Fertilizer Demand for Biofuel and Cereal crop Production in the United States

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Abstract

The emergence of biofuel production has impacted almost all sectors of the agricultural industry and the general economy and has produced a large body of research into how increased production of biofuels will impact the agricultural sector and the general economy. All research is in agreement that total biomass production will be required to increase to meet food and fuel demands. The increase in biomass will, of necessity, require increased use of fertilizers. Research on fertilizer demand has been scarce over the last decade. Because of the recent increase in the demand for grain crops and livestock in an era with little excess capacity in commodity production, the pressure to increase output will fall to increased use of fertilizers.   In addition, there is some evidence of increasing scarcity in the principle macro nutrients (eg phosphorus, nitrogen and potassium). Thus, there is an urgent need to initiate research into the demand for fertilizers to determine the economic implications of expanded crop and livestock production. This analysis can provide crop producers and policy makers with important information on the role of nutrients in the economics of expanding uses for the major grain and forage crops. Most researchers have focused on total fertilizer (N.P.K) demand for total crop production which does not capture the effects of individual fertilizers on the individual crops. This study focuses on nitrogen demand for biofuel and cereal crop production and the impact on crop prices in the United States using the method of feasible generalized least squares (FGLS) estimation by weighted least squares regression. The results show that nitrogen fertilizer is very much responsive to corn price, wheat price, nitrogen price, phosphate price, and potash price. Results also indicate that increase in nitrogen price decreases nitrogen demand while increases in the price of corn, wheat, and other fertilizers increases the demand for nitrogen fertilizer.

Keywords: Nitrogen demand, corn production, fertilizer prices, biofuel production.

Introduction

Corn has been an important American crop since well before the arrival of Columbus in 1492. There are about 40 different uses for corn (Oscar 1901). The major uses include; domestic consumption, livestock feeding, and biofuel production. In 2001-2002 the United States led the world in corn production with 9.5 billion bushels, about 40 percent of all corn produced in the world. With domestic consumption of only about 7.6 billion bushels the U.S. was also the leading corn exporter in 2001-2002. United States exported about 1.9 billion bushels which is 63 percent of the total corn exported in the world. Feed for animals was the largest part of U.S. corn consumption (58%), followed by the recent development in ethanol production with a total annual capacity of 7.3 billion gallons.

Manufacturing of ethanol fuel is now the second largest U.S. market for corn. It was also projected that the percentage of U.S. corn utilization for ethanol production will level out at around 30 percent of total U.S. corn yield by 2009-2010. The increased demand of ethanol production has aided in raising the price of corn from $2 per bushel in 2005 to $ 4.20 in 2007 with an average price peak at $5.40 in the year 2010. The USDA estimated that, 93.5 million acres of corn were planted in the year 2007 and 92.1 million acres in 2011. A slight reduction in planted acres might be due to a competing uses of land by other emerging crops like switchgrass for biofuel production, otherwise, a surging increase in prices would have triggered an increase in planted acres.

The yield of corn has increased from 36.9bu/acre in 1951 to about 113bu/acre in 1982 to an average corn yield of 152.8 bushels per acre in 2010. Without the appropriate genetic background, the corn plant will not respond to the fertilizer inputs and of course the corn plant cannot respond optimally if the fertilizer is absent, most importantly nitrogen. Therefore fertilizer

has become an important component in corn production. The use of fertilizer in corn production has been rising since 1945. Estimated nitrogen use per acre in 1945 was 7 pounds which has risen to 112 pounds during the1970's.

The demand for fertilizer in cereal and biofuel crop production will affect the relative profitability of the crops and thus may serve as a predicting tool for both farmers and fertilizer producers for predicting the quantity of nitrogen that may be required to meet increasing future food, feed and fuel demands. Thus with the estimated increase in corn production, it is certain that fertilizer demand would also increase.

As reported by Wen-yuan (2009), U.S. prices of fertilizer nutrients began to rise steadily in 2002 and increased sharply to historic highs in 2008 due to the combined effects of a number of domestic and global long and short run supply and demand factors. From 2007 to 2008, spring nitrogen prices increased by a third, phosphate prices nearly doubled, and potash prices doubled. The price spike in 2008 reflects low inventories at the beginning of 2008 combined with the inability of the U.S. fertilizer industry to quickly adjust to surging demand or sharp declines in international supply. Declining fertilizer demand, disruption in fall applications, increased fertilizer imports (July to August), and tightening credit markets for fertilizer purchases contributed to the decline of fertilizer prices in late 2008.

The objective of this study is to estimate a model for the demand of nitrogen fertilizer for cereal and biofuel production which can be used to forecast nitrogen demand with respect to expected cereal and biofuel production, expected price of nitrogen, expected price of phosphate, and expected price of potash. Studies by Griliches, and Heady and Yeh during the 1950s analyzed short-run and long run demand elasticities for total fertilizer use on a regional basis, but did not estimate fertilizer demand for each crop. Data for doing so are now available. It is

interesting and useful for crop-specific policy purposes to estimate empirically the changes in specific fertilizer use for different crops.

Models of both national and regional demand for fertilizer have been estimated in a number of empirical studies. A partial list includes reports by Griliches (1958, 1959), Heady and Yeh (1959), Brake, King and Riggan (1960), and Rausser and Moriak (1970). The models specified in these studies exhibit many similarities but also some differences. The dependent variable has most often been specified as total fertilizer use for a region or for the United States. Griliches (1958) deflated total plant nutrient use by an index of cropland acreage while Rausser and Moriak employed total nutrient use per acre as their quantity variable. Only Heady and Yeh examined the demand for the individual major nutrients (N, P, K). The variables affecting quantity demanded have included fertilizer prices, crop prices, total cash receipts from crops, total crop acreage, acres of specified crops, cash rent, wage rates, wholesale price index, and time. Each of the models was estimated by single equation methods on the assumption that prices of fertilizer, other inputs, and output prices can be regarded as predetermined at the time the purchase decision is made. Each study concentrated on estimating log linear functions.

Griliches (1958) estimated aggregate demand functions for fertilizer use on all crops in the US. He demonstrated for 1911 to 1956 that most of the increase in the fertilizer use could be explained by changes in fertilizer and crop prices and by the previous period's fertilizer use. Griliches (1959) used the same model found in 1958 to estimate the regional demand function for total fertilizer consumption over 1931 to 1956 periods. His model explained a large portion of the variation in regional fertilizer use, and he found that estimated price elasticities of demand varied across regions.

Heady and Ye (1959) estimated fertilizer demand functions for total fertilizer and for individual nutrients used in all crops in the US. In addition, the estimated relationships for total fertilizer use in ten different geographical regions of US. Their study allowed a comparison of aggregate fertilizer and individual nutrient demand elasticities with respect to fertilizer price, average crop price, and other relevant variables, across regions. Johnson (1958) derived from given experimental data, the parameters of physical production functions and, with these derived functions and particular price relationships, determined what rates of fertilization would yield maximum net revenue for the corn production enterprise.

Global fertilizer nutrient consumption increased at a compound annual growth rate of 4.2 percent during 2006-08, which is more than double the 1.7 percent rate from 1995 to 2005 (Mosaic, 2008; Vroomen, 2008). Increased global demand for fertilizers is the result of global population and general economic growth. The global population currently grows at 75 million per annum, and more people need to be fed every year (IDB). More fertilizer is required to grow crops to meet rising food demand that has necessitated intensification in crop production and or increased in acreage. The rate of increase in demand for food has outstripped the rate of population growth because of economic growth in developing countries (Babcock). Economic growth in developing countries is typically characterized by an increase in per capita calorie consumption and a higher consumption of meat, dairy products, and vegetable oils, which in turn, amplifies the increase in production of feed grains and oilseed. Because of economic growth, China and India imported large quantities of fertilizer raw materials and fertilizer products in 2008 to meet rising food demand, and their fertilizer contract prices set a benchmark for the prices of fertilizers sold in the world market and in the United States (Wen-yuan, 2009). The weak economic conditions since 2008 have dampened global fertilizer demand. But, over

the long run, population and income growth will continue to put upward pressure on demand for fertilizers.

Fertilizer consumption by the U.S. agricultural sector has increased dramatically for several decades. Nitrogen fertilizer use increased by 632% between 1952 and 1976. Phosphate and potash fertilizer use increased 138 and 229%, respectively, in the same period (USDA, 1978). However, the upward trend in fertilizer use was temporarily interrupted during early and mid- 1970s as the real fertilizer price began to increase after many years of decline. The law of demand states that quantity of demand decreases as price increases.

Theory

The demand for an input used in production is a derived demand based on the demand for the final product. A nutrient derived demand function can be formulated assuming farmers maximize profits under competitive conditions. Demand driven function of an input depends on the expected price of product, own price and other factors. Beattie and Taylor (1985, pp. 205-209) indicate that a profit maximization formulation which highlights determination of factor levels and factor demand as well as product levels and product supply is a Lagrangean function, which is expressed as:

$$L\pi = \sum_{j=1}^{m} p_j y_j - \sum_{i=1}^{n} r_i x_i + \lambda F(x_1, \dots, x_n, y_1 \dots, y_m) \qquad (1)$$

where $L\pi$ is Lagrangean profit function, p is product price, y is total product, r_i is the price of input i, and x_i is imput $i = 1, \dots, n$.

The simultaneous solution of the first-order conditions of equation (1) results in the unconditional long-run factor demand (2) and product supply equations (3).

$$x_i^* = x_i^*(r_1, \dots, r_n, p_1, \dots, p_m) \quad for\ i = 1, \dots, n \qquad (2)$$

6

$$y_j^* = y_j^*(r_1, \ldots, r_n, p_1, \ldots, p_m) \quad for \ j = 1, \ldots, m \tag{3}$$

$$\lambda^* = \lambda^*(r_1, \ldots, r_n, p_1, \ldots, p_m) \tag{4}$$

The above formulation is generic, thus a specific formulation to discuss a specific cereal crop and fertilizer would be expressed under the assumption of unconstrained profit maximizing for a competitive, one product, multiple input firm as:

$$\max_x E(\pi) = pE(y) - \sum_{i=1}^{3} r_i x_i - b \tag{5}$$

$$s.t. \ E(y) = F(x_i)$$

$$x_i \geq 0$$

where $E(y)$ is the expected yield per acre of corn, p is the price of corn, r_i is the price of fertilizer i (i = nitrogen, phosphurus, potassium), b is the fixed cost, x_i is the type of fertilizer i and $E(\pi)$ is the expected profit from producing corn. The partial derivatives of the profit function in (5) with respect to the input quantities, x_i and set equal to zero in (6) are solved simultaneously to obtain the derived demand functions in equation (7).

$$\frac{\partial E(\pi)}{\partial x_i} = \frac{\partial E'(\pi)}{\partial x_i} - r_i = 0 \tag{6}$$

which implies $pMPP = r \iff MPP = \frac{r_i}{p} \implies$ profit maximizing level of x_i is obtained.

$$x^* = x^*(p, r_i) \tag{7}$$

The derived demand for a particular nutrient is a positive function of the product prices and a negative function of its own price, however, the signs of the relationships with the other fertilizer input prices are indeterminate because their quantity requirements depend on the type of soil and the crop in question. According to the USDA, the acreage under corn production will increase because of the increase in expected price of corn which in turn will increase the production of corn. Therefore the total quantity demanded of a fertilizer input for a cereal crop

production can be represented as a function of corn price (or wheat price), nitrogen price, and other major fertilizer prices. The main independent variables are corn price (or wheat price) and fertilizer prices, and the dependent variable is the quantity of fertilizer. Total fertilizer demand will increase as corn yield per acre increases and as corn acreage increases. It is assumed that the fertilizer demand will increase with the expected increase in cereal crop production due to expected increase in cereal grain price and decline as fertilizer price increases. Since the objective of the study is to build a forecasting model which can be used to forecast the quantity and price of fertilizer that would be required for the production of a cereal crop in the United States, prices of all major fertilizers; nitrogen, phosphate and potash should have either a positive or a negative relationship with the quantity of the fertilizer whose demand is under estimation because they are compliments and are used together.

Data Sources

Time series data of 45 years (1964-2008) of U.S. average price of corn for grain (dollar/bushel), U.S. average price of wheat for grain (dollar/bushel), U.S. average price of nitrogen (dollar/ton), U.S. average price of phosphate (dollar/ton), and U.S. average price of potash (dollar/ton) were obtained from USDA/NASS. Data on the quantities of nitrogen, phosphate, and potash (1,000 nutrients tons) consumed for corn, and wheat production were obtained from USDA/NASS and the Association of American Plant Food Control Officials/The Fertilizer Institute (AAPFCO/TFI). Data on price indexes were obtained from U.S. Bureau of Labor Statistics, Division of Consumer Prices and Price Indexes.

Procedure

The demand for fertilizer (nitrogen, phosphate, and potash) for cereal (corn, and wheat) production was expressed as:

$$QF = QF(NPRICE, CEREALPRICE, PPRICE, KPRICE)$$

with the empirical form in a data generating process of a log-linear functional form as:

1) Nitrogen demand for corn production;

$$lnQN = \beta_0 + \beta_1 CORNPRICE + \beta_2 NPRICE + \beta_3 KPRICE + \beta_4 NPRICE^2$$
$$+ \beta_5(CPRICE * NPRICE) + \beta_6(NPRICE * KPRICE) + \varepsilon$$

2) Nitrogen demand for wheat production;

$$lnQN = \beta_0 + \beta_1 WPRICE + \beta_2 NPRICE + \beta_3 PPRICE + \beta_4 KPRICE + \beta_5 WPRICE^2$$
$$+ \beta_6 NPRICE^2 + \beta_7 PPRICE^2 + \beta_8(WPRICE * KPRICE)$$
$$+ \beta_9(PPRICE * NPRICE) + \beta_{10}(KPRICE * PPRICE) + \varepsilon$$

3) Phosphate demand for corn;

$$lnQP = \beta_0 + \beta_1 CORNPRICE + \beta_2 NPRICE + \beta_3 PPRICE + \beta_4 KPRICE + \beta_5 NPRICE^2$$
$$+ \beta_6 PPRICE^2 + \beta_7 KPRICE^2 + \varepsilon$$

4) Phosphate demand for wheat;

$$lnQP = \beta_0 + \beta_1 WPRICE + \beta_2 NPRICE + \beta_3 PPRICE + \beta_4 KPRICE + \beta_5 NPRICE^2$$
$$+ \beta_6 PPRICE^2 + \beta_7 KPRICE^2 + \beta_8(WPRICE * NPRICE)$$
$$+ \beta_9(WPRICE * KPRICE) + \beta_{10}(PPRICE * NPRICE) + \beta_{11}(PPRICE$$
$$* KPRICE) + \varepsilon$$

5) Potassium demand for corn production;

$$lnQK = \beta_0 + \beta_1 CORNPRICE + \beta_2 NPRICE + \beta_3 PPRICE + \beta_4 KPRICE + \beta_5 NPRICE^2$$
$$+ \beta_6 PPRICE^2 + \beta_7 KPRICE^2 + \beta_8(PPRICE * NPRICE) + \varepsilon$$

6) Potassium demand for wheat production;

$$lnQK = \beta_0 + \beta_1 WPRICE + \beta_2 NPRICE + \beta_3 KPRICE + \beta_4 KPRICE^2 + \varepsilon$$

where QN is the quantity of nitrogen, QP is the quantity of phosphate, QK is the quantity of potash, $NPRICE$ is the nitrogen price, $CORNPRICE$ is corn price, $WPRICE$ is wheat price, $PPRICE$ is the phosphate price, $KPRICE$ is the potash price, quadratic terms and interaction terms have been included, βs are the parameters to be estimated, and $\varepsilon \sim N(0, \sigma_\varepsilon^2)$ is an independently and identically distributed error term with mean zero and variance σ_ε^2. The law of demand implies that, quantity demand increases as price decreases, thus the quantity demanded of a fertilizer was expected to have a negative relationship with its own price. Corn or wheat farmers will increase production if the product price increases leading to increasing fertilizer demand, and thus fertilizer demand and product price are expected to have a positive relationship. Nitrogen, phosphate and potash prices were included in the model because they are complements and are mostly applied together. For example, increasing nitrogen application in corn production leads to increasing phosphate and potash application. Thus, phosphate and potash prices as independent variables in nitrogen demand should have positive relationship with quantity of nitrogen. The signs of the quadratic and the interaction terms are indeterminate because theory does not provide evidence on that.

Before the estimation, all the price data were deflated with the consumer price index (CPI) to control for the effects of inflation in prices over time. The estimation process started with a simple ordinary least squares (OLS) with SAS. Misspecification tests were conducted to determine any misspecification problem. Results from the misspecification tests dictated the final model specifications of the demand equations. Structural change tests dictated the number of observations used in each model specification. Economic and or policy change may have

10

resulted in a sharp change in the use of fertilizer in the 1960s and the early 1970s (figures 3 and 4), thus, choosing data after such structural change makes more sense in estimation.

Misspecification tests identified nonlinearity, autocorrelation, and heteroskedasticity. Therefore, interaction terms were included to manage nonlinearity as necessary. The autocorrelation and heteroskedasticity problems led to re-estimating the model by the method of feasible generalized least squares (FGLS) estimates by using weighted least squares regression. FGLS models adjust for the threats to valid inferences caused by heteroskedasticity and autocorrelation. FGLS eliminates serial correlation of the errors and then eliminates contemporaneous correlation of the errors. This is done by initially estimating the OLS equation. The residuals from this estimation are used to estimate the unit-specific serial correlation of the errors, which are then used to transform the model into one with serial independent errors. Residuals from this estimation are then used to estimate the contemporaneous correlation of the errors, and the data is once again transformed to allow for the estimation with errors without any complications.

Finally, elasticities were computed for the various demand equations. For a log-linear model, elasticity is specified as:

$$E_X = \frac{\partial y}{\partial x}\frac{x}{y} = bx$$

where E_X is the elasticity, b is the parameter estimate, and x is the mean value.

Results

Misspecification tests (tables 7-12) were conducted on the data for estimating a model for fertilizer demand for cereal production in the United States. The empirical form was initially

11

specified in a log-linear functional form. The various misspecification tests were conducted as follows:

Normality test was conducted using the K^2 and Bera-Jarque test. All the normality tests conducted on the data for the various estimations failed to reject normality at 5% level of significance. Test on joint conditional mean on nonlinearity, temporal or spatial dependence, and structural change was conducted on all of the demand specifications . Also joint conditional variance, Static and Dynamic heteroskedasticity tests were also conducted. Other tests conducted include individual conditional mean and conditional variance tests. Resuls show that all the demand models indicated nonlinearity with the KG2 test at 5% significance level. Dependence test indicated at 5% significance level that all the models had autocorrelation problem. Structural change test also failed to reject the null hypothesis at 5% level of significance in each case, indicating that the parameters of these models are not non-stable.

The misspecification tests identified problems of nonlinearity, heteroskedasticity, and autocorrelation. Thus the model was re-specified to include interactions and quadratic terms and re-estimated using FGLS estimation by using weighted least squares regression. Interactions were included to solve nonlinearity problem and the FGLS method of estimation helped to overcome the problem of autocorrelation and heteroskedasticity. Table 1 shows the results from the FGLS estimation by using weighted least squares regression.

Tables 7-12 show the parameter estimates of the various estimations. The demand for fertilizer input for crop production is e derived demand, thus the coefficients of the price of the fertilizers obeyed theory by assuming negative signs while the coefficients of the price of products having positive signs. The negative sign of the coefficient of the fertilizer price confirms a negatively sloped demand curve in which quantity demanded increases as the own

12

price decreases. Apart from the own price, other fertilizer prices as well as their interactions can assume any sign because they are also inputs and their needed quantities depend on the levels already in the soil. The crop price (corn price or wheat price) has positive relationship with fertilizer demand because, an increase in corn price, for example, motivates corn producers to increase corn production leading to an increase in nitrogen demand. The parameters/coefficients of the variables represent marginal changes in fertilizer demand with respect to a unit change in the respective variable. Therefore, a unit increase in the level of any of the explanatory variables in each model will cause a unit change in the fertilizer demand equivalent to the coefficient of that explanatory variable.

Elasticities (table 13) show the degree of responsiveness in the quantity of fertilizer demand to a percentage change in the independent variables (i.e. the ratio of a percentage change in the quantity of fertilizer demanded to a percentage change in a unit change in the independent variable). Table 13 indicates that none of the fertilizer demands for corn production is not responsive to corn price, however, nitrogen and phosphate demands for wheat are responsive to wheat price. It could also be seen that nitrogen and phosphorus fertilizers are responsive to their own prices, however, potassium demand was not found to be responsive to any of the independent variables including its own price.

Figures one and two shows the trends and the relationships between nitrogen consumed for corn production and nitrogen price, corn price, phosphate price, and potash price. The trends indicate that there is a vast fluctuation in nitrogen demand and fertilizer prices. There is a marked fluctuation in corn price than the fertilizer prices and movement is negatively related to quantity of nitrogen.

Summary and Conclusions

13

Fertilizer (nitrogen, phosphorus, and potassium) demand for crop (corn, and wheat) production in the United Sates could be explained by factors including but not limited to corn price or wheat price, nitrogen price, phosphate price, and potash price. The best model realized in this study was the one including quadratic and interaction terms which gave higher variations and significant levels. The model specification was dictated by tests results. For example, the KG2 test indicated that the models be specified as non-linear. Results from this studies show that fertilizer demand in the United States is not very much responsive to individual fertilizer prices but are responsive to crop (corn or wheat) prices. Also crop price has a positive relationship with fertilizer demand, therefore, crop price prices will continue to increase as far as fertilizer demand continues to increase.

fertilizer demand is a derived demand for crop production, thus, as the other competing uses of nitrogen fertilizer such as that for biofuel and corn production continue to be on the rise, fertilizer demand will therefore continue to increase which will consequently cause increases in the prices of food crops. Government will have to subsidize the prices of fertilizer inputs for farmers in order to offset their production cost while maintaining their profit margins so as to control the rising prices in food crops as a result of increased cost of fertilizer inputs.

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Table 1. Test Statistic from the Misspecification Testing on the Nitrogen Demand for Corn.

Misspecification testing	Test statistic
Normality test with K2 and Jarque-Bera	K2~$\chi^2_{(2)}$= 2.871 P-value = 0.238 JB~$\chi^2_{(2)}$= 1.91333 P-value = 0.38417
Joint conditional mean test on nonlinearity, temporal or spatial dependence, and structural change.	$F-value = 1.28$ $p-value = 0.3229$
Joint conditional variance, static and dynamic heteroskedasticity	$F-value = 1.70$ $p-value = 0.1630$
Individual conditional mean and conditional variance. KG2 test on nonlinearity	$F-value = 1.10$ $p-value = 0.4116$
Dependence test	$t-value = -1.27$ $p-value = 0.2171$
Structural change	$t-value = -0.50$ $p-value = 0.6208$
Static heteroskedasticity	$F-value = 1.87$ $p-value = 0.1185$
Dynamic heteroskedasticity	$t-value = -0.08$ $p-value = 0.9400$

Table 2. Test Statistic from the Misspecification Testing on the Nitrogen Demand for Wheat.

Misspecification testing	Test statistic
Normality test with K2 and Jarque-Bera	K2$\sim\chi^2_{(2)}$= 1.44329 P-value = 0.48595 JB$\sim\chi^2_{(2)}$= 0.70852 P-value = 0.70169
Joint conditional mean test on nonlinearity, temporal or spatial dependence, and structural change.	$F-value = 3.78$ $p-value = 0.0065$
Joint conditional variance, static and dynamic heteroskedasticity	$F-value = 1.57$ $p-value = 0.1901$
Individual conditional mean and conditional variance. KG2 test on nonlinearity	$F-value = 1.98$ $p-value = 0.0923$
Dependence test	$t-value = 3.43$ $p-value = 0.0019$
Structural change	$t-value = 1.56$ $p-value = 0.1308$
Static heteroskedasticity	$F-value = 1.71$ $p-value = 0.1468$
Dynamic heteroskedasticity	$t-value = -0.97$ $p-value = 0.3426$

Table 3. Test Statistic from the Misspecification Testing on the Phosphate Demand for Corn.

Misspecification testing	Test statistic
Normality test with K2 and Jarque-Bera	$K2 \sim \chi^2_{(2)} = 4.03820$ P-value = 0.13278 $JB \sim \chi^2_{(2)} = 3.02868$ P-value = 0.21995
Joint conditional mean test on nonlinearity, temporal or spatial dependence, and structural change.	$F - value = 6.69$ $p - value = 0.0001$
Joint conditional variance, static and dynamic heteroskedasticity	$F - value = 1.97$ $p - value = 0.0728$
Individual conditional mean and conditional variance. KG2 test on nonlinearity	$F - value = 11.22$ $p - value = 0.0001$
Dependence test	$t - value = 4.10$ $p - value = 0.0002$
Structural change	$t - value = -0.79$ $p - value = 0.4331$
Static heteroskedasticity	$F - value = 2.03$ $p - value = 0.0655$
Dynamic heteroskedasticity	$t - value = 3.03$ $p - value = 0.0044$

Table 4. Test Statistic from the Misspecification Testing on the Phosphate Demand for Wheat.

Misspecification testing	Test statistic
Normality test with K2 and Jarque-Bera	K2~$\chi^2_{(2)}$= 5.20507 P-value = 0.074086 JB~$\chi^2_{(2)}$= 3.98298 P-value = 0.13649
Joint conditional mean test on nonlinearity, temporal or spatial dependence, and structural change.	$F-value = 1.52 \quad p-value = 0.2021$
Joint conditional variance, static and dynamic heteroskedasticity	$F-value = 2.04 \quad p-value = 0.0794$
Individual conditional mean and conditional variance. KG2 test on nonlinearity	$F-value = 2.30 \quad p-value = 0.0494$
Dependence test	$t-value = 2.13 \quad p-value = 0.0415$
Structural change	$t-value = -0.41 \quad p-value = 0.6858$
Static heteroskedasticity	$F-value = 1.57 \quad p-value = 0.1797$
Dynamic heteroskedasticity	$t-value = -1.39 \quad p-value = 0.1750$

Table 5. Test Statistic from the Misspecification Testing on the Potash Demand for Corn.

Misspecification testing	Test statistic
Normality test with K2 and Jarque-Bera	$K2 \sim \chi^2_{(2)}$ = 3.89665 P-value = 0.14303 $JB \sim \chi^2_{(2)}$ = 3.24491 P-value = 0.19834
Joint conditional mean test on nonlinearity, temporal or spatial dependence, and structural change.	$F - value = 9.11$ $p - value = 0.0001$
Joint conditional variance, static and dynamic heteroskedasticity	$F - value = 1.67$ $p - value = 0.1322$
Individual conditional mean and conditional variance. KG2 test on nonlinearity	$F - value = 11.78$ $p - value = 0.0001$
Dependence test	$t - value = 5.33$ $p - value = 0.0001$
Structural change	$t - value = -0.21$ $p - value = 0.83612$
Static heteroskedasticity	$F - value = 1.75$ $p - value = 0.1142$
Dynamic heteroskedasticity	$t - value = 1.83$ $p - value = 0.0749$

Table 6. Test Statistic from the Misspecification Testing on the Potash Demand for Wheat.

Misspecification testing	Test statistic
Normality test with K2 and Jarque-Bera	$K2 \sim \chi^2_{(2)} = 3.62644$ P-value = 0.16313 $JB \sim \chi^2_{(2)} = 3.36169$ P-value = 0.18622
Joint conditional mean test on nonlinearity, temporal or spatial dependence, and structural change.	$F-value = 3.92$ $p-value = 0.0016$
Joint conditional variance, static and dynamic heteroskedasticity	$F-value = 1.97$ $p-value = 0.0720$
Individual conditional mean and conditional variance. KG2 test on nonlinearity	$F-value = 3.92$ $p-value = 0.0017$
Dependence test	$t-value = 2.97$ $p-value = 0.0051$
Structural change	$t-value = -5.05$ $p-value = 0.9589$
Static heteroskedasticity	$F-value = 2.34$ $p-value = 0.0353$
Dynamic heteroskedasticity	$t-value = 2.73$ $p-value = 0.0096$

Table 7. Parameter Estimates for the Demand of Nitrogen for Corn Production in the United States

Variables	Estimates	SE	t-value	p-value
Intercept	8.37159	0.21684	38.61	0.0001
Corn price	0.55353	0.48914	1.13	0.2681
Nprice	-0.01915	0.00823	-2.33	0.0280
Kprice	0.01905	0.00963	1.98	0.0586
$Nprice^2$	0.00043	0.00014	3.02	0.0056
Kprice*Nprice	-0.00034	0.00013	-2.51	0.0187
Cornprice*Nprice	-0.01564	0.00853	-1.83	0.0783
N	33			
R^2	0.76			

Table 8. Parameter Estimates for the Demand of Nitrogen for Wheat Production in the United States

Variables	Estimates	SE	t-value	p-value
Intercept	7.88039	0.39639	19.88	0.0001
Wheatprice	1.52786	0.65020	2.35	0.0273
Nprice	-0.01753	0.00877	-2.00	0.0572
Pprice	0.00576	0.01302	0.44	0.6619
Kprice	-0.02957	0.01461	-2.02	0.0542
$Cprice^2$	0.62368	0.17738	3.52	0.0018
$Nprice^2$	-0.00165	0.00038	-4.39	0.0002
$Pprice^2$	-0.00205	0.00042	-4.83	0.0001
Cprice*Kprice	-0.07583	0.02156	-3.52	0.0018
Nprice*Pprice	0.00346	0.00077	4.49	0.0002
Pprice*Kprice	0.00133	0.00029	4.60	0.0001
N	35			
R^2	0.92			

Table 9. Parameter Estimates for the Demand of Phosphate for Corn Production in the United States

Variable	Estimates	SE	t-value	p-value
Intercept	6.25875	0.21199	29.52	0.0001
Corn price	0.10344	0.09941	1.04	0.3048
Nprice	0.01238	0.00568	2.18	0.0357
Pprice	-0.01266	0.00957	-1.32	0.1941
Kprice	0.05668	0.01305	4.34	0.0001
$Nprice^2$	-0.00017	0.00004	-4.05	0.0003
$Pprice^2$	0.00023	0.00007	3.33	0.0020
$Kprice^2$	-0.00075	0.00014	-5.34	0.0001
N	45			
R^2	0.67			

Table 10. Parameter Estimates for the Demand of Phosphate for Wheat Production in the United States

Variable	Estimates	SE	t-value	p-value
Intercept	6.65108	0.52948	12.56	0.0001
Wheatprice	1.84298	0.66734	2.76	0.0106
Nprice	-0.02162	0.00711	-3.04	0.0055
Pprice	-0.04281	0.02480	-1.73	0.0966
$Nprice^2$	-0.00177	0.00050	-3.52	0.0017
$Pprice^2$	-0.00254	0.00040	-6.28	0.0001
$Kprice^2$	-0.00279	0.00130	-2.15	0.0415
Wheatprice*Nprice	0.02924	0.00719	4.06	0.0004
Wheatprice*Kprice	-0.09188	0.02438	-3.77	0.0009
Nprice*Pprice	0.00329	0.00093	3.55	0.0016
Pprice*Kprice	0.00415	0.00111	3.74	0.0010
N	37			
R^2	0.96			

Table 11. Parameter Estimates for the Demand of Potash for Corn Production in the United States

Variable	Estimates	SE	t-value	p-value
Intercept	7.58232	0.36567	20.74	0.0001
Cornprice	0.03984	0.10974	0.36	0.7187
Nprice	-0.00226	0.00786	-0.29	0.7750
Pprice	0.01532	0.01393	1.10	0.2789
Kprice	-0.02299	0.02594	-0.89	0.3814
$Nprice^2$	-0.00133	0.00022	-5.97	0.0001
$Pprice^2$	-0.00123	0.00037	-3.36	0.0019
$Kprice^2$	0.00024	0.00035	0.67	0.5080
Cornprice*Nprice	0.00255	0.00054	4.73	0.0001
N	45			
R^2	0.80			

Table 12. Parameter Estimates for the Demand of Potash for Wheat Production in the United States

Variable	Estimates	SE	t-value	p-value
Intercept	5.48908	0.38277	14.34	0.0001
Wheatprice	0.03914	0.12234	0.32	0.7507
Nprice	0.00211	0.00253	0.83	0.4100
Kprice	-0.00344	0.01996	-0.17	0.8641
$Kprice^2$	-0.00004	0.00018	-0.22	0.8259
N	45			
R^2	14			

Table 13. Elasticities of Demand for Nitrogen, Phosphate, and Potash for Corn, and Wheat.

|	Elasticities					
	Nitrogen Demand		Phosphate Demand		Potash Demand	
Variable	Corn	Wheat	Corn	Wheat	Corn	Wheat
Corn price	0.35		0.08		0.31	
Wheat price		1.45		1.86		0.04
Nprice	-1.09	-1.07	0.81	-1.32	-0.15	0.14
Pprice		0.35	-0.80	-2.61	0.96	
Kprice	0.74	-1.18	2.34	2.02	-0.95	-0.14
Nprice^2	1.51	-7.01	-0.80	-7.48	-6.39	
Pprice^2		-8.57	1.01	-10.53	-5.31	
Kprice^2			-1.37	-4.80	0.43	-0.07
Cornprice^2						
Wheatprice^2		0.69				
Cornprice*Pprice						
Cornprice*Nprice	-0.61					
Wheatprice*Nprice				2.07		
Wheatprice*Pprice						
Wheatprice*Kprice		-3.12		-4.01		
Nprice*Pprice		14.42		13.62	11.47	
Pprice*Kprice		3.53		10.99		
Nprice*Kprice	-0.82					
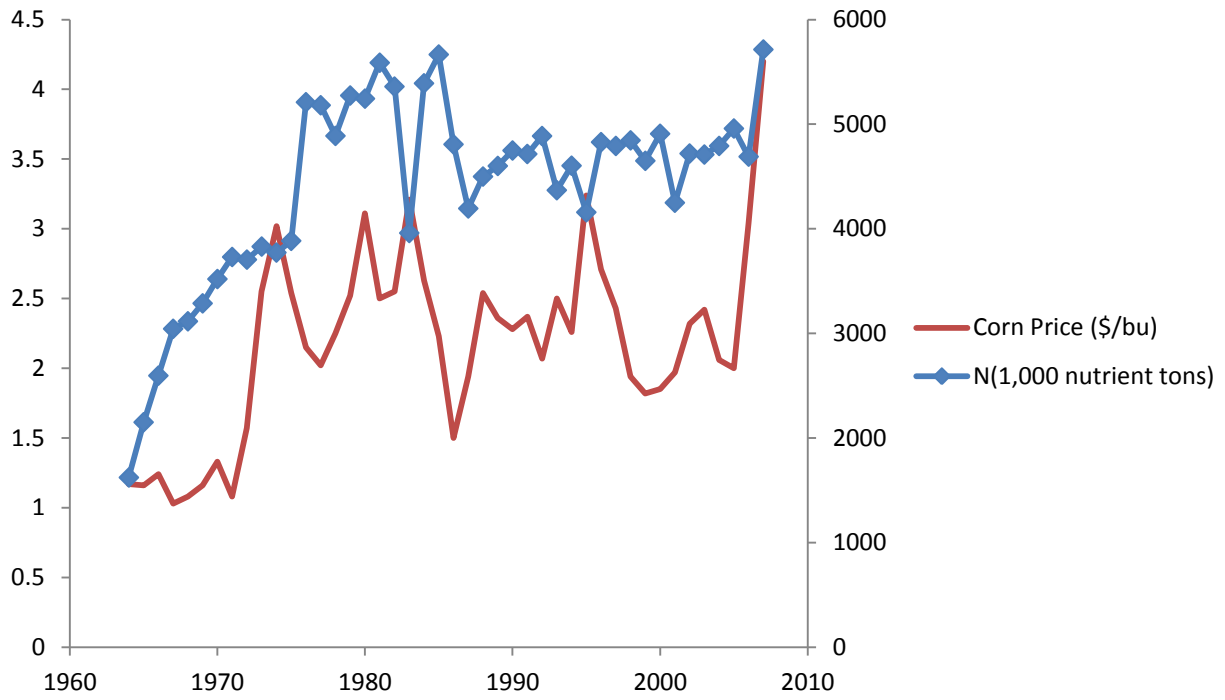
Figure 1. A plot of U.S. average corn price ($/bu) and quantity of nitrogen used for corn production in the United States (1,000 nutrient tons).
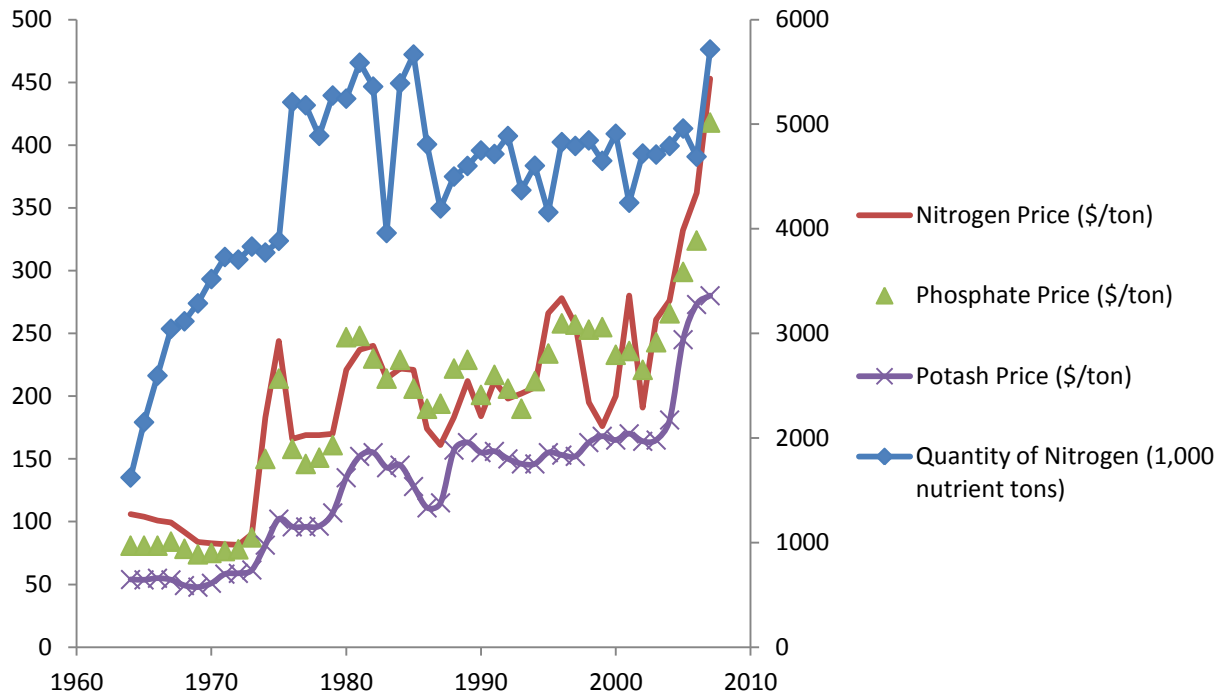
Figure 2. A plot comparing the trends and relationships between nitrogen price, phosphate price, potash price, and quantity of nitrogen used for corn production in the United States. All the prices are U.S. average prices.
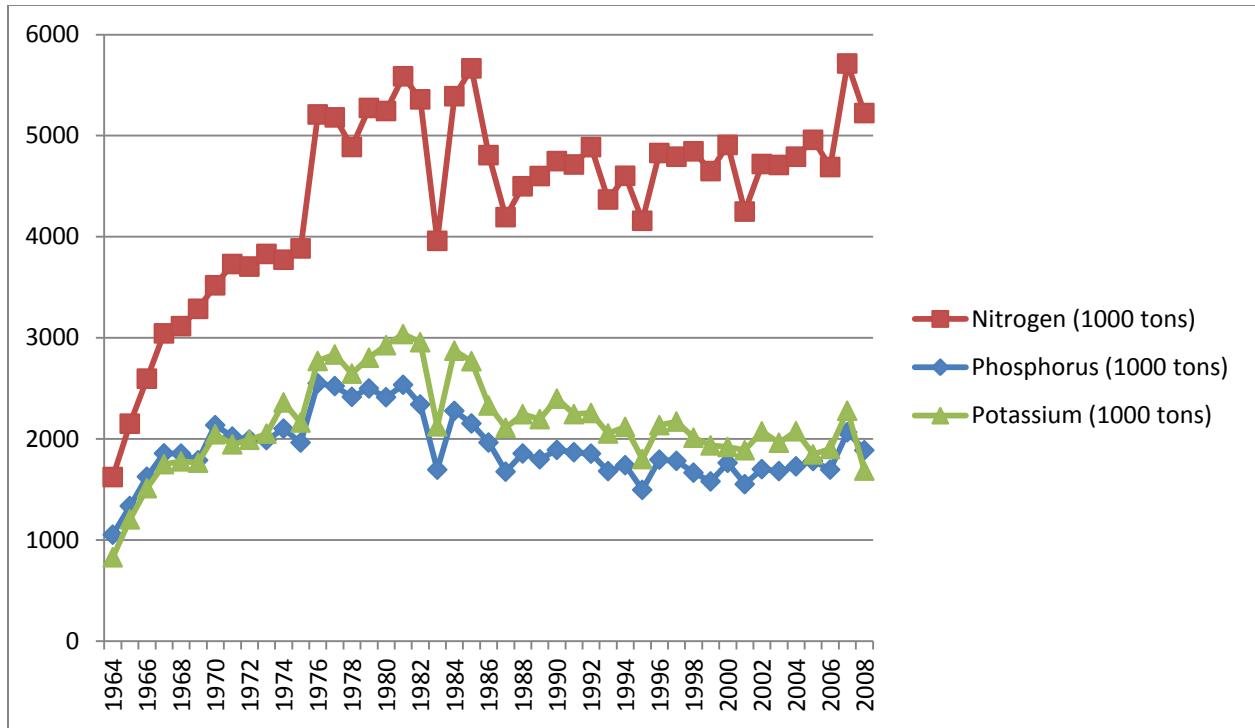
Figure 3. Quantities of nitrogen, phosphorus, and potassium fertilizers for corn production in the United States.
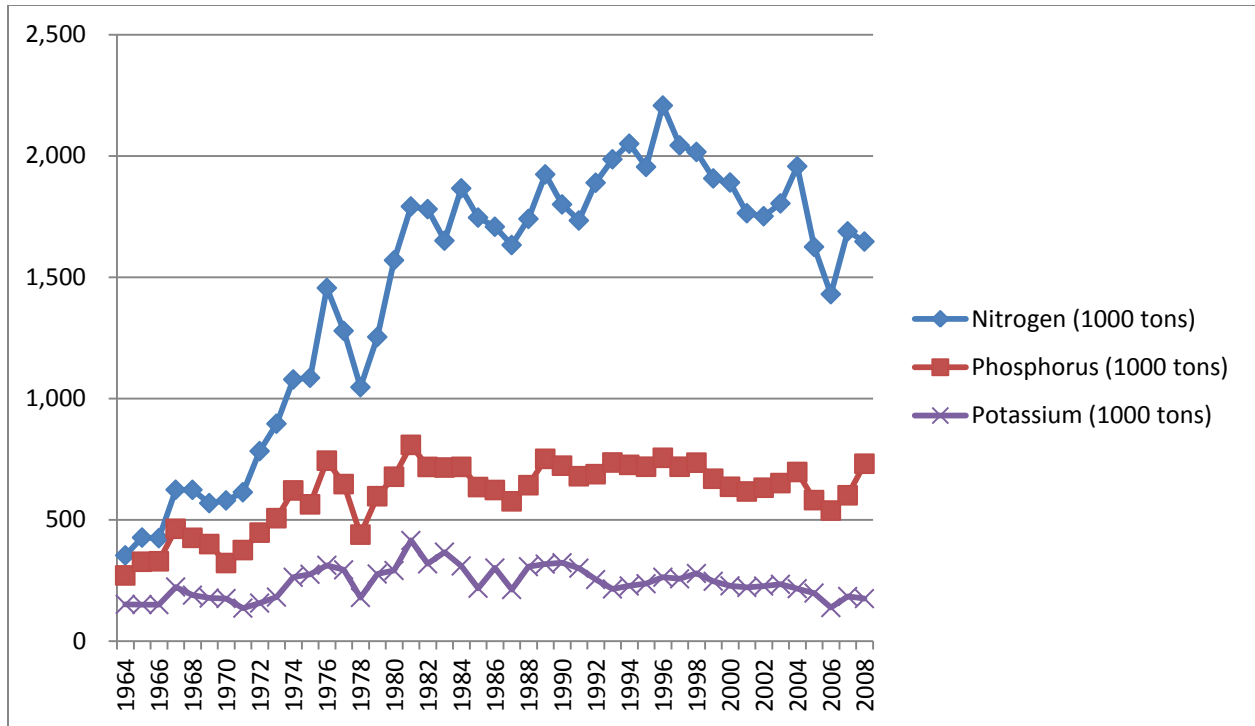
Figure 4. Quantities of nitrogen, phosphorus, and potassium fertilizers for wheat production in the United States.