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# FERTILIZER DEMAND IN THE ASIAN RICE ECONOMY†

In the successful agricultural development of Japan and Taiwan an intensive use of fertilizer, accompanied by improvements in water control and development of fertilizer-responsive rice varieties, compensated for a shortage of land (5). With the introduction of new rice varieties in the 1960s, a similar pattern of development is now taking place in many other Asian countries. As land is becoming scarce in South and Southeast Asia, a growing dependence is being placed upon yield per hectare and therefore upon those factors which raise yields—fertilizer, irrigation, and modern varieties.

Until a decade ago, in most Asian countries fertilizer was used primarily on plantation crops such as sugarcane. In 1970 the rates of fertilizer application and consequently the rice yields of the South and Southeast Asian countries, shown in Table 1, were still much below those in East Asia (Japan, Taiwan, and South Korea). The pattern of fertilizer-rice price ratios suggests one explanation for the variation in the rate of fertilizer consumption between these two groups of countries. Farmers in East Asia operate in a much more favorable price environment. However, other factors such as soil fertility, climate, water control, farm size, and education undoubtedly help to explain intercountry differences in fertilizer consumption.

Despite the importance of fertilizer in obtaining the yield potential of modern varieties, there are few empirical analyses of the factors affecting fertilizer use in less developed countries. (See 9). The objective of this paper is to analyze factors affecting fertilizer consumption in the rice economy of selected Asian countries using one aggregate and two farm level sets of data. Fertilizer demand functions are estimated to distinguish the impact of differences in production technology or in fertilizer response functions from the impact of changes in the relative price of fertilizer to rice. The effect of farmers' liquidity positions on their ability to purchase fertilizer is also examined from farm level data. Based on the estimates of the parameters of fertilizer demand, the relative contributions of each of the

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explanatory factors to the difference in the rate of fertilizer application are quantified.

The aggregate level data consist of time series observations of rice production, crop area, fertilizer input, proportion of area planted to modern varieties, and fertilizer and rice prices from 1950 to 1972 for 11 Asian rice-growing countries.[1] Two sets of farm survey information available at the International Rice Research Institute (IRRI) provided a unique opportunity to investigate the roles of various factors influencing farmers' demand for fertilizer. The Asian farm survey conducted during the crop year 1971-72 covered about 2,000 rice farmers in 36 villages located in the Philippines, Indonesia, Thailand, Malaysia, India, and Pakistan. The Laguna (Philippines) survey of about 150 farmers generated cross-section and time series farm data from 1966 to 1971. Since these surveys were originally conducted for different purposes, the scope of our analysis and the empirical model have been somewhat limited by data availability.

## CONCEPTUAL FRAMEWORK

Because of the nature of the available data, it was necessary to analyze the factors affecting fertilizer demand in a simultaneous manner. Time series analysis cannot ignore shifts in production technology through time, e.g., the significant upward shifts in the fertilizer response function in Asia in the late 1960s caused by the introduction and widespread adoption of the new fertilizer-responsive rice varieties. The use of cross-section data for farms, villages, or countries requires a relatively wide geographical range to obtain adequate price variation for econometric analysis. Interlocational differences in the production function are also important.

The nature of the problem is shown in Charts 1a and 1b where hypothetical shifts or differences in fertilizer response functions are depicted along with their corresponding demand schedules. Shifts or differences in fertilizer response functions over time or across location as represented by $p_1, p_2, p_3$ may be due to differences in physical environment, e.g., climate and soil fertility, differences in levels of omitted inputs, e.g., irrigation and management capacity, or differences in the rate of adoption of technological innovations, such as improved seeds. When no explicit consideration is given to these phenomena, the demand curve D (Chart 1b) will be estimated, leading to an overestimate of the short-run price elasticity of demand. What is estimated in effect is a long-run demand function which measures the response to changes in prices along a long-run production function ($P$), an average of the different or shifting fertilizer response functions.

To explain fertilizer demand in the Asian rice economy, we attempt to take into account the factors responsible for shifts in fertilizer response functions to obtain more accurate estimates of the short-run price elasticity of demand for fertilizer used on rice. The demand function ($D$, $d_1$, $d_2 \ldots d_n$) implied by the production function ($P$, $p_1, p_2 \ldots p_n$) will be estimated with aggregate and farm level sets of data. Policy analyses based on aggregate data have frequently been criticized for lack of relevance to individual farmers. A comparison of the results from the aggregate and farm level data strengthens the basis for the policy implications of our empirical analysis.

[1] See Appendix A for a more detailed discussion of the sources of data.

TABLE 1.—FERTILIZER INPUT, RELATIVE FERTILIZER-ROUGH RICE PRICE RATIO AND RICE YIELD IN SELECTED ASIAN COUNTRIES, 1970*

| | Fertilizer (*kilograms nutrient/hectare*) | Fertilizer-rice price ratio | Rice yield (*tons/hectare*) |
|---|---|---|---|
| Japan | 482 | 0.70 | 5.64 |
| South Korea | 309 | 1.04 | 4.55 |
| Taiwan | 219 | 2.24 | 4.16 |
| Malaysia | 41 | 2.31 | 2.72 |
| Ceylon | 101 | 1.40 | 2.64 |
| Indonesia | 19 | 3.38 | 2.14 |
| Thailand | 24 | 3.18 - 11.11 | 1.97 |
| Philippines | 43 | 2.47 | 1.72 |
| Burma | 9 | 8.06 | 1.70 |

*From C.P. Timmer and W.P. Falcon, "The Impact of Price on Rice Trade in Asia," in G. Tolley (ed.), *Agriculture, Trade and Development*, Ballinger Press, Chicago, 1975.

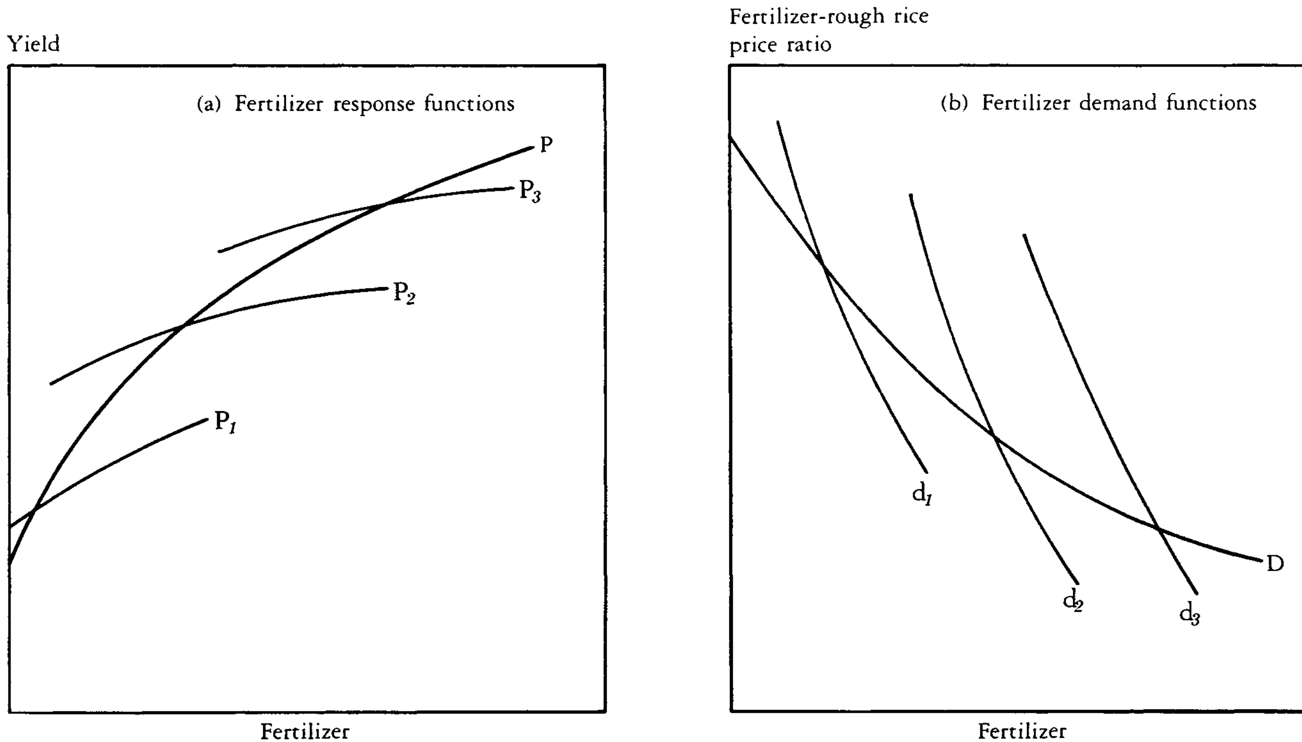
## THE MODEL

The demand models were developed to explain the wide variation in fertilizer application per hectare, across countries and across farms, in terms of differences in the fertilizer-rice price ratios, the variables representing differences (or shifts) in fertilizer response functions, and the liquidity position of farmers. The models are distinguished by the way differences in fertilizer response functions are measured among countries (Asian aggregate data), years (Laguna survey), and villages (Asian farm survey). Since the definitions of the variables differed for each set of data, only the basic outline of the models is presented in this section. Details of the models are presented in Appendix B.

In the aggregate data and Laguna survey analysis, variations in fertilizer response functions are assumed to be reflected in the differences in the intercept level and price elasticity coefficient of the fertilizer demand function. Covariance analysis is performed by including intercept and slope dummy variables pertaining to the fertilizer-rice price ratio by country in the aggregate analysis and by year in the Laguna data. The estimating equation is expressed in log linear form as:

$$\log F = \log a_1 + b_1 \log P + c_1 M + e_1 \log V + \sum_{2}^{m} a_i D_i + \sum_{2}^{m} b_i (D_i \log P) + u \qquad (1)$$

CHART 1.—HYPOTHETICAL SHIFTS IN FERTILIZER RESPONSE FUNCTIONS AND THEIR CORRESPONDING DEMAND FUNCTIONS



where $F$ denotes fertilizer input per hectare, $P$ is the relative price of fertilizer to rice, $M$ is the proportion of area planted to modern varieties, $V$ is the value of production (included only for the Laguna data), $D_i$ and $(D_i \log P)$ are the intercept and slope dummy variables to distinguish intercountry or interyear differences in the level and price elasticity of fertilizer demand, and $u$ is the disturbance term. By specifying the demand equation in log linear form, we implicitly assume a Cobb-Douglas fertilizer response function.[2]

Prices of other substitute inputs should theoretically have some impact on fertilizer demand. However, land, the input usually regarded as a substitute for fertilizer, can be assumed as fixed in the short run for the individual farmer and for the majority of the Asian countries.

Since the prices of fertilizer and of rice are included as a ratio instead of as separate arguments, it is implicitly assumed that the zero homogeneity condition holds for fertilizer demand. Under this assumption, farmers are expected to respond symmetrically between a lowering of the fertilizer price by one percent and a raising of the rice price by one percent. This assumption is made for convenience because of the difficulty in converting prices into a common currency in the intercountry analysis.

In the demand equations using farm level data, value of gross output is added as an independent variable to serve as a proxy for a farmer's ability to finance fertilizer similar to the role of income in other empirical estimations of fertilizer demand (6). Actual interest rates available to the farmer are a more direct measure of the credit constraint, but data on interest rates are not available. Farm size is another variable related to a farmer's ability to finance or borrow for the purchase of fertilizer. Contrary to our expectations, the data show fertilizer application to be generally higher among small farms. The role of fertilizer as a yield-increasing input to substitute for land appears to dominate farm size, offsetting the internal financing capability and access to institutional credit of larger farms.

Equation (1) cannot be applied to the Asian farm survey. Since the price data are already village-specific, specifying dummy variables to distinguish differences in price elasticity by village will lead to a singular model. Four variables have instead been specified in the demand equation to represent intervillage differences in the fertilizer response functions. In logarithimic form,

$$\log F = \log a_1 + b_1 \log P + c_1 M + c_2 \log N + c_3 \log W + c_4 R + e_1 \log V + u \qquad (2)$$

where $N$ is nitrogen required to obtain maximum yield based on experimental response functions from experiment stations located near the study village, $R$ is the average proportion of the rainfall for the two months prior to harvest

[2] Given a Cobb-Douglas production function with only one input, $Q = aF^{\beta}$ the input demand function derived by assuming profit maximization and constant product and input price is

$$F = \left(\frac{1}{a\beta}\right)^{1/\beta-1} (P)^{1/\beta-1}$$

where $Q$ denotes production and the other variables are defined as in equation (1).

(1967-71), and $W$ is the index of quality of irrigation (from 1-5) where 1 represents well-irrigated and 5 represents poorly irrigated or rainfed.

The variable $N$ needs further explanation. A large number of experiments showing the response of rice yield to nitrogen have been conducted at experiment stations throughout Asia. The approximate number of kilograms of nitrogen per hectare needed for maximum yield was determined from such experiments. In most cases, such information was available from stations reasonably near the study areas. When this information was unavailable, quantities were estimated using knowledge of the area and of similar areas. The considerable variation in the amount of nitrogen required to achieve maximum yield, ranging from 90 to 180 kilograms, is due largely to difference in soil and climatic factors. For example, in India the soils tend to be older and less fertile, and, as a consequence, maximum yields are obtained with much heavier rates of nitrogen than in the Philippines.

$R$ represents the weather. This variable is expected to be inversely correlated with yield since high rainfall would be associated with low solar energy in the critical period before harvest (*8*). The proportion of area planted to modern varieties, $M$, is a measure of the adoption of technological innovations that raise fertilizer response functions. The index of the quality of irrigation, $W$, was constructed by village, based primarily on the available description of the irrigation system in the village and on the proportion of farmers reporting inadequate water or poor drainage. The explicit specification of $W$ and $M$ is especially useful because these variables are amenable to policy induced changes.

## STATISTICAL RESULTS

The statistical results for the covariance analyses of the aggregate data and of the Laguna survey are presented in Tables 2 and 3, respectively. Table 4 contains the results of the analysis of the Asian farm survey based on a demand model using a different set of variables. All of the results of the stepwise regressions are presented in these tables because much can be learned from the attempt to compare alternative forms.

Both the aggregate and farm level regressions consistently demonstrated that relative prices 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 improved the goodness of fit of most equations dramatically.

The price elasticity derived from the simple relation between fertilizer use per hectare and the fertilizer-rice price ratio, which is remarkably stable across the three sets of data (-0.8 to -0.9), measures 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 since the estimation was based on the behavior of farmers under different situations of fertilizer productivity.

Covariance analysis requires relatively more observations to obtain meaningful estimates of short-run price elasticity since this procedure is equivalent to

TABLE 2.—FERTILIZER DEMAND FUNCTION ESTIMATED FROM ASIAN AGGREGATE DATA, 1950-72[a]

| | log a | Fertilizer-rice price ratio | Modern varieties | $R^2$ |
|---|---|---|---|---|
| Simple pooled analysis | 2.003 | -0.870 | — | 0.064 |
| | | (-3.490) | | |
| Covariance analysis | | | | |
| Japan | 1.660 | -0.723 | 1.191[b] | 0.928 |
| | [ 0.312] | [-0.191] | (3.927) | |
| South Korea | 1.389 | -0.931 | — | — |
| | [-0.157] | [-0.345] | | |
| Taiwan | 1.727 | -0.968 | — | — |
| | [ 0.397] | [-0.382] | | |
| Sri Lanka | 2.332 | -0.818 | — | — |
| | [ 1.230] | [-0.262] | | |
| Indonesia | 1.198 | -0.186 | — | — |
| | [-0.402] | [ 0.243] | | |
| Thailand | -0.277 | 1.192 | — | — |
| | [-2.563] | [ 1.412] | | |
| Philippines | 1.482 | -0.492 | — | — |
| | | (-0.416) | | |
| Burma | -0.200 | 0.563 | — | — |
| | [-2.394] | [ 0.875] | | |
| India | 2.045 | -1.671 | — | — |
| | [ 0.704] | [-0.845] | | |
| Pakistan-Bangladesh | 0.217 | 2.309 | — | — |
| | [-1.781] | [ 2.078] | | |

[a] Figures in parentheses refer to t-values of the variables above; 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.

[b] It is assumed that the coefficients for modern varieties do not vary by country.

estimating a separate equation for each group characterized by the same response function. The much shorter availability of time series data is the primary reason for the insignificant positive estimates of price elasticities in four of the countries (Indonesia, Thailand, Burma, and Pakistan-Bangladesh) shown in Table 2. Only about half of the time series was available for these countries and for India. It appears that our data do not permit the identification of the parameters of

TABLE 3.—FERTILIZER DEMAND FUNCTION ESTIMATED FROM LAGUNA FARM SURVEY, WET SEASON, 1966-71[a]

| | log a | Fertilizer-rice price ratio | Modern varieties | Value of output | $R^2$ |
|---|---|---|---|---|---|
| Simple pooled analysis | 2.005 | -0.800 (14.586) | — | — | 0.217 |
| Covariance analysis | | | | | |
| 1966 | 1.713 | -0.908 (-7.535) | 0.218b (7.134) | 0.023[b] (0.743) | 0.463 |
| 1967 | 1.592 [-1.218] | -0.321 [3.564] | — | — | — |
| 1968 | 1.934 [ 1.849] | -0.837 [ 0.335] | — | — | — |
| 1969 | 1.776 [ 0.636] | -0.842 [ 0.374] | — | — | — |
| 1970 | 1.844 [ 1.190] | -0.816 [ 0.475] | — | — | — |
| 1971 | 1.681 [-0.319] | -0.605 [ 1.512] | — | — | — |

[a] Figures in parenthesis 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 between the value of the coefficient for year to the coefficient of the base year, 1966.

[b] It is assumed that the coefficients for value of output and modern varieties do not vary by year.

fertilizer demand functions for these five countries. The values of the price elasticity estimates for the other countries are all negative and are generally of expected magnitudes. Among the countries with negative price elasticities, there appears to be more sensitivity to price changes in countries where fertilizer is relatively more important in the budget, such as Japan, Taiwan, and South Korea, in contrast to the Philippines, where fertilizer application is much lower.

In the Laguna data, the price elasticity of demand for fertilizer declined from -0.9 to -0.6 between 1966 and 1971. During this period, the rate of adoption of modern varieties rose from zero to 95 percent of total crop area in the sample farms. The spread of modern varieties is a highly significant factor shifting the short-run demand function through time in the Laguna survey and across countries in the aggregate data. Given the same relative price of fertilizer to rice, fertilizer demand would have been greater in 1971 than in 1966 and in the East Asian countries with complete adoption than in the Philippines (3).

In the analysis of the Asian farm survey, shown in Table 4, the use of variables, such as quality of irrigation and modern varieties, to represent differences in the productivity of fertilizer, allows policy implications to be derived directly from the analysis. As expected, maximum nitrogen, quality of irrigation, and proportion of area under modern varieties are all positively related to fertilizer demand. An inverse relationship between rainfall and fertilizer demand is expected since high rainfall prior to harvest implies low solar energy and thus low productivity of fertilizer.

The coefficient of value of output is statistically significant in the Asian farm survey, but 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 that either financing of fertilizer purchase is not a constraint to farmers' effective demand or value of output is not an appropriate proxy variable for farmers' liquidity of position, at least in the analysis of Laguna data.

## SOURCES OF FERTILIZER DEMAND

Table 5 contains estimates of the relative contributions of each of the explanatory factors to the gap in fertilizer consumption between the average and heaviest fertilizer user. The differences in the rate of fertilizer application per hectare are substantial—more than 200 percent in each case. Some significant differences exist in the estimated contributions of each factor across the three data sets. The results generally indicate, however, that differences in the fertilizer response functions provide the major explanation for the wide gap in fertilizer application. The contributions of the differences in the price elasticity in the aggregate data and the intercept level in the Laguna survey showed negative values. More important, however, is the sum of the contributions, since the inverse relationship between the values of the intercept and price elasticity estimates is simply a statistical phenomenon which does not have an economic interpretation.

The spread of modern varieties appears to be the dominant factor responsible for the shifting of the fertilizer response functions based on the aggregate data and on the Laguna farm survey. Modern varieties also include the effects of omitted variables in the demand function correlated with the adoption of modern varieties such as irrigation which may be particularly important for the aggregate data. In the Asian farm survey, maximum nitrogen (relating to the quality of environment) and quality of irrigation in the second model contribute more to the differences in fertilizer consumption than modern varieties, partly because very little within and between village variation in the adoption of modern varieties is present in the data.

Differences in the fertilizer-rice price ratio explain about one-third of the variations in fertilizer consumption except in the Asian farm survey where the average price ratio is very close to the average price ratio of the four villages with the highest fertilizer application. It is interesting to note the relatively higher contribution of the differences in the productivity of fertilizer (60 percent) to the differences in the 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 types of varieties and quality of environmental conditions in the Philippines in contrast to Japan.

TABLE 4.—FERTILIZER DEMAND FUNCTION ESTIMATED FROM DATA OF 33 SELECTED VILLAGES IN ASIA, WET SEASON, 1971-72[a]

| | log a | Fertilizer-rice price ratio | Modern varieties | Maximum nitrogen | Rainfall | Irrigation | Value of output | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| AFS - a | 2.035 | -0.863 | — | — | — | — | — | 0.170 |
| | | (-7.874) | | | | | | |
| AFS - b | 3.113 | -0.381 | 0.472 | 1.986 | 3.481 | -0.803 | — | 0.505 |
| | | (-3.444) | (12.196) | 10.475 | (22.635) | (-8.240) | | |
| AFS - c | 2.870 | -0.225 | 0.457 | 1.687 | 3.444 | -0.942 | 0.153 | 0.517 |
| | | (-1.993) | (11.868) | (8.737) | (22.570) | (-9.481) | (5.957) | |

[a] Figures in parenthesis are t-values.

TABLE 5.—PERCENT CONTRIBUTION OF THE VARIOUS FACTORS EXPLAINING DIFFERENCES IN LEVEL OF FERTILIZER USE BETWEEN TWO GROUPS OF FERTILIZER USERS IN EACH SET OF DATA

| | Means [a] | | Percent contribution to change in fertilizer input |
|---|---|---|---|
| | First group | Second group | |
| *Asian aggregate data* | | | |
| Fertilizer-rice price ratio | 3.2 | 0.8 | 40 |
| Intercept | 1.5 | 1.7 | 16 |
| Price elasticity | -0.5 | -0.7 | -10 |
| Modern varieties | 0.5 | 1 | 54 |
| *Laguna farm survey* | | | |
| Fertilizer-rice price ratio | 4.7 | 2.2 | 34 |
| Intercept | 1.7 | 1.6 | -5 |
| Price elasticity | -0.9 | -0.6 | 34 |
| Modern varieties | 0 | 0.9 | 35 |
| Value of output (*P/farm*)) | 2,517 | 4,563 | 2 |
| Fertilizer per hectare (*kg.N/ha.*) | 17 | 63 | — |
| *Asian farm survey* | | | |
| Fertilizer-rice price ratio | 3.2 | 3.0 | 4 |
| Modern varieties | 0.6 | 0.8 | 27 |
| Maximum N (*kg.N/ha.*) | 126 | 165 | 84 |
| Quality of irrigation | 2.7 | 2.0 | 52 |
| Rainfall | 0.3 | 0.2 | -73 |
| Value of output (*$/farm*) | 485 | 388 | 15 |
| Fertilizer per hectare (*kg.N/ha.*) | 63 | 130 | — |

[a] In the Asian aggregate data, the first group refers to the values of the variables for the Philippines representing the country with an intermediate level of fertilizer application per hectare and the second group refers to Japan, the country with the highest fertilizer consumption. 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. 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.

## CONCLUDING COMMENTS

Fertilizer response functions can be raised by improving the quality of irrigation or by developing modern varieties suitable to a wider range of environmental conditions. The costs of these changes relative to those of changing the fertilizer-rice price ratio should be considered in designing policies to raise fertilizer application on rice farms. More detailed information and a different methodology are required to determine the comparative costs of alternative policies to increase fertilizer demand, e.g., changing the relative price of fertilizer to rice by price supports versus subsidizing agricultural research or expanding irrigation. (See, for example, *4* and *1*.)

The time horizon facing the policy maker is one of the critical considerations affecting the choice of policy. Price policy may be preferred because of its short run impact on fertilizer demand in contrast to policies which shift the fertilizer response function. This study makes an important contribution to policy analysis by providing improved estimates of price elasticities of fertilizer used on rice. As emphasized in this analysis, differences in fertilizer response functions should be included in the derivation of accurate estimates of short-run price elasticities.

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