

Market Power and Cost-Efficiency Effects of the Market Concentration in the U.S. Nitrogen Fertilizer Industry

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ABSTRACT

This article examines the effects of increasing market concentration level in the U.S. nitrogen fertilizer industry. Results indicate that the costs of market power are greater than the benefits of market concentration, in terms of manufacturing cost efficiency. To provide a stable nitrogen fertilizer supply at a relatively low price, it may be necessary to control natural gas price and/or reduce new import barriers from Middle East and former member states of the Soviet Union, where low cost gas is produced as a byproduct.

Keywords: Nitrogen fertilizer, oligopoly, economies of size, market power, cost-efficiency.

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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 its composition (Morrison) which have led to structural changes in the farm-input industry, especially the fertilizer industry. The market share by the four largest firms, C.F. Industries, Farmland Industries, PCS Nitrogen, Inc., and Terra Nitrogen, each of which has over 2 million tons of annual production capacity, has increased to more than 47 percent in 2000 from less than 21 percent in 1976. An increase in market concentration through consolidation of plants often is associated with economies of plant size, but it may also create market power effects.

In 2000 the U.S. nitrogen fertilizer industry utilized less than its full production capacity due to largely higher natural gas prices. An average of more than 4.3 million tons of anhydrous ammonia on average were imported during the 1996-2000 period, accounting for more than 19 percent of the total U.S. consumption. Imports of anhydrous ammonia are primarily from off-shore production by multi-national companies (mainly the dominant firms in the U.S.) in Canada, which accounted for 41 percent of total imports, and in Trinidad-Tobago, which in 1997 accounted for 51 percent of total imports (Taylor). This trend is expected to exacerbate if U.S. natural gas prices remain high compared to world prices.

The domestic U.S. nitrogen fertilizer market has, however, been successfully protected from competition from Middle East and former member states of the Soviet Union, where low cost gas is produced as a byproduct, by the Ad Hoc committee of domestic U.S. nitrogen producers including Agrium, CF Industries, Coastal Chemicals, Mississippi Chemical, PCS Nitrogen, and Terra Industries (U.S. International Trade Commission, August 2000, December 2000). From January 1980 through December 1999 there were four anti-trust cases initiated

addressing antidumping and countervailing duty issues. As of April 30, 2001 there were nine cases of antidumping duty orders in effect, where multinational agribusiness firms such as ConAgra Inc. attempted to import urea from the former member states of the Soviet Union, including Belarus, Estonia, Lithuania, Romania, the Russian Federation, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.

Natural gas is the primary cost component in producing nitrogen fertilizers, approximately 34 million British thermal units (MMBtu) of natural gas are needed for producing one ton of anhydrous ammonia. Anhydrous ammonia (NH_3), the primary source of nearly all nitrogen fertilizer used in the United States, is produced through a chemical reaction between nitrogen elements derived from air with hydrogen derived from natural gas. From the beginning of 2000, the average daily price for natural gas jumped from \$2.37 per to an average in December 2000 of \$8.80 and a contract price for January 2001 at a record high \$9.90. As a result, in 2001 the cost of producing nitrogen fertilizer rose to unprecedented levels, which in turn, forced nitrogen fertilizer producers to either idle plants or to significantly curtail their production rate to the industry's lowest level in history. Accordingly, the effects on the supply of high prices of natural gas inputs, along with increased market concentration, have raised concerns about the potential impact on farmers and crop production.

The objective of this study is to examine the market power effects and the cost-efficiency effects associated with the economies of size of an increasing market concentration level (Azzam) in the U.S. nitrogen fertilizer industry.

Market Power Effects and Efficiency Effects

Natural gas is the primary cost component in producing nitrogen fertilizers. The energy content of natural gas is about 1.02 MMBtu per thousand cubic feet (Energy Information

Administration, May 2001). To address the economic effects of increased market concentration, let the profits to be maximized for the dominant nitrogen fertilizer firms, π_d , be represented by:

$$(1) \quad \pi_d = [P_y - 34P_{gI} (G_I)]y - c(y, v),$$

where

P_y = a unit price of nitrogen fertilizer (\$/ton),

G_I = the total amount of natural gas for industrial use,

P_{gI} = a unit price of G_I ,

y = the amount of nitrogen fertilizer production by the dominant firms,

c = fertilizer production costs other than the costs to the firm for natural gas, and

v = all other inputs necessary for nitrogen fertilizer production.

The first order condition for profit-maximization is then represented by:

$$(2) \quad P_y = [34P_{gI}(1 + \varepsilon\tau\theta) + \partial c(y, v)/\partial y] / (1 + \eta),$$

where

$\varepsilon = (\partial P_{gI}/\partial G_I)(G_I/P_{gI})$ is the price flexibility of natural gas for industrial use,

$\tau = (\partial G_I/\partial Y)(Y/G_I)$ is the nitrogen fertilizer transmission elasticity of natural gas for industrial use

where Y is an aggregate nitrogen fertilizer demand,

$\theta = (\partial Y/\partial y)(y/Y)$ is the transmission elasticity of the U.S. nitrogen fertilizer industry, and

$\eta = (\partial P_y/\partial y)(y/P_y)$ is the price flexibility of nitrogen fertilizer for the dominant firms.

Using equation (2), the marketing margin for nitrogen fertilizer producers is then represented by:

$$(3) \quad M = P_y - 34 P_{gI} \\ = [34P_{gI}(\varepsilon\tau\theta - \eta)] / (1 + \eta) + [\partial c(y, v)/\partial y] / (1 + \eta).$$

The first term in the bracket on the right-hand side from the equality in equation (3) represents the market power effects and the second represents the cost-efficiency effects for the nitrogen fertilizer industry.

Assuming that the processing cost function is a quadratic such that $c(y,v) = \alpha_1 y - \alpha_2 y^2$, equation (3) is rewritten as follow:

$$(4) \quad M = H_1 + H_2,$$

where $H_1 = 34P_{gI} [\varepsilon\tau(\partial Y/\partial y) - (\partial P_y/\partial y)(Y/P_y)](y/Y)/(1 + \eta)$ and $H_2 = [\alpha_1 - 2\alpha_2 Y(y/Y)]/(1 + \eta)$.

The net effects of increasing the market concentration level by one percent on the marketing margin are measured by:

$$(5) \quad \frac{\partial M}{[100 \cdot \partial(y/Y)]} = \frac{34P_{gI} [\varepsilon\tau(\partial Y/\partial y) - (\partial P_y/\partial y)(Y/P_y)]}{[100(1 + \eta)]} - \frac{2\alpha_2 Y}{[100(1 + \eta)]},$$

where, again, the first and second terms of the right-hand side from the equality represent the market power effects and the efficiency effects, respectively, resulting from one percent increase in the market concentration level.

An advanced knowledge of several economic factors is required to differentiate these effects for the nitrogen fertilizer industry including ε , τ , θ , η and the processing cost of nitrogen fertilizer, $c(y, v)$. Each of these economic factors will now be explored in turn.

The price flexibility of natural gas demand for industrial use, $\varepsilon = (\partial P_{gI}/\partial G_I)(G_I/P_{gI})$:

Natural gas utilization for the residential, commercial, industrial, and electric generation sectors accounted for 26, 15, 40, and 17 percent, respectively, during the period between 1976 and 2000. The remainder is used for transportation. Natural gas used for nitrogen fertilizer production accounts for nearly 8 of the 40 percent of that used by the industrial sector during the same period. The natural gas price varies across sectors depending upon the market service requirements of

pipeline companies, storage companies, local distribution companies, and natural gas marketers. Usually, residential consumers pay the highest price and the utility sector pays the lowest price.

There are 26 major energy companies with domestic U.S. oil and gas operations. The market share by the three largest companies accounted for slightly more than 50 percent of net income for this category in 2000 (Energy Information Administration, April 2001). Therefore, it is reasonable to assume that natural gas industry is characterized to have oligopolistic competition.

To derive an aggregate natural gas demand for each sector, natural gas industry is assumed to maximize the following profits

$$(6) \quad \pi = \sum_k^m [P_{gk}G_k - C(G_k)],$$

subject to the following quantity constraint

$$(7) \quad \sum_k^m G_k \leq E,$$

where

P_{gk} = the unit price of natural gas for the k th sector,

E = the aggregate amount of natural gas available in a given year (thousand cubic feet),

G_k = the amount of natural gas allocated to the k th sector (thousand cubic feet), and

$C(G_k)$ = the cost function associated with providing natural gas to the k th sector.

The Lagrangian equation is then represented by:

$$(8) \quad L = \sum_k^m [P_{gk}G_k - C(G_k)] + \lambda[E - \sum_k^m G_k],$$

where λ is the Lagrangian multiplier. The Kuhn-Tucker conditions for profit-maximization of the natural gas industry under oligopolistic competition are then given by:

$$(9a) \quad \partial L / \partial G_k = P_{gk} [1 + (G_k / P_{gk})(\partial P_{gk} / \partial G_k)] - \partial C(G_k) / \partial G_k - \lambda \left[\sum_{i=1}^m \partial G_i / \partial G_k \right] \leq 0$$

for $k = 1, 2, \dots, m$

$$(9b) \quad (\partial L / \partial G_k) G_k = 0 \quad \text{for } k = 1, 2, \dots, m$$

$$(9c) \quad G_k \geq 0 \quad \text{for } k = 1, 2, \dots, m$$

$$(10a) \quad \sum_k^m G_k \leq E,$$

$$(10b) \quad \lambda [E - \sum_k^m G_k] = 0$$

$$(10c) \quad \lambda \geq 0.$$

Inserting equation (9a) into equation (9b) results in the following equation for the k th sector:

$$(11) \quad P_{gk} G_k (1 + \sigma_k) - \rho_k C(G_k) - \lambda \sum_{i=1}^m \omega_{ik} G_i = 0 \quad \text{for } k = 1, 2, \dots, m$$

where

$\sigma_k = (\partial P_{gk} / \partial G_k)(G_k / P_{gk})$ is the price flexibility of natural gas demand in the k th sector,

$\rho_k = (\partial C(G_k) / \partial G_k)(G_k / C(G_k))$ is the cost elasticity in the k th sector, and

$\omega_{ik} = [(\partial G_i / \partial G_k)(G_k / G_i)]$ is the elasticity of conjectural variation.

The natural gas price for the k th sector is obtained by rearranging equation (11) as follows:

$$(12) \quad P_{gk} = [\lambda + \rho_k (\bar{C}(G_k)) / Z_k + \lambda \left[\sum_{i \neq k}^m \omega_{ik} (G_i / G_k) \right] / Z_k \\ = \alpha_{k0} + \alpha_{k1}(G_1 / G_k) + \alpha_{k2}(G_2 / G_k) + \dots + \alpha_{km}(G_m / G_k) \quad \text{for } k = 1, 2, \dots, m$$

where

$$Z_k = (1 + \sigma_k),$$

$$\bar{C}(G_k) = C(G_k)/G_k,$$

$$\alpha_{k0} = [\lambda + \rho_k \bar{C}(G_k)] / Z_k, \text{ and}$$

$$\alpha_{ki} = \lambda \omega_{ik} / Z_k \text{ for } i \neq k \text{ and } i = 1, 2, \dots, m.$$

Since $\bar{C}(G_k)$ and ρ_k in equation (12) represent average cost and cost elasticity of natural gas for the k th sector respectively, therefore, $\rho_k \bar{C}(G_k)$ represents the marginal cost (price) of natural gas for the k th sector. All parameters in equation (12) for $k = 1, 2, \dots, m$ are estimated with the Seemingly Unrelated Regression (SUR) method.

Transmission elasticity of natural gas, $\tau = (\partial G_I / \partial Y)(Y/G_I)$:

Natural gas used for nitrogen fertilizer production accounts for approximately 8 percent of aggregate natural gas used for industrial use during the period of 1976 - 2000. Therefore, the transmission elasticity of natural gas, τ , is simply assumed to be 0.08 in this study.

Price flexibility of nitrogen fertilizer demand, $\eta = (\partial P_y / \partial y)(y/P_y)$:

The price elasticity estimates of nitrogen fertilizer demand vary widely from very inelastic to very elastic depending upon what kinds of crops (and therefore location) for which nutrients are applied, whether the production function approach or the cost-function approach is used for estimation, and whether the concern is for short-run or long-run analysis (Adelaja and Hoque; Binswanger; Gopinath and Wu; Roberts and Heady; Rendleman). In an aggregate analysis, Binswanger noted that nitrogen fertilizer demand is price inelastic in the short-run, but it is elastic in the long-run due to technological changes.

Since the U.S. nitrogen fertilizer industry is characterized under the price leadership model for oligopolistic competition (see Appendix), a nitrogen fertilizer inverse demand function defined as

$$(13) \quad P_y = f [(P_q / y), (P_g / y)]$$

is estimated with the OLS method, where P_q is the price of agricultural outputs and all other variables are as defined earlier.

Processing cost, $c(y, v)$: For the U.S. nitrogen fertilizer industry, the processing cost function of the dominant firms, $c(y, v)$, which consists of nitrogen fertilizer production costs other than costs to the firm for natural gas, includes costs of electricity and other utilities, operating labor costs, maintenance costs, tax and insurance, and depreciation. Estimation of a nitrogen fertilizer processing cost function requires processing cost data at the plants owned by the dominant firms which are currently not available to us. But, annual average production cost data covering the period between 1992 and 1999 are available for two plant-size classes from The Fertilizer Institute: plants under 1,000 tons of capacity per day and those with a capacity of 1,000 tons and over per day. Therefore, we assumed in our study that the marginal processing costs obtained from samples and those from the dominant firms are the same. The processing cost function to be estimated is presented as follow:

$$(14) \quad c(y_s, v) = \alpha_0 + \alpha_1 y_s - \alpha_2 y_s^2 + D_1,$$

where y_s is the average amount of nitrogen fertilizer production from sampled plants and D_1 is a dummy variable such that $D_1 = 1$ for plants under 1,000 tons of capacity per day and $D_1 = 0$ for otherwise.

The transmission elasticity of nitrogen fertilizer industry, $\theta = (\partial Y / \partial y)(y / Y)$: Under the price leadership model for oligopolistic competition the nitrogen fertilizer price is observed along their product demand curve AA' in Figure 1 (Appendix), while the nitrogen fertilizer price for all other firms is observed along the aggregate marginal cost curve, m_c , for these firms (Figure 1). As the dominant firms increase their output by reducing their production costs so that their product price falls all other firms reduce their production. That is, changes in the amounts of nitrogen fertilizer

production by the dominant firms affects the aggregate outputs in the U.S. nitrogen fertilizer industry. Whether aggregate industry output would increase or decrease depends on whether the absolute value of the elasticity of the dominant firms' product demand curve is more price elastic than that of all other firms' aggregate marginal cost curve.

Because of limited data on nitrogen fertilizer production costs, the aggregate industry nitrogen fertilizer outputs are regressed with the dominant firms' output and time variable as follow:

$$(15) \quad \log Y = \alpha_0 + \alpha_1 \log y + \alpha_2 T,$$

where T is the time variable.

Data

Data for the annual nitrogen fertilizer production capacity and ownership of each plant are from the Tennessee Valley Authority for the period 1976 to 1995, and from the International Fertilizer Development Center for the period 1996 to 2000. Data for U.S. annual nitrogen fertilizer production are obtained from the U.S. Census Bureau, U.S. Department of Commerce. Data for the individual firm's nitrogen fertilizer production are not available to us so that the nitrogen fertilizer production by the four dominant firms are calculated by multiplying the U.S. annual nitrogen fertilizer production by the ratio between the dominant firms' production capacity and the annual industry production capacity.

Data on natural gas prices and natural gas consumption by sector are from the Energy Information Administration, Department of Energy. Production cost data are from the Production Cost Survey, The Fertilizer Institute. All nominal dollars were converted to real 1996 dollars using the chained gross domestic product deflator (U.S. Department of Commerce, 2000).

Estimation Results

SUR estimates of natural gas prices for residential, energy industry, commercial, and industrial uses are presented in Table 1. The sign of parameter estimates associated with the inverse demands of natural gas for commercial and industrial use are consistent with a priori expectation and parameter estimates are statistically significant. The sign of estimates associated with the inverse demand of natural gas for residential and energy industry uses are somewhat inconsistent with a priori expectation, which lead to positive price flexibility of natural gas demand. The estimated price flexibility of natural gas demand for industrial use from Table 1 is $\epsilon = -0.8323$, which indicates that the natural gas demand for industrial use is elastic (i.e., $1/\epsilon = -1.2015$).

Since the nitrogen fertilizer price is determined by dominant firms in price leadership model under oligopolistic competition, parameters of the inverse nitrogen fertilizer demand function in equation (13) are estimated with the OLS method (Table 2). The price flexibility of nitrogen fertilizer demand measured at mean values is $\eta = -0.8582$, indicating that the nitrogen fertilizer demand is price elastic (i.e., $1/\eta = -1.1652$), which is less elastic than -1.3690 estimated by Rendleman using a translog cost function approach with aggregate data covering the period between 1948 and 1989.

The cost function estimated with sampled data is presented in Table 2. Using mean values of real total costs and outputs produced by sampled plants, $\bar{c} = \$12,021,280$ and $\bar{y}_x = 362,320.2$ tons, respectively, the elasticity of total costs is estimated to be 0.78 indicating that the nitrogen fertilizer plants reveal economies of size so that larger-sized operations are more cost-effective. The estimated transmission function of the nitrogen fertilizer industry is also presented in Table 2. The elasticity of the dominant firms' nitrogen fertilizer production for the aggregate

nitrogen fertilizer production is estimated to be 0.5994, indicating that the dominant firms' product demand curve is less price elastic than all other firms' aggregate marginal cost curve.

Using estimates of $\varepsilon = -0.8323$, $\tau = 0.08$, $\eta = -0.8582$, $\theta = 0.5994$, $P_{gI} = \$3.8851$ (1996 dollars) per 1,000 cubic feet, $P_n = \$305.97$ (1996 dollars) per ton, and $Y = 17.164$ million tons, the market power effects and the cost-efficiency effects are estimated as follows:

(16) Market power effects: $\partial H_1 / [100 * \partial(y/Y)] = \17.28 (in 1996 prices),

(17) Cost-efficiency effects: $\partial H_2 / [100 * \partial(y/Y)] = \-11.14 (in 1996 prices).

The net effects of increasing the market concentration level by one percent on the marketing margin per unit of nitrogen fertilizer, $\partial M / 100 * [\partial(y/Y)]$, are estimated to be \$6.14.

These results suggest that the market power effects outweigh the cost efficiency effects in the U.S. nitrogen fertilizer industry. The relatively smaller size cost-efficiency effects may result from the relative weight of natural gas costs to total production costs for nitrogen fertilizer producers, which accounted for 60 percent during the period between 1976 and 2000. According to Phillips and Mathers, the cost of producing a ton of ammonia is about \$100 at \$2.19 per MMBtu with gas being 72 percent of the cost of production. At \$4.50 per MMBtu, the cost rises to about \$180 per ton of anhydrous ammonia, with gas being 84 percent of the cost of production. Since nitrogen fertilizer production costs, other than the costs for natural gas, account for a small portion of total production costs, the market power effects in the U.S. nitrogen fertilizer industry outweigh the cost-efficiency effects.

Conclusions

Empirical results, with data for the period between 1976 and 2000, indicate that for the U.S. nitrogen fertilizer industry, market power effects outweigh the cost-efficiency effects by 55 percent. This result is expected, because the nitrogen fertilizer production costs other than the

costs for natural gas account for about 30 percent or less of the total production costs for nitrogen fertilizer. These results have implications for U.S. agriculture that the prices farmers pay for nitrogen fertilizer are significantly higher than what farmers would have to pay if the nitrogen fertilizer industry operated under perfectly competitive market conditions, thereby reducing net farm income. On the other hand, if fertilizer prices were lower, application rates would be higher with accompanying higher crop production and higher potential for more nitrites in ground water.

The market power effects associated with the dominant firms evaluated in this study are a measure of economic rents agriculture is obligated to pay, that is, in higher nitrogen fertilizer prices, thereby reducing net farm income from levels that may exist otherwise if there were perfectly competitive market conditions in the U.S. nitrogen fertilizer industry. In addition, the strong market power effects in the U.S. nitrogen fertilizer industry has implications for the stability of both nitrogen fertilizer supply and prices to farmers. If the dominant firms do not raise the nitrogen fertilizer price enough in response to rising natural gas price, the dominant firms' profits would decline, which would lead to reduced production of nitrogen fertilizers, and thereby also create the potential for greater instability in market supplies of nitrogen fertilizer. Farmers ultimately pay the economic rents associated with pricing under oligopoly within the U.S. nitrogen fertilizer industry, or switch to produce alternative crops such as soybeans.

Long-term contracts by nitrogen fertilizer producers do not necessarily lead to stable nitrogen fertilizer supply at a relatively low price. As natural gas price rises, nitrogen fertilizer producers may be better off by selling their contracted natural gas rather than producing nitrogen fertilizers. With the current level of market concentration in the U.S. nitrogen fertilizer industry, policy options to prevent the resulting potential instability in nitrogen fertilizer supply and the burden of agricultural economic rents could include subsidizing nitrogen fertilizer producers,

removing new import restrictions imposed on natural gas rich countries in the Middle East and former member states of the Soviet Union, or imposing natural gas price controls.

Table 1. Seemingly Unrelated Regression estimates of natural gas prices for residential, energy industry, commercial, and industrial uses during the periods of 1976-1999.

Variables ¹	log P _R	log P _C	log P _I	log P _E
constant	2.0058 (0.2102) ²	1.7785 (0.2460)	1.2265 (0.4378)	0.9702 (0.5954)
log(C/R)	- 0.6639 (0.3160)			
log(I/R)	- 0.4839 (0.1718)			
log(E/R)	0.3439 (0.1229)			
log(R/C)		1.0302 (0.3106)		
log(I/C)		- 0.5689 (0.1888)		
log(E/C)		0.3879 (0.1338)		
log(R/I)			1.6526 (0.5053)	
log(C/I)			-1.2458 (0.6142)	
log(E/I)			0.4255* (0.2187)	
log(R/E)				1.8583 (0.6630)
log(C/E)				- 1.5011 (0.8153)
log(I/E)				- 0.8949 (0.4289)
R ²	0.87	0.87	0.84	0.81
Durbin-Watson Statistics	1.47	1.46	1.29	1.41

¹ The subscript R, C, I, and E represent residential, commercial, industrial use, and energy industry, respectively.

² Number in the parenthesis is standard error.

* Statistically insignificant at 95 percent confidence level.

Table 2. Parameter estimation results.

Nitrogen fertilizer demand:

$$P_y = 29,238.02 (P_q / Y) + 509,082.7 (P_{gl} / Y) \quad \text{where } \bar{y} = 0.4267 \bar{Y}$$

$$(13,116.64)^1 \quad (298,918.7)$$

$$R^2 = 0.74 \quad \text{D.W.} = 2.16$$

Processing cost function:

$$c(y_s, v) = -10,041,850 + 95.3755 y_s - 9.57E-05 y_s^2 + 4,393,833 D_1, \text{ where } \bar{y}_s = 0.04927 \bar{y}$$

$$(11,124,814) \quad (39.3192) \quad (4.36E-05) \quad (5,446,767)$$

$$R^2 = 0.89 \quad \text{D.W.} = 2.00$$

Nitrogen fertilizer industry transmission function:

$$\log(Y) = 4.5598 + 0.6389 \log y - 0.1858 \log (T)$$

$$(0.8220) \quad (0.0986) \quad (0.0376)$$

$$R^2 = 0.90 \quad \text{D.W.} = 1.73$$

¹ Number in the parenthesis is standard error.

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Appendix

To demonstrate whether the U.S. nitrogen fertilizer industry is characterized under the price leadership model for oligopolistic competition, the first step is to derive the plant-number function and this number function is then used to test for the price leadership in the U.S. nitrogen fertilizer industry (Kim, Hallahan, and Taylor). To derive the plant-number function, assume that the cost of producing output y_{i+1} equals the cost of producing y_i in N_i separate but identical plant operations such that:

$$(A1) \quad c_{i+1}(y_{i+1}(x_1, x_2, \dots, x_n)) = N_i(y_i(x_1, x_2, \dots, x_n))c_i(y_i(x_1, x_2, \dots, x_n)) \quad \text{for } i = 1, 2, \dots, m-1,$$

where $c_{i+1}(y_{i+1})$ is the cost function associated with the output level y_{i+1} ,

N_i is the number of plants in the i th size class,

x_k is the k th input, and

$c_i(y_i)$ is a cost function associated with the output level y_i .

Differentiating both sides of equation (A1) with respect to input price p_k associated with x_k and applying Shephard's lemma results in the following:

$$(A2) \quad [\partial \ln N_i(y_i) / \partial \ln p_k] = [p_k x_k(y_{i+1}) / c_{i+1}(y_{i+1})] - [p_k x_k(y_i) / c_i(y_i)] \quad \text{for } i = 1, 2, \dots, m-1.$$

The left-hand side from the equality in equation (A2) represents the k th input price elasticity for the number of the i th size plant. First and second terms of the right-hand side from the equality represent the k th input cost shares of the $(i+1)$ th size plant and the i th size plant, respectively.

Equation (A2) indicates that the input price elasticity for the number of plant in each size class can be used to determine whether structural changes in the U.S. nitrogen fertilizer industry are the k th factor saving or the k th factor using technical changes. If the right-hand side is positive (negative), the i th size plant is considered to have k th-input saving (using) technical change.

Summing both sides of the equality in equation (A2) can be represented by:

$$(A3) \quad \sum_{\kappa=1}^n [\partial \ln N_i(y_i) / \partial \ln p_k] = \eta(y_i) \left| \sum_{\kappa=1}^n [\partial \ln(y_i) / \partial \ln p_k] \right| - \eta(y_{i+1}) \left| \sum_{\kappa=1}^n [\partial \ln(y_{i+1}) / \partial \ln p_k] \right|$$

for $i = 1, 2, \dots, m-1$,

where $\eta(y_i)$ is the elasticity of total costs associated with the production of y_i from the i th size plant. In the case where the input price elasticities of output are the same across the size of plants, equation (A3) can be rewritten as:

$$(A4) \quad \sum_{\kappa=1}^n [\partial \ln N_i(y_i) / \partial \ln p_k] = [\eta(y_i) - \eta(y_{i+1})] \left| \sum_{\kappa=1}^n [\partial \ln(y_i) / \partial \ln p_k] \right|$$

In the case of cost neutrality, equations (A3) and (A4) are further reduced as:

$$(A5) \quad \sum_{\kappa=1}^n [\partial \ln N_i(y_i) / \partial \ln p_k] = \eta(y_i) - \eta(y_{i+1}) \quad \text{for } i = 1, 2, \dots, m-1.$$

In a conventional point estimate of economies of size obtained from a cost function, the plant reveals economies of size if $\eta(y_i) < 1$, so that larger-sized operations are more cost-effective, and diseconomies of size if $\eta(y_i) > 1$, so that many smaller-size plant operations are more cost effective. In equations (A4) and (A5), a plant reveals economies of size if $\eta(y_i) < \eta(y_{i+1})$ so that

$\sum_{\kappa=1}^n [\partial \ln N_i(y_i) / \partial \ln p_k] < 0$ and larger-size plant operation is more cost effective.

The functional form of $N_i(y_i)$ function derived from equation (A2) is presented by:

$$(A6) \quad N_i(y_i) = \exp \left\{ \int [\eta(y_{i+1})(\partial \ln(y_{i+1}) / \partial p_k) - \eta(y_i)(\partial \ln(y_{i+1}) / \partial p_k)] \delta p_k \right\},$$

which has an exponential form. Therefore, a decomposed Poisson regression model for the U.S. nitrogen fertilizer industry is represented by:

$$(A7) \quad E[N_{lh,t} | (w/P_y)_t, (r/P_y)_t, (P_g/P_y)_t]$$

$$= \exp \left\{ \sum_{l=1} \sum_{h=1} \alpha_{l,h} D_{l,h}(w/P_y)_t + \sum_{l=1} \sum_{h=1} \beta_{l,h} D_{l,h}(r/P_y)_t + \sum_{l=1} \sum_{h=1} \gamma_{l,h} D_{l,h}(P_g/P_y)_t \right.$$

$$\left. + \sum_{l=2} \sum_{h=1} \delta_{l,h} D_{l,h} + \zeta M \right\}$$

where, $N_{i,h}$ = the number of fertilizer plants which are in plant size category and firm ownership category h ,

w = the hourly wage of production workers in the fertilizer industry,

r = corporate bond rate,

P_y = unit price of nitrogen fertilizer,

P_g = unit price of natural gas,

$D_{i,h}$ = a dummy variable associated with the i th plant size-class of the h th firm ownership, and

M = a dummy variable equal to 1 for the dominant firms, and equal to zero for all other firms.

Profits to be maximized for the dominant firms can be presented by:

$$(A8) \quad \pi = \sum_i (P_y N_i y_i - N_i c_i)$$

where the subscript i represents the i th plant size class and c_i is unit cost of producing y_i .

Differentiating equation (A8) with respect to a unit price of the j th input results in the following:

$$(A9) \quad \partial \pi / \partial P_j \geq 0 \quad \text{iff} \quad \partial N_i / \partial P_j \geq N_i [x_j - P_y (\partial y_i / \partial P_j)] / (y_i P_y - c_i).$$

Summing equation (A9) over plant size classes and inputs results in the following:

$$(A10) \quad \sum_{j=1} [\partial \pi / \partial P_j] \geq 0 \quad \text{iff} \quad \sum_{i=1} \sum_{j=1} [\partial N_i / \partial P_j] \geq \sum_{i=1} \sum_{j=1} N_i [x_j - P_y (\partial y_i / \partial P_j)] / (y_i P_y - c_i).$$

Since both $[x_j - P_y (\partial y_i / \partial P_j)]$ and $(y_i P_y - c_i)$ in equation (A10) are positive, the positive input price elasticity for the number of plants owned by the dominant firms would result in positive profits.

From the plant-number function in (A7), the output price elasticity for the number of plants equals the negative sum of input price elasticities for the number of plants.

From Figure 1, the curves AA' and AR are the nitrogen fertilizer demand curve and the marginal revenue curve, respectively, for the dominant firms, and M_c and m_c are the marginal cost curves of the dominant firms and all other minor firms, respectively. The curve DHA' represents

the industry market demand curve. Under the price leadership model in oligopolistic competition, the dominant firms set their output price along their demand curve, AA', and all other firms sell all they can at that price along their marginal cost curve (or the supply curve of minor firms), m_c .

Therefore, if the U.S. nitrogen fertilizer industry is characterized by price leadership in oligopoly, then the output price elasticity for the number plants would be negative for the dominant firms and positive for all other minor firms.

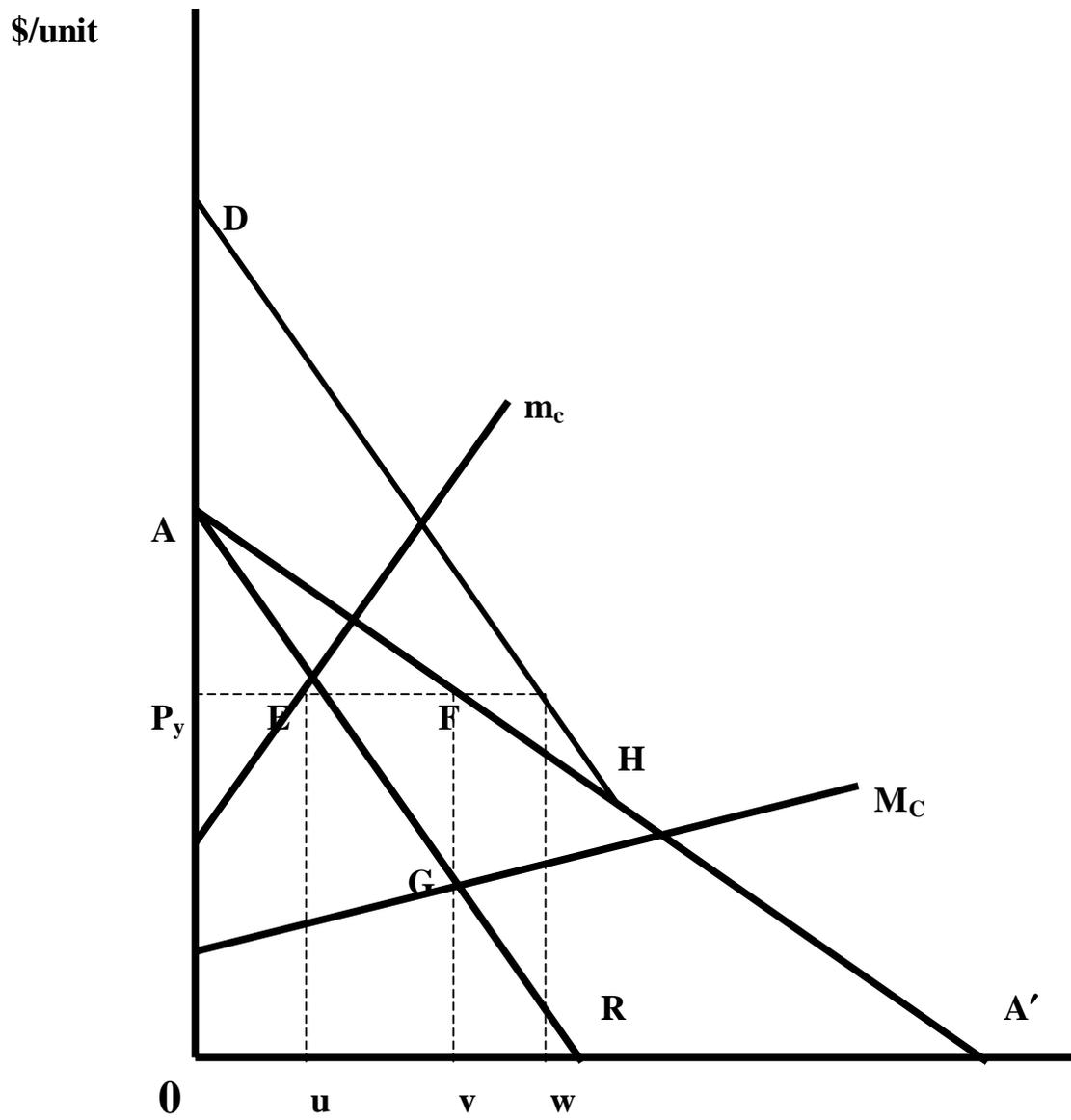


Figure 1. The dominant firm model.