self-sufficiency gap. A number of other measures would have been helpful, e.g., average and marginal values of the increase in rice production per unit, government expenditure per unit of gross or net income of producers by income class, etc. The results of the approach can be modified, then, to compare benefits for a *given level* of government expenditure. While large, expensive, government actions may yield high B:C ratios, the amount of expenditure to achieve this benefit may not be available.

Examination of the conclusions of the paper shows the issue of consequences of MV is really not explicitly addressed. Two comments are relevant here. First, the exercise involving irrigation presupposes that technological advance neutralizes the effect of increasing difficulty in irrigation development. That assumption is indeed testable; if correct, it provides a much more elastic land supply in the long run. However, the short-run case, which is fundamentally different, is unexplored in the paper. Second, comparing MV and TV technologies shows the *marginal* change in farmer income due to MV is indeed small, roughly 5 to 12% of the total. This consequence appears to have been overlooked.

The authors only implicitly provide a definition of the self-sufficiency policy objective. Within the paper, self-sufficiency in rice for the Philippines appears to be absence of trade, without regard to the pricing in product and factor markets. In a theoretical context of freely operating product and factor markets (within and between countries), self-sufficiency can be defined as the absence of trade given the relative income and prices of the economy. As one moves toward greater intervention by government in price mechanisms, the absence of trade in and of itself may no longer represent the self-sufficiency concept, even though none of the usual barriers to trade in rice are imposed. The illusion of self-sufficiency is achieved with substantial distortions in factor and product prices, which in themselves may provide substantial social benefit or loss.

In considering policy objectives in this light, it may be misleading to regard self-sufficiency as the objective. The term may indeed have political appeal, but it does not fairly represent the objective of government. “Import minimization at the least net social (and private‘?) cost” may more accurately define the path of government policy without leaving the illusion of freely operating factor and produce prices.

The difference in terminology may appear to be small on the surface, but the range of policy actions within true self-sufficiency are infinitely narrower than those within import minimization. The authors appear to have used the term self-sufficiency when the meaning implied is import minimization.

New rice technology and agricultural development policy

V. W. RUTTAN

THERE HAVE BEEN IMPORTANT shifts in development thought and policy in the decade since a *new agricultural strategy* based on the potential for rapid growth of agricultural production was opened up by the development and diffusion of the new *green revolution* technology.

During the first development decade (1950–60), policy was dominated by the perspective that the burden of custom and tradition represented the major constraint on rural development in poor countries. Much development effort focused on the need for modernization and reforms of rural institutions and for structural transformation of the entire economy.[1]

During the 1960’s there was a strong shift in development thought to the effect that growth of agricultural output and productivity could become a major source of growth in the total economy; that technology represented the major constraint on agricultural productivity growth; and that investment in agricultural research could become the “high-payoff” source of agricultural growth. This perspective was reinforced, and seemingly confirmed, by the development and dissemination of the new, fertilizer-responsive varieties of wheat and rice.

By the early 1970’s development thought had again shifted to a new concern about institutional performance (Crosson, 1975; Ruttan, 1975). The theme of the first development decade reappeared in a slightly modified form — how can the institutions that serve rural areas be modernized so that the potential productivity of the new *green revolution* technology can be realized? A second, and perhaps stronger, theme focused on the non-neutrality of rural institutions in partitioning the new income streams generated by the *green revolution* technology.

President, Agricultural Development Council, New York, USA.

[1] For a review of thought with respect to agricultural development in the 1950's and 1960’s, see Chapters 2 and 3 of Hayami and Ruttan (1971). For a review of the literature on rural development, see Ruttan (1975).

There has been a curious dichotomy in much of the new literature. Several critics have simultaneously insisted that the direct impact of the *green revolution* on crop production has been barely perceptible while its secondary impacts have been responsible for a pervasive erosion of equity and order in rural communities (Frankel, 1971; Griffin, 1974). The simultaneous emergence in the early 1970's of the third world-food crisis since World War II and a world energy crisis, and evidence of the increasing immiserization of substantial elements of the rural population in the poorest countries have seemingly reinforced this schizophrenic character of current development thought.

Any attempt to interpret the complex interrelationships between the new potentials for development opened up by the *seed fertilizer* revolution and the contribution of public policy to the realization of that potential must rest on a conceptual apparatus that is less constrained by ideological overburden and on a more rigorous interpretation of empirical evidence. There are several bodies of empirical materials that no student of agricultural development in South and Southeast Asia can afford to neglect. They include the resource papers prepared by the IRRI staff and their associates for this conference (published herein), the documents that have come out of the IRRI project on constraints to high yields on Asian rice farms, and the papers that have been produced for the Food Research Institute study of "Political Economy of Rice in Asia." The work of the IRRI constraints project is summarized in *Changes in rice farming in selected areas of Asia* (IRRI, 1975). The major results of the Food Research Institute study were assembled in three issues of Food Research Institute Studies in 1975 and 1976.

The objectives of this paper are more limited. I attempt to trace, in an impressionistic manner, the implications of the agricultural development experience, and evolution during the last two decades of development thought on the implementation of viable agricultural development strategies, policies, and programs.

INDUCED TECHNICAL AND INSTITUTIONAL CHANGE

A large normative literature on the institutional changes associated with the green revolution exists. But the radical and reformist thrust of that literature has been a barrier to analysis of the effects of the constraints that natural and social environments impose on the direction of institutional change. The tools of formal economic analysis have only occasionally been used to explain alternative historical paths of institutional change or to explore analytically the alternative future paths of institutional change. When the tools of economics have been brought to bear on the issue of institutional change, they have typically supported themes of revolution rather than incremental changes in institutional performance or the gradual, cumulation of institutional innovations with which history is more familiar.

The history of agricultural development reveals a complex pattern of dialectical interaction between technical and institutional change. The socialization of agricultural research was dependent on the ability of the state to generate public revenue. It involved the expansion of social control over the allocation of research resources. The institutionalization of agricultural research in the public sector has developed institutions capable of supplying new sources of productivity growth in agriculture. The outcome in turn has expanded the resources available to society. The institutional changes that have followed that expansion of resources have, in turn, reduced the control of the community over the allocation of resources and over the partitioning of income streams.

A review of the literature on the role of economic factors in the process of institutional change suggests two broad hypotheses with respect to the direction of institutional change.[2]

First, growth in the income flows available to a community or society induces institutional changes chat weaken the control of the community or of society over the allocation of resources and the partitioning of income flows. The new income flows may be generated by geographic or geologic discovery, by technical change, or by prior institutional change. An indication that the inducement mechanism for such changes is operative in agriculture is a rise in the price of labor relative to land, or a rise in the factor share accruing to labor relative to land.

Second, stagnation or decline in the income flows available to a society induces institutional changes that expand the control of the community or the society over the allocation of resources and the partitioning of income flows. The stagnation or decline in income flows may occur as a result of a rise in the pressure of population against resource endowments technological stagnation or retrogression, or institutional changes such as colonial or other external intervention into a society. An indication that the inducement mechanism for such changes is operative in the agricultural sector is a rise in the price of land relative to labor, or a rise in the factor share accruing to land relative to labor.

These hypotheses appear consistent with both historical experience and our understanding of the processes of dialectical interaction between technical and institutional change. Institutional change occurs:

- as a result of the efforts of economic units—households, firms, bureaus—to internalize the gains from economic activity and to externalize the costs of economic activity, and
- as a result of efforts by elements of the broader society to force economic units to internalize the costs and externalize the gains from economic activity.

The hypotheses suggest that during periods when new income flows are being generated, the innovating economic units are relatively successful in loosening social constraints to capture the gains from economic growth and in transferring the costs to other economic units and to the community or society

---

[2] Material summarized is detailed in Chapter 12 “Induced institutional change” and Chapter 13 “Induced innovation and the Green Revolution” of Binswanger and Ruttan (1977).

at large. In contrast during periods of economic stagnation or decline, the community in society is relatively effective in forcing innovation units to bear the costs of technical or institutional change and in transferring the gains to other economic units or to the community or society generally.

This process of technical and institutional change is dialectical rather than linear. Technical and institutional innovations that open new sources of growth — that generate low income streams — in traditional societies can be expected to induce further institutional innovations. The result is weak communal control over the allocation and use of resources. Conversely a period of rapid growth, followed by a period of relative decline or stagnation resulting from the exhaustion of resource endowments or of technological potential or from a failure of institutional innovation, can be expected to induce institutional innovations. In such a case, society gains greater social control over the allocation and use of resources. If this greater social control is used to mobilize the resources of society, and if those resources are directed to the generation of technical and institutional innovations that are consistent with the resource and cultural endowments of society, a new period of growth will be induced.

This induced-institutional-innovation hypothesis complements the theory of induced technical change. Together they provide us with the essential elements of an integrated theory of technical and institutional innovation that can both explain and predict the direction of technical and institutional change. The generality of the two hypotheses suggested can only be determined by testing them against a broad body of historical experience. Such a test should include periods of stagnation and decline as well as periods of growth. If the elements suggested here are fused into a more general theory, the models of induced technical and institutional innovation must be complemented by a more adequate understanding of technical and institutional stagnation and decline. Even in the absence of a more rigorous analytical institutional economics, the two hypotheses add to our power to interpret the institutional changes associated with the advances in agricultural technology of the last decade.

WHAT HAS BEEN ACCOMPLISHED?

Before exploring some of the implications of the changing institutional environment for agricultural development policy, it is useful to recall what the agricultural development efforts of the last two decades have, or have not, accomplished.

By the mid-1950's most of the countries of South and Southeast Asia had successfully surmounted the dislocation associated with World War II and the trauma of national rebirth as independent nations. The long-run trends in agricultural production had been reestablished and new programs to accelerate agricultural and rural development were being formulated.

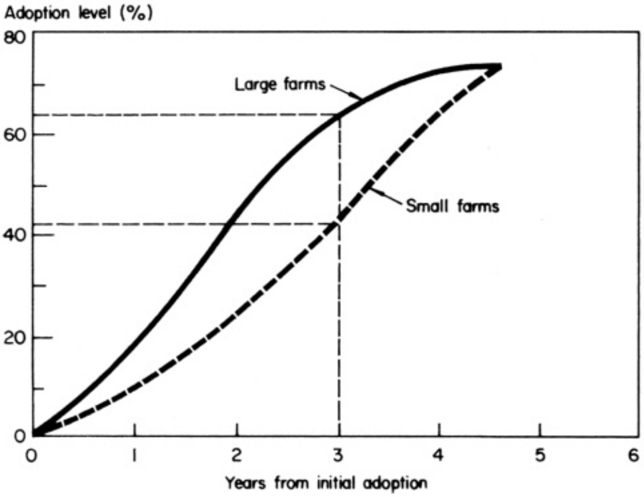
It is also useful to recall that two decades ago development thought and policy were still dominated by the Fisher-Clark structural transformation paradigm. The insights of W. Arthur Lewis (1954) that the strategic role of agriculture during the early stages of economic development was to provide a surplus that could be channeled into investment with the nonagricultural sector had not at that point in time been buttressed by the formal dual economy models proposed by Jorgenson (1961), and by Ranis and Fei (1961); nor had anyone been convinced that in order to hasten the process of structural transformation there should be as little leakage as possible into consumption in the rural areas (Hayami and Ruttan, 1971).

In the mid-1950's the institutional developments, which have since generated so much promise and debate, had not yet been conceived. In India the food crisis survey by the Ford Foundation, which led to the establishment of the Intensive Agricultural Districts Program, had not been initiated (Ford Foundation, 1959). The International Rice Research Institute was no more than a spark in the minds of F. F. Hill and George Harrar. The release of IR8 was a decade away. Neither the Comilla Academy nor the Taiwan Farmers' Association had yet emerged as models for rural development programs.

At the risk of extreme oversimplication I will condense the progress of agricultural and rural development in South and Southeast Asia during the past two decades in a series of five generalizations.

First, aggregate agricultural production has kept pace with rising rates of population growth. When ranked against population growth rates of about 3%/year, that must be counted as a major accomplishment. Progress has not been uniform. In Indonesia, Malaysia, Philippines, and Thailand food production has more than kept pace with population growth. Per capita food production levels have barely been maintained in much of South Asia, and in several countries of the region the rate of growth of agricultural production has fallen relative to the rate of growth of population. Few countries in the region can yet feel comfortable with their capacity to meet the demands for agricultural products required for economic development. Where the rate of growth in demand has exceeded the rate of growth in agricultural output, the dynamics of market processes imply that the rate in the nonagricultural sectors has been dampened, and the distribution of income in both urban and rural areas has worsened.

Second, the decade of the 1960's was for all practical purposes the decade of the closing of the agricultural land frontier for even the more favorably endowed countries of the region. Most of Asia is undergoing a transition from relying primarily on expansion in land area to increases in yield as a source of growth in agricultural (and food) production. The rice revolution has proceeded at a quieter pace than the wheat revolution. But in wide areas in both South and Southeast Asia expansion in area cultivated has virtually ceased and the momentum of output growth has been maintained by increase in yields. The transition is far from complete. In many areas of the region the less accessible and less productive lands — on the higher slopes of the mountains and in



1. Stylized model of HYV diffusion process.

the mangrove swamps along the coasts — are still being brought under cultivation at a pace and at a cost that will be difficult to sustain and which may be necessary to reverse.

Third, diffusion of the high yielding rice varieties has not been severely limited by differences in farm size or by differences in tenure arrangements (Binswanger and Ruttan, 1977). This is not to imply that differential rates of adoption by farm size and tenure have not been observed. What the available data seem to imply is that within relatively few years after introduction, lags in adoption rates due to size and tenure have typically disappeared. The stylized model of the diffusion process shown in Figure 1 describes a very large sample of the empirical literature on modern variety diffusion. And the evidence does not support frequent assertions that the modern varieties (MV) have been responsible for a worsening of income distribution in the rural areas.

The most valid criticism that can be leveled against the MV technology is that there has not been enough of it. In many areas there is still no MV technology capable of increasing yields by increments that are large enough to cover the additional input costs.

Fourth, investment in physical infrastructure remains a serious constraint on the achievement of higher yields from both traditional and high yielding crops. Two decades ago, most variation in yield among areas could be explained by differences in investment in land and water resource development (Hsieh and Ruttan, 1967). During the last two decades investment in physical infrastructure has, in most countries, been slow and erratic. If the potential opened up by the MV technology is to come anywhere close to being realized during the next two decades, it will require massive investment in physical infrastructure (irrigation, drainage, transportation, power) in rural areas (Okita and Takase, 1976).

Fifth, there are substantial areas in almost every country in Asia where the rural poor, primarily the landless, are worse off both relatively and absolutely than two decades ago. The available evidence seems to indicate that the widening of income differentials within rural communities is less serious than among communities and regions. Thus in India the number of kilograms of rice (or wheat) that a laborer can earn by weeding rice, or from other forms of daily labor has declined in most states but has risen sharply in Punjab-Haryana and in some wheat-growing areas of several other states (Baker, 1971; Jose, 1974). Studies conducted under the ILO Rural Employment Research Program indicate a declining real-wage rate in Bangladesh (Khan, 1976b) and in the Philippines (Khan, 1976a).

Scattered data from Indonesia also suggest a decline in the purchasing power of labor or the real wage rate in Central Java. My guess is that in South and Southeast Asia only Taiwan and, possibly, Malaysia have escaped from a situation in which the level of living of substantial numbers of the rural population continues to decline.

What I have depicted in this short review is a situation in which relatively heroic efforts over a period of two decades have barely enabled the agricultural sector of most developing societies in Asia to keep pace with demand. Yet one cannot help being impressed that compared to what they were a decade ago, the countries of South and Southeast Asia are characterized by vastly increased capacities to formulate the policies and implement the programs necessary to achieve national food production and rural development objectives.

AGRICULTURAL AND RURAL DEVELOPMENT POLICY

When considering the contribution of alternating economic policies, plans, and programs to progress in agricultural and rural development, it is well for comments to be relatively modest. The two largest countries in Asia—India and China—have followed radically different agricultural and rural development policies over the last two decades. Both have experienced periods of relative stagnation and growth. Yet in the same period, the two countries have achieved roughly comparable rates of growth in agriculture and production (Wong, 1975).

Do differences in ideology, policies, and programs make any difference? Clearly ideologues, intellectuals, and technicians—those responsible for formulating and implementing policies and programs—do not by their actions add directly to the amount of rice, or other agricultural commodities produced. Their actions do change the technical and institutional environment in which production is carried out by laborers, peasants, farmers, landlords, or plantation managers.

Any objective evaluation of the policy and program impact on the technical and institutional environment in which producers have been forced to function during the last two decades, both before and after the introduction of MV, would have to concede that producers have had to labor against a series of policies that were based on substantial misunderstanding of the production relationships in the rural economy and massive disregard of the welfare of food producers. In the absence of a detailed country by country policy review I will simply refer to a few examples.

The Philippines. In the Philippines the 1960's was the decade of the closing of the land frontier. During the 1950's 80% of the increase in agricultural output, which grew at an annual rate of 4.1%, was accounted for by area expansion. In contrast during the 1960's half of the 3.6% annual increase in agricultural output was accounted for by increase in yield per hectare. Investment in irrigation played a key role in the yield increase. The full potential of the MV technology could only be realized under conditions of effective irrigation.

Studies by Hayami and Kikuchi (this volume) have shown that the commitment of the Philippine government to irrigation has been both tentative and uncertain. New irrigation construction has repeatedly been initiated during the periods of rice shortage. Years of relatively good harvest have consistently been followed by sharp curtailment of irrigation investment. There was a rapid spurt of project initiation and project completion in the mid-l950's, stagnation in the early 1960's, a rapid spurt of new starts and completions in the late 1960's, stagnation in the early 1970's and a new burst of activity in the mid-1970's.

The same lack of sustained support has characterized other Philippine agricultural programs such as land reform, cooperative development, and rice price policy. Mangahas (1972) has shown, for example, that under the *old society* the most important variable influencing the price of rice was the timing of the national elections. Although there has been greater continuity in agricultural policy under the new society the fertilizer:rice price ratio became so unfavorable during the 1974–75 crop year that it weakened the effectiveness of the *Masagana 99* production campaign.

Indonesia. In Indonesia the government policies designed to increase rice production have centered on a series of rice production and procurement campaigns that have embittered the peasantry and weakened rural institutions. The most serious episodes were the *Bimas Gotong Royong* program that was initiated in 1968 and terminated in 1970 and the *Bulog* rice procurement program of 1973. The *Bimas Gotong Royong* program employed a combination of persuasion and coercion to induce peasant rice producers to adopt a rigidly specified package of practices that often failed to produce sufficient increase in rice production to offset the costs associated with the program. The Indonesian policy makers learned the lesson that farmers do not like to repay debts with stalk paddy at below market prices (Timmer, 1975).

The lesson was repeated three years later. In 1973 Indonesia reverted to a command approach to procure rice. During 1969–72 rice prices remained relatively stable in the face of a rising general price level. In spite of a 20% increase in rice production real incomes in rice-producing areas failed to rise. Because of poor harvests and inadequate imports, rice prices rose sharply in late 1972 and early 1973. To meet procurement targets, the newly established cooperatives (BUUD) were required to deliver quotas at the floor price that had been in effect since 1970. The producers resisted the program, in spite of strong efforts by some regional governors to reinforce Bulog procurement efforts with military support. By the time the program was discontinued in August 1973 the cooperatives had lost much of the little credibility they possessed.

In both Indonesian cases the short-run efforts to expand production (*Bimas*) and to meet procurement targets eroded the credibility of efforts designed to develop effective extension and marketing programs in rural areas.

India. In India there has been a continuing and vigorous debate as to whether public policy has on balance favored agricultural or consumer interests. What emerges from the debate is a picture of shifting commitments to rural development and agricultural commodity policy. Enforcement and administration of land tenure, food procurement, and land and water resource development policies have been erratic. Thus, the uncertainties of policy direction and program administration are added to the extreme environmental uncertainty that nature imposes on Indian agriculture.

The zonal price system, which had been introduced in support of grain procurement efforts, represented a continuing incentive to distortion in resource allocation (Mellor, 1968). Under the zonal pricing system market prices are depressed in surplus-producing states and are raised in deficit states by limiting the-interstate movement of grain. The burden of the zonal system falls on cultivators in the surplus states and on consumers in the deficit states. The gains go to consumers in the surplus states and producers in the deficit states. Thus, production is discouraged in those areas where it is most efficient. Although Indian administrative capacity has been able to operate the zonal price and levy system relatively successfully, the program has been a source of substantial unrest in surplus areas.

In spite of the natural and institutional environment in which he has been forced to operate, the Indian peasant has served the nation well since the early 1950's. Between 1951 and 1975 food grain production rose from 55.0 million tons to 115 million tons. During recent years an increasing share of the growth has come from yield increases rather than area expansion. It is not difficult to imagine the agricultural sector providing even more impressive support for India's development effort in an environment in which policy direction were more consistent and program administration more effective.

Pakistan. In the region Pakistan represents perhaps the most clear-cut example of failure to reinforce a favorable resource endowment and technological potential with the institutional innovations needed to achieve effective agricultural and rural development. During the early 1960's Pakistan achieved rapid growth in agricultural output and productivity through private-sector irrigation development. In the mid-1960's the favorable production trends were reinforced by the direct transfer of MV of wheat from Mexico and of rice from Taiwan and the Philippines. The Pakistan experience was widely cited as an example of successful development strategy. Since 1970 the trend in agriculture production has been severely hampered. The weakness in rural organization has become apparent and Pakistan is increasingly referred to as a development disaster.

Both the political institutions and the economic policies in Pakistan have been severely biased in favor of the large producer. The FAO reports that during the period of rapid growth in production during the mid- and late 1960's subsidies to mechanization, through favorable interest rates, remission of import duties, and foreign exchange licensing gave special advantages to the larger producers. The results to mechanization were reinforced by support prices that were well above world prices.

The policy adopted by Pakistan in the 1960's is described by Azam (1973) as one of concentration of the scarce public resources in the hands of those farmers who already possess an adequate resource base, giving them all the policy and institutional support, with a view to capturing the large agricultural surpluses that they generate. The attempt to organize rural political organization and rural services around the basic democracies, as a replacement for the largely defunct village *punchiat,* reinforced the concentration of political and economic resources in the hands of the larger farmers. The larger farmers have represented an effective lobby against the reform of land-tenure relationships and the initiation of effective rural development programs (Gotsch, 1972; Herring and Chaudry, 1974). One consequence of the policy was the failure to develop an institutional infrastructure capable of extending the development momentum that was initiated on the larger farms in the 1960's to the larger population of medium and small farmers. Haider and Khan (1976) report, for example, there is hardly any fertilizer sales depot, public or private, for each group of 150-200 villages.

Malaysia. The institutional environment for agricultural policy in Malaysia during the last several decades stands in sharp contrast to that in many other countries in the region. There has been a high degree of consistency in agricultural policy objectives and in the use of policy instruments. Well in excess of 50% of Malaysia's development budget has consistently been directed to agricultural and rural development objectives (MacAndrews, 1976).

The stated objective of rice policy in West Malaysia since the mid-1950's has been to achieve (almost) self-sufficiency. According to Goldman (1975) the self-sufficiency policy was seen as facilitating at least three major goals: reducing the risk attached to dependence on the world market; saving foreign exchange; and increasing the welfare of the Malay paddy farmers.

Three major instruments were employed to achieve those objectives: introduction and development of MV; land and water development to permit double-cropping; and a combination of import controls and market interventions to maintain the domestic price of rice at a premium typically falling 15-20% above the price that would have otherwise prevailed. That policy has produced a modest increase in yield per unit area, a sharp increase in the area that is double-cropped, and a rise in the self-sufficiency ratio from about 60% in the late 1950's to more than over 90% in the mid-1970's.

Rice is not the only agricultural commodity that has benefited from consistent policy and effective programming. The rubber and palm oil schemes of the Federal Land Development Authority represent another dramatic example of effective institutional capacity to implement effective agricultural and rural development objectives. The rice program has been criticized for its regressive price policy and the Federal Land Development Authority schemes for their relatively capital intensive approach. Yet both programs have developed impressive institutional capacity for program implementations in a field of activity where failure stories tend to dominate the success stories.

Thailand. Thailand has also followed a remarkably consistent policy with respect to rice policy during much of the period since World War II. Siamwalla (1975) argues that mobilization of government revenue, foreign exchange earnings, and consumer welfare have dominated farm income considerations in determining Thai rice policies. I would go one step further and argue that Thai rice policy has been run in the interests of the Thai military and civil bureaucracies.

The instruments used to complement these policies have included a complex of quantitative export controls and export taxes (the rice premium) to hold domestic prices 30–40% below export prices. Programs to expand production through irrigation, the development of MV, and more intensive use of modern inputs have not been strongly supported.

The major exception to this pattern of failure to provide economic incentives for expanded production occurred after the October 1973 revolution. The emergence of a more open political system put a greater weight on farmers' interests. Export constraints were used more cautiously to dampen price increases and the export premium was allowed to decline.

THE POLITICAL ENVIRONMENT FOR AGRICULTURAL POLICY

Which path of political development will most likely facilitate the continuing commitments to effective agricultural and rural development programs that will be necessary to meet the rapid increase in demand for food and the emerging demands for development in rural areas?

The regimes that have held office in much of South and Southeast Asia during most of the last two decades have typically been some combination of traditional rural elite-commercial-bureaucratic-military coalition. In some countries the commercial and rural elites have functioned as the junior partners (as in Indonesia and Thailand) and in other cases the military has played primarily a supporting rather than an active role (as in India and the Philippines). By and large these regimes have operated in a patron-client mode to assure the adherence of the several factions in the coalition. The comment that the element that distinguishes the political systems in the new states *seems not to be the intensity with which various regimes are attempting to bring their population into the political process but the skill with which they are maneuvering to keep them out of it* is increasingly characteristic of the political regimes of South and Southeast Asia. With relatively few exceptions neither peasant producers nor urban labor has represented important constituencies in these regimes. Nor have the regimes been able to provide the consistency in policy and the absence of corruption and exploitation that form the necessary environment for a vigorous industrial sector or for sustained progress in rural areas.

During the last decade the political instability or the economic stagnation, or both, that have been associated with such regimes had induced a shift toward greater centralization of authority within the coalition along the lines hypothesized in the induced-institutional-change model. Some observers have noted that new regimes seem to be demonstrating an enhanced capacity for program implementation (Mangahas, 1975). More critical observers have maintained that the new regimes are substituting the more dramatic forms of instability associated with the problem of succession for the short-run instability of governments based on shifting coalitions. In many respects they resemble the regimes which came to power in Japan, Germany, and Italy when the drive for modernization was frustrated by the economic stagnation of the 1930's.

In my judgment most of the countries of South and Southeast Asia, with the possible exception of Malaysia, have entered a period of relative stagnation in their political development. The new authoritarian regimes are so caught up in accumulating and husbanding political resources at the center that they are unable, or unwilling, to risk the consequences of the emergence of multiple centers of political power that would emerge with more effective organization for rural and urban development.

My observations with respect to agricultural and rural development policy in South and Southeast Asia lead me to place greater weight on the power of the political environment than on the quality of political will as a basis for effective policy. I conclude that effective organization, capable of reflecting the economic interests of the people living in rural areas, is a necessary condition for a political environment that will encourage the development programs and that can provide the continuity in program objectives and instruments necessary for the programs to become effective.

The contrast between Thailand and Malaysia, in both policy objectives and in capacity for program implementation, has been strongly conditioned by the differences in the effectiveness of political participation in rural areas in the two countries. Similarly the differences in the approaches that have been employed in India and Indonesia to mobilize food grain surpluses reflect the greater weight that peasant producers continue to carry in the political process in India relative to Indonesia.

Two alternative models of rural economic and political development seem capable of establishing the institutional conditions necessary for simultaneously meeting the production demands that a developing society places on its agricultural sector and the demands for development in rural areas that rural people have a right to expect in return for the contributions they make to national development. Both involve the decentralization or devolvement of political power and administrative authority.

One is a relatively open *reform* model. In this model an alliance among a modernizing industrial elite, urban workers, and the peasantry can neutralize the military-bureaucratic alliance. This pattern emerged in the Scandinavian countries in the last part of the 19th century and in Germany and Japan after World War II. This is also the model to which US aid policy was intellectually committed in Asia and Latin America during the postwar period, but which was consistently subverted whenever it appeared likely to be dominated by a center-left rather than a center-right coalition. This model has also been consistently opposed by the left intellectuals, who viewed the emergence of a political power in the hands of larger peasants — the *Kulaks* — as a barrier to more radical reform. An essential element in the model is the emergence of vigorous organization in rural areas representing the economic interests of peasant producers and, where they are numerically important, of landless workers.

The second model that offers the possibility of effective institutional development in rural areas is the Chinese model of *decentralized communism.* The fragmentary data on the development of rural areas in China still allow each visitor or scholar to combine a unique blend of casual empiricism and ideological perspective in interpreting developments in China. Nevertheless it is apparent that a skillful blend of central direction and decentralized decision making has proven reasonably effective in mobilizing human resources for the exploitation of the production potential of a traditional agricultural technology and in partitioning the growth dividends in a reasonably equitable manner among members of rural communities. The reports of the success of the Chinese model in rural development in the area of distribution have been sufficiently dramatic to overshadow the modest production achievements of the People's Republic (Wong, 1975; Ahn, 1975).

INFERENCES

Over the long run the pattern of political evolution in Asia will certainly tend toward replacement of the authoritarian patron-client regimes, which now dominate most countries, by regimes of greater complexity and sophistication in their capacity to achieve continuity and effectiveness in mobilization and use of political and economic resources. The induced innovation model outlined earlier in this paper suggests that in those areas where the problems of economic stagnation or regression have persisted the longest, and where the present regimes are most successful in frustrating the pressures for institutional reform, the successor regime will have to engage in radical institutional reorganization to mobilize the political and economic resources needed to reverse stagnation.

Those countries where the present authoritarian regime are more successful in responding to demands for political and economic reform by developing institutions capable of reflecting the economic and political aspirations of peasants, workers, and the smaller industrialists, while simultaneously maintaining rates of economic growth that permit the sharing of growth dividends, may emerge with political institutions that permit greater scope for individual than for group mobilizations of economic resources.

I see little hope that the next two decades will be much easier than the last two for most of the peasant producers and agricultural laborers in Asia. They will clearly have more productive technologies available to them. But it is not yet apparent whether the institutional reforms necessary to translate the new technical potential into rapid growth in agricultural production and into higher levels of living in rural areas will be made. I hope that the end of the century will see foundations that will ensure that the hardships that are inevitable for the next generation of rural people will not be wasted.

REFERENCES CITED

AHN, BYUNGJOAN. 1975. The political economy of the people's commune in China: changes and continuities. J. Asian Stud. 34:631–658.

AZAM, K. M. 1973. The future of the green revolution in West Pakistan: a choice of strategy. Int. J. Agrarian Affairs 5:402–429.

BAKER, E. A. 1971. Agricultural wages and production in India. MS. thesis, University of Illinois, USA. (unpubl.)

BINSWANGER, H. P., and V. W. RUTTAN. 1977. Induced innovation: technology, institutions, and development. The Johns Hopkins Press, Baltimore.

CROSSON, P. R. 1975. Institutional obstacles to expansion of world food production. Science 188:519–524.

FORD FOUNDATION. 1959. India's food crisis and steps to meet it. Government of India, Ministry of Food and Agriculture and Ministry of Community Development, New Delhi.

FRANKEL, F. 1971. India's green revolution: economic gains and political costs. Princeton University Press, Princeton, New Jersey.

GOLDMAN, R. H. 1975. Staple food self-sufficiency and the distributive impact of Malaysian rice policy. Food Res. Inst. Stud. 14:251–298.

GOTSCH, C. H. 1972. Technical change and the distribution of income in rural areas. Am. J. Agric. Econ. 54:326–341.

GRIFFIN, K. 1974. The political economy of agrarian change: an essay on the green revolution. Harvard University Press, Cambridge, Mass.

HAIDER, A. S., and D. ALI KHAN. 1976. Agricultural policy reconsidered. (mimeo.)

HAYAMI, Y., and V. W. RUTTAN. 1971. Agricultural development: an international perspective. The Johns Hopkins Press, Baltimore.

HERRING, R., and M. G. CHAUDRY. 1974. The 1972 land reforms and their economic implications: an economic analysis. Pak. Dev. Rev. 13:245–279.

HSIEH, S. C., and V. W. RUTTAN. 1967. Environmental, technological, and institutional factors in the growth of rice production: Philippines, Thailand, and Taiwan. Food Res. Inst. Stud. 7(3):307–341.

INTERNATIONAL RICE RESEARCH INSTITUTE (IRRI). 1975. Changes in rice farming in selected areas of Asia. Los Baños, Philippines. 377 p.

JORGENSON, D. W. 1961. The development of a dual economy. Econ. J. 71:309–334.

JOSE, A. V. 1974. Trends in real wages of agricultural laborers. Econ. Pol. Weekly:A25–30.

KHAN, A. R. 1976a. Growth and inequality in the rural Philippines. April, WEP 10–6/WP-4. International Labor Office, Geneva.

KHAN, A. R. 1976b. Poverty and inequality in rural Bangladesh. March, WEP 10–6/WP1. International Labor Office, Geneva.

KIKUCHI, M., and Y. HAYAMI. 1978. New rice technology and national irrigation development policy. Pages 315–332 *in* International Rice Research Institute. Economic consequences of the new rice technology. Los Baños, Philippines.

LEWIS, W. A. 1954. Economic development with unlimited supply of labor. Manchester Sch. Econ. Soc. Stud. 22:139–191.

MACANDREWS. 1976. Mobility and modernization: a study of the Malaysian federal land development authority and its role in modernizing the rural Malay. Ph. D. thesis, Massachusetts Institute of Technology. (unpubl.)

MANGAHAS, M. 1972. Philippine rice policy reconsidered in terms of urban bias. Philipp. Rev. Bus. Econ. 9:57–77.

MANGAHAS, M. 1975. The political economy of rice in the New Society. Food Res. Inst. Stud. 14(3):295–309.

MELLOR, J. W. 1968. The function of agricultural prices in economic development. Indian J. Agric. Econ. 23:23–37.

OKITA, S., and K. TAKASE. 1976. Doubling rice production in Asia. The Overseas Economic Cooperation Fund, Tokyo. (mimeo.)

RANIS, G., and J.C. H. FEI. 1961. A theory of economic development. Am. Econ. Rev. 51:533–565.

RUTTAN, V. W. 1975. Integrated rural development programs: a skeptical perspective. Int. Dev. Rev. 17(4):9–16.

TIMMER, C. P. 1975. The political economy of rice in Asia: Indonesia. Food Res. Inst. Stud. 14(3):196–231.

WONG, J. 1975. On the implications of China's agricultural development experience for development countries in Asia. University of Singapore Department of Economics and Statistics, Singapore. (mimeo.)

COMMENTS ON NEW RICE TECHNOLOGY AND AGRICULTURAL DEVELOPMENT POLICY

A. VALDEZ

THE READER SHOULD NOT be misled by the title of Ruttan's paper, which refers to the new rice technology. The paper is not specific to rice.

While tracing and interpreting agricultural development in Asia during the last 20 years, Dr. Vernon Ruttan sketches the basic elements of the theory of induced institutional innovation. He suggests that his theory, combined with the theory of induced technical change (Hayami and Ruttan, 1971), provides the essential elements of an integrated theory of technical and institutional innovation that explains and predicts the direction of technical and institutional change. The key issue, then, is to understand the dialectic interaction between technical and institutional change necessary to achieve agricultural development.

Ruttan's review leads him to two broad hypotheses that reflect a negative correlation between growth and society's control over the allocation of resources. Both growth and stagnation induce institutional changes, but with constrasting impact on the degree of society's control over resource allocation. The critical agents of change are Ruttan's *innovating economic units* — the households, firms, and bureaus.

Ruttan concludes with the simple and intuitively appealing message that given the need for institutional change, the pressures for change tend to be more effective than the desire to change. Stated in another way, the pressure created by an effective organization that is capable of reflecting the economic interests of people living in rural areas will succeed in mobilizing political participation. Emerging, vigorous farmer groups play a fundamental role because they encourage institutions to act with continuity in program objectives and instruments. Ruttan concludes that two alternative models of political development are capable of establishing the preconditions for institutional change: the reform model, and the Chinese model of decentralized communism.

Ruttan opened an area that, I believe, will become an important and fertile field for thought and research. Although at this stage his theory is not yet fully developed, it provides insight and offers opportunity for further work. The

International Food Policy Research Institute, Washington, D.C., USA.

specification of the causality of relationships, the dynamics or time frame, and the implication for action will, I presume, elicit follow-up efforts. The empirical testing that lies ahead also looks extraordinarily difficult.

I commend the author for using the tools of formal economic analysis to explain an alternative path of institutional change, and for stressing the importance of the accumulated value of incremental changes in institutions rather than stressing only the more dramatic theme of revolutionary change.

In Ruttan's postulated inverse relationship between income growth and decentralization, it is not clear to me whether the implication is that at low income-growth levels there is perhaps an inevitably high degree of control over resource allocation, or whether this is a generalization based on historic reality. Also, it is not clearly understood how it would apply to some middle-income countries in Eastern Europe and to the USSR, which have a relatively high degree of centralization and simultaneously a respectable rate of income growth, even though one must recognize that agriculture is not exactly a success story in many socialist countries. Perhaps a more specific description of what kinds of institutions and what forms of social control Ruttan has in mind would have clarified these points.

Broadly speaking, I share Ruttan's belief in the endogenous character of institutions and policies in the long run, but I argue that some of the necessary institutional changes cannot be treated as endogenous variables. In his book with Hayami (Hayami and Ruttan, 1971), Ruttan effectively used the theory of factor proportions to demonstrate, in the case of Japan, how the government corrected the *natural* differential disadvantage of traditional small farmers[1] by investment in services, infrastructure and research, along a land-saving, labor-intensive expansion path. Institutional change in this context seems susceptible to analysis as an endogenous factor.

There are other types of institutional factors — in particular, the structures that result from political pressures — which I believe should be treated as exogenous constraints, at least for a reasonable long-term planning horizon. The brief histories of agricultural policies in several countries seem to suggest that Ruttan is thinking about rather short cycles.

Contrary to what has often occurred in developed countries, forces in developing countries frequently operate in favor of the nonagricultural sector. The large number of electors in rural areas would dominate the urban pressure groups if the governments were democratic. That is not the case in many developing countries, where governments can continue an erratic agricultural policy without clear opposition to a disregard for farmers' welfare. This is not to say that pressure groups are ignored because power is concentrated, but with increasing urbanization and the existence of inflation, the urban pressures become more politically visible. The conflict between sectors is aggravated generally to the detriment of the rural sector.

---

[1] A natural differential disadvantage in the sense that relative to the modern sector, small traditional farmers usually face differential access to factor and product markets and public services.

In my opinion, the Ruttan theory does not clarify how and when the political system extracts itself from stagnation. The model helps to anticipate the chances for a better future for the rural sector (prior institutional change is one of the three sources of growth). The model also indicates that *if* greater control is used to mobilize resources a new period of growth will be induced, but it does not explain how. Nor does it specify which catalyst within the political system will eliminate the sort of stagnation that prevails in the countries described by Ruttan.

Stagnation does not induce institutional development; in fact, it probably makes an authoritarian structure easier to impose. Authoritarian regimes can use and, in fact, have, in a few instances, used their power to try to raise the standard of living of the rural poor; but this is a roulette game — who chooses such an enlightened ruler?

Ruttan does not include the external environment as a potentially influential element in shaping domestic institutions, except for a reference to *colonial or other external intervention* that results in stagnation. It would be interesting to examine the relationship between accessibility to foreign trade and institutional change across time. I believe that, consequent with Ruttan's model, more openness to external trade would help to decentralize a country, and hence increase its growth potential.

After reading Ruttan's five generalizations about Asian agricultural development, one cannot help being concerned about its progress. With the possible exception of Malaysia, all the countries described seem to have peasant producers and landless laborers that have not represented an influential constituency in the political regimes. Furthermore, none of the cases corresponds to the reform model or Chinese model of decentralized communism, the two alternative models for rural economic and political development presented as most likely to establish the institutional conditions necessary for a workable agricultural development strategy. As I interpret history in Latin America, the reform model does not necessarily appear to be a stable solution, but rather a step in the cycle of quasi-democratic reformism followed by authoritarian militarism and reformism again. Decentralised communism might be stable, at least in the way in which it is perceived from the outside.

One of the more disturbing and worrisome of Ruttan's five generalizations is the evidence of increasing immiserization of substantial elements of the rural population in poor countries in Asia. If true, that strengthens the belief that in the long run perhaps the most crucial institutional changes-are those that will affect population growth. Ruttan and other conference participants claim that today's rural poor are worse off than they were a few decades ago, but I am concerned about the extent to which this assertion is based on a rather narrow concept of income, such as money wages. I presume that family income estimates have at least been adjusted for factors such as increased family participation in the labor force, and that real income estimates have been adjusted for changes in access to services provided by the public sector, such as health and education. These factors could affect the ratio between money wages and real family income.

REFERENCES CITED

HAYAMI, Y., and V. W. RUTTAN. 1971. Agricultural development: an international perspective. Johns Hopkins University Press, Baltimore.

RUTTAN, V. W. The new rice technology and agricultural development policy. Pages 367–381 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

General comments

C. H. HANUMANTHA RAO

THE SEVERAL PAPERS presented at this Conference provide a wealth of data based on experience, particularly in the Philippines. One is impressed by the enormous amount of work of the IRRI economists. One wonders how such a mass of work could be accomplished. The answer seems to be the availability of useful data at the IRRI as well as the comparative freedom that the undoubtedly competent IRRI economists enjoy from the distractions of the rest of the world. The IRRI studies, which throw light on various aspects of the consequences of the new rice technology, are bound to interest readers for a long time to come and should stimulate further research and thinking on a subject of considerable importance to the peoples of South and Southeast Asia.

I discuss what I consider to be the major points emerging from conference papers and discussions and identify what I consider as major gaps in the research done. Such an approach, I hope, will provide a perspective for future lines of work.

One is struck by the enormous difference between the economically attainable potential yields of rice and its actual yields. Herdt and Wickham show the gap as almost three-fourths of the economically attainable potential. They feel that about three-fourths of the gap is realizable. Their analysis suggests three factors as equally important in realizing the potential: irrigation and flood control, factors such as credit and interest rates that bear on risk, and research to evolve technologies that can overcome environmental constraints. The Herdt and Wickham analysis suggests the need for

- investment in infrastructure such as the provision of new irrigation - particularly for the dry-season crop — and flood control,
- reform and development of institutions providing credit and extension services, and
- research to develop technologies to fit local conditions and unfavorable environments.

All provide equally important challenges for governments, scientists, and economists.

Institute of Economic Growth, University of Delhi, New Delhi, India.

INVESTMENT IN INFRASTRUCTURE

I find the importance of investments in infrastructure such as irrigation and flood control the most significant finding of these studies. A number of papers bring that out. Wickham and Barker note the high complementarity between irrigation and modern varieties (MV). They show that the yield performance is substantially better than that of traditional varieties (TV) at higher nitrogen levels with irrigation, particularly irrigation with high dependability. The shift from TV to MV makes the benefits attributable to irrigation 50% higher where there is efficient use of fertilizer and water.

Kikuchi and Hayami show that the profitability of investment in irrigation has increased recently and has induced government investment in irrigation systems. That has happened despite the increase in cost, or decreasing profitability trends, resulting from the completion of less costly projects. The rise in profitability of investment in irrigation is explained by the steep decline in per capita arable area, the increase in the marginal cost of opening new land, and the diffusion of the seed-fertilizer technology since the late 1960's. To these is added the fact that the available irrigated land is scarce and has been used intensively with the application of MV and fertilizers, which increases the rate of return on further investment in irrigation.

The increase in the international price of rice has also raised the profitability of investment in irrigation as a means of attaining food self-sufficiency. That is brought out by Barker, Bennagen, and Hayami.

David and Barker show that the demand for fertilizers is highly sensitive to price changes particularly in countries with high levels of fertilizer use, but Desai points out that the price elasticity may have been overestimated owing to the noninclusion of the diffusion factor representing the movement along the production function. Nevertheless, a significant response of fertilizer demand to changes in price is quite likely when a complementary input like irrigation is limited and the application of MV and fertilizers is concentrated in limited areas where the necessary institutional infrastructure is available and where, therefore, the product curves flatten out.

On the other hand, the yield response to price of rice or to the rice-fertilizer price ratio has increased as a result of the introduction of MV and the development of irrigation systems, which has the effect of making the application of fertilizers and related inputs more responsive. This result implies that the development of irrigation creates the necessary condition for the effective operation of policy variables regarding the input supply prices. This is clear from the study by Sison, Somsak, and Hayami on structural changes in rice supply relations.

The rise in the rate of return to investment in irrigation, the high sensitivity of fertilizer consumption to prices, and the rise in the output response to prices derive from the complementarity between irrigation on one hand, and the MV and fertilizers on the other. Thus a high sensitivity of fertilizer consumption to price may reflect either the insufficiency of investment in irrigation, or a misallocation of fertilizers from the social point of view (i.e. concentration in limited areas), or both. In either case, the implication would be to increase investments in irrigation and other related infrastructure, and to improve the allocation of resources through institutional changes. Mere reduction in the relative price of fertilizers so as to increase their consumption will only accentuate the misallocation of resources by further depressing the production per unit of fertilizer.

CONSTRAINTS

The papers also suggest the need to effect a change in the research focus toward overcoming environmental constraints. As mentioned earlier, the analysis of the constraints to the realization of the potential of new rice technology suggests that environmental constraints are a major factor and account for at least one-third of the gap between the economically attainable potential and actual yields.

More research is therefore needed to evolve flood-resistant and pest-resistant rice varieties and technologies, and cropping patterns that maximize income and employment per hectare per year. A visit to IRRI experiments on the first day of the conference was an eye-opener in this respect. The focus on research was on methods to overcome the environmental as well as capital constraints. Such research is bound to benefit regions poorly endowed in respect to climate and physical factors as well as capital resources. I venture the opinion that the biological scientists are now ahead of the economists in responding to the needs of the unfavorably placed regions and classes.

It has been argued at this conference that the payoffs to investments in such research may be less attractive than those to efforts toward the development of new technology for favorably placed regions. Such hypothesis needs to be tested. It is also suggested that investments in physical infrastructure, wherever it can be built up, would be more rewarding than investment in research to overcome environmental constraints arising largely from an inadequate infrastructure. All these issues need further examination.

There is no evidence to date to rule out as unprofitable the investments in research to overcome environmental constraints. The available evidence suggests that it has been profitable to evolve and adapt technologies to suit different environments and resource situations. The study on rice research by Evenson and Flores reveals extraordinarily high returns from investment and indicate that too little investment has been undertaken in the past, particularly by national governments.

EMPLOYMENT IMPACT

The impact of the new rice technology on employment and distribution of income has not been brought out clearly in the conference papers. The only exception is the analysis by Hayami and Herdt on the favorable distributional effects via lowering the output price. The new technology, insofar as it brings down the relative price of food, improves the real income of the urban and rural wage earners and small farmers who spend most of their income on food, whereas the real incomes of the rich farmers come down because of the decline in food prices. However, Hayami and Herdt point out that a real danger would arise if new technology is monopolized by a small number of large producers and does not cause a significant shift in the aggregate supply schedule. In such a case, the large farmers could capture the whole gain of technological progress by increasing output without a resultant decline in prices.

I have pointed out elsewhere (Rao, 1975) that this is exactly what happened in India because of the deficiency of public investment in infrastructure. The indivisible factor, such as irrigation, as Hayami and Herdt point out, may be too large for purchase by individual small farmers.

The relationship between farm size and employment per hectare was not analyzed systematically. Also, there is no investigation into the patterns of regional migration of labor under the impact of new technology, and the effect of technology on the aggregate employment in the developed and depressed regions together.

The discussion on the employment effects of new technology, particularly tractorization, has revealed certain methodological deficiencies. The typical approach to this question is to compare farms adopting new technology with those not adopting and then examine the differences in employment. Correction is, of course, made for the differences in employment arising from variation in the complementary inputs. It should not be surprising that many of the studies reveal that the impact of tractorization on employment is positive. Such an approach evades the basic question of capital:labor ratio or the choice of techniques.

In the Punjab, for instance, the output of agricultural commodities as a whole has been growing by about 8% a year. In the absence of mechanization, such an output would have required a labor force with a growth rate of about 6% a year, on the assumption that the labor coefficient is .75. However, the labor force within the Punjab may not have grown by more than 2% a year. The gap of about 4% has been filled partly by the migration of labor from regions such as eastern Utta Pradesh and partly by mechanization. Wage rates in the Punjab have been rising despite in-migration and the increase in employment because of the economic and psychological costs associated with migration both for the in-migrant labor as well as for the farmers employing them. Mechanization on a large scale has, therefore, proved profitable. The fact that mechanization has been associated with significant increase in employment in the Punjab should not detract from the fact that the aggregate employment for the agricultural sector as a whole would have been greater if the capital:labor ratio were smaller. That could have been made possible with a more balanced regional development of agriculture, through public infrastructural investments in the lagging regions, and through appropriate input price policies. My study (Rao, 1975) shows that the labor coefficient was highest for small-scale cultivation; it was followed in descending order by that for cropping intensity, irrigation, and MV with fertilizers. Tractorization had the lowest labor coefficient, which did not appear to be significantly different from zero.

The conference papers discussed were not concerned with such institutional factors bearing on employment and income distribution as the supply of credit, interest rates, tenancy, and farm size. Labor absorption under different techniques, such as extension of area, irrigation, fertilizers, cropping intensity, and tractorization, did not receive adequate attention either.

INGREDIENTS OF UNDERDEVELOPMENT

The conference papers and the experience with the new rice technology clearly underscore the importance of three common ingredients of underdevelopment — low level of investment, traditional technology, and outmoded institutions.

The growth models of the 1950’s and early 1960's emphasized investment with institutional changes in the agricultural sector as a strategy for growth in an underdeveloped economy.

Experience has shown a large degree of complementarity between growth and distribution in the developing economies. Despite the introduction of new technology, agricultural growth has been slow because of a narrow base caused by insufficient investment, and by outmoded institutions. Stepping up public investment and institutional changes, including those in administration and organization, would not only promote growth but improve the distribution of income as between different regions and classes of farmers.

In India, for example, public investment in the exploitation of surface water for irrigation would reduce regional disparities in income, and benefit all classes of farmers in proportion to the area they hold. Public investment in the exploitation of groundwater in the Indo-Gangetic plains would benefit millions of small and marginal farmers who cannot exploit the water on their own because of inadequate resources.

Failure of public investment in the infrastructure, insofar as it results in slow growth, will cause a rise in output prices. Such a rise in prices may stimulate private investment in factors including irrigation. However, such a strategy would lead to poor results in terms of both growth and distribution. Growth is bound to be slow because the scope as well as capacity for private investment in agriculture is limited. Only a few affluent farmers can undertake such investment. The experience in India indicates that distribution of public sources of irrigation is less unequal than that of private sources.

Because the conference has not faced squarely the question of factor-use bias in technology, the distributional question has been neglected. Hayami and Ruttan (1971) pointed out how agricultural techniques tend to be adapted to the factor endowments and factor prices of each country, and emphasized the need for land-augmenting techniques for the countries of South and Southeast

Asia. I have argued (Rao, 1976) that techniques that increase output per hectare with the intensive application of fertilizers along with new seed are not necessarily best suited to the factor endowments of those economies. The South and Southeast Asian economies need land-augmenting techniques that maximize the use of their abundant factor — labor — and economize on the use of scarce resources — capital. That may involve the use of techniques such as irrigation and multiple cropping to maximize output per hectare per year by maximizing employment per hectare per year. The focus so far has been to use new seeds and fertilizers to maximize output per hectare per crop.

RESHAPING OF INSTITUTIONS

Apart from the evolution of techniques, the reshaping of the existing inititutions affecting land use and credit may be essential for meeting the objectives of growth and improved distribution. Credit institutions, administrative organization for supply of inputs, farm tenancy, and farm size impinging on land-use patterns are important in this context. I agree with Ruttan that institutional changes to make the most effective use of the labor resource, which is an abundant factor in these economies, should receive the greatest attention in the next decade. This objective can be achieved only through institutional changes involving greater supply of capital resources to the small farmers (who have more labor resources) and by evolving techniques that maximize the employment of labor per hectare per year. Farm size must be appropriate in terms of maximum labor absorption. Mechanization also belongs to this area. Ruttan's proposition has to be translated concretely into such policies and strategies.

It has been argued that IRRI is not the appropriate place for economic research bearing on such institutional questions. I believe, however, that it is precisely in a place like IRRI that such research becomes essential, because of the need for interaction between the biological scientists and economists for evolving technologies suited not only to specific environments but also to specific resource situations. IRRI scientists appear to be already on the way to doing good work bearing on the distributional aspects. Such work by the economists should further be strengthened through appropriate economic analysis of the interaction between the factor-use bias of technology and the institutional factors that bear on the resources and resource prices. Incidentally, the authors quoting the Indian examples seem to ignore the enormous amount of empirical evidence on the distributional aspects of new seeds in Indian agriculture.

Economists have done several studies recently to show how farmers of the developing economies are *rational* in the sense that they respond to the changes in the relative prices of crops by reallocating their resources. Kikuchi and Hayami show how even governments are *rational* insofar as their investment decisions respond to changes in prices. They, however, point out that this apparent *rationality* may be traceable to the basic irrationality represented by the deficiency in the allocation of government resources earlier, which has made public investment in irrigation highly profitable. It is clear now that an apparently *rational* behavior, whether by government or peasants, in the cobweb fashion, is not inherently rational. Unfortunately, experience in the last two decades shows that economists too tend to be rational like peasants and governments, by responding to changing prices or current crises.

Insensitivity of economic analysis to changing needs would render economists irrelevant, but it must be recognized that the given situations are often the result of lack of perception, imagination, and forethought in the past, whether in scientific analysis or in public decision making. Economists as social scientists can be more perceptive and imaginative than the short-run income-maximizing farmers or the security-conscious public decision makers.

REFERENCES CITED

BARKER, R., E. BENNAGEN, and Y. HAYAMI. 1978. New rice technology and policy alternatives for food self-sufficiency. Pages 337–361 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

DAVID, C. C., and R. BARKER. 1978. Modern rice varieties and fertilizer consumption. Pages 175–211 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

EVENSON, R., and P. M. FLORES. 1978. Social returns to rice research. Pages 243–265 in International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

HAYAMI, Y., and R. W. HERDT. 1978. Market price effects of new rice technology on income distribution. Pages 283–302 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

HAYAMI, Y., and V. W. RUTTAN. 1971. Agricultural development: an international perspective. Johns Hopkins. 367 p.

HERDT, R. W., and T. H. WICKHAM. 1978. Exploring the gap between potential and actual rice yields: the Philippine case. Pages 3–24 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

KIKUCHI, M., and Y. HAYAMI. 1978. New rice technology and national irrigation development policy. Pages 315–332 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

RAO, C. H. HANUMANTHA. 1975. Technological change and the distribution of gains in Indian agriculture. Macmillan, New Delhi. 249 p.

RAO, C. H. HANUMANTHA. 1976. Factor endowments, technology and farm employment: comparison of East Uttar Pradesh with West Uttar Pradesh and Punjab. Econ. Pol. Weekly Rev. Agric. (September 25) 11(39):A-117, A-119, A-123.

RUTTAN, V. W. 1978. New rice technology and agricultural development policy. Pages 367–381 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

SISON, J.F., S. PRAKONGTANAPAN, and Y. HAYAMI. 1978. Structural changes in rice supply relations: Philippines and Thailand. Pages 31–48 *in* International Rice Research

Institute. Economic consequences of new rice technology. Los Baños, Philippines.

WICKHAM, T. H., R. BARKER, and M. W. ROSEGRANT. 1978. Complementarities among irrigation, fertilizer, and modern rice varieties. Pages 221–232 *in* International Rice Research Institute. Economic consequences of new rice technology. Los Baños, Philippines.

General comments

G. RANIS

ONE OF THE CONSEQUENCES of this conference has been that the complexities of the problems before us have become a lot more evident, while the hopes for *answers* seem to have somewhat receded. It is, of course, not unusual for conferences to end with an agenda for future research that is longer than the list of conclusions. But because this particular conference was presumably called by physical scientists to ask the social scientists to provide some illumination on some troubling aspects of the new rice technology, there must have been temptation to try to respond. That the temptation was resisted, and that the participants at least are generally satisfied with the emergence of a better set of questions, are noteworthy. The management of IRRI is to be especially congratulated, not only for organizing such a conference — the first of its kind, I believe, in the *system* — but also for its long-demonstrated recognition that it is on a journey of many steps, best taken jointly, and with maximum interaction along the way.

A lot of papers and materials were thrown at us in the space of a few days — perhaps too much for optimum digestion and discussion — and that is the only negative note on an otherwise well-planned conference. But the frustration many participants felt, I know, was that no matter how hard the conference tried, the problem of where to place the boundaries of inquiry, in order to find the way between the Scylla of irrelevant microlevel precision and the Charybdis of relevant macrolevel generalities, continued to raise its ugly — or beautiful — head. It soon became clear, for example, that it was difficult to adequately discuss the socioeconomic impacts of the new rice technology without reference to nonrice agriculture, nonagricultural rural activities, and the overall growth path and export orientation of the total economy. Even the appropriateness of the Conference title became suspect early on, because it is clearly difficult to disentangle the consequences of the new technology on rice pure and simple from the consequences of such other changes simultaneously occurring as in the terms of trade, to cite one example. But this also is not surprising, certainly not to the economist. Pragmatic compromises have to be made — and

Yale University, New Haven, Connecticut, USA, and Universidad de los Andes, Colombia.

were made — but perhaps, from this observer's point of view, too many were in favor of a too restricted approach to the issue at hand.

With these ruminations as prologue, I am foolhardy enough to record what I perceive to be some of the points of substantial agreement that emerged from the papers and the discussion.

CONSENSUS POINTS

First, and perhaps surprising only to the relatively uninitiated general economists, is the realization that the scientific research effort, both international and national, is not something easily turned off tomorrow leaving the world at a new and higher plateau of production potential ever after; but rather, that minimum continuing efforts will be required merely to avoid losing ground, and substantial effort will be needed to continue to sustain any reasonable rate of technology change in the years ahead. Quite aside from the economic consequences of new technology, the new technology itself probably requires the world's agricultural scientists to run ever faster in order to stand still — to prevent erosion of past gains with new varieties by blast, viruses, pests, weeds, and lower drought tolerance.

I am much impressed with the brown planthopper and all his relatives, and the fact that *denovation* following innovation is possible in agriculture while unlikely (except in unusual circumstances like in the Dark Ages in Western Europe) in nonagricultural activities. This, perhaps is the reason the term high yielding varieties has gradually given way to *modern varieties* — and that there was the occasional hint that the scientific community may have a *bear by its tail, and cannot afford to let go.*

Second, given such a forever shifting (in both directions) maximum output potential, a good deal of time was spent discussing the meaning and usefulness of the economically-recoverable-gap concept. A good deal of effort has apparently gone into assessing variation in the maximum output potential depending on variations in the *rice environment,* but less on how variations in the *economic environment* affect the profit-maximizing output position, relevant to each of the five maximum physical output environments. To obtain a real indication of the output forgone (quite aside from alternative distributional and employment outcomes), the study of some minimal cross-sectional variation in the economic as well as the physical attributes of the environment seems necessary.

Third, there seemed to be consensus that mechanization per se tends to displace family labor, and the introduction of the *modern* varieties per se tends to absorb more hired labor — mainly via the multiple cropping made possible. How much of the first — and of what kind — is necessary for the second, and how much is an independent phenomenon induced by independent government action clearly remain a controversial subject. The timing element is obviously critical, and the need to differentiate between land preparation, harvesting, and irrigation (pumping) activities is essential. The only point of agreement reached here was that the greater divisibility of the biological and fertilizer type of technology change requires less institutional modifications, which are often most difficult to achieve. Unlocking the *secrets of nature* may not be as easy as had once been supposed, but these difficulties pale in comparison with those of man and the basic motivation that leads to *consensus action.*

Fourth, there was considerable agreement on the difficulty of overestimating the importance of the trade-off, in the farmer's mind, between the higher expected value of output associated with the modem varieties and the higher variance or risk involved. All too few of the models pay sufficient attention to the different shapes of personal risk and return preferences at low levels of income. The uncertainty elements influencing adoption rates include not only such production-specific features as increased risk of pest infestation and nonavailability of water, but also — and less well understood — the possible unavailability of timely credit to purchase the additional inputs required.

Fifth, while conference participants, like most economists today, showed themselves a little weary of the parrot refrain of *getting relative prices right,* the quantitative implications of not doing so for output, for employment, and, most of all, for distribution remained much neglected. Such implications include the difference it may make with respect to the possible loss, or potential recapture, of a *natural* comparative advantage for a particular region or for the system as a whole, in the open economy case.

Finally, on a quite different, political-economy plane, there was agreement on the importance of the mutual interactions between growth, technology, and institutional change — but there was doubt on how to tackle them satisfactorily. Some saw the less than desirable employment and distributional fallout as part of a conspiracy by vested interests that are manipulating the economy to their advantage. Others, myself included, were not so sure that it is a question of a minority of wicked knaves knowing better than the majority of simple fools how the system functions, but felt rather that basic behavioral relationships are generally still poorly understood and that the elite can be persuaded to opt for change if they can be convinced that their ox need not be gored, i.e., there is no *necessary* conflict between their profits and a restructuring of the way in which output is generated. When there is doubt, change will be resisted, more so when there are enough natural resources to keep fueling the old system and put off the day of reckoning.

It is undoubtedly my good fortune that I did not have to submit any of these *consensus points* to a vote and, more important, that I am not charged with being all-inclusive, i.e., trying to touch all the bases. Thus, I openly pursue my own prejudices. Moreover, I expect to exercise the same privilege with respect to the ruminations that follow on what is likely to be the most productive focus for future research in this general area. I resisted, in other words, the temptation to list several score additional research topics, and restricted myself to those items which, based on my experience (and biases), warrant more attention.

FOCUS OF FUTURE RESEARCH

Who should do the additional research work? Certainly not the small economics staff at IRRI, which, one would judge, is overextended now. Rather, the insertion of the IRRI initiative within a much wider framework of national and international social science research is suggested. International institutions that come to mind include the ILO's World Employment hogramme — which has sadly neglected the agricultural sector — the World Bank, and the Council for Asian Manpower Studies. More important, as in the case of IRRI's scientific contributions, is the establishment of more regular contact between national research institutes in the region. Any research map extends far beyond IRRI's reach, even if such an *outreach* program were being financially and otherwise encouraged. But it would be a shame if the imaginative initiative already taken were not pursued and IRRI's unique catalytic potential not realized.

I believe that the role of IRRI within such a broader research network should be focused more heavily on cross-country and cross-regional comparisons, rather than continuing with a heavy Laguna emphasis. IRRI, after all, is an international organization, not a Philippine and certainly not a Laguna institution. There is much to be learned by comparing Laguna with more typical areas in Luzon and by bringing to bear much more material than in the past from the other rice-producing countries of Asia represented at the Conference.

An increase in the comparative dimension of the total research portfolio, carried on in part — but mostly only encouraged — by IRRI would have a high payoff in increasing understanding of basic behavior patterns. I would especially enter a plea to include such relative *success* cases — in terms of various dimensions of the economic consequences of the new technology — as mainland China and Taiwan. The extent to which those two systems, sharply contrasting in organizational and institutional structure, have apparently solved some of the problems of employment and distribution in the context of agricultural growth, the extent to which they are *special cases,* as well as the extent to which at least portions of their experience — aggregative or micro — may be relevant to the other rice economies of Asia should be highly illuminating for the problems at hand.

Central, of course, to the whole problem before us is the extent of complementarity achievable between output growth, employment, and distribution of income under the impact of the new technology — including some quantitative notions of the size of trade-offs, if they do exist. It is necessary to concentrate on how output growth is itself generated in the first place, especially if it is agreed, as I believe, that most Asian mixed economies will find it organizationally and fiscally difficult to *pick up* the unemployed, or to redistribute income *after the fact* — after the production dust has settled.

Specifically, this requires inquiry beyond assessing the net consequences of the additional employment made possible by the labor-using consequences of the new technology proper and the additional labor displacement occasioned by at least that part of the new mechanization required to render the new technology feasible. It requires an examination at the same time of at least the possibilities for secondary, higher valued crops, which may be made more or less possible by the new rice technology. And ideally, it requires an examination of the employment and distributional consequences of nonagricultural rural growth complementary to agriculture in either the input-output or market sense. It is, for example, of great analytical interest that it was the poorest agricultural families — the landless workers and smallest holders — who participated relatively more fully in the mushroom and asparagus boom as well as in the rapidly growing rural industries and services in Taiwan.

In the study of the level and pattern of rural income distribution over time, the initial distribution of assets that were affected by land reform and the way in which — and by whom — additional output was generated suggest questions of great political as well as economic importance.

At a minimum, much more of the research carried out in the future should attempt to disaggregate performance — with respect to the generation of rice, agricultural, and nonagricultural income and employment — by size of holdings or total family income level. While this is not the place to go into it in detail, the overall distributional impact of the new technology can probably best be traced by examining each source of rural family income over time, and linking it to the growth path of the rural sector as a whole.

Another line of inquiry that seems promising is comparative research on output, employment, and distributional results for each of the five or so rice environments within a given region of a country. The heavier weight of scientific inquiry that IRRI recently placed on upland and deep-water environments, for example, is per se highly correlated with the greater attention placed on smaller farmers. That research, however, still needs to be complemented by more attention to variations in the economic environment (previously referred to), as they affect the complementarity or competitiveness of the various social goals. Changes in the economic environment for a given rice environment over time would provide another excellent laboratory for gaining a better understanding of the social impact of farmers' technology and output decisions. It is, after all, obvious but still worth emphasizing that changes induced in the profit maximization position of individual farmers will determine not only the size of the output potential forgone but also of employment and distributional opportunities neglected.

Still at a fairly aggregative level, the role of national science — as distinct from technology — seems to have been neglected in the past, and would seem to be a *natural* for IRRI stimulation and participation. Within the Evensonian framework of analysis, which permits a start at distinguishing between the respective contributions of international and national agricultural research, the analysis should be pushed back somewhat further. While the impact of technology on growth, as well as employment, distribution, etc., is well recognized — even if as seen, it is still inadequately analyzed — there is insufficient recognition of the question of where and how much basic scientific capacity is needed to underpin the capacity for technology change.

The easy way out is to call *science* a universal good freely available to all comers. But in a field such as agriculture that approach does not even come close to reality. The very existence of IRRI and the other institutions in the system argues otherwise, as does the growing realization of the need for a national scientific capacity to absorb and modify chemical- and Mendelian law-based advances in science. While developing countries obviously cannot afford to *show the flag* on the frontier of every field of basic science relevant to, say, agriculture (mediocre science is probably the most wasteful of all activities), they cannot afford to sit back and let others incur all the heavy costs. At a minimum, they need a basic scientific capacity to guarantee the necessary access to the international networks and to minimize the inevitable costs of search, identification, and transfer. Utilizing the experience of the best decade or so to illuminate these issues that have been relatively neglected, but that are important to policy makers on both sides, would constitute a large step forward.

RESEARCH AND DEVELOPMENT INVESTMENTS

In related area, the recent record with respect to the size of research and development (R & D) investments and the choice between imported, domestic, and imported and adapted agricultural technology has been, to my knowledge, inadequately analyzed. Meiji Japan, contrary to many fanciful notions, started off by making some large-sized mistakes, initially using western wheat-related technology in its rice fields. Somewhat later the importance of diffusing already known *best* domestic technology was recognized. That was followed in importance (and time) by mainly domestically generated improvements in the *best* domestic technology. Yet most contemporary less developed countries, including those in Asia, spend substantially more R & D on their agricultural export crops (usually other than rice) than on their staple domestic food crops. What has actually happened in the countries of the region, in terms of the allocation of resources and energies to the search for new technologies as well as the preferences exhibited with respect to their source and composition, is probably somewhere in IRRI's files and collective institutional memory and would constitute immensely valuable raw material for research.

Still, with respect to technology choice but on a more modest plane, the relationship between small variations in output quality and the additional technological flexibility that may thus be gained appears to me to be a neglected topic for research. To most economists, technology change is synonymous with the discovery of new techniques to produce a given defined output. Most others think of technology change in terms of new products or at least in terms of small variations in old product quality. In the field of agriculture, and specifically of rice, the semidwarf varieties also represent a quality change. But this is usually viewed as an unintended by-product of an innovation basically aimed at increasing yields. What has not been looked at much is the possibility of making quality variation a purposive (exogenous) variable as a way of enhancing the complementarity between output and employment. Small (planned) changes in output quality can mean large changes in the efficient absorption of labor. Similarly, although I am less sure of the technical grounds here, changes in input quality, e.g., fertilizer or herbicides, could, theoretically at least, permit greater flexibility in the use of abundant factor labor en route to a given quality rice output.

Let me conclude with two additional references to what appear to me at least to be important and neglected areas for future research. Time and again in this conference, the importance of investments in irrigation and its quantity and timeliness for determining the consequences of the new technology were referred to. What was more or less left out, however, was the level at which decision on irrigation is made, the kind of irrigation, and its location. The overall numbers governing a country's public sector irrigation investment really tell us little. What often makes the difference — in output, employment, and distributional terms — is the decision as to how much is to be spent on large-scale irrigation works and how much on small-scale feeder channels and — in both cases — the extent to which the location of the activity is to be responsive to local as opposed to central economic and political pressures. An analysis of the relative impact of mini and maxi irrigation infrastructure for the same amount of total expenditure, in different areas of the same country or across countries, would be highly instructive.

These discussions similarly brought home to me the relative neglect of the landless labor phenomenon in much of the literature on agricultural development, including that on land reform. The causal importance of a population growth (in the case of Java) and of the labor-saving bias of mechanization accompanying the modem varieties (in the case of the Philippines) was touched upon. But an idea of the quantitative importance of each of these, the extent to which the consequences are inevitable or avoidable, plus the possible impact of primogeniture and land reform, would undoubtedly serve to shed new light, especially on the low-end poverty problem in the countries of the region.

As a general economist attending a conference of mainly agricultural economists, I appreciate the chance to become better acquainted with a sector whose overwhelming importance for overall developmental performance in less developed countries I have long recognized. At the same time I apologize for the inevitable naivete and possibly plain inaccuracy of any of my statements or comments.

PARTICIPANTS

AHSAN, AKRAMUL. Bangladesh Rice Research Institute, Bangladesh
ANWAR, AFFENDI. Institute Pertanian Bogor, Indonesia
BARKER, R. International Rice Research Institute, Philippines
BEKURE, S. International Livestock Center for Africa, Ethiopia
CALKINS, P.H. The Asian Vegetable Research and Development Center, Republic of China
CASTILLO, G. T. University of the Philippines at Los Baños, Philippines
CORDOVA. V. G. International Rice Research Institute, Philippines
DAVID, C.C. University of the Philippines at Los Baños, Philippines
DESAI, G. Indian Institute of Management, Ahmedabad, India
DUFF, J.B. International Rice Research Institute, Philippines
EVENSON, R.E. University of the Philippines at Los Baños, Philippines
FLORES-MOYA, P. International Rice Research Institute, Philippines
GRIFFIN, K. Oxford University, Oxford, England
HAYAMI, Y. Tokyo Metropolitan University, Japan
HEDLEY, D.D. The Rockefeller Foundation, Indonesia
HERDT, R.W. International Rice Research Institute, Philippines
ISHIKAWA, S. Hitotsubashi University, Japan
KIKUCHI, M. National Research Institute of Agricultural Economics, Japan
LIBRERO, A.R. Philippine Council for Agriculture and Resources Research, Philippines
LUNING, H. Agricultural State University, The Netherlands
MANGAHAS, M. University of the Philippines at Los Baños, Philippines
MORRIS, R.A. International Rice Research Institute, Philippines
PINSTRUP-ANDERSEN, P. International Fertilizer Development Center, USA
PRICE, E.C. International Rice Research Institute, Philippines
RANIS, G. Yale University, USA
RAO, C.H. HANUMANTHA. University of Delhi, India
ROCKWOOD, W.G. International Rice Research Institute, Philippines
ROSEGRANT, M.W. University of Michigan, USA
RUTTAN, V.W. University of Minnesota, USA
RYAN, J.G. International Crops Research Institute for the Semi-Arid Tropics, India
SANDOVAL, P. University of the Philippines at Los Baños, Philippines
SCOBIE, G.M. North Carolina State University, USA
SIAMWALLA, AMMAR. Thammasat University, Thailand
SINAGA, R.S. Institute Pertanian Bogor, Indonesia.
SISON, J. F. University of the Philippines at Los Baños, Philippines
SMALL, L. Rutgers University, USA
TSUJII, H. Kyoto University, Japan
VALDES, A. International Food Policy Research Institute, USA
WICKHAM, T. H. International Rice Research Institute, Philippines