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MEASURING THE SOURCES OF GROWTH IN RICE YIELDS: ARE GROWTH RATES DECLINING IN ASIA?†

The development of fertilizer-responsive rice varieties at the International Rice Research Institute (IRRI) in the 1960s and their dissemination over a large part of South and Southeast Asia in the 1970s, coupled with a highly successful rice research program in China, have led to high rice yield growth rates over the past two decades in Asia. Production has grown faster than demand, despite the seriously constrained scope for expansion of land planted to rice, and world rice prices have fallen significantly.

Siamwalla and Haykin (1983) demonstrate how countries that have been traditional importers of rice have benefited particularly from the new technologies. This has reduced the volume of rice traded in the international market, further thinning an already thin market. In view of these developments, more recently there has been an understandable reluctance on the part of governments in the region and on the part of international lending institutions to invest heavily in future increases in rice production, for example, for irrigation (Rosegrant and Svendsen 1993). Policies have focused instead on the diversification of agricultural production. Barker and Herdt (1985) warn, however, that substantial investments in irrigation and productivity gains on irrigated and more favorable rainfed land will be necessary requirements for meeting future demand. They conclude, based on country-specific simulation analyses, that the most likely future scenario will be some combination of productivity increases and higher prices.

Whether or not growth in supply will continue to keep pace with or to

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exceed growth in demand over the next decade, has obvious and important implications for how Asian governments, international lending agencies, and the Consultative Group on International Agricultural Research should best allocate resources in anticipation of continued low international prices for rice. Will rice prices continue to remain low? Are the necessary productivity increases being realized?

This paper takes a pessimistic view of prospects for future growth in rice production. There has been a clear and broadly experienced deceleration in rice yield growth rates in South and Southeast Asia since 1981, as compared with the previous decade and a half. A detailed analysis (below) of this deceleration for the Philippines suggests that yield growth rates will continue to decline without a major shift of emphasis in government policy. To the extent that the Philippine experience is driven by factors common to other countries in South and Southeast Asia, and to the extent that governments and international agencies are slow to react to these trends, production growth rates could fall significantly.

The first section of this paper presents data on aggregate growth rates for rice yields for 23 countries in Asia for 1951-86. Rice area growth rates have declined steadily over time all over Asia. Rice yield growth rates increased for Asia as a whole during 1981-86 because of high yield growth rates in China, but growth rates fell in South and Southeast Asia as compared with 1966-81.

The second section of this paper briefly summarizes an analysis by Hayami (1975) of rice yield growth rates for Japan for the period 1880 to 1935, when rice yields increased from about two tons of brown (husked, unpolished) rice per hectare to about three tons. He divides this period into three phases: (1) an initial growth phase during which modern varieties were widely adopted in eastern prefectures, (2) a second growth phase during which modern varieties spread to and were widely adopted in western prefectures, and (3) a third phase during which yield growth rates stagnated. This paper argues that there are indications that the rice sectors in many countries in South and Southeast Asia may have already entered, or are about to enter, this third stagnation phase.

The sources of growth over time in rice yields for the Philippines are analyzed in detail in the third section. Philippine rice yield growth rates accelerated during 1966-81, as compared with 1951-66, and have declined since 1981, a pattern typical of many countries in South and Southeast Asia, although yield growth rates in the Philippines remain above average for this subregion. The analysis shows a striking similarity with the earlier experience of Japan in that recent aggregate national growth rates have been sustained by above average growth rates in the southern Philippines, where modern varieties were adopted last.

Methodologically, the analysis in the third section introduces a formula (analogous to the well-known formula that attributes production growth to changes in area and changes in yield) that decomposes changes in aggregate yields into percentage contributions from increased irrigation, increased fertil-

izer use, the diffusion of modern varieties, and technological innovation.[1] Conclusions are drawn in the final section.

PAST TRENDS IN ASIAN RICE YIELD GROWTH

Tables 1 and 2 show rice yield levels and growth rates for 1950 through 1987 for Asia, by country and by four subregions in Asia: South and Southeast Asia (excluding Indochina), East Asia, Indochina, and West Asia. Asia as a whole accounted for over 90 percent of world rice production during this period. Indochina and West Asia accounted for only about 5 percent of Asian production. Indochina is separated from the analysis for South and Southeast Asia because of the difficulties of controlling for the effects of the major dislocations caused by the war there on sustained increases in rice production experienced by most other Asian countries over several decades.

Rice production in South and Southeast Asia (Region 1) and East Asia (Region 2) is presently about equal, each region accounting for roughly 45 percent of world production. China, accounting for about 85 percent of both production and area harvested, overwhelmingly influences the totals for Region 2. India in Region 1 also looms large, contributing about half of area harvested and just over 40 percent of production. Tables 1 and 2 present aggregate figures for Region 1, which both include and exclude India, to show that aggregate growth rates for Region 1 are not unduly affected by the data from India.

Rice yields in Region 2 are presently somewhat more than twice as high as yields in Region 1. With the exception of Taiwan at 4.9 tons, all countries in Region 2 now have aggregate yields that are above 5 tons of rough rice per hectare. Most countries in Region 1 presently have aggregate yields between 2 and 3 tons per hectare, with the notable exception of Indonesia where yields have approached 4 tons per hectare. Since 1950, Region 1 and Region 2 yields have roughly doubled.

What are the prospects for rice production in Asia over the next 10 to 15 years? The production growth rate (not shown) for 1966-81 at 2.9 percent per annum was somewhat above the 2.6 percent experienced for 1951-66. More recently, production growth rates remained relatively high at 2.8 percent for 1981-86. Long-run real rice prices have fallen, suggesting prospects for a relative surplus of rice if past production growth rates can be maintained. During the second 15-year period, modern varieties of rice developed at IRRI were introduced over much of Region 1. The break at 1981 is somewhat artificial in that area planted to these modern varieties continued to expand, although at a

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[1] Definitions of technological innovation vary in the literature. As it is used in this paper, technological innovation may be thought of as observed shifts in the fertilizer response curves for specific technologies, for example, modern varieties grown on irrigated land. Thus, technological innovation is distinguished from diffusion of modern varieties.

Table 1.— Rice Yields in Asia by Country, 1950-87
(Metric tons of rough rice per hectare)

Country	Average annual yield							
	1950-52	1955-57	1960-62	1965-67	1970-72	1975-77	1980-82	1985-87
REGION 1								
Bangladesh	1.32	1.39	1.62	1.65	1.62	1.86	1.99	2.18
Burma	1.51	1.51	1.66	1.59	1.68	1.89	2.95	3.18
India	1.11	1.28	1.49	1.38	1.66	1.82	1.94	2.13
Indonesia	1.62	1.66	1.77	1.77	2.41	2.73	3.51	3.99
Malaysia	1.67	1.84	2.07	2.11	2.42	2.67	3.13	2.94
Nepal	1.90	1.90	1.92	1.88	1.89	1.92	1.79	1.85
Pakistan	1.31	1.27	1.36	1.48	2.29	2.33	2.54	2.36
Philippines	1.17	1.14	1.22	1.34	1.60	1.87	2.33	2.66
Sri Lanka	1.47	1.64	1.89	1.91	2.10	2.01	2.71	2.93
Thailand	1.29	1.37	1.59	1.79	1.93	1.75	1.92	2.01
REGION 2								
China	2.33	2.62	2.13	3.05	3.31	3.54	4.45	5.34
Japan	4.17	4.78	5.02	5.26	5.57	5.95	5.48	6.25
Taiwan	2.55	2.96	3.38	3.98	4.16	4.37	4.81	4.88
South Korea	3.95	3.45	3.80	4.15	4.61	6.03	5.43	6.30
North Korea	2.97	2.95	4.45	4.79	5.61	5.93	6.37	6.99
REGION 3								
Vietnam	1.35	1.48	1.96	1.89	2.19	2.12	2.27	2.79
Kampuchea	0.99	0.95	1.02	1.13	1.47	1.28	0.92	1.13
Laos	0.77	0.96	0.84	0.82	1.27	1.28	1.49	2.26
REGION 4								
Afghanistan	1.83	1.46	1.52	1.72	1.82	2.03	2.20	2.21
Iran	1.88	1.62	2.41	2.73	3.00	3.19	3.14	3.73
Iraq	1.53	1.79	2.37	2.87	2.69	2.77	2.93	2.81
Turkey	3.39	3.30	3.90	4.02	4.15	4.73	4.54	4.86
Others	1.80	1.94	1.97	2.00	2.06	2.06	1.96	2.23
REGION 1	1.26	1.37	1.55	1.53	1.79	1.94	2.22	2.44
(excluding India)	1.42	1.47	1.63	1.68	1.92	2.07	2.50	2.74
REGION 2	2.55	2.84	2.53	3.33	3.55	3.83	4.59	5.46
REGION 3	1.16	1.31	1.60	1.55	1.92	1.90	1.94	2.40
REGION 4	1.92	1.74	2.23	2.53	2.70	2.92	2.96	3.31
ALL ASIA	1.69	1.88	1.86	2.10	2.37	2.55	2.92	3.31

Source: International Rice Research Institute, *World Rice Statistics 1987*, Los Baños, 1988, Table 3, 1988.

Table 2.— Rice Yield Growth Rates in Asia by Country, 1950-87
(Percent)

Country	Average annual growth rates								
	1951-56	1956-61	1961-66	1966-71	1971-76	1976-81	1951-66	1966-81	1981-86
REGION 1									
Bangladesh	1.2	3.1	0.3	-0.4	2.8	1.4	1.5	1.3	1.8
Burma	0.1	1.9	-0.8	1.1	2.4	9.3	0.4	4.2	1.5
India	2.9	3.0	-1.5	3.8	1.8	1.3	1.5	2.3	1.9
Indonesia	0.4	1.3	-0.0	6.4	2.6	5.1	0.6	4.7	2.6
Malaysia	2.0	2.4	0.3	2.8	2.0	3.2	1.6	2.7	-1.2
Nepal	0.0	0.2	-0.4	0.0	0.4	-1.5	-0.1	-0.4	0.7
Pakistan	-0.6	1.4	1.7	9.1	0.3	1.8	0.8	3.7	-1.5
Philippines	-0.4	1.3	1.9	3.6	3.2	4.5	0.9	3.8	2.7
Sri Lanka	2.2	3.0	0.2	1.9	-0.9	6.1	1.8	2.3	1.6
Thailand	1.2	3.1	2.4	1.5	-1.9	1.8	2.2	0.5	1.0
REGION 2									
China	2.3	- 4.0	7.4	1.7	1.3	4.7	1.8	2.6	3.7
Japan	2.8	1.0	0.9	1.2	1.3	-1.6	1.6	0.3	2.7
Taiwan	3.1	2.6	3.4	0.9	1.0	1.9	3.0	1.3	0.3
South Korea	-2.7	2.0	1.8	2.1	5.5	-2.1	0.3	1.8	3.2
North Korea	-0.2	8.6	1.5	3.2	1.1	1.5	3.2	1.9	1.9
REGION 3									
Vietnam	1.9	5.7	-0.7	3.0	-0.6	1.3	2.3	1.2	4.2
Kampuchea	-0.7	1.5	1.9	5.5	- 2.8	-6.3	0.9	-1.3	4.1
Laos	4.4	-2.6	-0.6	9.1	0.2	3.1	0.4	4.1	8.7
REGION 4									
Afghanistan	-4.4	0.8	2.5	1.1	2.2	1.6	-0.4	1.7	0.1
Iran	-2.9	8.3	2.5	1.9	1.2	-0.3	2.5	0.9	3.5
Iraq	3.2	5.8	3.9	-1.3	0.6	1.1	4.3	0.2	-0.8
Turkey	-0.5	3.4	0.6	0.6	2.6	-0.8	1.1	0.8	1.4
Others	1.6	0.3	0.3	0.6	0.0	- 1.0	0.7	-0.1	2.6
REGION 1	1.7	2.5	-0.4	3.2	1.7	2.7	1.3	2.5	1.9
(excluding India)	0.7	2.1	0.6	2.7	1.5	3.9	1.1	2.7	1.9
REGION 2	2.2	-2.3	5.6	1.3	1.5	3.7	1.8	2.2	3.5
REGION 3	2.4	4.1	-0.6	4.4	-0.2	0.5	1.9	1.5	4.3
REGION 4	-2.0	5.1	2.5	1.3	1.6	0.2	1.8	1.1	2.3
ALL ASIA	2.2	-0.2	2.5	2.5	1.5	2.7	1.4	2.2	2.6

Source: Table 1.

slower pace.[2] However, this breaking point gives an additional five-year period, reflective of more recent trends, for which rice yield growth rates can be compared with growth rates for previous periods.

Apart from the disincentive of lower prices, there are at least two major reasons to think that these growth rates might not be maintained. First, area increases are contributing a smaller and smaller proportion over time of total production growth, which means of course that yield increases are contributing a larger and larger proportion. Increases in yields, then, are even more crucial for future production growth than they have over the past two decades, as land constraints have been reached in several countries.

In Region 2, where rice area *declined* for 1981-86, growth in rice yields actually accelerated from 1951-66 to 1966-81 to 1981-86. This, in turn, reflects the accelerated growth in yields for China, where the aggregate yield is now between 5 and 6 tons per hectare. While the experiences of Japan and Korea demonstrate that it is feasible for China to attain a yield increase of an additional 1.5 tons per hectare on a nationwide scale, such a level would be fully attained in less than a decade at present growth rates. The data for Japan and Korea show that growth rates in yields slowed considerably once a benchmark yield of approximately 5.5 tons was reached.

It is reasonable to expect, then, and this is the first reason for anticipating a slowdown in the growth of Asian rice production, that the growth rate of yields in China (and so in Region 2) will decline in the future, perhaps substantially. The rate at which yields will increase in China will depend on a number of technological and policy factors that are well beyond the scope of the present paper to evaluate.

Future production prospects for Region 1 would appear to be fundamentally different from production prospects for Region 2. First, aggregate yields are much lower in Region 1, so that there is possibly considerable scope for increasing yields without a major new breakthrough in biological technology. However, realization of these higher yields (1) would likely require large investments in irrigation and increases in fertilizer use, (2) may be seriously constrained by the shorter days and more limited solar radiation available near the equator during summer months, as compared with growing environments at higher latitudes in Region 2 (while their position near the equator of many countries in Region 1 permits year-round cultivation, this enhances production potential through *area* increases), and (3) would require that low-potential, marginal lands, often cultivated by the poor, be taken out of rice production.

The second reason for anticipating a slowdown in the growth of Asian rice production is that the rate of growth in rice yields in Region 1, although

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[2] More precisely, "1981" actually refers to a simple average of data for 1980-82. Three-year averages presented in Table 1 were used to compute the growth rates cited in Table 2.

positive, has been declining more recently. Table 2 shows that during 1966-81 when modern varieties were introduced in Region 1, rice yields grew faster at 2.5 percent per annum than for the rest of Asia, and at twice the rate of growth in yields for Region 1 for 1951-66. More recently, however, during 1981-86, the rate of growth in rice yields for Region 1 fell to 1.9 percent. Table 2 shows that this decline was a fairly broad-based phenomenon. Seven out of ten countries in Region 1 had yield growth rates above 2 percent a year for 1966-81, and in all seven of these countries yield growth rates fell for 1981-86. Yield growth rates increased in the other three countries over the same period, but only marginally, and yield growth rates in all three countries remained below 2 percent per annum for 1981-86.

Can this downward trend in yield growth rates be expected to continue? In order to answer this question, it is essential to have some understanding of the relative contributions of the key factors that have been responsible more recently for the observed increases in yields, in particular: the expansion of irrigated area, increased fertilizer use, the spread of modern varieties, and the more effective use of these inputs over time through training and experience with the modern varieties (technological innovation). Such an understanding would provide the basis for evaluating the prospects that these particular sources of growth could continue to contribute to overall yield gains.

The third section below develops a methodology for measuring the relative contributions of the four factors to growth in yields. That methodology is then applied to data from the Philippines, the country with highest growth rate in yields for any country in Region 1 for 1981-86. The analysis will demonstrate that the rate of technological innovation in rice production has been relatively slow in regions in the Philippines where modern varieties were *first* introduced. Technological innovation in regions where modern varieties were *last* introduced, more than any other factor, has accounted for the very substantial increases in aggregate yields experienced during the decade of the 1970s.

Before turning to this analysis, it is instructive to review the historical experience of Japan. A comparison of the two experiences shows strong similarities, although the length of the invention-diffusion cycle has been greatly compressed in the case of the Philippines.

ACCUMULATION AND DIFFUSION OF TECHNOLOGICAL POTENTIAL

Hayami presents a framework in which technical progress, defined as the upward shifting of the aggregate production function, is viewed as the combined effect of two processes: invention and diffusion.[3] He defines S_t as the actual shift and U_t as the potential shift in the aggregate production function. He specifies the process as:

[3] Hayami attributes this dichotomy to Schumpeter.

$$S_{t+1} - S_t = \lambda_t (U_t - S_t) \quad \text{where} \quad 0 \le \lambda_t \le 1 \tag{1}$$

λ_t determines the rate of diffusion. U_t represents the potential shift in the aggregate production function if all producers were to adopt and practice the best techniques currently available. S_t will approach U_t if no new techniques are developed over time. To test this hypothesis Hayami estimates:

$$\frac{Y_t - Y_{t-1}}{Y_{t-1}} = \alpha \frac{U_t - U_{t-1}}{U_{t-1}} + \beta \frac{V_t - V_{t-1}}{V_{t-1}} + e_t \tag{2}$$

where:

Y_t = national aggregate yield in year t,

U_t = simple average of yields in the five prefectures with the highest yields in year t, and

V_t =the unweighted standard deviation divided by the unweighted mean of prefecture yields in year t.

The higher α, the more that increased technological potential has contributed to growth (early adopters make a relatively large contribution to raising aggregate national yields); the higher β, the more that rapid diffusion (the realization of that potential among later adopters) has contributed to growth. The fitted equation for (2) was used to evaluate the relative contributions of increased potential $(\partial U / U)$ and diffusion $(\partial V / V)$ for three periods. Annual aggregate yield growth rates for these three periods were 0.80 (1885-1905), 1.13 (1905-20), and 0.27 (1920-35).

Hayami finds that the absolute contribution of increased potential declined over time. However, diffusion of this potential during the middle period led to an increased aggregate yield growth rate, despite the declining absolute contribution of breakthroughs in research. The trend growth rate in aggregate yields during the middle period of 1.13 percent per annum certainly provides no hint of the impending decline in yield growth rates of 0.27 percent for the final period. The tipoff that the invention-diffusion "pipeline" was about to run dry might have been the decline in the contribution of $(\partial U / U)$, but which was masked by an increase in $(\partial V / V)$.

From 1883/87 until 1933/37, western prefecture yields (Y_W) were above eastern prefecture yields (Y_E); starting in 1938/42 through 1963/67, this relationship was reversed. Hayami concludes:

> This contrast in the ways Y_E and Y_W had grown seems to reflect what we may call "the eastward movement in rice-farming technology." This refers to the process in which the backward districts caught up with and surpassed the traditionally advanced western districts ... At the beginning only pioneering farmers in the relatively advanced districts in the east tried to transplant the advanced techniques. In other words, the diffusion of the advanced technology was not uni-

form among the eastern prefectures in the earlier periods, resulting in the rise in V_E. It was ap-proximately 1903-07 when diffusion among eastern prefectures had reached a stage at which V_E began to fall.

In the next section, a very similar pattern is evidenced for the Philippines. Rice yields in Luzon were once much higher than in the technologically less advanced regions of the Visayas and Min-danao. Yields are now higher in the south. Is the recent Philippine experience a repeat of the Japa-nese situation summarized above and is this a general phenomenon for the countries in Region 1? *Suggestive* evidence has already been presented in Tables 1 and 2 that is consistent with a repeat of the Japanese case.

In order to provide more conclusive proof and because the duration of the invention-diffusion process has been greatly compressed, it is necessary to develop a different methodo-logical approach than that used by Hayami that is less dependent on information contained in a long time series. In the methodology presented below and applied to Philippine data, more detailed regional data on utilization of irrigation, fertilizer applications, and the spread of modern varieties substitute for this time series information.

ANALYSIS OF SOURCES OF YIELD GROWTH FOR THE PHILIPPINES

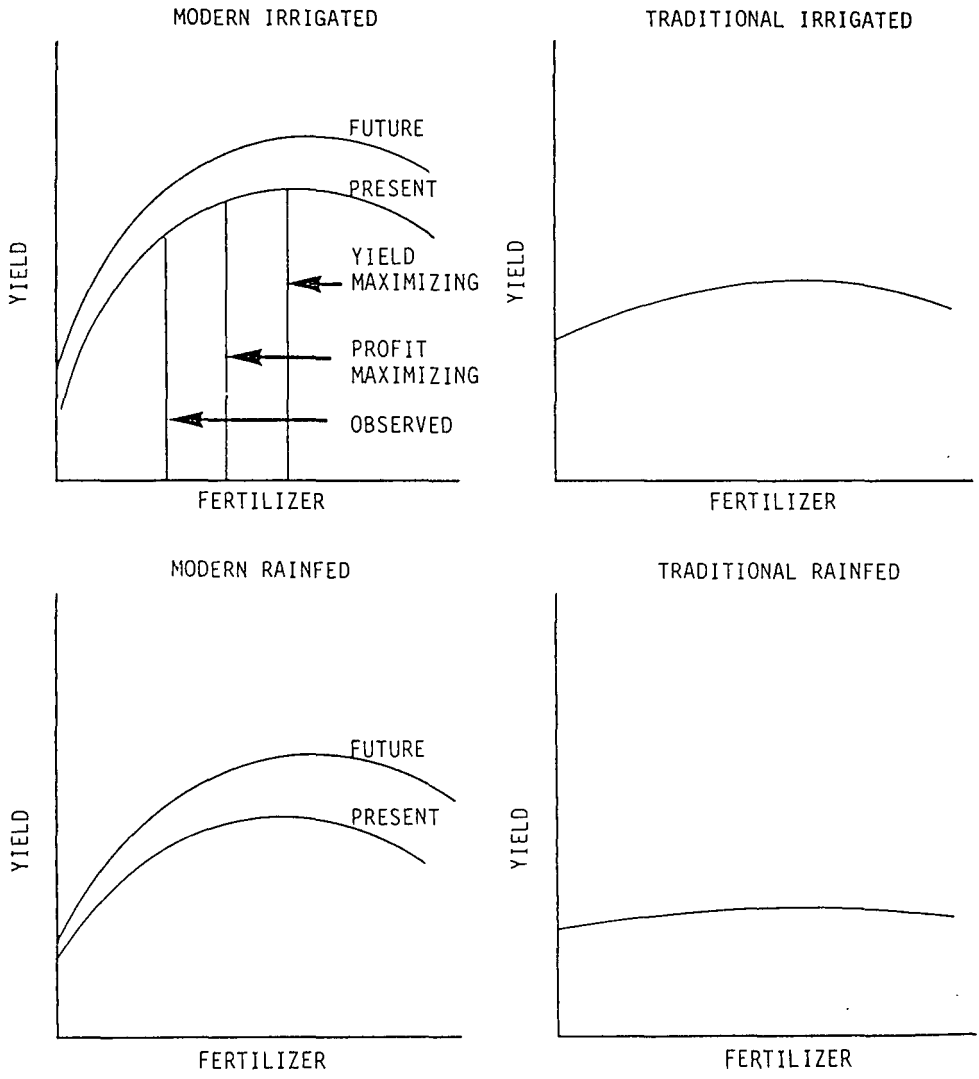
Rice production in the Philippines roughly doubled during 1961-82 with relatively little growth in area harvested. Growth in production, then, was due to increased yields. Much of the yield increase was due to the introduction of modern varieties of rice, especially where they were grown on irrigated land. Can aggregate yields continue to grow at the same pace as occurred in 1970s? To answer this question, a framework is required for looking at the factors responsible for past yield growth in a systematic way.

Developing A Mathematical Formula

In any given season, rice production may be divided into four types of technologies: (1) irrigated-modern varieties, (2) irrigated-traditional varieties, (3) rainfed-modern varieties, and (4) rainfed-traditional varieties (see Chart 1).[4] Aggregate yield from one period to another may be increased in four ways: (1) increasing the proportion of land which is irrigated, (2) increasing the proportion of land planted to modern varieties, (3) increasing fertilizer applications, and (4) upward shifts in the fertilizer response curves. Analogous to the well-known expression for attributing (disaggregating) *production* growth to changes in area and changes in aggregate yields, an expression can be developed for attributing growth in aggregate *yields* to these four

[4] This type of framework was originally developed by Herdt, Barker, and Te (1977/78).

Chart 1.—Disaggregation of Rice and Production into Four Categories



factors, which may be influenced by government policies. While output and input prices certainly affect the rate at which each of these factors change individually (e.g., fertilizer use), it is useful to emphasize at the outset that the accounting system to be developed is based primarily on physical inputs.

To begin derivation of this equation, consider the expression below where change in yield recorded between two periods is expressed as the weighted average of land grown on irrigated and rainfed land:

$$\Delta Y = \frac{A_{I_2} Y_{I_2} + A_{R_2} Y_{R_2}}{A_{I_2} + A_{R_2}} - \frac{A_{I_1} Y_{I_1} + A_{R_1} Y_{R_1}}{A_{I_1} + A_{R_1}} \tag{3}$$

where:

A = area harvested;
Y = yield per hectare;
I = a subscript denoting irrigated land;
R = a subscript denoting rainfed land;
and 1, 2 = subscripts denoting periods 1 and 2.

Equation (3) may be rewritten as

$$\Delta Y = \left[\theta_I \Delta Y_I + \theta_R \Delta Y_R\right] + \left[\Delta\theta_I Y_I + \Delta\theta_R Y_R\right] + \left[\Delta\theta_I \Delta Y_I + \Delta\theta_R \Delta Y_R\right] \tag{4}$$

where $\theta_{I,R}$ = the proportion of land which is irrigated or rainfed in period $1\,(\theta_I + \theta_R = 1)$, and Δ = denotes the change in either yield or area proportion between periods 1 and 2 (for example, $\theta_{I_1} + \Delta\theta = \theta_{I_2}$). Use of the " Δ " terms makes use of period subscripts redundant, so they are dropped.

In (4), the change in aggregate yield is disaggregated into three components (shown in square brackets): (i) the change in yields on irrigated and rainfed land, holding the proportions of irrigated and rainfed land constant, (ii) the change in proportions of irrigated and rainfed land, holding irrigated and rainfed yields constant, and (iii) an interaction term which multiplies the changes in proportions and changes in yields.

Simultaneous changes in proportion modern, proportion irrigated, and technology-specific yields. Irrigated land itself may be disaggregated into land that is planted to modern varieties of rice and land that is planted to traditional varieties. Thus, an expression analogous to (4) may be developed for ΔY_I, and substituted back into (4). And the same procedure may also be followed for ΔY_R. The formula for this expression is given in the Appendix.

An analogous expression may be developed by following the opposite order, disaggregating by modern and traditional varieties and then by irrigated

and rainfed land. These two formulas may be combined to express (aggregate) ΔY as the sum of the following effects (as shown in the Appendix):

<1> Change in technology-specific yields (i.e., ΔY_{IM}, ΔY_{IT}, ΔY_{RM}, and ΔY_{RT})—holding proportion modern and proportion irrigated constant;
<2> Change in proportion modern—holding proportion irrigated and technology-specific yields constant;
<3> Change in proportion irrigated—holding proportion modern and technology-specific yields constant;
<4> Simultaneous changes in proportion modern and proportion irrigated—holding technology-specific yields constant;
<5> Simultaneous changes in proportion modern and technology-specific yields—holding proportion irrigated constant;
<6> Simultaneous changes in proportion irrigated and technology- specific yields—holding proportion modern constant; and
<7> Simultaneous changes in technology-specific yields, proportion irrigated, and proportion modern.

Disaggregating changes in technology-specific yields to increased fertilizer applications and shifts in fertilizer-response functions. <1> through <7> make no explicit mention of the effect of technological innovation or changes in fertilizer applications. Changes in technology-specific yields, i.e., ΔY_{IM}, ΔY_{IT}, ΔY_{RM}, and ΔY_{RT}, are decomposed into these two effects in the following way. Assume a technology-specific fertilizer response function in time t of the form:

$$Y_t = a_t + b_t + c(F_t)^2 \tag{5}$$

with fixed coefficients for b and c, and the intercept a_t allowed to vary across time periods. Given data for Y_t, F_t, Y_{t+1}, and F_{t+1}, the change in yield due to increased fertilizer use (ΔY^F) is given by the difference in yield computed by alternatively substituting F_t and F_{t+1} into (5). The change in yield due to the shift in the fertilizer response function (ΔY^S) is given by $Y_{t+1} - Y_t - \Delta Y^F$.

Interpreting the Formula

Before applying this accounting framework to data for the Philippines, some clarification of implicit assumptions being made will facilitate interpretation of the results. First, technological innovation, the weighted sum of shifts in the fertilizer response functions for each of the four specific technologies, is a residual calculation: the change in yield *for each technology* that cannot be explained by increased fertilizer use. Such shifts may be the result of many factors, such as (i) the introduction and adoption of a second

generation modern variety (for example, on irrigated land already planted to modern varieties), (ii) farmer adaptation to a new technology through experience (e.g., more timely application of the same amount of fertilizer), and/or (iii) increased inputs of factors of production (other than fertilizer), such as labor.

All factors that cause the fertilizer response functions to shift may be influenced by changes in output and input prices, which are not included in the accounting system implemented here. However, wide disparities in the measured shifts in the fertilizer response curves *across regions* (see Table 4), where farmers have faced more or less the same structure of changes in input and output prices over time (see Table 5), argue against a conclusion that the observed shifts are due primarily to price influences, and for a conclusion that the shifts are due to technological innovation (in the sense of Hayami as described in the previous section).[5]

Second, that part of the change in yields explained by increased fertilizer applications is limited only to movements along the fertilizer response functions *within* each of the four individual technologies. Aggregate fertilizer applications per hectare increased rapidly for the period studied, but nearly

---

[5] In comparing rice yield data for the Philippines, Thailand, and Taiwan, Hsieh and Ruttan (1967) have shown that differences in aggregate yields across regions may depend more importantly on differences in the quantity/quality of irrigation available and other environmental factors, and less importantly on such factors as new varieties, better cultural practices, or more intensive use of technical inputs such as fertilizer. Their recalculation of regional yields for the Philippines (their Table 3), under an assumption that the regional percentage distributions of area harvested by wet and dry seasons and by irrigated, rainfed, and upland conditions were all equal to the national average, is a similar strategy methodologically as is being followed in this paper. This paper develops a more disaggregate mathematical framework.

While Hsieh and Ruttan concentrated for the most part on identifying factors that explained cross-sectional differences in yields between regions, this paper analyzes factors that explain differences in yields across time for the same region. Ruttan (personal communication) has suggested that the framework developed in this paper might be applied cross-sectionally as well (for intercountry comparisons, or comparison of regions within the same country). Cross-sectional comparisons, however, require some re-interpretation of the "shifts" in the fertilizer response curves (between regions for the same technology). For example, solar radiation (length of day) and soil type may differ between regions, which is not a consideration in time series comparisons.

Hsieh and Rattan also discuss institutional factors that accounted for shifts in the fertilizer-response functions (to use the framework presented in this paper, not their terminology) over time in Taiwan, in particular development of farmers' associations and land reform.

the entire increase can be explained by a substantial increase in the proportion of rice area planted to fertilizer-intensive, modern technologies. That is, for each of the individual four technologies, there was only a modest increase in fertilizer use. That part of the change in yields attributed to increases in the proportion of area planted to modern varieties, includes not only the effect of planting a modern seed, but the effect as well of the whole package of inputs that goes along with planting that seed (as practiced on average by adopting rice farmers), such as increases in fertilizer and pesticide use.

Third, the accounting framework presented here is based on *proportion* of area irrigated. It is possible (though not necessary) that substantial investments could be made in expanding and upgrading irrigation systems without any (apparent) effect of irrigation on yields. For example, suppose that production is impossible without irrigation. Irrigated *area* could increase markedly over the period being studied, substantially increasing production, but this would have no effect at all on the proportion of area irrigated or on average yield. The upgrading of an existing irrigation system so that water deliveries are more reliable provides a second example. In this case rice yields on irrigated land presumably would increase, but official statistics would indicate no change in irrigated area. Under the accounting system developed above, any increase in rice yields due to such irrigation investments would be attributed to a shift in the fertilizer response function on irrigated land.

In conclusion, the proposed framework does not identify specific factors that cause shifts in the fertilizer response functions. However, to the extent that a high proportion of aggregate yield growth is explained by shifts in the fertilizer response functions, discovering that growth in aggregate yields was *not* primarily due to increased fertilizer use, or irrigation construction, or the initial switch to modern varieties (or interactions among the three), still can constitute valuable information for policy planning as demonstrated in the concluding section.

Data Requirements

The data requirements for using the above framework to evaluate sources of growth in yields are time series data disaggregated by region, season, irrigated and rainfed land, and modern and traditional varieties for yield, area, and fertilizer applications. Time-series data are not required for coefficients for the fertilizer response functions as they are assumed to remain constant over time, with the exception of the intercept term which is calculated from the data as described earlier.

This paper examines changes in yields between an average for 1970-72 and an average for 1980-82. The required data for yields and areas were available from the Bureau of Agricultural Economics (BAEcon, various years). Three-year averages were used to minimize the effect of year-to-year variations in weather.

Much is known about the response of rice yields to fertilizer applications, in part because it is relatively easy to design and implement controlled trials for which fertilizer applications are varied by plot; several studies have estimated Equation (5) for various growing environments in the Philippines using both experiment station and farm-level information. The fertilizer-response coefficients to be used in this study are based on estimates presented in David and Barker (1978) and Herdt and Webster (1982). David and Barker present estimates that show differences in coefficients between irrigated and rainfed conditions and modern and traditional varieties. The Herdt and Webster coefficients give some indication of the variation in coefficients across seasons.

Data for fertilizer applications disaggregated by region, season, irrigated and rainfed land, and modern and traditional varieties are available for only one crop year (1982) from BAEcon. The information from this one survey was combined with time-series data on total fertilizer use on rice (1970-82) to generate the required data for fertilizer applications for 1970-1981.

Empirical Results

National aggregate summary. The results of applying the formulas developed earlier to Philippine data for 1970-72 and 1980-82 are summarized in Table 3. Shifts in the fertilizer response functions (holding other factors constant) accounted for half of the growth in wet season yields and two-thirds of the growth in dry season yields. Increases in proportion of area planted to modern varieties was the other major source of growth. However, now that proportion has approached 90 percent for the Philippines. It can no longer be counted on as a source of growth in the near future. No new generation of modern varieties with a substantially higher yield potential is immediately available.

Increases in fertilizer applications within technologies accounted for only about 10 percent of the growth in yields. While irrigation investments may have been important in terms of expanding the *area* available for cultivation in the dry season and in terms of maintaining existing irrigation facilities, the *proportion* of rice area irrigated changed little, and so accounted for only a small portion of increased yields.

Regional results. Table 4 shows estimated shifts in the fertilizer response functions by region for irrigated modern varieties in the wet and dry seasons. For the wet season, the largest shifts on irrigated land occurred for regions to the south and west, that is those least affected by the prevailing monsoon rains, which enter the country on the eastern coast heading in a northwesterly direction. In the dry season, the same general pattern occurs, despite the absence of the monsoons, except that Northern Mindanao moves from last position for the wet season to third position in the dry season.

In 1970-72 irrigated modern yields for the wet season in Luzon, Western

Table 3.— Factors Explaining Changes in Wet and Dry Season National Aggregate Yields Between 1970-72 and 1980-82, Philippines

1980-82	Wet season yield	2.15 mt/ha
1970-72	Wet season yield	1.64 mt/ha
Absolute change in yield to be explained:		0.51 mt/ha
1980-82	Dry season yield	2.41 mt/ha
1970-72	Dry season yield	1.68 mt/ha
Absolute change in yield to be explained:		0.73 mt/ha

	Wet season	Dry season
A. Percent of yield change explained by indicated factor, holding other factors constant		
1. Shift in fertilizer response function	47.2	64.8
2. Increase in proportion modern	20.7	5.9
3. Increase in proportion irrigated	5.2	-0.6
4. Increase in fertilizer use	6.4	7.6
B. Percent of yield change explained by indicated pairs of factors, holding other factors constant		
1. Simultaneous increase in proportion modern and shifts in fertilizer response function	28.0	16.9
2. Simultaneous increase in proportion modernand increases in fertilizer use	2.6	2.9
3. Other possible pairs	-5.4	-2.8
C. All possible combinations of three factors and four factors varying simultaneously	-4.6	-6.0
D. Shift in land proportions among regions and simultaneous shifts in yields and regional land proportions	-0.1	11.3
TOTAL	100.0	100.0

Visayas, and Mindanao were nearly equal. Highest yields now occur in South and Western Mindanao and Western Visayas. Dry season, irrigated yields were somewhat higher in Luzon than in Mindanao and Western Visayas in 1970-72. The opposite pattern now holds. On rainfed land, although the data are not shown, again the southern regions made the largest overall gains with Western Visayas, Northern Mindanao, and Southern Mindanao among the top four regions in both the wet and dry seasons.

Effects of prices. It was stated earlier that changes in output and input prices are a subset among several factors that potentially determine the extent of shifts in the fertilizer response functions. Are the regional disparities in shifts in the fertilizer response functions seen in Table 4 generated by differential movements in output and input prices across regions across time? The empirical evidence suggests that they are not.

Table 4.—Estimated Shifts in Fertilizer Response Functions for Irrigated Modern Varieties by Region, Wet and Dry Seasons, 1970-72 to 1980-82, Philippines
(50 kg bags of rough rice per ha)

	Wet season, irrigated modern			Dry season, irrigated modern		
Region	Shift in function	1980-82 yield	1970-72 yield	Shift in function	1980-82 yield	1970-72 yield
Ilocos	+ 5.4	51.4	46.0	+ 2.3	50.6	47.3
Cagayan	+ 7.7	53.8	44.6	+16.8	59.4	38.2
Central Luzon	+14.1	58.5	42.2	+22.3	73.2	49.7
Southern Tagalog	+ 6.7	47.6	39.8	+11.6	52.3	40.1
Bicol	+ 7.7	52.2	43.2	+10.6	53.8	42.1
Eastern Visayas	+ 3.9	46.9	39.1	+11.3	48.8	33.3
Central Visayas	+16.7	43.2	23.3	+13.7	40.1	21.2
Western Visayas	+18.5	61.2	41.2	+28.7	62.5	30.7
Northern Mindanao	+ 2.2	52.0	46.2	+23.1	61.7	37.2
Western Mindanao	+31.7	78.3	42.3	+20.3	59.5	35.7
Southern Mindanao	+28.1	71.7	42.5	+26.4	69.3	41.7

Note: Regions are ordered geographically from north to south.

Table 5 shows prices for rice (farmgate) and fertilizer, and wages paid to agricultural laborers by region for 1970-72 and 1980-82. In all regions, fertilizer prices and agricultural wages rose faster (in nominal terms) than rice prices. Despite these unfavorable price movements for rice producers, fertilizer applications apparently increased somewhat. While this may seem counter-intuitive, marginal value products of a kilogram of nitrogen remained well above marginal costs even in the early 1980s. Such behavior is consistent with the

notion that as farmers gained experience with modern varieties, they learned that heavier fertilizer applications resulted in higher profits. To use Hayami's terminology, farmers were undergoing a process of realizing the full technological potential of the modern varieties.[6]

Table 5.—Prices of Rice and Fertilizer, and Wages for Agricultural Labor, By Region, 1970-72 and 1980-82

	Price of rice [a]		Price of fertilizer [b]		Agricultural wages [c]		Ratio of prices/wages 1980-82 over 1970-72			Ratio of rice prices over ratio of	
Region	70-72	80-82	70-72	80-82	70-72	80-82	Rice	Fert.	Wages	Fert.	Wages
Ilocos	.53	1.39	32.69	123.56	3.93	12.35	2.61	3.78	3.14	.69	.83
Cagayan	.54	1.27	33.69	125.85	3.65	11.88	2.34	3.74	3.25	.63	.72
Central Luzon	.60	1.40	32.02	118.94	4.18	14.67	2.35	3.71	3.51	.63	.67
Southern Tagalog	.57	1.29	33.69	123.62	4.80	15.89	2.25	3.67	3.31	.61	.68
Bicol	.50	1.18	35.36	124.13	3.32	12.05	2.38	3.51	3.63	.68	.66
Eastern Visayas	.52	1.16	34.36	124.58	2.91	12.29	2.22	3.63	4.23	.61	.53
Central Visayas	–	1.29	34.02	119.58	–	10.80	–	3.52	–	–	–
Western Visayas	.54	1.23	31.35	119.58	3.15	11.13	2.27	3.81	3.53	.60	.64
Northern Mindanao	.55	1.28	35.36	126.13	4.08	11.77	2.34	3.57	2.89	.66	.81
Western Mindanao	.49	1.21	34.02	127.51	3.79	11.38	2.48	3.75	3.00	.66	.82
Southern Mindanao	.49	1.27	32.35	122.77	3.79	11.36	2.59	3.80	3.00	.68	.86
Philippines	.54	1.27	33.35	123.47	3.68	12.16	2.36	3.70	3.30	.64	.71

Source: Bureau of Agricultural Statistics, Various statistical series, Ministry of Agriculture, Quezon City, Philippines, various years.

[a] Pesos per kilogram at farmgate for unhusked rice, three-year average of nominal values.
[b] Pesos per 50 kg bag of urea (45 percent nitrogen), three-year average of nominal values.
[c] Pesos per day, three-year average of nominal values.

[6] Not only did fertilizer applications increase, but the fertilizer response functions also continued to shift upward, in particular in regions south of Luzon; these

Summary for the Philippines

The evidence suggests that the wide regional variation in shifts of the fertilizer-response curves to a large extent represent improved use of crucial inputs, rather than increased input levels such as labor. Differences across regions in changes in input levels could not have explained such a wide regional variation in shifts, given reasonably well operating input and output markets. Whereas the initial yield gains from modern varieties were made in the Central Luzon and Southern Tagalog regions in the late 1960s and early 1970s due to their proximity to where research was taking place, sufficient time has passed that the benefits have spread to the south.

For national aggregate yields to grow at the same pace in the future as occurred in the 1970s, either above-average shifts in the south will have to continue to make up for below average shifts in the north, or shifts in the north will have to increase. The latter eventuality seems unlikely without development of a new generation of modern variety since most research takes place in the north. It would also seem unlikely that shifts in the south will continue at the same pace, in that the technological "pipeline" from north to south would appear to be empty.

A detailed examination of the sources of growth in Philippine yields for 1970-72 to 1980-82, then, reveals some rather disturbing trends in terms of prospects for future growth in yields. Despite the fact that this was a period of relatively large investments in irrigation and aggregate fertilizer use increased, these two factors explained very little of the increase of rice yields over time. The low rates of technological innovation in the northern Philippines suggest that a new initiative is required to develop varieties with significantly increased yield potential if past yield growth rates are to be maintained. The pattern of sources of yield growth across regions for the Philippines suggests a repeat of the Japanese experience for 1918/22 to 1933/37, one of stagnating yields. As shown in Table 6, the recent record of growth in Philippine rice yields is consistent with such a conclusion.[7]

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functions might have shifted even more had the price environment been more favorable. To investigate the possibility that the differential shifts in fertilizer response functions across regions were due primarily to differential shifts in regional prices, the regional ratios of the rice price increase over the agricultural wage increase were regressed on the measured regional shifts in functions for modern varieties shown in Table 4. In none of the regressions was the coefficient on the price ratio statistically significant.

[7] The slowdown in yield growth rates in the first half of the 1970s is explained by the susceptibility to pests and diseases of the earliest modern varieties that were released.

Table 6.—Growth in Philippine Rice Yields, 1964-66 to 1988-90

Years	Three-year average yield *(mt/ha)*	Annual growth rate from previous 3-year period *(percent)*
1964-66	1.29	–
1967-69	1.47	4.5
1970-72	1.60	2.9
1973-75	1.68	1.6
1976-78	1.99	5.8
1979-81	2.25	4.2
1982-84	2.46	3.0
1985-87	2.66	2.6
1988-90	2.72	0.7

IMPLICATIONS FOR FUTURE ASIAN RICE SUPPLY/DEMAND BALANCES

The Philippines experienced an accelerated growth rate in rice yields during 1966-81 as a result of the introduction of improved varieties of rice, an experience common to most other countries in South and Southeast Asia. Also like most other countries in this region, yield growth rates have declined after 1981, although yield growth rates in the Philippines remained well above the regional average through 1987.[8]

The foregoing analysis raises a number of points for projecting the medium-run Asian rice supply situation. First, any such exercise is inherently hazardous since government policy, which is so central to the eventual supply/demand balance outcome, is endogenous, a function of the short-run

[8] While there is a certain presumption of a commonality of supply and demand structures in the rice-based agricultural sectors of Asia, it is by no means certain that the Philippine experience is generalizable to other countries in the region. In principle it would be a simple matter to duplicate the methodology used for identifying the sources of growth in yields, for various sub-regions of other countries in South and Southeast Asia. If the same pattern of sources of growth in rice yields were to come out of the analysis for these other countries (where yield growth rates also are declining), this would, of course, reinforce the sense that emerges from the Philippine data that yield growth rates will continue to decline. However, while the data requirements for a particular region and year are not severe, the disaggregated data are usually not available over time.

balance outlook. If yield growth rates do decline all over Asia, and as rice import requirements and international prices increase, because rice is such an important commodity for consumers as well as producers in these countries, past experience shows that governments will undoubtedly take steps to increase domestic production and to keep domestic rice prices from rising substantially (or would continue to reduce rice sector investments if domestic and world prices remain low). Over the medium-term the issue is not so much whether supply and demand will grow at similar rates, but how well governments (sometimes with cooperation from international agencies) can successfully even out expansion of productive capacity to avoid politically necessary but costly, and for poor consumers often painful, intensive programs to increase production in the short run by moving up along the production function, rather than by shifting out the production function.[9]

Second, a fundamental problem for planners is that (lower cost) outward shifts of the production function are difficult to predict, with long lag times between investment and uncertain returns. To the extent that the Philippine experience with modern varieties of rice is common to other countries in Region 1, one conclusion is that not only are production functions not going to shift out as rapidly in the near future, but governments (and international agencies) have not yet recognized this fact and therefore its implications. The conclusion, then, is that the eventual policy reaction will be relatively more skewed toward short-run investments than might otherwise have been the case, and therefore less efficient.

Third, because production in China is such a large share of total Asian production and because such a small share of total Asian production is traded, production prospects for China, even if they run counter to prospects for South and Southeast Asia, alone could determine whether world rice prices will remain low or rise. Yield growth rates for China for 1981-86 approached 4 percent annually, which was substantially higher than yield growth rates for 1966-81. Yields in China are now approaching those of Japan and Korea, the highest in Asia. If these highest observed yields represent an upper bound under existing technologies, the conjecture was made earlier that Chinese yield growth rates could not continue at this high pace. A careful study of the sources of growth in Chinese yields is particularly important in determining future prospects for Asian rice supply/demand balances.

Fourth, any cogent analysis of prospects for international rice prices, of course, must address the issue of future demand for rice. While a detailed analysis of demand issues will need to be undertaken elsewhere, a conservative assumption is that demand will increase linearly with population growth. Ruttan (1990), inter alia quoting Asian population figures of 3.2 billion and 4.2 billion in the years 2000 and 2025 respectively from a base of 2.5 billion in

---

[9] See Rosegrant and Pingali (forthcoming) for a discussion of policy measures that will need to be undertaken to maintain rice productivity growth in Asia.

1987, states that most Asian countries will experience a doubling of food demand before the end of the second decade of the next century. In land-constrained Asia, this suggests that rice prices will rise if yield growth rates continue to decline.

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APPENDIX

Derivation Of Expressions For Attributing Total Growth In Yield To Increased Irrigation, Adoption Of Modern Varieties, And Shifts In The Fertilizer Response Functions For Specific Technologies

Disaggregating by irrigated and rainfed varieties and then by modern and traditional varieties, gives the following expression:

$$
\Delta Y =
\begin{array}{|l|l|}
\hline
\theta_I\ \theta^I_{IM}\Delta Y_{IM} + \theta_R\ \theta^R_{RM}\Delta Y_{RM} & + \Delta\theta_I\ \theta^I_{IM}\Delta Y_{IM} + \Delta\theta_R\ \theta^R_{RM}\Delta Y_{RM} \\
+ \theta_I\ \theta^I_{IT}\Delta Y_{IT} + \theta_R\ \theta^R_{RT}\Delta Y_{RT} & + \Delta\theta_I\ \theta^I_{IT}\Delta Y_{IT} + \Delta\theta_R\ \theta^R_{RT}\Delta Y_{RT} \\
\hline
+ \theta_I\Delta\theta^I_{IM}\ Y_{IM} + \theta_R\Delta\theta^R_{RM}\ Y_{RM} & + \Delta\theta_I\Delta\theta^I_{IM}\ Y_{IM} + \Delta\theta_R\Delta\theta^R_{RM}\ Y_{RM} \\
+ \theta_I\Delta\theta^I_{IT}\ Y_{IT} + \theta_R\Delta\theta^R_{RT}\ Y_{RT} & + \Delta\theta_I\Delta\theta^I_{IT}\ Y_{IT} + \Delta\theta_R\Delta\theta^R_{RT}\ Y_{RT} \\
\hline
+ \theta_I\Delta\theta^I_{IM}\Delta Y_{IM} + \theta_R\Delta\theta^R_{RM}\Delta Y_{RM} & + \Delta\theta_I\Delta\theta^I_{IM}\Delta Y_{IM} + \Delta\theta_R\Delta\theta^R_{RM}\Delta Y_{RM} \\
+ \theta_I\Delta\theta^I_{IT}\Delta Y_{IT} + \theta_R\Delta\theta^R_{RT}\Delta Y_{RT} & + \Delta\theta_I\Delta\theta^I_{IT}\Delta Y_{IT} + \Delta\theta_R\Delta\theta^R_{RT}\Delta Y_{RT} \\
\hline
\end{array}
$$

$$
\begin{array}{|l|}
\hline
+ Y_I\Delta\theta_I + Y_R\Delta\theta_R \\
\hline
\end{array}
$$

$$
= \qquad (1.1)
$$

$$
\begin{array}{|l|l|}
\hline
A_{IR} & + E_{IR} \\
\hline
+ B_{IR} & + F_{IR} \\
\hline
+ C_{IR} & + G_{IR} \\
\hline
\end{array}
$$

$$
\begin{array}{|l|}
\hline
+ D_{IR} \\
\hline
\end{array}
$$

where (subscripts):
IM = yield or area proportion for modern varieties grown on irrigated land,
RM = yield or area proportion for modern varieties grown on rainfed land,
IT = yield or area proportion for traditional varieties grown on irrigated land, and
RT = yield or area proportion for traditional varieties grown on rainfed land;
(superscripts):
I = area proportion calculated over total irrigated land, and
R = area proportion calculated over total rainfed land.

Next, disaggregating by modern and traditional varieties and then by irrigated and rainfed land, gives an analogous expression:

$$
\Delta Y =
\begin{array}{|c|c|}
\hline
\theta_M\ \theta^M_{IM}\Delta Y_{IM} + \theta_T\ \theta^T_{IT}\Delta Y_{IT} & + \Delta\theta_M\ \theta^I_{IM}\Delta Y_{IM} + \Delta\theta_T\ \theta^T_{IT}\Delta Y_{IT} \\
+ \theta_M\ \theta^M_{RM}\Delta Y_{RM} + \theta_T\ \theta^T_{RT}\Delta Y_{RT} & + \Delta\theta_M\ \theta^M_{RM}\Delta Y_{RM} + \Delta\theta_T\ \theta^T_{RT}\Delta Y_{RT} \\
\hline
+ \theta_M\Delta\theta^M_{IM}\ Y_{IM} + \theta_T\Delta\theta^T_{IT}\ Y_{IT} & + \Delta\theta_M\Delta\theta^M_{IM}\ Y_{IM} + \Delta\theta_T\Delta\theta^T_{IT}\ Y_{IT} \\
+ \theta_M\Delta\theta^M_{RM}\ Y_{RM} + \theta_T\Delta\theta^T_{RT}\ Y_{RT} & + \Delta\theta_M\Delta\theta^M_{RM}\ Y_{RM} + \Delta\theta_T\Delta\theta^T_{RT}\ Y_{RT} \\
\hline
+ \theta_M\Delta\theta^M_{IM}\Delta Y_{IM} + \theta_T\Delta\theta^T_{IT}\Delta Y_{IT} & + \Delta\theta_M\Delta\theta^M_{IM}\Delta Y_{IM} + \Delta\theta_T\Delta\theta^T_{IT}\Delta Y_{IT} \\
+ \theta_M\Delta\theta^M_{RM}\Delta Y_{RM} + \theta_T\Delta\theta^T_{RT}\Delta Y_{RT} & + \Delta\theta_M\Delta\theta^M_{RM}\Delta Y_{RM} + \Delta\theta_T\Delta\theta^T_{RT}\Delta Y_{RT} \\
\hline
\end{array}
$$

$$
\begin{array}{|c|c|}
\hline
+ Y_M\Delta\theta_M & + Y_T\Delta\theta_T \\
\hline
\end{array}
$$

$$
= \tag{1.2}
$$

$$
\begin{array}{|c|c|}
\hline
A_{MT} & + E_{MT} \\
\hline
+ B_{MT} & + F_{MT} \\
\hline
+ C_{MT} & + G_{MT} \\
\hline
\end{array}
$$

$$
\begin{array}{|c|}
\hline
+ D_{IR} \\
\hline
\end{array}
$$

To derive expressions for the seven effects defined in the text:

$$
\begin{aligned}
\Delta Y &= \langle 1\rangle + \langle 2\rangle + \langle 3\rangle + \langle 4\rangle + \langle 5\rangle + \langle 6\rangle + \langle 7\rangle \\
&= A_{MT} + B_{MT} + C_{MT} + D_{MT} + E_{MT} + F_{MT} + G_{MT} \\
&= A_{IR} + B_{IR} + C_{IR} + D_{IR} + E_{IR} + F_{IR} + G_{IR}
\end{aligned} \tag{1.3}
$$

First:

$$
\langle 1\rangle = A_{MT} = A_{IR} \tag{1.4}
$$

Next, holding technology-specific yields constant:

$$\Delta Y_{\substack{constant\ technology-\\ specific\ yields}} = \langle 2\rangle + \langle 3\rangle + \langle 4\rangle = B_{MT} + D_{MT} + F_{MT}$$
$$= B_{IR} + D_{IR} + F_{IR} \tag{1.5}$$

Now:

$$\langle 2\rangle = D_{MT} \tag{1.6}$$

and

$$\langle 3\rangle = D_{IR} \tag{1.7}$$

So that:

$$\langle 4\rangle = B_{MT} + D_{MT} + F_{MT} - D_{MT} - D_{IR} = B_{MT} + F_{MT} - D_{IR}$$

or

$$\langle 4\rangle = B_{IR} + D_{IR} + F_{IR} - D_{MT} - D_{IR} = B_{IR} + F_{IR} - D_{MT} \tag{1.8}$$

This leaves the C, E, and G terms to explain <5>, <6>, and <7>:

$$\langle 5\rangle + \langle 6\rangle + \langle 7\rangle = C_{MT} + E_{MT} + G_{MT} = C_{IR} + E_{IR} + G_{IR} \tag{1.9}$$

Because:

$$\langle 5\rangle = E_{MT} \tag{1.10}$$

and

$$\langle 6\rangle = E_{IR} \tag{1.11}$$

Therefore:

$$\langle 7\rangle = C_{MT} + E_{MT} + G_{MT} - E_{MT} - E_{IR} = C_{MT} + G_{MT} - E_{IR}$$

or

$$\langle 7\rangle = C_{IR} + E_{IR} + G_{IR} - E_{MT} - E_{IR} = C_{IR} + G_{IR} - E_{MT} \tag{1.12}$$

INCORPORATING EFFECTS OF REGIONAL SHIFTS IN THE DISTRIBUTION OF RICE AREA

Assume that the change in aggregate yield ΔY in (1.1) or (1.2) represents the change for a particular region of the country. This regional change in aggregate yield is itself a component of the change in national aggregate yield, as given below:

$$\begin{aligned} \Delta Y_{NAT} = & \left[\theta_A \Delta Y_A + \theta_B Y_B + \cdots + \theta_N Y_N \right] + \\ & \left[\Delta\theta_A Y_A + \Delta\theta_B Y_B + \cdots + \Delta\theta_N Y_N \right] + \\ & \left[\Delta\theta_A \Delta Y_A + \Delta\theta_B \Delta Y_B + \cdots + \Delta\theta_N \Delta Y_N \right] \end{aligned} \tag{1.13}$$

where subscripts A, B, ..., N designate the N regional yields.