AN ECONOMETRIC ANALYSIS OF THE FERTILIZER INDUSTRY IN THE U.S.

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Introduction

Throughout the 1950s and 1960s, increases in the productive capacity of the U.S. fertilizer industry outweighted growth in demand, resulting in excess capacity and absolute declines in fertilizer prices. Because on increasing capital and energy costs, the situation reversed between 1971 and 1975. The supply glut disappeared, and fertilizer prices stopped escalating. Between 1976 and 1980, U.S. imports of all fertilizer materials increased by 32.5 percent, while exports increased by 43 percent. Total U.S. acreage planted increased from 332.4 million acres in 1975 to 356.5 million acres in 1980 (Fertilizer Reference Manual). Legislation was passed in 1978 designed to deregulate new natural gas supplies by 1985. Crop-fertilizer price ratios, the output prices relative to fertilizer prices, did not follow a consistent pattern, being more favorable for some crops than others (Douglas, Harre, and Simpson).

The objective of this paper is to develop a model of the U.S. fertilizer industry, containing equations representing the supply, demand, price, imports, and exports of fertilizer products (both aggregate and specific). The model will be empirically estimated, and parameter estimates used to analyze the structure of the fertilizer industry. A disaggregated model for the various nutrients and products, showing the linkages and interrelationships of the nutrient types in system, provides explicit analysis of the energy-cost fertilizer price ratios. A disaggregated model allows for greater accuracy in the measurement of explanatory variables and provides detailed information for explaining future trends in fertilizer consumption.

Fertilizer as an input in agricultural production has been the focus of several studies, including works by Griliches (1958; 1959); Heady and Yeh; Brake, King and Riggan; Rausser and Moriak; Carman; Boadu; and Roberts and Heady. Most of the studies were done prior to a slowing in demand, emergence of imports or the dramatic price increases during the 1970's. Roberts and Heady estimated separate nutrient demand functions for N, P, and K applied per acre of corn, wheat, and soybeans from 1952-76. Boadu provided the only attempt at statistically estimating the supply and demand for fertilizer in a simultaneous framework. All studies provided estimates for N, P, and K but not for specific products. Yet farmers do not buy, nor do manufacturers produce nitrogen; rather they buy and produce, respectively, specific fertilizer products such as urea or muriate of potash. Most previous studies assumed anhydrous ammonia and triple superphosphates were the only forms of nitrogen and phosphates, respectively. However, consumption of the various nutrient types varied considerably between 1970 and 1980 in response to expansion in crop acreages and changing economic conditions (Table 1). Current trends in fertilizer consumption suggests that farmers are becoming more selective in their choice of product. For example, while there has been a tremendous increase in the use of nitrogen solution and urea, there has been a marked decrease in the use of normal superphosphates and ammonium nitrate.

Conceptual Framework

Supply and Demand Functions

Assume that there exist two kinds of firms, consisting of fertilizer producers and farm firms. Each fertilizer producer and each farmer have profit maximization as goals. Duality theory ~~could~~ can be used to directly derive some of the equations in the fertilizer model.

Following McFadden, Varian, or Beattie and Taylor, the indirect profit function for fertilizer manufacturing firms producing N, P or K can be expressed as:

[1] $\Pi_p^* = f^*(p_i, p_x)$

$i = N, P, \text{ or } K$

where Π_p^* is the maximum profit obtainable from a given expenditure on inputs used in fertilizer production, p_i is the price of the fertilizer product and p_x is a vector of prices of inputs used in fertilizer production. The indirect profit function is assumed to satisfy all the nonnegativity, homogeneity and convexity requirements (McFadden).

Differentiation of [1] with respect to product price and applying Hotellings lemma yields the product supply function for the producer of N, P, or K as:

[2] $\partial \Pi_p^* / \partial p_i = y_i$

$i = N, P \text{ or } K.$

Similarly, differentiation with of [1] respect to input prices yields the demand function for the jth of n inputs used in fertilizer production as:

[3] $\partial \Pi_p^* / \partial p_{xj} = -x_j$

$j = 1, \ldots, n$

The indirect profit function for the farmer can be expressed as:

$$[4] \quad \Pi^*_f = f^*(p_y, p_x)$$

x = N, P, or K or other inputs

where Π^*_f is the maximum profit obtainable by farmers, p_y is a vector of prices of outputs such as corn or wheat, and p_x is a vector of input prices to farmers including the prices of N, P, and K.

Differentiating [4] with respect to output prices yields the product supply function for outputs produced by farmers such as corn or wheat as:

$$[5] \quad \partial \Pi^*_f / \partial p_k = y_k$$

where $k = 1, \ldots, m$ representing products such as corn and wheat

Differentiating [4] with respect to the prices of the fertilizer products yields the derived demand for that particular fertilizer product as:

$$[6] \quad \partial \Pi^*_f / \partial p_i = f_i$$

i = N, P or K.

actually shouldn't i refer to products such as ammonium nitrate, a potassium chloride, not just N, P or K.

The empirical analysis that follows focuses on the parameter estimates of equations [2] and [6]. Using equation [6] as the basis, both demands for directly applied products, such as ammonium nitrate as well as individual nutrients were estimated.

The supply of fertilizers as represented by equation [2] was expressed as a function of its own price and prices of inputs used in production; natural gas, labor and electricity for ~~N~~ nitrogen products, labor and electricity for ~~P and K~~ phosphate and potassium products. These inputs were weighted by their proportions of the 1980 price of a ton of nutrients. The supply function also included a time trend to account for investments in fixed and quasi-fixed factors in fertilizer manufacture. Thus, the supply function for each primary nutrient was a function of its own wholesale price, weighted cost of inputs and a time trend variable.

The derived demand for fertilizer by farmers as expressed by equation [6] was a function of both crop and input prices. The price of corn was selected as the proxy for the output price since corn is the largest consumer of N, P, and K in the U.S., accounting for approximately 43 percent of the total nitrogen applied in the United States. A weighted index of prices recieved for crops would not accurately take into account the dominance of corn in fertilizer use. For example soybeans, a legume, requires little if any fertilizer nitrogen.

Prior fertilizer demand studies such as Carman; and Roberts and Heady, used a time trend to account for shifts in the production function over time This study rather used the total acreage planted of 20 principal crops. This variable not only contains a strong trend component but also has economic meaning. Therefore, the quantity demanded of each fertilizer nutrient was a function of its own price, farm price of corn and total acreage planted of 20 principal crops.

Might say something about potential bias in results because of this.

As indicated in the theoretical derivation, prices of substitute and complementary inputs should be included in the derived demand function, but because of a high degree of correlation between the input price vectors, other input prices were excluded. Specifications were also estimated which included prices of other nutrients in each equation, but this approach was again abandoned due to a high degree of correlation among nutrient prices.

I'm afraid the reviewer will nail us on this one if we leave as is.

Prices

The approach used in this study was to estimate the wholesale prices of individual products and use ~~that~~ the estimated wholesale prices to estimate retail prices. In the case of nitrogen only the wholesale price of ammonia was estimated as ammonia is the base product for all nitrogenous products. According to Labys, if the data interval is short relative to the consumption and if inventories vary considerably, then a price relationship can be specified as:

[7] $p_t = \phi(s_t, z_t, \varepsilon_t)$

where p_t is the price level in time t, s_t is the inventory levels in time t, z_t represents other exogenous variables influencing the price in time t and ε_t is a random error term.

Following the rationale of equation [7], wholesale prices were specified as functions of inventory levels and weighted costs of inputs. The wholesale price of phosphate rock was included in the phosphate equations. Beginning inventory levels were expected to be inversely related to prices while weighted input prices exert a positive influence on wholesale prices.

Retail prices of individual products were assumed to be functions of their respective wholesale prices, a stock to production ratio of individual products and the general wholesale price index. The ratio describes the presessure exerted on available stocks by production and, consequently on prices while the wholesale price index was included to measure the effects of inflation on retail prices.

Imports and Exports

Following Leamer and Stern, import demand for an intermediate good is given by:

[8] $q^m = \theta(p,o)$

where q^m is the quantity imported of a commodity, p is the common price level for both the imported and domestic good and o is a variable that influences output level. In the case of nitrogen, the output level is influenced by input cost (natural gas) and the amount of land cultivated. Hence, nitrogen imports were expressed as a function of the wholesale price of natural gas, total acreage planted of 20 principal crops and net income from farming. The wholesale price of rock phosphate and the wage rate in the chemical and allied industries were included in the phosphates and potash equations, respectively, as variables that influence imports.

By analogous reasoning, the export demand should be a function of world prices and a measure that shifts world output levels. The exchange rate has an important bearing on the rate of adoption of new technology and the distribution of benefits of new technology between the U.S. economy and the rest of the world (Schuh). Total world population and the U.S. short-term interest rates were used as proxies for the shifter and world prices, respectively, in the nitrogen and potash models. The direction of trade in the fertilizer industry is influenced by the value of the dollar. When the value of the dollar is high, ~~which discourages~~ international buyers are discouraged, resulting in a decrease in exports. An increase in total world population increases demand for food and, hence, an increase in U.S. exports of fertilizers. The data set contained an index of world wholesale price of phosphates and this was used as the only explanatory variable in the phosphates exports equation.

Statistical Model, Data and Estimation

The fertilizer industry was disaggregated into three sectors: nitrogen, phosphates and potash. A balance sheet showing sources and uses of fertilizers was estimated for each sector. A simultaneous-equation model was developed for each primary nutrient, encompassing supply, demand, price, stocks, imports, and exports. The number of equations in each sector depended on the number of products included. The same theoretical model was used as the basis for equations representing each sector.

Aggregate domestic supply and quantities imported were estimated for each sector to obtain the supply function for nutrients. The demand for each aggregate nutrient was obtained by summing the quantities of total directly-applied nutrient, those used in mixes, and quantity exported. Total supply, total demand, and ending stocks were identities. The latter was an identity in that stocks represented the difference between available supplies and total demand. Fertilizer prices at both the wholesale and retail levels were estimated for individual products. Since price is inextricably linked with demand, quantities demanded of the individual products were estimated to determine the demand response to changes in the economic environment, such as changes in acreage planted or changes in fertilizer prices.

The specific directly-applied nitrogen products included were anhydrous ammonia, ammonium nitrate, ammonium sulfate, nitrogen solutions, and urea. The directly-applied phosphates products included were ammoniated phosphates, such as diammonium phosphates, normal and triple superphosphates. Potassium chloride was the only directly-applied potash product included as it is the dominant directly-applied product. The products selected for this study were the most important in terms of total quantities produced and used in the U.S. and have consistent data series for the study period.

The reduced form equation for each sector was specified as:

[9] $Y = \Pi X + V$

where

Y = g x n matrix of endogenous variables

Π = g x k matrix of reduced form coefficients

V = g x n matrix of stochastic error terms

The nitrogen sector consisted of 16 structural equations (E1-E16), and an identity; with 16 jointly-dependent variables and 15 predetermined variables. The phosphates sector had 14 structural equations (E17-E30), and an identity; with 14 jointly-dependent variables and 16 predetermined variables. The potash sector had 8 structural equations (E31-E38) with 8 jointly-dependent variables and 12 predetermined variables.

All data were from various government publications. Quarterly observations were used on all variables from 1960 to 1980. This is the first study to utilize quarterly data in fertilizer studies, which reflect purchasing and production decisions for the period 1960-1980. The three-stage least squares (3SLS) technique was used to estimate all structural equations. The 3SLS takes into account the correlation of residual vectors across equation, and uses the additional information to improve the assymptotic efficiency of the parameter estimates.

Analysis of Results

The 3SLS estimates of parameters and the respective standard errors for each sector is provided in Tables 2 - 4. The predictive ability of the estimated models were evaluated using Theil Inequality Coefficients with changes in the variables, also in Tables 2 - 4.

On the basis of the statistical evidence, the models generally performed well and were largely consistent with the theoretical development. The u_1 statistic for all equations lies within the generally accepted bounds. The majority of the explanatory variables has signs hypothesized by theory with their estimated parameters much larger than their standard errors.

Impact Multipliers

The underlying interrelationships within the econometric model were further investigated in an effort to understand the behavior of the fertilizer industry and markets. Reduced form impact multipliers and structural elasticities were used as the basis for the analysis Impact multipliers indicate the net impact of a change in a current value of an exogenous variable on the current value of indogenous variable (Intriligator). Equation [9] is the reduced form for all N equations. The elements of Π are the impact multipliers. each element of Π represents the total change in the y_ith endogenous variable with respect to a change in the x_jth predetermined variable.

Table 5 provides the impact multipliers for the nitrogen sector of the model. For example, a $1.00 increase in the price of corn (x_{14}), increased demand for anhydrous ammonia (y_{12}) by 34,900 nutrient tons and increased demand for ammonia nitrate (y_{13}) by 6,000 nutrient tons. A 1 million increase in total acreage planted of 20 principal crops (x_{14}) increases demand for anhydrous ammonia (y_{12}), ammonium nitrate (y_{13}) by 60,290 and 24,160 nutrient tons, respectively, while decreasing the demand for urea (y_{16}) by 3,000 nutrient tons.

From table 6, a one million acre increase in total acreage planted of 20 principal crops (x_4) increased the demand for diammonium phosphates (y_{12}) by 15,000 nutrient tons and triple superphosphates (y_{14}) by 5,100 nutrient tons while decreasing the demand for normal superphosphates (y_{13}) by 600 nutrient tons. A $1.00 increase in the price of rock phosphate (x_{24}) increased the retail price of diammonium phosphates (y_7) by $0.53, triple superphosphates (y_{11}) by $1.78, while decreasing its demand (y_{14}) by 3,900 nutrient tons. As indicated earlier, demand for normal superphosphates, which is lower in plant nutrient, has been declining since the late 1960's in favor of triple superphosphates which is higher in plant nutrient. Thus, the negative impact multipliers of acreage planted and the price of corn is consistent with real-world phenomena. An increase in total acreage planted of 20 principal crops (x_4) of one million acres increased demand for potash (y_8) by 18,300 nutrient tons while a $1.00 increase in the price of corn (x_{10}), increased the demand for potash (y_8) by 60,800 nutrient tons (Table 7).

Structural Elasticities

Direct calculation of elasticities from the estimated structural equations are not strictly valid (Haidacher and Penn), but nevertheless they do yield a useful yardstick for comparison with other studies. The income elasticities of demand with respect to imports of all nutrients were positive and highly inelastic, implying that an increase in net incomes of farmers would not lead to drastic increases in imports of fertilizers. This may be due to the fact that the U.S. was net exporter of N and P; even for K the bulk of the imports came from Canada.

The elasticity of imports with respect to total acreage of 20 principal crops planted was highly elastic, ranging from 2.6 to 3.9 This implied that as acreage planted increased, import levels of N, P, and K would increase dramatically. The estimated elasticity of natural gas price index to imports ports of N was inelastic (.43). This was not surprising since natural gas is the most important input in the production of nitrogen fertilizer in the U.S. Therefore, if gas prices increase, it might be cheaper to import nitrogen from low-cost producing areas. The elasticity of K with respect to the wage rate in the chemical industry was inelastic (.77), implying that K will continue to be imported regardless of the domestic wage rate. This makes sense since domestic sources of potash are limited. In fact, the most important important reason for increases in potash imports was the declining quantity and quality of potash available in the U.S. with higher domestic prices resulting. The coefficient of phosphate rock had the wrong sign.

All the own price elasticities of demand for directly applied N, P and K were enelastic, reinforcing the fact that directly-applied products had become the dominant form of fertilizer usage (Table 9). More than 50 percent of all potash and approximately 80 percent of all nitrogen was used as direct application material (Fertilizer Trends, 1976). The elasticities with respect to corn prices were quite quite small for all equations. A 1 percent increase in corn price led to an increase in demand for directly applied N of 0.334 percent. Also, a 1 percent increase in acreage planted to 20 principal crops led to 3.6, 3.7, and 4.1 percent increases in demand for N, P, and K, respectively.

All the own price elasticities of demand for specific nutrients had the hypotheized signs, except three equations-- urea, ammoniated phosphates and potash (Table 10). Those with the hypothesized signs were all inelastic, and range from -.004 to -.746. Thus, increases in own prices did not lead to drastic cutbacks in the demand for these specific nutrients.

Direct comparison of the elasticities and other parameter estimates from this model with others was difficult as no other study had disaggregated nutrients. Previously published elasticity estimates demonstrated considerable variation based on the time period considered and the geographical region under consideration. For instance, own price elasticities estimated by Rausser and Moriak ranged from -.50 in 1949 to -.70 in 1964. Heady and Yeh's estimate of own price elasticities for N, P, and K were -.449, -.448 and -.403, respectively. Boadu found own price elasticities in his study for anhydrous ammonia and triple super-phosphates, the most popular forms of N and P, respectively, to be -.378 and -.539.

The elasticity of demand for ammonium sulfate with respect to own price was -.56 and compared favorably with those estimated by Carman for the 11 Western States where ammonium sulfateis widely used. A 10 percent increase in nutrient prices would have a greater reductive effect on the demand for ammonium nitrate (7.5 percent) and ammonium sulfate (5.6 percent) than on anhydrous ammonia (3.8 percent) and nitrogen solutions (.04 percent). This was in conformity with expectations. Over 75 percent of nitrogen applied directly since 1975 has been in the form of anhydrous ammonia and nitrogen solutions. Furthermore, despite the doubling in the prices of all fertilizer nutrients since 1973, there has not been any significant reduction in quantities used of fertilizer materials.

Total acreage planted of 20 principal crops responded positively to the demand for all nutrients and its elasticity was quite large with the expected sign except for normal superphosphates. The elasticities range from 1.63 to 5.4. This finding was very significant in that any increase in total acreage planted should lead to a more than proportionate increase in demand for these specific nutrients. This was consistent with what was known about the demand for fertilizer in the 1960's and 1970's.

The nutrient demand responses to corn price were all inelastic and had the expected sings except for urea and normal superphosphates. The elasticities ranged from .07 to .5. The estimated elasticities were also quite comparable to those reported by Roberts and Heady. An implication of this finding was that government programs such as higher loan rates or export promotion aimed at supporting corn price by, say 10 percent, would only increase demand for anhydrous ammonia by 4 percent, ammonium nitrate by 5 percent, triple superphosphates by 3 percent, and potash by only 1 percent.

Concluding Comments

An theoretical and econometric model was developed for each of the three primary fertilizer nutrients, revealingthe interrelationships among supply, demand, prices, exports and imports. The linkages between fertilizer and agricultural sectors were also explored. The analysis suggests that demand for all the major plant nutrients are price inelastic. Furthermore, demand for all directly-applied products, and mixtures were inelastic with respect to the farm price of corn. The elasticity was greatest for nitrogen and more than twice as large as phosphate. Consequently, a major agricultural economic recovery either through a market process or by government program will not cause a recovery in the fertilizer industry.

Total acreage planted of 20 principal crops largely determined the quantity demanded of the various fertilizer nutrients. The huge increases in demand for fertilizer nutrients in the 1960's and 1970's was triggered by over 60 million acre increasing acreage planted of 20 principal crops. Results of this study suggests that without a major acreage expansion, the fertilizer industry, particularly nitrogen, will not grow as it did in the 1970's, and the value of the dollar will act to restrict exports while encouraging imports. The current crop surpluses also confirm the fact that acreage planted of 20 principal crops will not fuel a major increase in fertilizer consumption in the U.S.

Imports of nitrogen, the most important fertilizer material, were inelastic with respect to the price of natural gas. Nitrogen imports increased rapidly in the 1970's as 60 million acres were brought into production. This study revealed that elasticity of imports with respect to planted acreage was elastic and led to an explosion in imports. At the same time, natural gas prices were escalating as contracts were being renegotiated, and this did not help to restrict imports. Any escalation in in the prices of natural gas would lead to the construction of newer, more efficient plants which utilize less natural gas. These plants, if built, would probably become concentrated near sources of natural gas, principally in the gulf states.

Table 1. Total Fertilizer Consumed by Nutrient Type (Tons).

Fertilizer type	1970	1980	Percent Change
Nitrogen			
Anhydrous Ammonia	3,468,363	5,483,349	58.1
Ammonium Nitrate	2,844,360	2,627,660	-7.6
Ammonium Sulfate	781,874	870,722	11.4
Nitrogen Solutions	3,242,892	6,669,503	105.7
Urea	533,535	2,144,628	302.0
All Nitrogen	11,898,188	19,052,771	60.1
Phosphates			
Ammoniated Phosphates	644,120	657,881	2.1
Normal Superphosphate	294,979	83,587	-71.7
Triple Superphosphate	1,159,355	782,247	-32.5
All Phosphates	2,521,905	2,320,124	-8.0
Potash			
PotassiumChloride	2,172,572	5,065,855	133.2
Potassium Sulfate	37,943	38,913	2.6
All Potash	2,409,859	5,521,850	129.1

SOURCE: Adapted from Consumption of Commercial Fertilizers in the United States -- 1970 and 1980.

Table 2. Estimates for the Nitrogen Sector (Standard Errors in Parentheses).

	R^2
Total Domestic Supply of Nitrogen:	UI y_1
E1 : $y_1 = .1250 - .0021\ y_6 - .0007 x_1 + .0421\ x_{15}$	.84
(.0685) (.0006) (.0002) (.0011)	
Imports of Nitrogen:	
E2 : $y_2 = 2.2010 + .0020\ x_2 + .0087\ x_4 + .0060\ x_5$	.43
(.2290) (.0001) (.0008) (.0023)	
Total Directly Applied Nitrogen:	
E3 : $y_3 = -15.0075 - .0125\ y_7 + .0662\ x_4 + 1.1814\ x_{14}$	.69
(1.3771) (.0016) (.0051) (.2154)	
Demand for Nitrogen In Mixes:	
E4 : $y_4 = -1.5869 + .0114\ x_4 - .0051\ x_6 + .2082\ x_{14}$	.69
(.2573) (.0010) (.0005) (.0394)	
Exports of Nitrogen:	
E5 : $y_5 Y5 = -2.6461 + .0009\ x_7 + .0016\ x_8$	.78
(.3368) (.0001) (.0003)	
Wholesale Price of Nitrogen:	
E6 : $y_6 = 49.7940 + .2812\ x_1 + 11.3173\ x_3$	.67
(6.3689) (.0221) (6.0489)	
Retail Price of Anhydrous Ammonia:	
E7 : $y_7 = 37.1402 + .9332\ y_6$	.77
(4.1050) (.0338)	

Retail Price of Ammonium Nitrate:

P R O B L E M **T H I S** **E Q U A T I O N**

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E8 : $y_8 = 15.4844 + .6192\ y_2$ .74

(3.3403) (.0314) (3.1251) (.0258)

Retail Price of Ammonium Sulfate:

E9 : $y_9 = 3.3351 + .3866\ y_6 - 11.2790\ x_{10} + .2406\ x_{13}$ .73

(3.2222) (.0314) (3.1251) (.0258)

Retail Price of Nitrogen Solutions:

E10 : $y_{10} = 13.7740 + .4563\ y_6 + 5.8365\ x_{11} + .1297\ x_{13}$ .76

(2.7155) (.0302) (2.8415) (.0263)

Retail Price of Urea:

E11 : $y_{11} = 26.0205 + .8320\ y_6 - 90.1732\ x_{12} + .1509\ x_{13}$ .75

(4.5402) (.0481) (17.1857) (.0398)

Demand for Anhydrous Ammonia:

E12 : $y_{12} = -8.1846 - .0071\ y_7 + .0349\ x_4 + .6029\ x_{14}$ .66

(.7820) (.0010) (.0029) (.1237)

Demand for Ammonium Nitrate:

E13 : $y_{13} = -.8504 - .0060\ y_8 + .0009\ x_4 + .0421\ x_{14}$ .77

(.1983) (.0005) (.0007) (.0354)

Demand for Ammonium Sulfate:

E14 : $y_{14} = -.0907 - 0012\ y_9 + .0009\ x_4 + .0421\ x_{14}$ .62

(.0280) (.0001) (.0001) (.0055)

Demand for Nitrogen Solutions:

E15 : $y_{15} = -3.5876 -.0001\ y_{10} + .0144\ x_4 + .1043\ x_{14}$ .67

(.2706) (.0007) (.0010) (.0408)

Demand for Urea:

E16 : $y_{16} = -2.1367 + .0022\ y_{11} + .0075\ x_4 - .0299\ x_{14}$ .68

(.1785) (.0003) (.0007) (.0312)

Table 3. Estimates of the Phosphate Sector (Standard Errors in Parentheses).

41

Supply of Phosphates:

$$E17 : y_{17} = -.0215 + .0048\ y_{22} + .0087\ x_{16} - .0055\ x_{23} + .0087\ x_{15} \qquad .43$$
$$(.0938) \quad (.0014) \quad (.0039) \quad (.0015) \quad (.0018)$$

Imports of Phosphates:

$$E18 : y_{18} + -5606 + .0025\ x_4 + .0025\ x_5 - .0043\ x_{24} \qquad .73$$
$$(.0959) \quad (.0003) \quad (.0007) \quad (.0006)$$

Demand for Directly Applied Phosphates:

$$E19 : y_{19} = -4.3946 - .0010\ y_{23} + .0192\ x_4 + .1314\ x_{14} \qquad .70$$
$$(.4182) \quad (.0007) \quad (.0016) \quad (.0663)$$

Demand for Phosphates in Mixes:

$$E20 : y_{20} = -1.9072 + .0182\ x_4 - .0090\ x_6 + .1529\ x_{14} \qquad .67$$
$$(.3823) \quad (.0015) \quad (.0008) \quad (.0496)$$

Exports of Phosphates:

$$E21 : y_{21} = -1.5838 + .0210\ x_{19} \qquad .66$$
$$(.0760) \quad (.0005)$$

Wholesale Price of Diammonium Phosphates:

$$E22 : y_{22} = 44.1998 + 1.0987\ x_{16} - 35.5219\ x_{18} + .4218\ x_{24} \qquad .48$$
$$(4.5212) \quad (.1145) \quad (7.4656) \quad (.2836)$$
$$+ .4543\ y_6$$
$$(.0424)$$

Demand for Ammoniated Phosphates:

$$E28 : y_{28} = -3.8216 + .003\ y_2\ 3 + .0150 + .1118\ x_{14} \qquad .69$$
$$(.3201) \quad (.0006) \quad (.00120) \quad (.0530)$$

Demand for Normal Superphosphates:

$$E29 : y_{29} = .2527 - .0003\, y_{25} - .0006\, x_4 - .0031\, x_{14} \qquad .71$$
$$(.0176) \quad (.0001) \qquad (.0001) \qquad (.0019)$$

Demand for Triple Superphosphates:

$$E30 : y_{30} = -.9926 - .0022\, y_{27} + .0051\, x_4 + .07881\, x_{14} \qquad .72$$
$$(.1350) \quad (.0002) \qquad (.0005) \qquad (.0170)$$

Table 4. Estimates of the Potash Sector (Standard Errors in Parentheses).

Supply of Potash:

$$E31 : y_{31} = \underset{(.1883)}{3.4000} - \underset{(.0099)}{.0070}\, y_{36} - \underset{(.0048)}{.0037}\, x_{25} - \underset{(.0030)}{.0079}\, x_{15} \qquad .87$$

Imports of Potash:

$$E32 : y_{32} = \underset{(.9430)}{-8.2085} + \underset{(.0596)}{.0277}\, x_{26} + \underset{(.0037)}{.0277}\, x_{4} + \underset{(.0085)}{.0153}\, x_{5} \qquad .69$$

Demand for Directly Applied Potash:

$$E33 : y_{33} = \underset{(.5810)}{-5.8990} - \underset{(.0028)}{.0168}\, y_{37} + \underset{(.0023)}{.0203}\, x_{4} - \underset{(.0795)}{.0101}\, x_{14} \qquad .71$$

Demand for Potash in Mixes:

$$E34 : y_{34} = \underset{(.3445)}{-1.7913} + \underset{(.0014)}{.0156}\, x_{4} - \underset{(.0010)}{.0038}\, x_{6} + \underset{(.0541)}{.538}\, x_{14} \qquad .68$$

Exports of Potash:

$$E35 : y_{35} = \underset{(.1521)}{-1.3295} + \underset{(.0001)}{.0006}\, x_{7} - \underset{(.0001)}{.0008}\, x_{8} \qquad .76$$

Wholesale Price of Potash:

$$E36 : y_{36} = \underset{(.8145)}{12.2846} + \underset{(.0162)}{.3146}\, x_{25} - \underset{(2.7129)}{9.43108}\, x_{27} \qquad .64$$

Retail Price of Potash:

$$E37 : y_{37} = \underset{(1.1541)}{-3.3901} + \underset{(.1094)}{1.1587}\, y_{36} + \underset{(7.3828)}{4.1689}\, x_{28} + \underset{(.0218)}{.3167}\, x_{13} \qquad .46$$

Demand for Potassium Chloride:

$$E38 : y_{38} = \underset{(.5876)}{-5.4760} + \underset{(.0028)}{.0168}\, y_{37} + \underset{(.0023)}{.0183}\, x_{4} + \underset{(.0817)}{.0608}\, x_{14} \qquad .67$$

Definition of Variables:

y_1 = Domestic supply of N, Million Nutrient Tons.

y_2 = Nitrogen Imports, Million Nutrient Tons.

y_3 = Dem. for Directly-Applied N, Million Nutrient Tons.

y_4 = Dem. for Nitrogen in Mixes, Million Nutrient Tons.

y_5 = Nitrogen Exports, Million Nutrient Tons.

y_6 = Wholesale Price of Ammonia, \$/Material Ton.

y_7 = Ret. Price, Anhydrous Ammonia, \$/Material Ton.

y_8 = Ammonium Nitrate, \$/Material Ton.

y_9 = Ret. Price, Anhydrous Ammonia, \$/Material Ton.

y_{10} = Ret. Price, Nitrogen Solutions, \$/Material Ton.

y_{11} = Ret. Price, Urea, \$/Material Ton.

y_{12} = Dem. for Anhydrous Ammonia, Nutrient Tons.

y_{13} = Dem. for Ammonium Nitrate, Nutrient Tons.

y_{14} = Dem. for Ammonium Sulfate, Nutrient Tons.

y_{15} = Dem. for Nitrogen Solutions, Nutrient Tons.

y_{16} = Dem. for Urea, Nutrient Tons.

y_{17} = Domestic Supply of P, Million Nutrient Tons.

y_{18} = Phosphates Imports, Million Nutrient Tons.

y_{19} = Dem. for Directly-Applied P, Million Nutrient Tons.

y_{20} = Dem. for P in Mixes, Million Nutrient Tons.

y_{21} = Phosphates Exports, Million Nutrient Tons.

y_{22} = Wholesale Price, Diammonium Phosphates, \$/Material Ton.

y_{23} = Ret. Price, Diammonium Phosphates, \$/Material Ton.

y_{24} = Wholesale Price, Normal Superphosphates, \$/Material Ton.

y_{25} = Ret. Price, Normal Superphosphates, \$/Material Ton.

y_{26} = Wholesale Price, Normal Superphosphates, \$/Material Ton.

y_{27} = Ret. Price, Triple Superphosphates, \$/Material Ton.

y_{28} = Dem. for Ammoniated Phosphates, Million Nutrient Tons.

y_{29} = Dem. for Normal Superphosphates, Million Nutrient Tons.

y_{30} = Dem. for Triple Superphosphates, Million Nutrient Tons.

y_{31} = Domestic Supply of Potash, Million Nutrient Tons.

y_{32} = Potash Imports, Million Nutrient Tons.

y_{33} = Dem. for Directly-Applied Potash, Million Nutrient Tons.

y_{34} = Dem. for Potash in Mixes, Million Nutrient Tons.

y_{35} = Potash Exports, Million Nutrient Tons.

y_{36} = Wholesale Price of Potash, \$/Material Ton.

y_{37} = Ret. Price of Potash, \$/Material Ton.

y_{38} = Dem. for Potassium Chloride, Million Nutrient Tons.

x_1 = Weighted Cost of Natural Gas, Electricity and Labor.

x_2 = WPI, Natural Gas, 1967=100

x_3 = Beginning Stocks of all N, Nutrient Tons.

x_4 = Acreage Planted of 20 principal crops, Millions

x_5 = Net Farm Income, Billion dollars

x_6 = WPI, Mixed fertilizers, 1967=100

x_7 = Total World Population

x_8 = Prices Paid for Interest, 1967=100

x_9 = Stock - Production ratio, Ammonium Nitrate

x_{10} = Stock - Production ratio, Ammonium Sulfate

x_{11} = Stock - Production ratio, Nitrogen Solutions

x_{12} = Stock - Production ratio, All Nitrogen

x_{13} = WPI, 1967=100

x_{14} = Farm Price of Corn, \$/Bushel

x_{15} = Time Trend

x_{16} = Weighted Cost of Labor and Electricity

x_{17} = Wholesale price of Sulfuric Acid, \$/Material Ton

x_{18} = Beginning Stocks, All P, Million Nutrient Tons

x_{19} = Wholesale Price Index, All P, 1967=100

x_{20} = Stock - Production ratio, Ammonium Phosphates

x_{21} = Stock - Production ratio, Normal Superphosphates

x_{22} = Stock - Production ratio, Triple Superphosphates

x_{23} = WPI, Phosphoric Acid, 1967=100

x_{24} = Wholesale Price, Rock Phosphates, \$/Material Ton

x_{25} = Weighted Cost of Labor, Electricity and Transportation

x_{26} = Wage rate in the Chemical Industries, \$/Hr.

x_{27} = Beginning Stocks, All Potash, Million Nutrient Tons.

x_{28} = Stock - Production ratio, Potash

Table 5. Impact Multipliers for the Nitrogen Sector.

Endogenous Varibles	Exogenous Variables			
	x_1	x_4	x_{14}	x_2
Ret. Price Anhy. Ammonia (y_7)	.2624			
Ret. Price, Amm. Nitrate (y_8)	.1741			
Ret. Price, Amm. Sulfate (y_9)	.1087			
Ret. Price, Nit. Solutions (y_{10})	.1283			
Ret. Price, Urea (y_{11})	.2339			
Dem. for Anhy Ammonia (y_{12})	-.0029	.6029	.0349	
Dem. for Amm. Nitrate (y_{13})	-.0018	.2416	.0060	
Dem. for Amm. Sulfate (y_{14})	-.0010	.0415	.0009	
Dem. for Nit. Solutions (y_{15})	-7.046E-06	.1043	.0144	
Dem. for Urea (y_{16})	.0011	-.0300	.0075	
Imports for Nitrogen (y_2)				.0020

Where x_1, x_4, x_{14}, and x_2 are Weighted Costs of Input, Acreage Planted of 20 Principal Crops, Farm Price of Corn, and Wholesale Price Index of Natural Gas, respectively.

Table 6. Impact Multipliers for the Phosphates Sector.

Endogenous Variables	Exogenous Variables x_4	x_{13}	x_{14}
Ret. Price, Diammonium Phosphates (y_{23})			.5311
Ret. Price, Normal Superphosphates (y_{24})			.1045
Ret. Price, Triple Superphosphates (y_{27})			1.7838
Dem. for Ammoniated Phosphates (y_{28})	.0150	.1118	.0001
Dem. for Normal Superphosphates (y_{29})	-.0006	-.0031	-2.706E-05
Dem. for Triple Superphosphates (y_{30})	.0051	.0781	-.0039

Where x_4, x_{13}, and x_{14} are Acreage Planted of 20 Principal Crops, Farm Price of Corn, and Wholesale Price of Rock Phosphates, respectively.

Table 7. Impact Multipliers for the Potash Sector.

Endogenous Variables	Exogenous Variables x_1	x_4	x_{10}
Ret. Price, Potassium Chloride (y_{37})	.3640		
Dem. for Potassium Chloride (y_{33})	.0061	.0183	.0508

Where x_1, x_4, and x_{10} are Weighted Costs of Inputs, Acreage Planted of 20 Principal Crops, and Farm Price of Corn, respectively.

Table 8. Import Elasticities of Demand for N, P, and K at the Sample Means.

Explanatory Variables	N	P	K
Net Farm Income	.100	.214	.097
Acreage Planted of 20 Crops	2.627	3.900	3.187
WPI, Natural Gas	.428		
WP. Rock Phosphates		-.308	
Wage Rate, Chemical Industries			.774

Table 9. Estimated Elasticities for Directly Applied N, P, & K.

Explanatory Variables	N	P	K
Own Price	-.300	-.087	-.782
Acreage Planted of 20 Crops	3.593	3.686	4.126
Farm Price of Corn	.334	.132	.091

Table 10. Elasticities of Demand for Specific Nutrients.

Dependent Variables	Explanatory Variable		
	Own Price	Acreage Planted 20 Crops	Price of Corn
Dem. for Anhydrous Ammonia	-.378	4.169	.377
Dem. for Ammonium Nitrate	-.746	2.327	.494
Dem. for Ammonium Sulfate	-.560	1.634	.405
Dem. for Nitrogen Solution	-.004	4.375	.166
Dem. for Urea	.671	5.448	-.113
Dem. for Amm. Phosphates	.038	4.536	.177
Dem. for Normal Superphosphates	-.279	-2.825	-.084
Dem. for Triple Superphosphates	-.539	3.464	.279
Dem. for Potassium Chloride	.808	3.863	.067

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