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THE DEMAND FOR FERTILIZER IN DEVELOPING COUNTRIES*

Fertilizer demand in developing countries has been an important topic for a long time. Projections of demand of varying sophistication have been made by international agencies, the fertilizer industry, and individual experts for over two decades. Perhaps a fresh look and reappraisal would have been desirable in any circumstance, but the markedly changed economic environment for food and fertilizer made a new assessment essential. Projection methodologies primarily tuned to population and income growth and interaction with new seed technologies must be re-tuned to answer questions about the short-run and long-run impact of changing prices.

This paper will focus primarily on the impact of the new price environment on the demand for fertilizer in the developing countries. The topic is too broad to handle unselectively; major emphasis is devoted to the demand for nitrogenous fertilizers for application on the major cereal crops. This narrowly defined demand holds most of our interest, however. In 1971/72 the consumption ratio of $N:P_2O_5:K_2O$ for the developing countries was 1.0:0.47:0.26 (*5*, p. 43). Nitrogen applications formed well over half the total, and scattered but consistent reports indicate that a significant majority of this was applied to cereal crops. Since the major cause of present concern about fertilizer supply and demand is their direct bearing on the adequacy of the world's food supply, primarily food grains, the narrowed focus of this paper seems defensible.

No new projections are provided here. The primary intent is not to compete with those individuals and organizations who have far superior knowledge of the basic data and underlying national environments but rather to review some of the existing methodology for understanding fertilizer demand and to put some of the empirical results in comparative perspective. The focus is on basic parameters and their interaction rather than projections.

A major shortcoming of nearly all existing work on fertilizer demand is its micro-perspective. The demand for fertilizer is derived, via the physical production function, from the demand for food and fiber. The derivation via the production function has been used extensively to determine normative demand

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curves as output or input price varied exogenously. Alternatively, a number of long-run fertilizer demand projections assume a growth in food demand from income and population and work backward by way of some response function to the level of fertilizer applications needed to produce a food supply adequate to meet the projected demand. But seldom are the equilibrium conditions for food price connected to fertilizer demand. The implications of this macro-connection are examined in this paper after the review of existing micro-work. The last section attempts to summarize the state of knowledge about the basic parameters affecting the outlook for fertilizer demand. Several areas of relative weakness are identified with present major opportunities for high payout research by both agronomists and economists.

DETERMINING THE IMPACT OF FACTORS AFFECTING FERTILIZER DEMAND

Even a cursory review of the literature reveals an amazing number of variables that have been specified in equations attempting to explain fertilizer consumption. Fertilizer price, crop price, and acreage are the major factors suggested by the simplest economic model, but farm income, capital assets, interest rates, education, experience, distance from town, and time are some of the more reasonable factors that have also been included in some manner.

The primary focus here is to understand the impact of price; considerable attention is devoted to methodology and to results with respect to price. But other variables are not neglected altogether, especially those whose impact might logically be an indirect function of price in either the short run or long run.

Indirect Estimation

Perhaps the most appealing approach to economists for determining the impact of price on fertilizer demand is by using the profit maximization conditions applied to agronomic fertilizer response functions. The calculus is straightforward for most common production and response functions, and E. O. Heady and L. G. Tweeten (*13*) provide a wide range of examples, especially for various *ceterus paribus* assumptions. This approach has two critical elements. First is the necessity to assume some sort of maximizing behavior on the part of farmers and second is knowledge of the relevant agronomic function.

Risk.—Profit maximization without regard to risks, uncertainty, knowledge and perhaps other constraints would almost certainly be a poor characterization of the behavior of nearly all farmers anywhere in the world. As a result, the ratio of marginal revenue to marginal cost of fertilizer application nearly always exceeds one. For the years 1960–64 in the United States, for instance, the average marginal return per dollar spent on fertilizer was $2.50, but it varied from $1.60 in the Corn Belt to $7.30 in the Northern Plains (*18*). Even higher returns would be expected and have been reported for underdeveloped countries where farmers have less knowledge and may face greater risks (or be more averse to risk). Thus the extent to which farmers fail to equate marginal revenues and marginal costs is an additional and critical variable in any indirect approach to determining the impact of price on fertilizer use by farmers. Very little is known about the factors affecting this proportion; it may well be that price, or price variability, should be one of the arguments in the function. The work by Alain de Janvry on optimal levels of fertilization under risk in Argentina is a very helpful point of departure (*19*).

Knowledge.—The other essential element in the indirect approach is knowledge of the proper agronomic response function with respect to fertilizer and other inputs. The problem is not finding the functions; literally thousands have been estimated. The problem is finding the *appropriate* function because of their incredible diversity. The diversity cuts through many sorting criteria: crop, location, year, water control, and so on. This is not the place to reveal fully the diversity nor to attempt to understand its causes. Still, some glimpse of the problem is essential to understanding the difficulty in using these micro-response functions to explain adequately likely farmer response to changing prices.

Response functions.—Over a decade ago R. W. Herdt and J. W. Mellor (*15*) noted the impact of vastly different responses of rice to nitrogen in India and the United States. The most profitable application rate of nitrogen in the United States was nearly four times higher than in India, and net profit per acre was from ten to fifteen times higher. Obviously, fertilizer demand *levels* at a given price are very different in India than in the United States, but there is no apparent lesson in this as to how fertilizer demand changes as price changes. Relatively flat fertilizer response functions, such as those shown by Herdt and Mellor for India, *imply* relatively substantial changes in fertilizer application for small changes in price while the steeper and more rounded functions for the United States *imply* relatively smaller changes. But since the risk-uncertainty-knowledge parameter in India is almost certainly different from that of the United States, it is difficult to predict *a priori* where response to price will be greater, especially if price level or variability affects the size of the risk-uncertainty-knowledge parameter.

Given both the theoretical and empirical importance of the yield response to fertilizer in determining the demand for fertilizer, the fact that it varies all over the map is slightly distressing. Tables 1, 2, and 3 report a small sampling of the available yield response data for various crops around the world. Nitrogen response for rice in Asia varies from 4.7 to 10.5 kilograms. For rice in Africa the response to mixed fertilizer varied from 2.3 to 13.7 kilograms of rice per kilogram of fertilizer nutrient. Response of wheat in North Africa and West Asia varied from 2.4 to 8.2 kilograms per kilogram of nutrient. The implied net return per dollar of fertilizer cost varied from $0.80 to $12.00.

The differences are not just because of different cereals in different countries. Variety is also critical within the developing countries. This has been demonstrated for maize for many years, as Table 3 shows, and the International Rice Research Institute (IRRI) and the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) have produced high-yielding varieties of wheat and rice as well. Randolph Barker and associates at IRRI have summarized the great diversity they found in analyzing experimental results of nitrogen response of rice (2, p. 1):

> The spread of the seed-fertilizer revolution to South and Southeast Asia has increased the need for information on the optimum level of fertilizer input

TABLE 1.—RESULTS OF FERTILIZER TRIAL DEMONSTRATION ON RICE AND WHEAT, SELECTED COUNTRIES*
(Kilograms unless otherwise specified)

Crop and country	Fertilizer applied per hectare (N, P_2O_5, K_2O)	Increase in yield per hectare	Increase in yield per kilogram of fertilizer	Net return per dollar of fertilizer (*dollars*)
Rice (paddy)				
El Salvador	45-45-45	1,052	7.7	$ 4.60
Ghana				
Forest	22-22-22	903	13.4	3.70
Savannah	45-45-45	1,847	13.7	3.80
Nigeria				
Forest	22-22-22	506	7.6	1.70
Savannah	22-34-67	289	2.3	1.00
Senegal				
Casamance	0 - 0 -45	497	11.0	12.00
Fleuve	0 - 0 -45	396	8.8	10.00
Sine Saloum	45- 0 - 0	425	9.4	3.50
Wheat				
Lebanon				
Akkar	40-35-20	780	8.2	2.80
Morocco				
Casablanca-Rabat	20-37-47	386	3.7	1.40
Fes Meknes-Taza	20-37-47	245	2.4	.80
Tetouan	20-37-47	462	4.4	1.70
Syria				
Irrigated	60-60-60	866	4.8	1.10
Non-irrigated	0 -40- 0	252	6.3	1.30
Turkey				
Central Anatolia	0 -60- 0	430	7.2	2.30
Thrace	60-60-60	1,010	5.6	2.70

* Data are from Food and Agriculture Organization, *Review of Trial Demonstration Results, 1961–62, FFHC Fertilizer Program*, January 1964, here reproduced from *25*, p. 6. Results shown include only that fertilizer application showing the largest additional return per hectare of the crop. In some instances, a different fertilizer application than that indicated produced a larger increase in yield and a higher net return per dollar spent for fertilizer.

> in this part of the world. But the physical and cultural rice growing environment of tropical Asia is large and heterogeneous, technology is changing fairly rapidly, and hence the task of obtaining adequate information is both difficult and challenging.

The tables and figures attached to that analysis are even more striking in terms of the amazing diversity they show. Similar diversity is shown in other materials. An especially useful source is the crop response data generated by the Freedom From Hunger Campaign (FFHC) fertilizer program (*6*).

Prescriptive approach.—Both the work done by Barker and his associates and similar analyses done under the auspices of the Agricultural Diversification and Marketing (ADAM) project in the Philippines (*26*) are changing the relevant questions about fertilizer response functions. In a different paper Barker argues that (*1*, p. 4):

TABLE 2.—RICE YIELD RESPONSES FROM FERTILIZER APPLICATIONS, SELECTED APPLICATIONS*
(Kilograms per hectare)

Country	Yield per hectare without fertilizer	Increase in yield per kilogram of		
		Nitrogen	Phosphate	Potash
Burma	1,432	4.7	2.6	1.0
Ceylon	1,476	5.2	5.6	1.0
East Pakistan	991	10.5	7.1	3.3
Ghana	749	9.1	9.1	6.1
India	1,230	9.9	6.5	—
Iran	2,049	7.6	8.2	1.2
Thailand	1,172	9.0	8.8	3.2
Vietnam	1,271	5.4	4.9	.7
South Korea	2,350	8.0	.5	1.1

* Computed from the Food and Agriculture Organization report, *Statistics of Crop Responses to Fertilizer* (Rome, 1966). Increases in yields are those resulting from application of 30 kilograms of each plant nutrient per hectare except in the case of South Korea where yield increases are those resulting from 60 kilograms. Based on field trials in the late 1950s and/or early 1960s.

TABLE 3.—INTERACTION OF VARIETY AND FERTILIZER ON MAIZE YIELDS, NORTHERN INDIA, 1960 AND 1961*
(Kilograms per hectare)

Practice	Bushels per acre	Yield	Increase
Native variety, no fertilizer	37.5	2,000	—
Native variety, plus fertilizer	55.3	3,100	1,000
Hybrid, no fertilizer	57.8	3,300	1,200
Hybrid, plus fertilizer	92.3	5,200	3,100

* Data are from C. E. Kellogg, "Interactions in Agricultural Development," in *United States Papers Prepared for the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas, Vol. III–Agriculture* (U.S. Agency for International Development, Washington, D.C., 1962).

> The analysis of fertilizer response can be useful. But the major problem is not necessarily one of determining the optimum level of fertilizer input, but rather of identifying the factors that constrain yield response on farmers' fields. Our objective should be one of identifying and removing constraints so that returns to fertilizer become more profitable and involve less risk. We must examine carefully the whole management package—water management, weed control, disease and insect control, etc., so that the potential of the high yielding varieties that is clearly visible in the experiment station can become a reality on a larger number of farmers' fields.

This approach is even more important when fertilizer is an expensive and scarce commodity. It then becomes critical that the farmer actually realize the high potential response to his fertilizer application.

The approach that Barker advocates would solve the problem of projecting fertilizer demand by determining what is necessary in terms of satisfactory agricultural development and then finding the ways to achieve that desirable level. This prescriptive rather than predictive approach is entirely acceptable as an agricultural development strategy, but if it is not practiced uniformly around the world, it still leaves a global predictive problem. Also, to the extent that shortcomings exist in achieving the prescription, then further demand models are needed.

Direct Estimation

In other words, neither the indirect demand functions derived from agronomic response functions nor the prescriptive approach to fertilizer demand that has evolved from research on such functions offers much hope of understanding in an aggregate fashion the factors affecting the demand for fertilizer and especially the likely impact of the new price environment. These shortcomings were perceived long ago, and considerable work has been done in the past two decades on a more direct approach: estimating fertilizer demand functions directly from observed market data on fertilizer consumption, prices, and the prices of farm output.

Distributed lag models.—Modern work on direct estimation of fertilizer demand functions dates from the results using Nerlove's distributed lag technique reported by Zvi Griliches in 1958 (*8*). Prior to this, very few attempts had been made to estimate fertilizer demand functions directly, even in the simplest fashion of fertilizer demand as a function of the relative price of fertilizer to product price. Griliches reports such an attempt by E. E. Vail (*34*) in 1927 with insignificant results. Subsequent estimations of simple static demand functions have also frequently failed to discern significant price impact on demand. A. K. Parikh, in his work on Indian demand for nitrogenous fertilizers, for instance, found the price of nitrogen an insignificant factor in all states between 1951 and 1960. The sign was not even consistently negative (*24*).

The Nerlovian adjustment model used by Griliches and many subsequent workers seems to capture some of the dynamic elements in fertilizer demand better than simple static models without merely resorting to time trends. The model itself is straightforward. Let capital letters denote logarithms of the relevant variables. Then

$$F_t^* = \alpha_0 + \alpha_1 P_{ft} + \varepsilon_t, \tag{1}$$

where F_t^* = desired fertilizer consumption in long-run equilibrium,
P_{ft} = price of fertilizer at time t relative to the price of agricultural output at time t, and
ε_t = a random disturbance term.

Naturally, other prices might enter equation (1) as well. Economic theory dictates that the relative prices of other variable inputs (that have market prices) should also be included. These prices were statistically insignificant in Griliches' work and are omitted here for simplicity. In addition, the zero homogeneity condition on the demand function predicted by economic theory is imposed here so that the price of fertilizer enters only relative to the price of agricultural output. Considerable discussion has taken place on the empirical validity of this assumption. What little empirical evidence exists does not contradict it, but the evidence is all for developed countries (*4*; *12*, p. 334; *13*). Whether the assumption holds for developing countries as well is doubtful, and the issue is of great importance for policy formulation. If, as Raj Krishna (*20*) argues, the impact on fertilizer demand of a one percent increase in a crop price is not symmetric with a one percent decline in the price of fertilizer, the consequences for governmental price policy, not to mention fertilizer demand projections, are enormous.

Actual fertilizer use does not adjust immediately to desired use, but only through proportional changes. Thus

$$F_t - F_{t-1} = \gamma(F_t^* - F_{t-1})\,, \qquad (2)$$

where F_t = actual fertilizer consumption in time t, and
γ = adjustment coefficient ($0 \leqq \gamma \leqq 1$).

With the variables in natural units, equation (2) states that $f_t/f_{t-1} = (f_t^*/f_{t-1})\gamma$, or that the relative (percent) change in actual consumption is a power function of the relative (percent) difference between the desired level and the actual level.

Substituting equation (1) directly into equation (2) and rearranging terms yields equation (3), which, with appropriate assumptions about and behavior of the error term, is suitable for estimation by ordinary least squares (or a variation if autocorrelation of the residuals is a problem).

$$F_t = \alpha_0 + \alpha_1\gamma P_{ft} + (1-\gamma)F_{t-1} + \gamma\varepsilon_t\,. \qquad (3)$$

Since the variables are in logarithms, the *short-run* elasticity of demand for fertilizer with respect to its relative price is given by the estimate of $\alpha_1\gamma$ and the *long-run* elasticity is given by $\alpha_1 = \alpha_1\gamma/1 - (1-\gamma)$.[1] Griliches' results for United States demand for total fertilizer nutrients over the 1911–56 period indicated a highly significant, short-run price elasticity for fertilizer of about −0.5 and an adjustment coefficient of approximately 0.25. Combined, these indicate a long-run price elasticity for fertilizer of about −2.0. The fraction of the disequilibrium eliminated within one year depends on the initial magnitude of the disequilibrium, but for the relevant range "approximately 25 percent of the indicated adjustment is completed within one year and 78 percent in five years" (*8*, p. 602).

A significant amount of work has been done by Griliches on United States fertilizer demand using this model, especially on a regional basis (*7*). The model nearly always performs well because the presence of the lagged dependent variable "captures" the effects of excluded but otherwise relevant independent variables, thus yielding a more fully specified equation. As Griliches firmly points out (*7*, pp. 39–99), this leads to difficulty in interpreting the estimated value of the adjustment coefficient. Since the coefficient attached to the lagged dependent variable $(1-\gamma)$ is likely to be biased upward, the resulting estimate of the adjustment coefficient itself (γ) will be too small. But similar specification bias probably leads to an underestimate (in absolute terms) of the short-run elasticity,

[1] Short-run and long-run are used throughout this study in the Marshallian sense that consumers require some time to adjust fully to a price change. This usage, also adopted by Griliches, does not correspond to the distinction between short-run and long-run cost curves developed by Viner. The long-run to Viner meant only that all costs had become variable and thus it had no necessary time dimension. The Marshallian and Vinerian concepts can be merged by assuming that management is an input to the production function and its level of input (with respect to choosing the profit-maximizing level of fertilizer use) is a function of time of exposure to a new price environment.

TABLE 4.—SUMMARY OF FERTILIZER DEMAND STUDIES IN DEVELOPING COUNTRIES

Country and source	Time period	Elasticity of demand[a]		Adjustment coefficient	Comments
		Short-run	Long-run		
Brazil (*21*)	1949–71	−1.12[b]	—	—	OLS estimate with area cultivated included in equation. Real average price of all fertilizer, significant autocorrelation.
		−0.33[c]	−1.94	0.17	Same as traditional model but no autocorrelation using dynamic model.
India (*27*)	1953/4–67/8	−0.31[d]	−0.34	0.92	Demand function for nitrogen fertilizer contains area irrigated.
		−0.53[c]	−6.63	0.08	Same, but equation excludes area irrigated.
(*23*)	1958/9–63/4	−1.2[d]	−2.5[b]	0.50	Analysis of covariance results for nitrogen consumption using Indian state data. The short-run response is from an equation that includes separate state intercepts; the long-run elasticity excludes them. The adjustment coefficient is calculated from the two responses.
Japan (*10*)	1883–1937	—	−0.74[b]	—	Price elasticity estimated by OLS for total fertilizer use utilizing five years averages as observations. Thus the elasticity is more long-run than short-run in nature.
Korea (*31*)	1960–72	−0.17	−0.88	0.2	Lagged adjustment model using deflated price index of total fertilizer paid by farm.
(*29*)	1971	−0.70[b]	—	—	OLS estimate from cross-section survey of 300 farmers. Equation contains many other farm specific variables.
Philippines (*28*)	1958–72	−0.59[b]	—	—	OLS: Equation includes sugar and corn hectarage and rice yield. Price elasticity for CIF nitrogen value deflated by consumer price index.
Taiwan (*17*)	1950–66	−0.55[c]	—	—	Demand function for nitrogen using relative price of rice to nitrogen. Equation contains lagged yield which is highly significant.
		−2.03[b]	−2.99	0.68	Dynamic equation excludes lagged yields but price and fertilizer variables the same.

[a] Demand elasticity for all nutrients unless otherwise noted.
[b] Denotes significance at 0.9 or higher.
[c] Denotes significance between 0.8 and 0.9.
[d] Denotes significance between 0.7 and 0.8.

and so the calculated long-run elasticity may in fact not be biased too badly (*7*, pp. 96–97).

Application in developing countries.—Despite the success of the adjustment model in capturing the dynamics of adjustment to fertilizer price changes in the United States and other mature agricultural economies (see the highly successful work by K. Cowling, D. Metcalf and A. J. Rayner [*4*] for the United Kingdom), the model is difficult to apply in developing countries primarily because of inadequate fertilizer price statistics at the farm level and typically short data series. Four examples have been located so far: the work on Brazil by a group at Ohio State (*21, 22, 38*), on South Korea by B. Y. Sung, D. C. Dahl, and Y. K. Shim (*29, 30, 31*), by R. C. Hsu for Taiwan (*17*) and by M. S. Rao for India (*21*). The works by M. H. Yeh for Manitoba (*39*), Gil Rodriguez for the Philippines (*28*), Yujiro Hayami for Japan (*10*), and A. K. Parikh for India (*23*) are intermediate examples. The major results from these works are summarized in Table 4.

The results for Brazil show the significant differences between traditional static demand models and dynamic adjustment models. The price elasticity estimated from the traditional model is −1.12, a value nearly midway between the short-run and long-run elasticities of −0.33 and −1.94 respectively estimated with the dynamic adjustment model. The low adjustment coefficient of 0.17 is almost certainly due to the propensity of the lagged dependent variable to capture the contribution of excluded variables. Consequently, following Griliches' reasoning, the short-run elasticity is probably also too low while the long-run elasticity of about −2.0 is likely to be about right. Better specification would probably yield a short-run elasticity closer to that estimated from the traditional static model, with an implied adjustment coefficient closer to 0.5 than to 0.2.

Although a much shorter time series led to lower price elasticities and little statistical significance for the Korean estimates (*31*), the results for the dynamic model are similar to those for Brazil. The conclusion that the time series estimates are too low is based on the cross-section elasticity of −0.7, a value that is highly significant (*29*). Enough variation in fertilizer price was caused by transportation and marketing costs to permit significant cross-section price elasticities even when many other farm specific variables were included as well. Correction for individual farm characteristics generally transforms a long-run price response to a smaller short-run response. The value of −0.7 for Korea can thus be interpreted as a reasonable estimate of the short-run elasticity of farmer response to changes in fertilizer price.

Hsu attempts to use both a traditional static demand model and a dynamic adjustment model to explain consumption of individual fertilizer nutrients in Taiwan from 1950 to 1966. Only the functions for nitrogenous fertilizers are reasonably satisfactory. The static model, which contained both lagged yields (a proxy for income and hence ability to buy fertilizer) and time, suffered from significant multicollinearity. When only the relative price of nitrogen to rice and lagged yields were included, the price elasticity was −0.55 and significant at a 20 percent confidence level while the coefficient of lagged yield was highly significant with an elasticity of 1.5. The dynamic adjustment model was much more successful, however. The short-run price elasticity was −2.0 and the adjustment coefficient was 0.68 (the coefficient attached to the lagged dependent variable was

0.32), implying a long-run price elasticity of −3.0. Both coefficients were very highly significant. Thus the dynamic adjustment model was much superior to the static model, even when the latter introduced time or income proxy variables.

The work by Rao for India is not nearly so conclusive. No static demand functions are reported, but the two dynamic demand equations for nitrogenous fertilizer can be given a partial static/dynamic interpretation. Table 5 reports Rao's results more fully than the summary in Table 4.

On the basis of the second equation Rao reports that the short-run elasticity of demand for nitrogenous fertilizers with respect to their real price is −0.53 while the long-run elasticity is −6.36 with an adjustment coefficient of 0.08 (*27*, p. 37). This result must be interpreted very carefully because of the probability of the type of specification bias outlined by Griliches (*6*). In fact, the long-run elasticity calculated from Rao's first equation is only −0.34. The dramatic difference—the long-run elasticity from the first equation is smaller than the short-run elasticity from the second equation—is caused by dropping the irrigated-acreage variable from the first equation where it had been very highly significant. The result was that the lagged dependent variable captured most of the impact of the acreage variable and its coefficient flip-flopped from 0.08 to 0.92. Since irrigated acreage almost certainly exerts a significant and independent influence on nitrogen application, its omission will badly bias the estimate of the adjustment coefficient. Thus the long-run price elasticity of −6.36 is certainly too large, possibly by a factor of two or three. With this proviso, the short-run and long-run responses to prices of fertilizers reported for Brazil, Korea, Taiwan, and India are reasonably consistent with each other and, perhaps surprisingly, also consistent with Griliches' values for the United States.

Three other studies report results of fertilizer demand estimations using forms other than the dynamic adjustment model. The simple ordinary least squares (OLS) estimate by Rodriguez for the Philippines (*28*) shows a significant response of nitrogen fertilization to price for the 1958–72 period, with an elasticity at mean values of about −0.6. His attempt to include the fertilizer demand function in an entire system of simultaneous equations yields smaller and less significant elasticities.

TABLE 5.—DEMAND EQUATIONS FOR NITROGENOUS FERTILIZER (N) INDIA, 1953–54 TO 1967–68*

Dependent variable	Independent variables			
	Log real price of fertilizer	Log area irrigated	Log N_{t-1}	$\bar{R}^2$
Log N_t	−0.31[a] (0.24)	7.15[c] (2.08)	0.08 (0.25)	0.99
Log N_t	−0.53[b] (0.32)	—	0.92[c] (0.07)	0.98

* Source: M. S. Rao, "Protection to Fertilizer Industry and Its Impact on Indian Agriculture" (*27*). Figures in parentheses are standard errors.

[a] Denotes significance at 24 percent.

[b] Denotes significance at 13 percent.

[c] Denotes significance at one percent.

Hayami, using a simpler model than Griliches, attempts to separate the increased demand for fertilizer in Japan from 1883 to 1937 into a price-induced component and a technology-induced component (*10*). Due to limited data he was forced to use a time variable as a simple surrogate for technological change. To avoid adjustment problems and the difference between short-run and long-run response, Hayami estimated his logarithmic functions with five-year averages (quinquennia) as observations. Both time (technology) and price were significant variables in explaining total fertilizer consumption with price changes accounting for over a quarter of the total change in consumption. The price elasticity of −0.74 should be interpreted as close to a long-run response due to the use of five-year averages as observations. An adjustment coefficient of 0.5 implies that after a price change, about three quarters of the total adjustment to a new equilibrium occurs in five years. On the other hand, the adjustment is not total and hence the response coefficient may well be biased somewhat downward. It would be interesting to try the Griliches model directly on Japanese fertilizer data now that a sufficient time series of observations is available.

Parikh has reported results on consumption of nitrogenous fertilizers in India for the period 1958–59 to 1963–64 (*23*). Although he did not use a Nerlovian dynamic adjustment model because of the short time series, Parikh was able to estimate an analysis of covariance response function (which included irrigated acreage) because he had a cross section of observations by state. Without separate intercept terms for each state the implied price elasticity (at sample means) was −2.5. Parikh interprets this as a long-run response. When separate intercept terms are introduced for each state, the price elasticity drops to −1.2 and is only marginally significant. Because different states have different resource endowments and long-run adaptations to them, controlling for state differences leaves only the short-run impact of price. While no adjustment coefficient is estimated in this model, such a coefficient is implicit in the difference between the short-run and long-run coefficients. For Parikh's data and results, the implied adjustment coefficient is approximately 0.5. These values, too, are reasonably consistent with the results discussed previously.

Impact of Other Factors

Apart from goodness of fit criteria, the dynamic adjustment model is appealing for its simple elegance. A great deal is explained from a single economic variable and a simple assumption about adjustment behavior in disequilibrium situations. Still, other factors than relative fertilizer prices influence farmer demand for fertilizer: the farmer's knowledge of the profitability of fertilizer, availability of liquid capital to purchase fertilizer for application at planting time although the benefits are not reaped until harvest, credit-worthiness and interest rates if liquid capital is not available, form of land tenure, and so on. These are difficult variables to measure in their correct form, and suitable proxies are difficult to find. The dynamic adjustment model finesses the difficulties by specifying that the long-run demand model depends only on relative prices of fertilizer and other inputs. Although capital availability and knowledge may be limiting in the short-run, for instance, *their impact is via the rate of adjustment* and not the level of long-run demand.

Capital constraints.—Farm income is the variable most frequently used to serve as a proxy for capital availability and hence farmers' ability to buy fertilizer. But Griliches points out that "There is no good theoretical reason for including income in the demand equation for a factor. At least it is not derivable from the traditional theory of the firm" (9, p. 310). But this is true only for unconstrained profit maximization. Consider the theoretical implications of a firm operating under a liquid capital constraint, equal to K. Then profit maximization is no longer unconstrained.

If output is taken to be an exponential function of fertilizer applications, with other inputs held constant, and profit maximization is unconstrained, then the optimum level of fertilizer use is shown in equation (4):

$$f_0 = \left(\frac{1}{\beta}\right)^{\frac{1}{\beta-1}} \left(\frac{p_f}{p}\right)^{\frac{1}{\beta-1}}, \tag{4}$$

where f_0 = optimum level of fertilizer application,
β = output elasticity of fertilizer ($q = f^{\beta}$),
p_f = price of fertilizer, and
p = price of output (q).

When a capital constraint K is introduced, it is necessary to alter the simple profit calculus. Using the same response function as above, the constrained profit maximization expression is formed as follows:

$$\pi = pq - p_f f + \lambda(K - p_f f), \tag{5}$$

where π = profit,
K = maximum amount of capital funds available for purchasing fertilizer, and
λ = a Lagrangean multiplier used to introduce the constraint K. Note that when K is a binding constraint that $K - p_f f = 0$. If $K > p_f f$, then $\lambda = 0$.

The same maximization technique that led to equation (4) now yields a new expression for the optimum level of fertilizer use under a capital constraint:

$$f_0 = \left(\frac{1+\lambda}{\beta}\right)^{\frac{1}{\beta-1}} \left(\frac{p_f}{p}\right)^{\frac{1}{\beta-1}}. \tag{6}$$

The only impact of introducing a capital constraint on fertilizer purchases is to shift the *intercept term* in the demand function for fertilizer because of the presence of λ. Price responsiveness is not a function of λ or of K. Thus capital constraints affect the level of fertilizer use but not the extent to which farmers react to prices. This is an important distinction in the short-run. On the other hand, the value of λ is a function of both K and p_f so that a change in either the capital constraint or the price of fertilizer will (at least when $\lambda \neq 0$) change the value of λ and hence indirectly affect the demand for fertilizer. This indirect, possibly longer-run, adjustment mechanism may also be important, but no evidence exists within the context of dynamic adjustment models to confirm or deny this hypothesis.

Substantial evidence from static demand models, however, attests to the importance of some sort of capital constraint on fertilizer use. Griliches notes that several studies conducted by the United States Department of Agriculture (USDA) in the 1940s examined factors affecting fertilizer use. "Most of these studies were concerned with the relationship between expenditures on fertilizers and lagged farm income. It was claimed that farmers spend a constant proportion of their income on fertilizers" (*8*, p. 593). While this naive hypothesis was not very powerful, subsequent work reported by Heady and Yeh (*12*), Heady and Tweeten (*13*), and Cowling, Metcalf and Rayner (*4*) demonstrates the significance of some specification of income in explaining fertilizer demand. Heady and Yeh consistently find elasticities of demand for fertilizer with respect to lagged cash receipts from farming of 0.6 to 0.8 for the United States and between 0.24 and 1.27 for the 10 agricultural regions. While somewhat variable these values are all highly significant even with time in the equation as well. On the other hand, the significance does not stand up when an index of crop prices is introduced because of the high correlation between crop prices and crop receipts.

The work on British agriculture reported by Cowling, Metcalf and Rayner shows a similar significance for lagged farm income in static fertilizer demand functions. They use a three-year weighted income index with declining weights of 3, 2, 1. For total plant nutrients they report an elasticity of 0.63 when time is included in the specification. The own price elasticity in this equation is −1.7. For consumption of nitrogenous fertilizers alone the lagged weighted income elasticity rose to 1.9 and was much more significant, while the price elasticity dropped somewhat to −1.1. The authors attributed this shift to the importance of grassland applications in total nitrogenous fertilizer demand. Neither Heady and Yeh nor Cowling, Metcalf and Rayner report any results of including an income variable in a dynamic adjustment model.

The work reported by Heady and Tweeten on time series demand functions is the only material to come to light so far that bears directly on the impact of the credit constraint relative to static or dynamic specification of the demand model. Even this extraordinarily extensive empirical work does not speak directly to the issue of aggregate United States demand. Only a single equation (7.4), is shown to indicate that income or capital assets play a role even in static functions (*13*, p. 167); a variable defined as "the stock of productive farm assets on January 1 of the current year" has a highly significant elasticity of 2.6.

But when fertilizer consumption is disaggregated to the 10 major agricultural regions, Heady and Tweeten report some very interesting results of including an income variable in both static and dynamic functions. When cash receipts from farming are included in the 10 regional demand equations with the ratio of fertilizer prices to crop prices and time, the *average* elasticity for the 10 regions is 0.9004 with an average t-statistic of 2.93. When the same cash receipts variable is included in a similar equation but with a lagged endogenous variable included as an independent variable (i.e., in a dynamic adjustment model), its average estimated elasticity drops to 0.3528 with an average t-value of only 1.4, indicating that the variable is only marginally significant. However, when the lagged endogenous variable is included without the cash receipts variable, but with relative prices and time, its average coefficient is 0.5950 with an average t-value of 5.34. In the equation where both cash receipts *and* lagged fertilizer consumption are included with fertilizer price and time, the average value of the lagged consumption variable drops to 0.4321 with a *t*-value of 3.5 (calculated from Tables 7.13 and 7.14, *13*, pp. 186–7). Thus the income term in the dynamic model remains only marginally significant.

The picture that emerges from these studies tends to support the hypothesis that income (or some capital constraint) is important in short-run, static demand equations but that its impact is much diminished in the long-run when suitable account is taken of dynamic adjustment mechanisms. This evidence suggests that a means of reconciling and integrating the static demand factors with the more satisfactory dynamic adjustment model is through their impact on the magnitude of γ, the adjustment coefficient. Griliches (7) and Heady and Tweeten (*13*) have already speculated on some factors that might influence the speed of adjustment (size of γ) for different regions in the United States. W. Huffman (*16*) has taken a more direct approach by making γ functionally dependent on education variables (*16*). Both approaches offer considerable insight into the nature of the adjustment process, an insight that may prove crucial in understanding how farmers in developing countries will react to a new price environment.

Speed of Adjustment

Regional patterns.—Griliches, Heady and Tweeten observe the speed of adjustment and consequent differences in long-run price elasticity in the context of the regional fertilizer demand curves already discussed. Griliches notices a pattern in his nine regional adjustment coefficients and price elasticities (7, pp. 99–100):

> Two hypotheses about these coefficients seem to be consistent with the estimates. The first hypothesis says that the more experience people have had with fertilizer the faster will they adjust to price changes. That is, areas with a long history of fertilizer use, widespread fertilizer use and high levels of fertilization will have higher adjusted coefficients. The Spearman rank correlation coefficient between the estimated adjustment coefficients . . . and the 1931–56 geometric average of plant nutrients used per acre of cropland is 0.67. The rank correlation coefficient between the regional adjustment coefficient and the percentage of all farmers reporting expenditures on fertilizers in 1954 is 0.52.
>
> The second hypothesis is that the demand for fertilizer is more price elastic, in the long run, in regions with low levels of fertilizer use. This hypothesis is based on the probable form of the physical relationship between the level of fertilizer use and crop yields. The effect of additional fertilizer eventually reaches a ceiling and no matter what the price relationship would be fertilizer use may not go above a certain level. Presumably regions of low levels of use are further away from their "ceilings" and hence the same magnitude price change may result in larger percentage changes in fertilizer use there than in the high use areas. The rank correlation coefficient between the absolute value of the long-run price elasticity . . . and the average quantity of plant nutrients used per acre of cropland used for crops is −0.50 . . . and with the average expenditure on fertilizer per farm reporting fertilizer use in 1929 is −0.72.

Heady and Tweeten observe essentially the same patterns of coefficients as Griliches and offer similar hypotheses. But their underlying reasoning differs substantially on some issues (*13*, pp. 183–89):

> The elasticity of demand in respect to fertilizer/crop price ratio was greatest in the regions which have increased use mostly in recent years, namely the Corn Belt, Lake States, Great Plains, Mountain and Pacific regions. These elasticity coefficients ranged from −0.425 in the Northeast to −3.839 in the Northern Plains. We can hypothesize that fertilizer price elasticities are expected to be lower in the South, or "old using" area, because farmers have been highly short on capital and have not used fertilizer to a point where its marginal product is driven to the level of the price ratio. Hence, they could still use fertilizer profitably, even with some increase in its relative price, but lack capital to use much when the price falls. Perhaps also fertilization of hay crops for dairy feed more nearly dominates the picture in the Northeast, with responsiveness to the relative prices for fertilizer being greatest in the Midwest and West where grain and cash-crop production predominate....
>
> Technical change and knowledge, provided gradually over time to farmers, certainly has been important along with price ratios in causing an increase in demand for fertilizer. While technical knowledge has increased in the older using regions, this change probably has been relatively less important than the price ratio, institutional alterations affecting farm size and the level of managerial abilities for fertilizer in determining fertilizer demand quantities....
>
> The older using regions of the South tended to have the highest elasticity with respect to cash receipts, an expected outcome for this region where capital is more nearly a limiting resource in decisions....
>
> The long-run elasticities generally are at least two or three times the short-run elasticities, magnitudes similar to those mentioned for the U.S. Depending on the adjustment coefficient, a considerable difference exists among regions in the short- and long-run elasticities, and the relative differences tend to be greatest for the newer using regions. These results would suggest that the period required for adjustment to change in the price ratio is slower in the older using regions. We might expect a longer period of adjustment in those older regions where farm income is lower, credit is more restrained and the effect of increased revenue and savings would allow a more gradual acquisition of more resources as the price ratio decreases. We believe, however, that the greater long-run elasticity, relative to short-run elasticity suggested for the newer using regions, is partially a reflection of the strong upward (and nearly linear) trend in use due to greater technical knowledge of fertilizer response or productivity —especially over a major part (the 1940's and 1950's) of the full period when the price ratio was declining.

Although Griliches differs with Heady and Tweeten about some of the fundamental causes for the observed patterns of adjustment coefficients and price responses, they tend to agree on the patterns themselves. The areas of long-standing fertilizer use have lower response to price changes. Griliches argues that long experience and high use lead to rapid adjustment to price changes while Heady and Tweeten argue that the older regions adjust more slowly primarily because incomes are lower. These positions can be partially reconciled by recognizing that Griliches requires the *joint* occurrence of high use and long-standing use for a rapid adjustment to take place. Heady and Tweeten say that low income areas are also low level users and hence adjust more slowly. But the two positions are not totally consistent nor will available published evidence permit an adequate test of their validity. However, both data and technique are now available for further treatment of the issues, and it is important that the research be done.

Even as the matter stands now there are obvious implications for the likely pattern of changes in demand for fertilizer in the developing countries with the new price environment. Areas where fertilizers have been used for a long time can be expected to adjust fairly quickly, but the response will be fairly small if they are near optimum levels of use. Areas where use is more recent will be slower to react, but the magnitude of change is likely to be large because they are still on the steep part of their response function.

The implications for grain production are disturbing—the largest relative changes can be expected where physical response rates are highest, and hence grain losses will be more substantial. The income constraint also cuts in the same direction. Wealthier farmers (and countries) are higher up on their response functions than their poorer counterparts and will be better able to maintain their fertilization levels at higher prices. The fertilizer supply shortage will thus hit the poor farmers and nations with high physical response rates relatively harder. The resulting grain deficit will be greater than it would be under arrangements for more egalitarian distribution of available fertilizer supplies. Needless to say, the resulting grain shortage will have very similar unequal distribution of welfare effects with the poorer countries being worst hit.

Although the evidence from Griliches and from Heady and Tweeten is somewhat inconsistent, it is fairly plausible. However, it lacks any significant feel for the quantitative impact of the several factors indicated as causing the observed regional differences. Further, it does not suggest how well the American experience will transfer to less developed countries.

Role of education.—W. Huffman reports some progress on determining the quantitative impact of one factor on the rate of adjustment (*16*). He attempts to make the adjustment coefficient γ a function of the farmer's educational level. The empirical test is for nitrogen application on corn at the county level in the Corn Belt between 1959 and 1964. Since the relative price of nitrogen to corn declined between these two census years, farmers should have used more nitrogen fertilizer in 1964 than in 1959. The model attempts to measure the impact of years of schooling of farm operators on how rapidly the adjustment took place.

The more satisfying specification of the model is as follows:

$$f_{64} - f_{59} = \gamma(y)\,(f_{64}^* - f_{59}), \text{ with } 0 \leqq \gamma(y) \leqq 1 \text{ and } -\infty \leqq (y) < \infty \quad (7)$$

$$f_{64}^* = f_n(p_c, p_f, p_i \ldots), \quad (8)$$

$$(y) = \frac{1}{1 + e^{a_0 + a_1 y}}, \; a_0 > 0, a_1 < 0, \text{ where} \quad (9)$$

f_{64}, f_{59} = level of nitrogen application in 1964 and 1959,

$\gamma(y)$ = the adjustment coefficient, a function of y,
$f_{64}{}^*$ = the optimal level of nitrogen application in 1964,
p_c = the price of corn in 1964,
p_f = the price of nitrogen fertilizer in 1964,
p_i = the price of other inputs in 1964, if significant,
a_0, a_1 = coefficients in the logistic function determining the value of the adjustment coefficient $\gamma(y)$, and
y = the ratio of farm operators with 9-16+ years of schooling to farm operators with 0-8 years of schooling (unweighted).

Alternative specifications of y are reported, primarily for the two-fold split into the ratio of 0-8 to 9-12 and 13-16+ to 9-12 years. In the simple one variable case the expected coefficient of a_1 is negative. With two education variables the lower education variable is expected to have a positive coefficient and the higher educational variable a negative coefficient. Thus greater education leads to *faster* adjustment to price changes.

The model is formulated for estimation by including a random disturbance term in the γ function and performing the following manipulations:

$$f_{64} - f_{59} = \gamma(y, a, u)(f_{64}{}^* - f_{59}), \tag{10}$$

$$\gamma(y, a, u) = \frac{1}{1 + e^{a_0+a_1y_1+a_2y_2+u}}.$$

$$\text{Let } \Delta f_{64} = f_{64} - f_{59} \text{ and } \Delta f_{64}{}^* = f_{64}{}^* - f_{59}. \tag{11}$$

$$\text{Then } \Delta f_{64}/\Delta f_{64}{}^* = \frac{1}{1 + e^{a_0+a_1y_1+a_2y_2+u}}, \text{ and} \tag{12}$$

$$\ln[(\Delta f_{64}{}^*/\Delta f_{64}) - 1] = a_0 + a_1y_1 + a_2y_2 + u. \tag{13}$$

Equation (13) is used for estimation. The variable $f_{64}{}^*$ "takes a different value for each of the 20 state parts of agricultural subregions (SASR) included in the sample. Its value for all counties of a particular SASR is the maximum number of pounds of nitrogen per acre of corn fertilized from among the counties of that SASR included in the sample" (*16*, p. 12).

The values of a_0, a_1, and a_2, when linear weights were attached to years of schooling, were −0.830 (−3.25), 0.986 (4.28), and −1.580 (−1.36), respectively, with t-values in parentheses. The evidence is very clear that education does affect the speed of adjustment.

This model does not go nearly far enough, however. Griliches (*7*) and Heady and Tweeten (*13*) have suggested a number of additional variables that are likely to affect the rate of adjustment—income or assets, length of experience, extent of knowledge, types of crops and so on. Such variables could easily be included in this model to specify better quantitatively the factors influencing the difference between short-run and long-run response to fertilizer prices. Along with a more suitable specification of f^* than that used by Huffman, this would seem to be a very promising area of research. Inevitably it will begin with data from the United States or other developed countries where the data base is good, but every effort should be made to locate suitable data for developing countries as well.

An understanding of the factors influencing the magnitude of the adjustment coefficient in less developed countries would substantially further our understanding of farmers' response to changing fertilizer prices.

Direct and Indirect Effects

A functional specification of the adjustment coefficient γ would be a major advance in our knowledge about how farmers react to changes in the long-run demand function for fertilizer. But prices of output and all inputs are not the only variables likely to have an impact in the long-run function. Level of education and degree of knowledge about fertilizer profitability almost certainly affect the rate of adjustment. In addition, an argument can be made that similar variables should be included in the long-run equilibrium demand function as well. This is especially true for underdeveloped countries where an innovation such as fertilizer use can diffuse fairly quickly even with constant prices merely because farmers are learning about the existence and profitability of chemical fertilizers.

A dynamic adjustment model is still entirely appropriate in this context. The adjustment is not to changes in prices, however, but to changes in the demand function through added knowledge. Thus knowledge may play a double-edged role in determining effective demand for fertilizer, especially in developing countries. It partially determines both the long-run equilibrium level of use and the speed at which the equilibrium is reached from original, lower levels. One last feedback mechanism may also be critical here. The rate at which knowledge of an innovation diffuses effectively into the countryside is almost certainly a function of its profitability which depends on relative prices. The influence of price thus permeates into yet another aspect of fertilizer demand. Keeping all the aspects separate may not be possible empirically, but it is useful analytically. This is especially true of the rather different roles price seems to play with respect to equilibrium level of fertilizer use and speed of adjustment to that level. Since knowledge enters both functions and the spread of knowledge is likely to be a function of fertilizer and product prices, fertilizer price has a *direct and indirect* effect in determining the equilibrium level of demand and an *indirect* effect on the speed of adjustment. In arguing the role of price policy in speeding the rate of growth of fertilizer demand, it is essential to keep these mechanisms separate. For the direct impact there is no substitute for the price role. For the indirect impact several substitutions are possible, including greater extension efforts, fertilizer trials and demonstrations, an active private fertilizer marketing system, and so on. Whether they are better social investments than an incentive price policy is obviously an empirical issue to be resolved in specific contexts.

FERTILIZER DEMAND IN A MACRO-PERSPECTIVE

Despite its differentiation of price response into short-run and long-run components via an adjustment coefficient, the dynamic adjustment demand model is primarily focused on the short-run, micro-aspects of fertilizer demand. This is true because the prices of both fertilizer and output are taken as given to the decision-maker, and hence the model's perspective is short-run, static equilibrium. This is not acceptable for the longer-run when equilibrium price in the produce market depends on supplies coming forth from farms which in turn depend (at least partially) on fertilizer applications.[2] This section will examine the implications for fertilizer demand of the interrelationships that lead to this longer-run equilibrium.

The Simple Macro-Model

The issues can be drawn most clearly with an extremely simple model that yields some useful although fairly simple-minded results. The results are important for all their simplicity, for they substantially alter our expectations about the relative magnitudes of short-run and long-run price responses.

The model is built from an aggregate production function and an aggregate consumption function for the commodity in question, assumed to be one of the major food grains. In view of the significant heterogeneity of micro-production and response functions a word in defense of the use of a macro-function is necessary. A substantial literature exists on the existence and estimation of aggregate production functions. In his excellent survey article, A. A. Walters (*35*) remains skeptical on principle but finds the aggregate production function a useful empirical tool. Griliches argues further that the aggregate function is as good as disaggregated functions in some circumstances. On the basis of his regional fertilizer demand functions he observes that (7, p. 101):

> There is no difference between the aggregate equation and the nine regional regressions in how well they explain aggregate U.S. fertilizer use. If the goal here were only to explain aggregate U.S. fertilizer "history," *nothing would be gained* [emphasis original] from disaggregation to the regional level. It is outside the scope of this paper to explore the theoretical reasons for this apparent paradox. It will suffice here to indicate briefly why such a result is not unreasonable. The major explanatory variable in the model is the "real" price of fertilizer. While there are some regional differences, the annual movements in this variable are mostly common to all regions. It is a "synchronized" variable. Therefore, if all the subaggregates are affected essentially by the same variable then there is not much to be gained from disaggregation, *even though the regional parameters may be quite different* [emphasis added].

There are two essential points. If the goal is to explain aggregate fertilizer demand and not individual farm demand, then an aggregate response function *may* be perfectly suitable. This will depend on the second point. The explanatory variable in the aggregate function must be largely synchronous across the micro-units. Since much of the source of variation in the micro-functions is farm or region specific and changes little from year to year, an aggregate response function may be perfectly adequate for the task at hand.[3]

For simplicity the macro-model is specified in terms of price and fertilizer only. After the impact of equilibrium conditions is demonstrated in this context, a

[2] A similar link would cause fertilizer price to be connected to demand through a supply mechanism, but that is beyond the scope of this paper. A simple hypothetical general equilibrium model incorporating fertilizer supply response is briefly discussed by Heady and Tweeten (*13*, pp. 58–62).

[3] Further discussion of the relevance and validity of aggregate production functions with empirical estimates for rice for a sample of nine Asian countries is contained in Timmer and W. P. Falcon (*32, 33*).

fuller specification will be outlined and discussed. For the moment, however, the structural relationships of the model are as follows:

$$q_d = a_1 p_0^{\alpha}, \tag{14}$$

$$q_s = a_2 f^{\beta}; \tag{15}$$

where q_d, q_s = quantity of food grain demanded and supplied respectively in a given year,

p_0 = price of the food grain in year t,

f = fertilizer applications in year t,

α = elasticity of demand for the food grain with respect to its price, and

β = elasticity of response of output with respect to fertilizer application.

Both α and β are assumed constant in this model to keep the algebra simple, Alternative specifications are possible but messier. In the short-run, when farmers take the price of output p_0 and the price of fertilizer p_f as given, the demand function for fertilizer derived from the profit maximization calculus is as follows:

$$f_{sr}^* = \left(\frac{1}{a_2\beta}\right)^{\frac{1}{\beta-1}} (p_f/p_0)^{\frac{1}{\beta-1}} = \left(\frac{1}{a_2\beta}\right)^{\frac{1}{\beta-1}} p_0^{\frac{1}{1-\beta}} p_f^{\frac{1}{\beta-1}}. \tag{16}$$

Equilibrium price for the food grain is determined by setting the demand and supply functions equal and solving for p_0 as follows:

$$a_1 p_0^{\alpha} = a_2 f^{\beta}, \text{ and} \tag{17}$$

$$p_0 = \left(\frac{a_2}{a_1}\right)^{1/\alpha} f^{\beta/\alpha}. \tag{18}$$

To determine the long-run equilibrium level of fertilizer use when the impact of fertilizer applications on food grain supply is allowed to influence the price of food grain, the expression for p_0 in equation (18) is substituted into equation (16), the fertilizer demand function. The new expression is the long-run equilibrium demand for fertilizer as a function of fertilizer price:

$$f_{lr}^* = \left(\frac{1}{a_2\beta}\right)^{\frac{\alpha}{\beta+\alpha(\beta-1)}} \left(\frac{a_1}{a_2}\right)^{\frac{1}{\beta+\alpha(\beta-1)}} p_f^{\frac{\alpha}{\beta+\alpha(\beta-1)}}. \tag{19}$$

A striking difference between equation (16) and equation (19) is apparent. Whereas the short-run, static elasticity of response to fertilizer price is $1/(\beta\text{-}1)$, the longer-run equilibrium elasticity of response to fertilizer price is $\alpha/[\beta+\alpha(\beta\text{-}1)]$. Thus the degree of price response from the *demand* function becomes a critical factor in determining the equilibrium response of fertilizer applications to fertilizer price.

Quantitative impact.—The quantitative significance of the interrelationships that determine longer-run equilibrium is not trivial. Chart 1 demonstrates the alternative values that the elasticity of price response for fertilizer takes for a range of likely values of α and β, the structural demand and supply parameters of the model. When the short-run price elasticity derived from equation (16) is considered, $1/(\beta\text{-}1)$, the value is -1.111 when $\beta = 0.10$ and -1.333 when $\beta = 0.25$. These two values of β are used for illustrative purposes in Chart 1 as well. They are the short-run and long-run response coefficients of rice production to fertilizer reported by Timmer and Falcon for their nine-country sample of Asian countries (*33*).

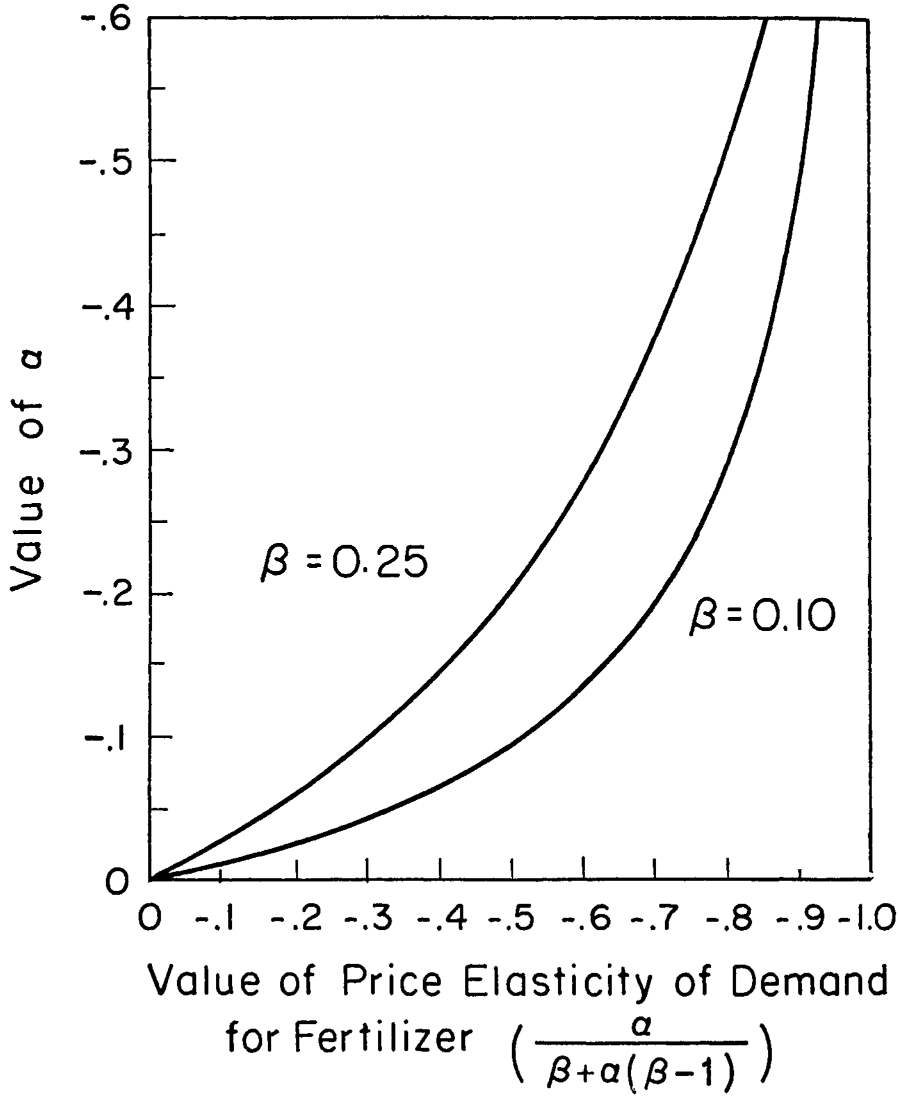
It is clear from Chart 1 that the effect of the interrelationships that determine long-run equilibrium in the food grain market is to markedly *reduce* the absolute size of the fertilizer price elasticity. When $\beta = 0.10$ and $\alpha = -0.2$, the fertilizer price elasticity in the long-run is only -0.714 compared with -1.111 in the short-run, before the long-run equilibrium conditions are imposed. As α approaches zero, i.e., as food demand responds less and less to price changes, the fertilizer price elasticity also approaches zero for any reasonable value of β. Thus the conclusion of the macro-equilibrium model is distinctly different from that of the dynamic micro-demand function. In a macro-setting the longer-run fertilizer price elasticity is smaller in absolute size than the short-run elasticity. The impact of the adjustment coefficient in the dynamic micro-function is that long-run response to price change is greater than short-run response due to the lag in farmers' adjustments to new prices.

It is not hard to find the source of the apparent paradox. The driving mechanism of the macro-demand model is the link between price of food grain and supplies forthcoming from the production function. In the very simple model used here those supplies depend entirely on the level of fertilizer application. When the price of fertilizer rises exogenously, perhaps due to a shortage of feed stocks for fertilizer plants, the short-run effect is to cut back fertilizer applications according to the short-run elasticity $1/(\beta\text{-}1)$. But this has a direct impact on the equilibrium conditions that determine price in the food grain market. When food supplies are cut back even a small amount, a large price rise is necessary to choke off demand. Herdt observes with respect to recent food price increases that (*14*, pp. 1–2):

> It is a well-known economic fact that if the quantity of the staple food of a country is slightly less than the amount normally desired by the population, the price will increase sharply. This is true for wheat in wheat-eating countries, for potatoes in potato-eating countries and for rice in rice-eating countries.... Thus, the rice crisis of 1973 can be characterized as consisting of a relatively minor reduction in total world rice production in 1972 followed by an extremely large increase in prices that occurred as the reduction became generally recognized.

In the extreme case where consumers refuse to alter their consumption of food grain when the price changes, i.e., when $\alpha = 0$, the long-run equilibrium model dictates that fertilizer applications will not change either, *no matter what happens to fertilizer price.* The only mechanism in the model by which equilibrium can be maintained in the product market when consumer demand changes is through fertilizer-induced changes in supply. If consumer demand does not change when food prices change, farmer demand for fertilizer will not change. The mechanism, of course, is that the food grain price must rise to whatever level is necessary to call forth the additional fertilizer applications. A supply shortage that reduces fertilizer demand because of higher prices will have as its longer-run effect a rise in the price of food grains that will call forth additional fertilizer applications. Some positive response of fertilizer supplies to price is implied if

CHART 1.—RELATIONSHIP BETWEEN α, β, AND THE ELASTICITY OF DEMAND FOR FERTILIZER IN LONG-RUN EQUILIBRIUM



this cobweb-type mechanism is ever to converge to a stable long-run equilibrium.

Although some additional discussion is necessary about the effect of a fuller specification of both the demand and supply equations in the macro-model as well as some consideration of short-run versus long-run response in this context, it should be clear that the model has direct relevance with respect to the present fertilizer situation. The feedback effect of low consumer price elasticities for basic foods to equilibrium prices for those foods and hence to relative profitability of applying fertilizer is too powerful to ignore. In effect, the model says that fertilizer applications *must* be profitable. If they are not, then relative prices must change until profitability returns.

Toward a More Fully Specified Macro-Model

These rather stark conclusions should be softened by two factors: consideration of what happens in the short-run and the effect of fuller specification of the model.

Timing.—Because of the time lag between planting decisions and harvest results, it is natural to think of agricultural production and price formation in a recursive framework.[4] When the price of fertilizer goes up, the level of application goes down. The consequent reduced supply is not felt in the marketplace until six months or so later, and thus the higher price of food is not felt until after farmers have made their fertilizer application decisions.

Of course, some farmers might anticipate (correctly) that this will be the case and fertilize according to their expectation of higher prices at harvest, but if all farmers did, the expectation would be self-defeating. Alternatively, actual market participants who determine the day-to-day formation of prices may anticipate the result and start bidding up future prices even at planting time and thus influence farmers to use more fertilizer than they otherwise would in the absence of this rise in the future price. If knowledge were reasonably good, either mechanism could lead to the long-run equilibrium being approximately reached in the short-run.

But especially in developing countries knowledge is not likely to be reasonably good nor are markets functioning well enough institutionally for current knowledge to affect future prices in such a way that farmers could take advantage of the information. Thus the recursive model is the more likely one, and several periods will be needed before the new equilibrium is reached (provided convergence and stability conditions are met). Hence response to fertilizer price is likely to be significant in the short-run but much diminished in the long-run.

This suggests that the dynamic adjustment model may not be entirely appropriate in situations where the feedback mechanism is significant. Equation (19) specifies the long-run demand for fertilizer as a function of its own price when the feedback is operative.[5] Equation (2) specifies the adjustment mech-

[4] The most powerful arguments along these lines are contained in H. Wold and L. Jureen (*37*).

[5] The feed-back mechanism is inoperative either in the short-run before equilibrium is established or in the long-run if $\alpha \rightarrow \infty$. The latter condition is relevant when the country is open to international trade in the commodity concerned and is small enough to be considered a price-taker. Then domestic supplies have no impact on the price because additional supplies are always forthcoming (or outgoing) at the existing price p_0.

anism normally assumed in this context. Actual fertilizer demand f_t as a function of price can then be written as follows:

$$f_t = \left(\frac{1}{a_2\beta}\right)^{\frac{\alpha\gamma}{\beta+\alpha(1-\beta)}} \left(\frac{a_1}{a_2}\right)^{\frac{\gamma}{\beta+\alpha(\beta-1)}} p_{ft}^{\ \frac{\alpha\gamma}{\beta+\alpha(\beta-1)}} f_{t-1}^{1-\gamma} . \qquad (20)$$

An empirical estimation of equation (20) will not yield an unambiguous estimate of either the long-run or short-run price response. The model would indicate a short-run price elasticity of $\gamma/(\beta-1)$ when a lag is present. But the *estimated* short-run elasticity will be $\alpha\gamma/[\beta+\alpha(\beta-1)]$. The difficulty is the obvious mis-specification of the short-run adjustment process. Also, since there is a further source of discrepancy than γ between short-run and long-run price response, a long-run response calculated using only γ and an estimated short-run elasticity will almost certainly not be correct. The only solution is probably to estimate the entire system of relationships including an adequate specification of the short-run farmer adjustment mechanism. This will most likely be a recursive system and include adjustment lags.

Fuller specification.—Part of the starkly different implications from the micro-adjustment model and the macro-equilibrium model derives from the simple specification of the demand and supply functions. The demand function should also include income, population, tastes and possibly variables to account for income and age distributions.[6] The production function requires all the other factors that make a contribution at the margin to output. Land, labor, water, pesticides, power and so on are likely to be significant factors for some or all countries.

The effect of the fuller specification is fairly complex to work through algebraically, but it is easy to see intuitively what the impact will be. From the demand side, consumer incomes, population, and so forth will enter the fertilizer demand function directly. On the supply response side, fertilizer will no longer be the only factor permitting higher output as food prices rise. More acreage, more labor intensive cultivation, and better water control will also make a contribution. This will make fertilizer demand *more* responsive to price, thus offsetting to some extent the inclusion of α (and income and population growth elasticities when the model is more fully specified) in the fertilizer price elasticity term.

The extent of offset will depend on the particular situation. But in those countries where population pressures on the available land resources are great, as in much of Asia, the marginal productivity of ever more labor intensive techniques is very small. Further, the potential for increasing the land area devoted to food crops is relatively limited. For a significant part of the underdeveloped world then, the gloomy implications of the macro-equilibrium model are directly relevant. For countries with a more balanced resource endowment other options exist and the implications are greatly softened, or negated entirely.

Technological change.—For all countries technological progress in the form of greater output *for given inputs* is an unmixed blessing. But the technological change typified by the Green Revolution has attendant complications. The real

[6] See R. Weisskoff (*36*) for further discussion of the impact of distribution variables on consumption functions.

breakthrough was the development of grain varieties that had high yield responses to fertilizer in the tropics. When fertilizer was cheap and getting cheaper, this looked like a blessing. With the availability of fertilizer subject to political decisions on the price and availability of petroleum-based raw materials and the subsequent escalation in fertilizer prices, the reliance of the world on fertilizer as the primary means of producing enough to eat looks less benign.

ISSUES AND OUTLOOK

The only safe summary of our quantitative understanding of the impact of price on fertilizer demand is "yes, it has an impact." But there are no angels in the fertilizer demand game, so. . . .

The immediate impact of a relative price rise of 10 percent will be reduced fertilizer consumption of anywhere from 5 to 10 percent. In the longer run, *if the same relative prices are maintained*, the reduction could be two or three times greater. But for many countries the longer run "if" is not viable. A feedback mechanism will force food prices to rise relative to fertilizer prices and thus cause higher fertilizer applications.

No policymaker would dare use these numbers if better ones were available. But that is the disturbing reality; little is known about the factors affecting fertilizer use which is relevant at a policy level. This ignorance will yield to efforts to learn more. Both data and methodology exist to answer the questions that have suddenly become relevant. Some became obvious only as the discussion in this paper unfolded; they are restated and expanded in the following list:

1. Is it possible to specify micro-fertilizer response functions more fully in order to determine the causes of the great variability? This is a direction Barker is pushing, and he and his colleagues at IRRI are making significant progress.
2. What factors determine the extent to which the ratio of marginal revenue product to marginal cost for fertilizer exceeds one? Does price play a role? Price variance? Yield variance? What role can education and extension programs have in reducing the ratio?
3. Does the zero homogeneity condition hold for fertilizer demand functions? That is, is the effect of raising the crop price by one percent symmetric with the effect of lowering the fertilizer price by one percent? If not, on what factors do the differences depend? Is the homogeneity condition more nearly met in mature fertilizer-using economies? Does the extent of the divergence between marginal revenues and marginal costs influence the extent to which homogeneity holds?
4. Can the work on United States fertilizer demand by Griliches and by Heady and Tweeten be updated with better specification of the variables affecting long-run fertilizer demand? In particular, can significant coefficients be estimated in the dynamic adjustment model for other variables than fertilizer price in order to reduce the effect of specification bias on the lagged endogenous variable? This would permit a much better estimate of the adjustment coefficient.
5. How do capital or income constraints affect fertilizer use? Is their impact through an influence on the rate of adjustment, directly on the short-run demand function, or both?
6. What are the functional arguments affecting the rate of adjustment? Many variables that could be influenced by policy may be important here; it is essential,

therefore, to have some understanding of the approximate magnitudes of impact. This area is especially promising because a suitable methodology has already been developed.

7. Almost nothing is known about the empirical parameters in the long-run equilibrium macro-model. How long is long? Can any results be obtained fairly simply or will an entire system have to be estimated? Can the macro-model be merged with the dynamic adjustment model? Are there countries where the stark implications of the macro-model have already been demonstrated in historical evidence?

One possible impact of price on fertilizer demand has not been mentioned at all. Hayami and Ruttan's theory of induced innovation (*11*) argues that the high-yielding, fertilizer-responsive rice and wheat varieties developed for the tropics by scientists at IRRI and CIMMYT during the past two decades were partly a response to rising grain prices and falling fertilizer prices. If fertilizer is no longer expected to be cheap and readily available, what other possibilities lie on the "innovations possibility frontier?"

First, and probably most important, still greater yield response to fertilizer will make its application profitable even at higher prices. Clearly then redoubled agronomic breeding efforts in this direction are likely, as are the efforts Barker is pushing to discover and remove on-farm constraints to the potential yield response already demonstrated on experimental plots. Also, improved transportation and marketing facilities in some parts of the world would offer farmers lower fertilizer prices at the farm gate even with present price levels in international trade. The payoff to these investments is higher than ever before.

Apart from intensification of research efforts in this field where major breakthroughs have already been induced it seems likely that the expansion path through the innovation possibility frontier has shifted. Sulfur-coated urea for slow release and the "mud-ball" technique for placing fertilizer in the root zone developed by S.K. deDatta at IRRI are examples of innovations already being tested that reflect this shift. Plant varieties that can respond better to higher labor intensity would seem to be very desirable in terms of the new relative price (employment and income distribution considerations aside). Higher-yielding varieties of rice for upland planting with low fertilizer application are already in the works. And the social payoff to rice and wheat varieties with genetic or inoculated capability to "fix" the majority of their nutrient needs from atmospheric nitrogen would be enormous. Only the seed would have to be adopted by poor peasants with little knowledge of fertilizer technology. The fertilizer would adopt itself.

Beyond this, the crystal ball gets cloudy indeed.

The outlook for the short-run is not so tenuous. Fertilizer use in 1974 will decline in a number of important developing countries. It must. Supplies to these countries are smaller than last year. In some ways the relevant question is how high must fertilizer prices go to translate this supply shortage into a reduction in effective demand. And in the longer-run the important question is how high food prices must go in order to choke off demand and to call forth additional supplies. These can come from renewed profitability of increased fertilizer applications or elsewhere. But for many countries elsewhere is nowhere. Fertilizer is their only hope and their internal price structure must adapt to that reality.

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