Economic Analysis of the Changing Structure of the U.S. Fertilizer Industry

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ABSTRACT

This article evaluates structural changes in the U.S. nitrogen fertilizer industry by using a decomposed Negative Binomial Regression model. Results indicate that the U.S. nitrogen fertilizer industry can be characterized as an industry involving price leadership in oligopoly. Declining profit-margins might have forced fertilizer producers to consolidate and eliminate duplicate operations. The market concentration level is expected to intensify as the natural gas price rises.

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In recent years, economists have increasingly confronted structural changes in the farm input industry. Increases in energy prices and labor costs, relative to both capital and materials prices, have induced shifts in both input use and composition (Morrison), which have lead to structural changes in the farm input industry. Cost-saving technologies and their adaptations in production processes are important factors contributing to industry structural changes, but the farm input industry, especially the fertilizer industry, has not attracted major economic research attention from economists. The objectives of this study are to answer the following four questions: (1) What structural changes have occurred in the U.S. nitrogen fertilizer industry? (2) What economic factors have contributed to these structural changes ? (3) What are the effects of structural changes in the U.S. nitrogen fertilizer industry on farmers in terms of nitrogen fertilizer prices and supply? (4) What are the effects of increasing natural gas prices on nitrogen fertilizer price and supply?

The U. S. fertilizer industry is essentially composed of three separate industries, including nitrogen, phosphate, and potash industries, where each uses different material and process requirements in production. While more than 90 percent of potash fertilizer consumed in the U.S. is imported from Canada, the U.S. is the world's largest phosphate fertilizer exporter. Florida and North Carolina account for more than 90 percent of the U.S. phosphate rock production, which is the main ingredient of phosphate fertilizer, while Tennessee and a few

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Rocky Mountain States produce the remainder of the phosphate rock supply. Anhydrous ammonia is the primary source of nearly all nitrogen fertilizer used in the United States, which is produced through a chemical reaction between nitrogen elements derived from air with hydrogen derived from natural gas. Ammonia is also used to produce the ammoniated phosphates such as diamonium phosphate and monoammonium phosphate. Commercial nitrogen fertilizer use currently accounts for more than 57 percent of all fertilizer use in the U.S. However, the U.S. is a net importer of nitrogen fertilizer, which ranges between more than 7 percent of total U.S. consumption in 1990 to 23 percent in 1999 with a record high 27 percent in 1994.

The U.S. nitrogen fertilizer industry has experienced significant structural change in size, location, and in the concentration of market power during the last three decades. The number of firms of the U.S. anhydrous ammonia industry has declined from 58 firms in 1976 to 27 firms in 2000 and the total number of plants has been reduced from 113 to 39 during the same time period. Meanwhile, production capacity has increased from 16.8 million tons in 1976 to 21.4 million tons in 2000. The number of plants with an annual production capacity less than 250,000 tons has steadily declined from 86 in 1976 to 9 in 2000, and the number of plants with an annual production capacity greater than 250,000 tons but less than 500,000 tons has also declined from 23 to 15 with minor fluctuations during the same time period (Table 1). However, the number of plants for the annual production capacity greater than 500,000 tons has increased from 4 in 1976 to 15 in 2000. As a result of an increased number of larger plants, however, the average production capacity per plant has increased from 170.7 thousand tons per year in 1976 to 498.5 thousands tons per year in 2000.

In addition, the market share by the four largest firms, which include C.F. Industries, Farmland Industries, PCS Nitrogen, Inc. (formerly Arcadian Corporation), and Terra Nitrogen, where each has over 2 million tons of annual production capacity, has also increased to 47.1 percent in 2,000 from 20.5 percent in 1976. Given these statistics, both economies of scale in plant size and capital requirements would seem to have contributed to erecting barriers to entry. In fact, according to the Production Cost Survey by the Fertilizer Institute, ammonia production cost per ton was $123.71 in 1999 for a plant size under 1,000 tons of capacity per day, while it was $98.97 for a plant size over 1,000 tons per day. Declining profit-margin might have forced nitrogen fertilizer producers to consolidate and eliminate duplicate operations, which leads to increased market concentration. Significantly increased market power could then enhance both prices and firm profits beyond that which would occur under a perfectly competitive market.

Most fertilizer plants prior to 1960 were built in the major Midwest market area. During the 1960s' and 1970s', however, fertilizer plants were built in the Delta (Arkansas, Louisiana and Mississippi) and in Southern Plains (Oklahoma and Texas) where the natural gas price is relatively lower. All three of these regions accounted for 32 percent of U.S. ammonia production before 1960, 60 percent in 1990, and currently account for 70 percent of production. The cost of shipping nitrogen fertilizer relative to shipping natural gas was lowered as a result of the advent of unit-train technology. Most nitrogen fertilizer plants with more than a half million tons of annual production are currently located in the Delta and Southern Plains regions.

While most researchers have used either market structure-based models (Alston, Sexton, and Zang; Azzam; Muth and Wohlgenant; Sexton and Zhang) or cost function-based models (McDonald and Ollinger; Morrison 1997, 1999) or production-based models (Arrow, Chenery, Minhas, and Solow; Lianos) to evaluate industry structural changes, we use a decomposed Poisson regression model (PRM), which is closely related to production-based models, to identify economic factors contributing to the structural changes in the U.S. fertilizer industry.

Both plant size classes and firm size classes are included in the decomposed PRM to simultaneously evaluate structural changes in size distribution, the changing number of plants in each size class, and the changing concentration level of market power of the U.S. fertilizer industry. Model estimation results are then used to test the hypothesis that price leadership in oligopoly characterizes the U.S. nitrogen fertilizer industry. Finally, we evaluate the effects of increasing natural gas prices on nitrogen fertilizer price and supply.

A Decomposed Poisson Regression Model of Structural Changes in the U.S. Nitrogen Fertilizer Industry

Several factors contribute to structural changes occurring in the U.S. nitrogen fertilizer industry. Increased demand for grain products (especially corn), economies of scale, and natural gas price all contribute to the consolidation of the industry into larger fertilizer plants. Changes in natural gas prices, the hourly wages of production workers in the fertilizer industry, and corporate bond rates send market signals that lead to changes in technology and economies of scale. Therefore, from among many other variables, we model structural changes in the U.S. nitrogen fertilizer industry using the following four variables: the hourly wages of production workers in the fertilizer industry, the corporate bond rate, and the unit price of commercial natural gas, and the unit price of anhydrous ammonia price.

A decomposed Poisson regression model (PRM) presented by Kim et al. acknowledges diverse effects from such economic factors including natural gas price, wage rate, corporate bond rate, and output price on the nitrogen fertilizer industry, depending upon plant size and firm size. When the wage rate rises, for instance, nitrogen fertilizer firms would gain economic efficiency by shifting from a labor-intensive operation to a capital-intensive operation. Since smaller fertilizer plants are generally considered to have a more labor-intensive operation than larger-size fertilizer plants, the number of smaller plants would decline and the number of larger-size plants would increase, as the wage rate rises. Similarly, as the corporate bond rate rises, nitrogen fertilizer firms would gain economic efficiency by shifting from a capital-intensive operation to a labor-intensive operation. Therefore, the number of larger-sized plants would decline, while the number of smaller-sized plants would increase. However, the number of plants across all size classes would decline as natural gas price rise, and would increase as the nitrogen fertilizer price rises. However, the relative changes in the number of plants as the natural gas price and nitrogen fertilizer price increase would vary across both plant size and firm size.

Considering diverse effects of economic factors on both plant and firm sizes, the decomposed Poisson regression model (PRM) is represented by:

(1) $$U_j(k) = E[N_j(k) \mid (w/r), (g/p)]$$

$$= \exp [\alpha + \sum_{\ell=1}^{m} \beta(l)D^f(l)(w/r) + \sum_{\ell=1}^{m} \gamma (l)D^f(l)(g/p) + \delta \sum_{\kappa=1}^{n} D^p(\kappa) \quad (g/p)$$
$$+ \sum_{\ell=1}^{m-1} \lambda(l)D^f(l) + \sum_{h=1}^{n-1} \theta(h)D^p(h) + T\ ], \qquad j = 1, 2, \ldots, m; \quad k = 1, 2, \ldots, n,$$

where $U_j(k)$ is the conditional mean of the *j*th plant size class owned by the *k*th group (such as the four dominant firms as a group and the remaining plants grouped separately), m is the number of plant size classes, n is the number of firm size classes, *w* is the hourly wage of production workers in the fertilizer industry, *g* is a unit price of natural gas, *p* is a unit price of fertilizer, *r* is corporate bond rate, α, β, γ, δ, λ and θ are parameters, T is a time variable representing technological changes, $D^f(l)$ is a dummy variable associated with the *l*th plant size-class such that:

$$D^f(l) = \begin{cases} 1 & \text{if } l = j \\ 0 & \text{otherwise,} \end{cases}$$

and $D^p(h)$ is a dummy variable associated with the *h*th ownership group such that:

$$D^p(h) = \begin{cases} 1 & \text{if } h = k \\ 0 & \text{otherwise.} \end{cases}$$

Given the relationship between size class, the number of nitrogen fertilizer plants in each size class, and concentration of market power, as wage rates increase, fertilizer firms would achieve greater economic efficiency by shifting from labor-intensive to capital-intensive production processes. Since larger nitrogen fertilizer plants are considered to have a more capital-intensive operation than smaller plants, the number of larger-size nitrogen fertilizer plants would increase, while the number of smaller-size fertilizer plants would decline as wage rates increase. Therefore, as the wage rate rises, the parameter $\beta(l)$ in equation (1) associated with smaller-size fertilizer plants is expected to be negative, while it is likely to be positive for larger-size fertilizer plants. Similarly, rising corporate bond rates would increase capital costs, and therefore, nitrogen fertilizer firms would shift from a capital-intensive production process to a labor-intensive production process. Therefore, as the corporate bond rate rises, the parameter $\beta(l)$ in equation (1) associated with smaller-size nitrogen fertilizer plants is expected to be negative, while it would be positive for larger-size fertilizer plants.

When the average natural gas price is $2.20 per million British thermal unit (MMBtu), natural gas costs accounts for more than 75 percent of ammonia production costs. Therefore, the number of plants across all size classes would decline at varying rates as natural gas price rises. The effects of nitrogen fertilizer price on the number of plants, however, differ across the size classes depending upon the market structure. To demonstrate this, let the $\bar{Q}_j$ be the average amount of nitrogen fertilizer production for the *j*th size class plant. The amounts of nitrogen fertilizer production for the *j*th size class plants are then represented by $\bar{Q}_j E(N_j(k))$. The nitrogen fertilizer price elasticity of the total amount of nitrogen fertilizer for the *j*th plant size class is represented by:

$$(2) \qquad [\partial \bar{Q}_j E(N_j(k)) \,/\, \partial p][p \,/\, \bar{Q}_j E(N_j(k))] = -\gamma(j)D(j)(g/p), \qquad j = 1, 2, \ldots, m,$$

and the nitrogen fertilizer price elasticity for the dominant nitrogen fertilizer firms is represented by:

$$(3) \qquad [\partial \bar{Q} E(N(k)) \,/\, \partial p][p \,/\, \bar{Q} E(N(k))] = -\delta\left(\sum_{\kappa=1}^{n} D(\kappa)\right)(g/p).$$

Under a competitive market structure, each firm produces nitrogen fertilizer at the level where its marginal cost equals its average revenue (or market price) so that the dominant firm would produce nitrogen fertilizer Q_c at the price P_c, while all other firms would produce q_c, and the nitrogen fertilizer price elasticity would be positive so that the parameter γ in equation (2) would be negative.

When geographically divided regional markets are dominated by a few large firms, price leadership by one or a few firms is one type of market solution of oligopolistic price competition. The dominant firm sets its output price, p, along its consumer demand curve where its marginal cost equals its marginal revenue. All other firms, meanwhile, will sell all they can at that price. If the U.S. nitrogen fertilizer industry is characterized by price leadership in oligopoly, then the nitrogen fertilizer price for the dominant firm would be observed along its consumer demand curve, while nitrogen fertilizer prices for all other firms would be observed along the firms' marginal cost curve. In other words, if the price elasticity of nitrogen fertilizer in equation (3) is negative for the dominant firm, and it is positive for all other firms in equation (2), then the U.S. nitrogen fertilizer industry would be characterized as price leadership in oligopoly.

Effects of Natural Gas Costs on Nitrogen Fertilizer Supply

Natural gas is the primary cost component in producing nitrogen fertilizers. Approximately 34 million British thermal units (MMBtu) of natural gas is needed for producing one ton of anhydrous ammonia (NH_3) (Crop Nutrients Bulletin). As natural gas price rises from \$2.20 to \$9.00 per MMBtu, as we have experienced in January 2001, natural gas cost as a share of the cost of ammonia production rises from 75 to approximately 92 percent. Without a sharp increase in nitrogen fertilizer prices, the higher natural gas price creates pressure for nitrogen fertilizer producers to curtail production.

As natural gas price rises, the marginal cost curves MC for the dominant firms and *mc* for all other forms would shift to the left toward MC′ and *mc*′, respectively. The dominant firm would then set its nitrogen fertilizer price at p′, where its marginal cost curve MC′ intersects its marginal revenue curve MR. All other firms, after a natural gas price rise, would sell their outputs q′ at prices p′, where their marginal cost equals nitrogen fertilizer price. Following Pinstrup-Anderson, Ruiz de Londoño and Hoover, and Lindner and Jarett, a nitrogen fertilizer price set by the dominant firm after a natural gas price increase is estimated by:

(4) $$p' = p[1 + k\varepsilon / (\varepsilon + |\eta|)],$$

and its associated nitrogen fertilizer production is estimated by:

(5) $$Q' = Q[1 - k\varepsilon|\eta| / (\varepsilon + |\eta|)],$$

where ε is the price elasticity of the marginal cost curve MC and η is the price elasticity of the marginal revenue curve, and k is the proportionate increase in costs of nitrogen fertilizer production. As a result of an increasing natural gas price, nitrogen fertilizer price would also rise to p′ from p, and total nitrogen fertilizer production would decline from (Q + q) to (Q′ + q′).

An important question must be answered, which is whether the increased nitrogen fertilizer price p' is competitive enough to compete with an already lower price for nitrogen fertilizers from countries including the former Soviet Union, the Middle East, and Caribbean countries such as Trinidad, Tobago, and Venezuela. The U.S. is a net importer of nitrogen fertilizer, accounting for between more than 7 percent of total U.S. consumption in 1990 to 23 percent in 1999, with a record high 27 percent in 1994 (Brookins). While imports can cover some of the shortfall in U.S. production, it is important to understand that transportation limitations can exaserbate problems in the short term. Ammonia and its solutions require special (i.e., refrigerated) tanks and vessels, which are generally in more limited supply (Phillips and Mathers). As natural gas price continues to rise, however, U.S. imports of nitrogen fertilizers would undoubtedly increase, while U.S. domestic production would decline.

Empirical Results

The size of nitrogen fertilizer plants varies widely, ranging from less than 100 thousand tons per year to 2 million tons per year. Therefore, for this analysis, nitrogen fertilizer plants are arbitrarily grouped into three size classes based on the size of annual operational production capacity. Plant size classes include: $0 < S_1 \leq 250$ thousand tons; 250 thousand tons $< S_2 \leq 500$ thousand tons; and $S_3 > 500$ thousand tons.

Data for the annual nitrogen fertilizer production capacity and ownership of each plant are from the Tennessee Valley Authority (TVA) for the period 1976 to 1995, and from the International Fertilizer Development Center (IFDC) for the period 1996 to 2000. Data on hourly wage rates were obtained from the Production Cost Survey conducted by The Fertilizer Institute and from the Census of Manufactures, Industry Series, U.S. Department of Commerce. Natural gas prices were obtained from the Office of Energy Policy and New Uses, U.S. Department of

Agriculture (USDA). Corporate bond rates were obtained from the Resource Economics Division, Economic Research Service, USDA. The time variable T is assigned as T=1 for 1976, T=2 for 1977, etc.

Since the data reveals an overdispersion problem, where its conditional variance is greater than its conditional mean, we adopted the scale option in SAS GENMOD associated with a 2-way classification with interaction. Parameter estimates for a decomposed Poisson Regression model of the number of plants by both plant and firm size classes for the U.S. nitrogen fertilizer industry are presented in Table 2. Natural gas price normalized with the unit price of nitrogen fertilizer (*g*/*p*) is statistically insignificant for plant size class 2, while all other variables are statistically significant.

Parameters for equation (1) derived from Table 2 are presented in equation (6) as follows:

$$\text{(6)} \quad E[N_j(k) \mid (w/r), (g/p), T] = \exp [0.8932 - 0.2985\, D(1)(w/r) + 0.2034\, D(2)(w/r)$$

$$+ 0.5438\, D(3)(w/r) - 59.5874\, D(1)(g/p) + 2.7823\, D(2)(g/p) + 40.6059\, D(3)(g/p)$$

$$+ 56.1287 \left(\sum_{\kappa=1}^{n} D(\kappa)\right) (g/p) - 0.052\, T + 4.0583\, D(1) + 2.0447\, D(2) - 1.7157\, D(1)].$$

The signs of all estimators is consistent with a priori expectations. The effects of wage rate and corporate bond rate on the number of plants for the largest size class 3 (i.e., 0.5438) are roughly twice those for the smaller size class 1 (- 0.2985), but in the opposite direction. As we have discussed earlier, these results may indicate that smaller nitrogen fertilizer plants, size class 1, involve more labor-intensive operations, while nitrogen fertilizer plants of size class 3 involve more capital-intensive operations. As the wage rate (corporate bond rate) rises, firms would achieve efficiency by shifting from labor-intensive (capital intensive) operation to capital-intensive (labor-intensive) operations. Similarly, the natural gas price elasticity is - 0.78 for the smaller plant size-class 1 and 0.53 for the larger plant size-class 3, but it is 0.73 for the plants owned by the four largest dominant firms (Table 3). As the natural gas price rises, firms would also achieve economic efficiency through consolidation and elimination of duplicate operations by shifting from labor-intensive to capital-intensive operations. For instance, total production cost per ton was $123.71 for plants under 1,000 tons of capacity per day, while it was $98.97 for plants over 1,000 tons per day (The Fertilizer Institute).

The price elasticity of nitrogen fertilizer is positive for the smaller plant size class 1 (i.e., 0.78), and it is negative for both the four dominant firms within the industry (i.e., - 0.73) and the larger size class 3 (i.e., - 0.53) which also include plants from the four dominant firms. Consequently, these results appear to support our hypothesis that the U.S. nitrogen fertilizer industry is characterized by price leadership in oligopoly. Under price leadership in an oligopolistic market structure, nitrogen fertilizer price would rise and its supply would be reduced as natural gas prices rise.

To measure the effects of both the concentration of market power and increasing natural gas prices on nitrogen fertilizer price and supply, it is necessary to have information on the cost function for nitrogen fertilizer firms. However, we do not have firm-level nitrogen fertilizer production cost data at this time, but it is our intention to collect more production cost data to estimate firm-level cost functions, and then to extend this research to evaluate the impacts of market power concentration and natural gas price increases on nitrogen fertilizer price and supply.

Conclusions

It is often hypothesized that U.S. nitrogen fertilizer firms are price-takers so that no firm has a significant impact on nitrogen fertilizer price and supply. This proposition was examined and statistically tested in this paper by applying a decomposed Poisson Regression model (PRM) of structural changes in the U.S. nitrogen fertilizer industry. Both plant size classes and firm size classes are included in the decomposed PRM to simultaneously evaluate structural changes in size distribution, the changing number of plants in each size class, and the changing concentration level of market power of the U.S. nitrogen fertilizer industry.

The results indicate that the U.S. nitrogen fertilizer industry can be characterized as an industry involving price leadership in oligopoly, which is contrary to common belief that nitrogen fertilizer firms are price-takers. Declining profit-margin over the past 25 years might have forced nitrogen fertilizer producers to consolidate and eliminate duplicate operations, which leads to increased market concentration such that the market share by the four largest nitrogen fertilizer firms has increased from less than 21 percent in 1976 to more than 47 percent in year 2,000. Economies of scale in plant size and capital requirements would also have contributed to increased market concentration. Anhydrous ammonia production cost per ton for a plant size under 1,000 tons of capacity per day was 25 percent higher than production cost for a plant size over 1,000 tons per day. The increased concentration level in market power undoubtedly has contributed to a higher nitrogen fertilizer price and less supply than would have occurred under a perfectly competitive market.

Natural gas is the primary cost component in producing nitrogen fertilizers. Since experiencing a record high natural gas price at $9.00 per MMBtu in January 2001, natural gas cost has accounted for about 92 percent of the cost of ammonia production. Without a sharp increase in nitrogen fertilizer prices, the higher natural gas price creates significant pressure for nitrogen fertilizer producers to curtail production.

To measure the effects of both the concentration of market power and increasing natural gas prices on nitrogen fertilizer price and supply, we are currently collecting more production cost data to estimate appropriate firm-level cost functions. Future research will use those cost functions to provide additional information on structural changes within the nitrogen fertilizer industry.

Table 1. Number of nitrogen fertilizer plants by plant and firm-size classes in selected years.

Plant size[1]	1976 Firm size[2] I	1976 Firm size[2] II	1990 Firm size[2] I	1990 Firm size[2] II	2000 Firm size[2] I	2000 Firm size[2] II
Class 1	79	7	17	5	9	0
Class 2	15	8	12	7	5	10
Class 3	3	1	4	3	9	6

[1] Plant size class 1 represents the annual production capacity less than 250,000 tons; size class 2 represents the annual production capacity greater than 250,000 tons, but less than 500,000 tons; class 3 represents the annual production capacity greater than 500,000 tons.

[2] Firm size I represents the four largest nitrogen fertilizer firms and firm size II represents all other nitrogen fertilizer firms.

Table 2. Parameter estimates for a decomposed Poisson regression model of the number of plants by both plant and firm size-classes for the U.S. nitrogen fertilizer industry.

Intercept	-0.8745 (0.5973)
<u>Wage variable normalized by the corporate bond rate (w_i/r_i):</u>	
Constant	0.5438 (0.1813)
D_1 (plant-size 1)	4.0583 (0.5478)
D_2 (plant-size 2)	2.0447 (0.5815)
D_3 (plant-size 3)	0.0000 (0.0000)
$(w_i/r_i)*D_1$	-0.8423 (0.1081)
$(w_i/r_i)*D_2$	-0.3405 (0.1050)
$(w_i/r_i)*D_3$	0.0000 (0.0000)
<u>Natural gas price normalized with the unit price of nitrogen fertilizer (g_i/p_i):</u>	
Constant	96.7347 (43.2377)
$(g_i/p_i)*D_1$	-100.1930 (39.4313)
$(g_i/p_i)*D_2$	-37.8237 (41.8172)
$(g_i/p_i)*D_3$	0.0000 (0.0000)
D_1 (firm-size 1 for all other firms)	1.7157 (0.3559)
D_2 (firm-size 2 for the four largest firms)	0.0000 (0.0000)
$(g_i/p_i)*D_1$	-56.1287 (27.1766)
$(g_i/p_i)*D_2$	0.0000 (0.0000)
Time (trend)	-0.0520 (0.0264)
Scale	1.4319

Table 3. Wage rate, Corporate bond rate, natural gas price, and nitrogen fertilizer price elasticities by plant and firm size classes, measured at mean values.

		Elasticity			
Size class		η_w	η_r	η_g	η_p
	Class 1	- 0.52	0.52	- 0.78	0.78
Plant size:	Class 2	0.36	- 0.36	0.04	- 0.04
	Class 3	0.95	-0.95	0.53	- 0.53
Firm size:	Dominant firms	—	—	0.73	- 0.73

Refereces

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