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ABSTRACT

"AN ECONOMETRIC MODEL OF THE NITROGEN FERTILIZER INDUSTRY IN THE U.S."

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Empirical estimates of supply, demand, prices, imports and exports of nitrogen fertilizer (aggregate and specific) products in a simultaneous framework are provided. Impact multipliers derived provide information on effects of increasing costs of nitrogen fertilizer on farm level demand and impacts of rising natural gas prices on production.

# AN ECONOMETRIC MODEL OF THE NITROGEN FERTILIZER INDUSTRY IN THE U.S.

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 these studies were concerned with farm level demand, with little attention paid to what happens to industry output. Roberts and Heady estimated separate nutrient demand functions for N, P, and K applied per acre of corn, wheat and soybeans, utilizing time series data from 1952 to 1976. Boadu provided the only attempt at statistically estimating the supply and demand for fertilizer for 1967-78 in a simultaneous framework.

All studies provided estimates for nitrogen, but not specific products. Yet farmers do not buy, nor do producers produce nitrogen, rather they buy and produce, respectively, specific fertilizer products such as anhydrous ammonia, or urea. Anhydrous ammonia was used in most previous studies as if it was the only form of nitrogen. Yet, current trends in fertilizer consumption suggests farmers being more selective in their choice of products.

U.S. production of nitrogen, the most widely used plant nutrient, is heavily dependent on natural gas, both as a hydrogen source and fuel. The price of natural gas to fertilizer producers increased from $0.66 per 1,000 cubic feet in 1975 ( 46.6 percent of total ammonia production cost) to $2.33 per 1,000 cubic feet or 72.6 percent of the total cost of a ton of ammonia in 1981 (Fertilizer Reference Manual). Thus, fluctuations in the price of natural gas leads to fluctuations in the price of nitrogen fertilizers. With deregulation of natural gas prices expected by 1985 under the Natural Gas Policy Act of 1978, natural gas prices and with it, fertilizer prices, are expected to increase.

The objective of this paper is to provide empirical estimates of supply, demand, prices, exports and imports of nitrogen fertilizer (both aggregate and specific products ) and draw policy implications. The period of the study includes the volatile period of the 1970's where domestic demand fluctuated, imports of nitrogen surged and exports grew at a rapid rate. This period was also characterized by escalating prices of natural gas. This study examines individual products and not just aggregate demand for Nitrogen. We also examined the supply side of fertilzer by accounting for fertilizer manufacturing inputs such as wage rates and basic feedstock input prices. Quarterly data were used in estimation to capture seasonal distribution and production of fertilizers.

The specific nitrogen products included were anhydrous ammonia, ammonium nitrate, ammonium sulfate, nitrogen solutions and urea. The total demand for nitrogen was obtained by summing demand for individual products, those used in mixes and quantity exported. Aggregate domestic supply and quantities imported were estimated to obtain total supply. Fertilizer prices at both the wholesale and retail levels were estimated for individual products to determine their response to changes in the economic environment.

## CONCEPTUAL FRAMEWORK

Demand: The demand for a production input such as fertilizer is a derived demand. A producer's demand function is derived from the underlying production function for the commodity he produces. Farmers are assumed to be profit maximizers. Under competitive market conditions, the profit function can be expressed as revenues ( output price times the production function ) less costs ( sum of input quantities times their respective prices ). Setting the partial derivatives of the profit function with respect to input quantities equal to zero, and solving simultaneously, yields the derived demand curves as functions of output and input prices. The sufficient second order conditions for a profit maximum require that the demand function be a positive function of output price and a negative function of input prices. Theoretically, the prices of land, labor, machinery and seeds should be included in the derived demand function, but as Rausser and Moriak have shown, only land and labor have any significant impact on fertilizer demand.

A time trend was included in prior studies to represent shifts in the production function over time. This model included acreage planted of 20 principal crops to account for such shifts as well as other less measurable influences such as technological change in agriculture. Thus, the demand for each nitrogen fertilizer product was a function of its own price, farm price of corn and acreage planted of 20 principal crops. Price of corn was included as the output price since most nitrogenous products are applied on corn.

Supply: The same profit maximixing assumptions were made in deriving the supply function. The producer's profit function was defined as revenue (product price times the production function for fertilizer) less costs (sum of input quantities times their respective prices). Simultaneous solution of the first order partial derivatives with respect to input quantities yields the demand for any of the inputs used in fertilizer production. Substitution of these optimal input demand functions into the firm's production function yields supply as a function of input and output prices:

$$y = f\ (x_i^*\ (\ w_1 \ldots\ldots\ldots\ldots w_m\ ), P\ ) = S\ (\ w_1 \ldots\ldots\ldots w_m, P\ ) \qquad (1)$$

$$i = 1 \ldots m$$

where xi = inputs used in nitrogen fertilizer production

wi = input prices

P = Output ( Fertilizer ) Price

The domestic supply of nitrogen, therefore, is a function of the weighted input prices ( natural gas, labor and electricity ) and the wholesale price of ammonia, since all nitrogen products are derived from ammonia. A time trend representing investments in fixed or quasi-fixed factors of production was included in the supply function.

Prices: Following Labys, the wholesale price of ammonia was specified as a stock adjustment process, being a function of beginning stocks, and the weighted costs of inputs. Retail prices of individual products were then specified as a function of the wholesale price of ammonia, a stock to production ratio, and the wholesale price index in the general economy. The ratio describes the pressure placed on available stocks by production, and, consequently, on prices. The wholesale price index was included to capture the effects of inflation on retail prices.

Imports and Exports: The basic explanatory variables for imports and exports are suggested by the theory of consumer demand, whereby the consumer allocates his income among the consumption bundle to achieve maximum satisfaction (Leamer and Stern). The theory postulates that the quantity purchased of any good depends on the consumers' (domestic) income, prices of imports and prices of other goods. If imports and domestic goods are perfect substitutes, quantity imported can be expressed as a function of income, the common price of the good and a variable that shifts the supply of the good in question. Following this reasoning, the import of nitrogen was specified as a function of net farm income, the wholesale price index of natural gas and acreage planted of 20 principal crops.

Export demand following analogous reasoning should be a function of world income and world wholesale price of nitrogen but both variables have serious biases and are difficult to compute. A key factor determining the direction of trade in the fertilizer industry is the value of the dollar. When the value of the dollar is high, short term interest rates tend to be relatively high and discourage international buyers, resulting in a decrease in exports. Hence, world population and short term interest rates were used as proxies for world price and exchange rates, respectively.

Stocks: Nitrogen stocks were expressed as an identity consisting of the the sum of beginning stocks, domestic production and imports less total domestic demand and exports.

DATA

Total nitrogen supply and stocks are available from the U.S. Department of Commerce, Inorganic Chemicals, Series M28-A. Nitrogen exports and imports were obtained from the U.S. Department of Commerce, Exports FT410 and Imports FT135 reports, respectively. Retail prices of the specific nitrogen products are available from various issues of USDA Agricultural Prices, while demand for the specific products are available in USDA Commercial Fertilizer Series. Total acreage planted of 20 principal crops was obtained from USDA Crop Production.

## SUMMARY OF THE ECONOMETRIC MODEL

Table 1 presents a summary of the econometric relationships to be used in the empirical estimation. Definition and units of measurements of the variables are provided in appendix A.

Table 1: STRUCTURAL EQUATIONS[a]

1. Domestic Supply of Nitrogen: QPN' = f (PANH', WGEL, TIME)
2. Total Import of Nitrogen: IN' = f (RMI, AC2OP, PNG)
3. Demand for Nitrogen in Mixes: AQDXNN' = f (PMIX, AC2OP, PCRN)
4. Exports of all Nitrogen: EN' = f (WPOP, PPINT)
5. Wholesale Price of Ammonia: PANH' = f (WGEL, SNL)
6. Ret. Price of Anhy. Ammonia: PPANH' = f (PANH')
7. Ret. Price of Amm. Nitrate : PPANIT'= f (PANH', SPRAN, WPI)
8. Ret. Price of Amm. Sulfate: PPAS' = f (PANH', SPRAS, WPI)
9. Ret. Price of Nit. Solution: PPNSOL' = f (PANH', SPRNS, WPI)
10. Ret. Price of Urea: PPU' = f (PANH', SPRU, WPI)
11. Demand for Anhydrous Ammonia: QDAANS' = f (PPANH', AC2OP, PCRN)
12. Demand for Ammonium Nitrate: QDANNS' = f (PPANIT', AC2OP, PCRN)
13. Demand for Ammonium Sulfate: QDASNS' = f (PPAS', AC2OP, PCRN)
14. Demand for Nitrogen Solution: QDNSNS' = f (PPNSOL', AC2OP, PCRN)
15. Demand for Urea: QDNUNS' = f (PPU', AC2OP, PCRN)

a Prime (') denotes endogenous variables

Quantities demanded of spcific nutrients were measured in Seasonally Adjusted Annual Rates ( SAAR ) while prices were defined in terms of dollar/nutrient ton. Quarterly observations were used on all the variables, starting from the second quarter of 1960 to the end of the second quarter of the 1980 fertilizer year, a total of 84 observations.

## RESULTS AND IMPLICATIONS

The 15 structural equations were estimated simultaneously by 3SLS technique since the error terms may be correlated across equations. Using information on the correlation of the stochastic disturbance terms of the structural, equations improves the assymptotic efficiency of the parameter estimates. The 3SLS estimates together with their standard errors are provided in Table 2. The predictive ability of the estimated model were evaluated using Theil Inequality Coefficients with changes in the variables, also in Table 2.

The model generally performed well from both a statistical and theoretical perspective. The U1 statistic for all the equations lies within the acceptable bounds. Most of the explanatory variables had signs hypothesized by theory with the estimated parameters much larger than their standard errors.

Impact multipliers derived from the reduced form equations are provided in Table 3 with several interesting results. Total acreage planted of the 20 principal crops was the major factor determining the demand for specific nutrients. The impact multipliers were all positive except for urea, and ranged from .0415 for ammonium nitrate to .6029 for anhydrous ammonia. The huge increases in fertilizer demand during the 1970's were triggered by about 60 million acre expansion in crop

## TABLE 2: 3SLS ESTIMATES OF THE NITROGEN MODEL

## (STANDARD ERRORS IN PARENTHESIS)

| | U1 |
|---|---|
| QPN = .1250 - .0021 PANH - .0007 WGEL + .0421 TIME<br>(.0685) (.0006) (.0002) (.0011) | .84 |
| IN = 2.2010 + .0020 PNG + .0087 AC20P + .0060 RNI<br>(.2290) (.0001) (.0008) (.0023) | .43 |
| AQDXNN = -1.5869 + .0114 AC20P - .0051 PMIX + .2082 PCRN<br>(.2573) (.0010) (.0005) (.0394) | .69 |
| EN = -2.6461 + .0009 WPOP + .0016 PPINT<br>(.3368) (.0001) (.0003) | .78 |
| PANH = 49.7940 + .2812 WGEL + 11.3173 SNL<br>(6.3689) (.0221) (6.0489) | .67 |
| PPANH = 37.1402 + .9332 PANH<br>(4.1050) (.0338) | .77 |
| PPANIT = 15.4844 + .6192 PANH - 22.3737 SPRAN + .1351 WPI<br>(3.3403) (.0349) (5.3882) (.0276) | .74 |
| PPAS = 3.3351 + .3386 PANH - 11.2790 SPRAS + .2406 WPI<br>(3.222) (.0314) (3.1251) (.0258) | .73 |
| PPNSOL = 13.7740 + .4563 PANH + 5.8365 SPRNS + .1297 WPI<br>(2.7155) (.0302) (2.8415) (.0363) | .76 |
| PPU = 26.0205 + .8320 PANH - 90.1732 SPRU + .1509 WPI<br>(4.5402) (.0481) (17.1875) (.0398) | .75 |
| QDAANS = -8.1864 - .0071 PPANH + .0349 AC20P + .6029 PCRN<br>(.7820) (.0010) (.0029) (.1237) | .66 |
| QDANNS = -.8504 - .0060 PPANIT + .0060 AC20P + .2416 PCRN<br>(.1983) (.0005) (.0007) (.0354) | .77 |
| QDASNS = -.0807 - .0012 PPAS + .0009 AC20P + .0421 PCRN<br>(.0280) (.0001) (.0001) (.0055) | .62 |
| QDNSNS = -3.5876 - .0001 PPNSOL + .0144 AC20P + .1043 PCRN<br>(.2706) (.0007) (.0010) (.0408) | .67 |
| QDNUNS = -2.1367 + .0022 PPU + .0075 AC20P - .0299 PCRN<br>(.1785) (.0003) (.0007) (.0312) | .68 |

## TABLE 3: IMPACT MULTIPLIERS

| Endogenous Variables | Exogenous Variables | | | | |
|---|---|---|---|---|---|
| | WGEL | AC20P | PCRN | PNG | WPOP |
| Total Suppply of N | -.0012 | | | | |
| Imports of Nitrogen | | .0087 | | .0020 | |
| Demand for N in Mixes | | .0144 | .2082 | | |
| Exports of Nitrogen | | | | | .0009 |
| Wholesale Price-Ammonia | .2812 | | | | |
| Ret. Price, Anhy. Ammonia | .2624 | | | | |
| Ret. Price, Amm. Nitrate | .1741 | | | | |
| Ret. Price, Amm. Sulfate | .1087 | | | | |
| Ret. Price, Nit. Solution | .1283 | | | | |
| Ret. Price, Urea | .2339 | | | | |
| Dem. for Anhy. Ammnia | -.0029 | .6029 | .0349 | | |
| Dem. for Amm. Nitrate | -.0018 | .2416 | .0060 | | |
| Dem. for Amm. Sulfate | -.0010 | .0415 | .0009 | | |
| Dem. for Nit. Solution | -7.046E-06 | .1043 | .0144 | | |
| Dem. for Urea | .0005 | -.0299 | .0075 | | |

production. Consequently, changes in the level of demand for fertilizer were effected by restricting how much land is put into cultivation. The results indicate that a 1 million acre increase in acreage planted of the 20 principal crops increased demand for anhydrous ammonia by 60,290 nutrient tons and increased demand for ammonium nitrate by 24,160 nutrient tons.

Input costs (natural gas, labor and electricity) exert a positive impact on the prices (both wholesale and retail) of nitrogen products. The greatest impact was on the retail price of anhydrous ammonia (.2624) and urea (.2339). Input costs also had a negative impact on the demand for specific nitrogen products, the greatest impact being on anhydrous ammonia, conforming with expectations. An increase in the costs of natural gas, labor and electricity increases the retail prices which in turn reduces the demand by farmers for nitrogenous products.

An increase in the wholesale price index for natural gas had a positive impact on nitrogen imports. A 10 percent rise in the natural gas price would increase nitrogen imports by 20,000 nutrient tons. This is not surprising as natural gas was the largest cost component in domestic ammonia production, accounting for about 70 percent of the total cost in 1980. Increases in the price of natural gas should lead to increases in the price of domestic-produced ammonia, and consequently increased ammonia imports from cheaper-producing sources, such as the U.S.S.R., Mexico, and Trinidad and Tobago.

The farm price of corn had a positive impact on the demand for specific nitrogen products, with anhydrous ammonia experiencing the greatest impact. A $1.00 increase in the price of a bushel of corn should increase demand for anhydrous ammonia and ammonium nitrate by

34,900 and 6,000 nutrient tons, respectively.

## CONCLUDING COMMENTS

This study examined the interrelationships in the nitrogen fertilizer industry, the most important plant nutrient used in the U.S. Most of the estimated coefficients were more than twice as large as their standard errors and had the expected signs. Direct comparison of the results of this paper with others is difficult and inappropriate because previous studies did not disaggregate nitrogen by specific nutrient types or account for the supply, prices, imports and exports of fertilizer nutrients.

However, this study provides new insights into the fertilizer industry as a whole. It indicates the interactions which occur in the fertilizer and agricultural sectors and the determinants that influence production or purchasing decisions. It indicates the need for examining all the nitrogen fertilizer products. Furthermore, it provides policymakers with information on the effects of increasing costs of nitrogen fertilizer on farm level demand, and the impacts of rising natural gas price on production.

The rising cost and the role of natural gas in nitrogen production necessitates further investigation concerning new plant location in the U.S. or in other places where cheaper sources of natural gas can be obtained. We need to decide whether nitrogen fertilizer should be increasingly imported or domestically produced.

## APPENDIX A: DEFINITION OF VARIABLES

QPN = Domestic Supply of Nitrogen, Million Nutrient Tons.

IN = Nitrogen Imports, Million Nutrient Tons.

AQDXNN = Total Demand for Nitrogen in Mixes, Million Nutrient Tons.

EN = Nitrogen Exports, Million Nutrient Tons.

PANH = Wholesale Price of Anhydrous Ammonia, $/material ton.

PPANH = Retail Price of Anhydrous Ammonia, $/material ton.

PPANIT = Retail Price of Ammonium Nitrate, $/material ton.

PPAS = Retail Price of Ammonium Sulfate, $/material ton.

PPNSOL = Retail Price of Nitrogen Solutions, $/material ton.

PPU = Retail Price of Urea, $/material ton.

QDAANS = Demand for Anhydrous Ammonia, Nutrient Tons, SAAR.

QDANNS = Demand for Ammonium Nitrate, Nutrient Tons, SAAR.

QDASNS = Demand for Ammonium Sulfate, Nutrient Tons, SAAR.

QDNSNS = Demand for Nitrogen Solutions, Nutrient Tons, SAAR.

QDNUNS = Demand for Urea, Nutrient Tons, SAAR.

WGEL = Weighted Costs of Natural Gas, Labor and Electricity.

PNG = Wholesale Price Index of Natural Gas.

SNL = Beginning Stocks, Million Nutrient Tons.

AC20P = Acreage Planted of 20 Principal Crops.

RNI = Realized Net Farm Income, Billion $, SAAR.

PMIX = Wholesale Price Index of Mixed Fertilizers, 1967=100.

WPOP = Total World Population

PPINT = Prices Paid for Interest, 1967=100.

SPRAN = Stock to Production Ratio, Ammonium Nitrate.

SPRAS = Stock to Production Ratio, Ammonium Sulfate.

SPRNS = Stock to Production Ratio, Nitrogen Solutions.

SPRU = Stock to Production Ratio, all Nitrogen

PCRN = Farm Price of Corn, $/bushel

WPI = Wholesale Price Index, 1967=100.

## REFERENCES


Boadu, F.O. " An Econometric Analysis of Demand and Supply of Fertilizer in the U.S., Ph.D Dissertation, University of Kentucky, 1981.

Brake, J.R., R.A. King, and W.B. Riggan, " Prediction of Fertilizer Consumption in the U.S., the East North Central Region, and the South Atlantic Region." North Carolina State College Agricultural Economics Information Series, No. 78, 1960.

Carman, H.F. " The Demand for Nitrogen, Phosphorous and Potash Fertilizer Nutrients in the Western United States."Western Journal of Agricultural Economics, 4(1979):23-31.

Griliches, Zvi. " The Demand for Fertilizer: An Economic Interpretation of a Technological Change."Journal of Farm Economics, 40(1958):591-606.

Griliches, Zvi. " Distributed Lags, Disaggregation, and Regional Demand Functions for Fertilizer."Journal of Farm Economics, 41(1959):90-102.

Heady, E.O., and M.H. Yeh, "National and Regional Demand Functions for Fertilizer."Journal of Farm Economics, 41(1959):332-48.

Henderson, J.M. and R.E. Quandt, Microeconomic Theory: A Mathematical Approach. New York: McGraw Hill Book Co., 1980.

Intriligator, M.D. Econometric Models, Techniques and Applications. Englewood Cliffs, N.J.: Prentice Hall, Inc., 1978.

Labys, W.C. Dynamic Commodity Models: Specification, Estimation and Simulation. Lexington, D.C. Heath and Co. 1973.

Learmer, E.E. and R.M. Stern, Quantitative International Economics. Chicago, Aldine Publishing Co., 1970.

Paul, D. et.al, "The Changing U.S.Fertilizer Industry." USDA/ERS, Agricultural Economics Report, No.378, 1977.

Rausser, G.C., and T.F. Moriak, "The Demand for Fertilizer, 1949-64: An Analysis of the Coefficients from Periodic Cross-Sections." Agricultural Economics Research, 22(1970):45-56.

Roberts, R.K. and E.O. Heady, "Fertilizer Demand functions for Specific Nutrients Applied to Three Major U.S. Crops."Western Journal of Agricultural Economics.7(1982):265-277.

Russell, R.R., and M. Wilkinson, Microeconomics: A Synthesis of Modern and Neoclassical Theory. New York, John Wiley and Sons, 1979.

The Fertilizer Institute, "Fertilizer Reference Manual." Washington D.C. June 1982.