THE EFFECTS OF CHANGING FERTILIZER PRODUCTION COSTS ON U.S. AGRICULTURAL MARKETS: A PARTIAL EQUILIBRIUM ANALYSIS

A Thesis

Presented to

The Faculty of the Graduate School

University of Missouri

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

Submitted by

BRAYDON ALAN MINEAR

Dr. Wyatt Thompson, Thesis Supervisor

MAY 2015

APPROVAL FORM

The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled

THE EFFECTS OF CHANGING FERTILIZER PRODUCION COSTS ON U.S.
AGRICULTURAL MARKETS: A PARTIAL EQUILIBRIUM ANALYSIS

presented by Braydon Alan Minear,

a candidate for the degree Master of Science,

and hereby certify that, in their opinion, it is worthy of acceptance.

____

Associate Professor Wyatt Thompson, Ph.D.

____

Professor Patrick Westhoff, Ph.D.

____

Professor Leon Schumacher, Ph.D.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my family, friends, co-workers and mentors for their support during the completion of this study. The research conducted would not have been possible without the work performed and the assistance provided by the staff at FAPRI-MU. I am especially grateful for the guidance and encouragement received from Dr. Wyatt Thompson, Dr. Patrick Westhoff and Dr. Leon Schumacher while serving on my thesis committee. Finally, this thesis research would not have been accomplished without the mentoring of Dr. Abner Womack. Thank you for sparking my interest in agricultural economics and providing direction during my time at Mizzou.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

Recent fertilizer price volatility motivates this partial equilibrium simulation analysis of fertilizer markets. Previous studies have utilized a simultaneous supply and demand framework to examine important relationships among economic variables in the fertilizer industry. In order to update and build on prior research, this study estimates an econometric model of U.S. nitrogen, phosphate and potash fertilizer markets and links it to the FAPRI-MU agricultural commodities model system in order to analyze relationships between domestic fertilizer production costs and key agricultural commodity variables. Fertilizer production input price shock responses indicate inelastic U.S. fertilizer demand, unique fertilizer use decisions across nutrient and crop sectors and a low responsiveness to fertilizer costs in U.S. agriculture in general.

I: INTRODUCTION

In the past, the majority of studies of the U.S. fertilizer industry have been motivated by possible environmental risks associated with the over-application of fertilizer. More recently, the uncertainty surrounding volatility in fertilizer prices and the implications of their production costs has prompted additional analysis. Previous examinations, which have mainly focused on demand, have econometrically analyzed the U.S. fertilizer industry in a simultaneous supply and demand, partial equilibrium framework. This study builds on prior research by estimating a partial equilibrium model with a simultaneous supply and demand framework of nitrogen, phosphorus, and potassium fertilizer markets and linking it to an existing U.S. agriculture model system in an effort to quantify and examine the impacts of fertilizer production cost changes on crop prices and other key agricultural economic variables. More specifically, this study evaluates the effects of a natural gas, sulfur and electric power price change on key economic variables in the U.S. fertilizer and agricultural commodity markets.

The purpose of this research is to estimate and test a partial equilibrium model of the U.S. fertilizer industry and link it to the Food and Agricultural Policy Research Institute of the University of Missouri (FAPRI-MU) agriculture commodities model in order to analyze important relationships among economic variables impacting the fertilizer and crop production industries. The model is used to produce a baseline and scenario values of future supply, demand and price variables that can be analyzed in order to quantify their relationships. Specific objectives are to:

1. Estimate empirically domestic nitrogen, phosphate and potassium fertilizer input demand equations for corn, soybeans, wheat, cotton and other crops at the aggregate level;
2. Estimate empirically domestic fertilizer supply equations for nitrogen, phosphate and potassium nutrients;
3. Project baseline values for supply, demand and price variables;
4. Analyze the impacts of fertilizer production cost changes on variables such as fertilizer prices, crop prices, planted acreages and farm returns; and
5. Attempt to quantify a link between fertilizer production input prices and key economic variables in U.S. agricultural commodity markets.

As discussed in Chapter III, previous research has focused mainly on the demand side of the fertilizer industry. Few studies, besides Gyawu et al. (1984), Zelaya (1991) and Steiner (2014), look at a supply-demand equilibrium determined using simultaneous price signals. This study examines the U.S. fertilizer industry and crop market in a simultaneous framework and links it to an agricultural commodities model.

The impact of fertilizer and crop prices on farmers' application of nutrients has been the focus of prior studies as environmental risks have been discovered. Researchers have found that excess amounts of nitrogen might cause disruptions in ecosystem functions via eutrophication and hypoxia (Ribaudo et al. 2011). With the introduction of environmental risk, economic and environmental optimization becomes a balancing act for the farmer. Applying too much nitrogen provides insurance of greater yields in optimum weather but increases the likelihood of nitrogen escaping into the environment;

applying too little increases the risk of reduced yields and lost income (Ribaudo et al. 2011). Results from this study might answer questions about the responsiveness of farmers' total fertilizer use to fertilizer prices not only in terms of application rates, but also relating to varying planted acre totals due to fertilizer costs per acre.

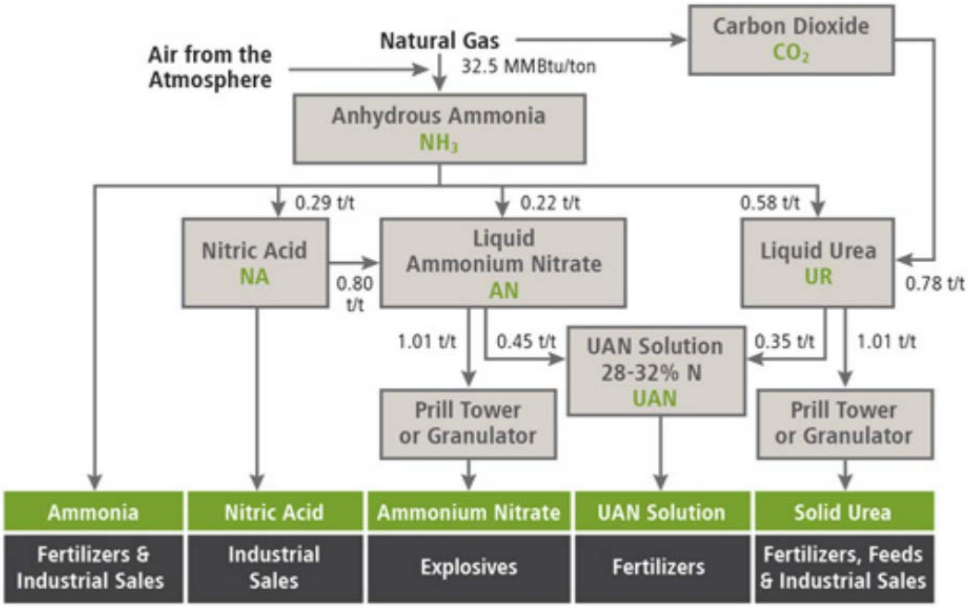
The comparison of scenario induced outputs of this model to the projected baseline will produce valuable information to market participants and policy makers. By linking this fertilizer model to the FAPRI-MU agricultural model, additional relationships can be analyzed in agricultural markets, allowing for better understanding of the impacts of proposed policy instruments and changing market conditions.

II: INDUSTRY OVERVIEW

Nitrogen Sector

Since the development of the Haber-Bosch process to convert gaseous nitrogen into a biologically usable form in the early 1900s, farmers have been able to use each acre of land more efficiently for crop production (Follett, Follett and Herz 2010). This relatively inexpensive fertilizer has allowed producers to be less dependent on leguminous plants and manure. Natural gas is the main feedstock for nitrogenous fertilizers in the U.S., accounting for about 72 to 84 percent of its cost (Huang 2007). Ammonia (NH_3) is a concentrated form of nitrogen that is the basic feedstock for all upgraded nitrogen products. It can also be applied directly as a fertilizer or used to make industrial products.

Figure 2.1: Nitrogen Flow Diagram

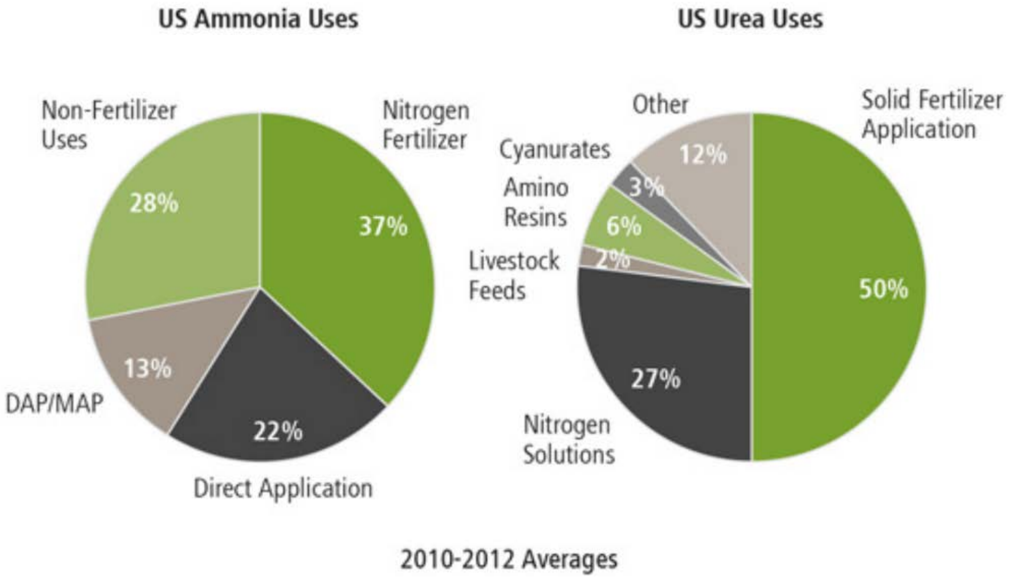


Source: PotashCorp (2014)

According to PotashCorp (2014), 70 percent of U.S. ammonia is used for direct fertilizer application or the production of downstream fertilizer products. The remaining 30 percent is used as a feedstock for plastics, resins, adhesives, explosives and increasingly for emissions control.

Of the three primary nutrients, nitrogen production is the most geographically diverse because of the widespread availability of natural gas. Ammonia is primarily consumed close to the areas in which it is produced due to the high cost of transportation. PotashCorp (2014) states China is the largest ammonia producer while the U.S., Europe and India are major producers and importers. Trinidad, Russia and Middle Eastern countries are primarily focused on exporting their production.

Figure 2.2: Ammonia and Urea Uses



Source: PotashCorp 2014

In most recent years, producers in China have faced higher input costs of coal and natural gas. Producers in the U.S. have profited from lower natural gas prices and strong domestic demand for nitrogen fertilizers. Even with this development, Trinidad still remains a very competitive supplier given its proximity to the large U.S. market.

Higher net returns for U.S. nitrogen producers have motivated an increase in domestic production capacity. This increased domestic production is likely to reduce the amount of nitrogen imports needed. Trinidad is currently responsible for approximately 70 percent of U.S. imports, and half of U.S. consumption is provided by imports from producers like Trinidad, Canada, the Middle East and China (PotashCorp 2014).

Natural Gas

The EIA (2011) describes how the extraction of natural gas from shale deposits has grown recently. The shale boom found its start with the use of horizontal drilling in conjunction with hydraulic fracturing. This process greatly expanded the ability of producers to recover natural gas and oil from shale plays. The EIA (2011) goes on to discuss how this technique grew rapidly in the 1950’s leading to research in the relatively shallow Devonian (Huron) shale in the eastern United States in the 1970’s. This research eventually became crucial to the production of natural gas from shale rock. In the early 1980s, practical application of horizontal drilling to oil production was developing. The focus of activity into new shale plays, notably the Bakken Shale in North Dakota and Montana, has noticeably increased dry shale gas production in the United States (EIA 2011).

According to the EIA (2011), dry shale gas production has increased from 4 trillion cubic feet in 2009 to 12 trillion cubic feet in 2013. This has caused total natural gas production to increase from 26 to 30 trillion cubic feet or by 15.3 percent over the same time period. The 12 trillion cubic feet of shale gas accounted for 40 percent of the total natural gas production in the U.S. in 2013. During this period of production expansion, the price of natural gas has decreased. Since the 2009 citygate price of $6.48 per thousand cubic feet, it has decreased by 25 percent to $4.88 in 2013 (EIA 2013b).

Figure 2.3: U.S. Ammonia and Natural Gas Price Comparison

Source: PotashCorp (2014)

Prior to 2009 however, the price of natural gas had been increasing. According to Huang (2009), low returns for ammonia fertilizer products led to a 42 percent reduction in ammonia capacity in the U.S. from 1999 to 2008. During the beginning of this period, capacity was underutilized, but by 2007 capacity limits were being reached in response to increasing corn acres. The U.S. had gone from being the world's largest nitrogen exporter in the 1980's to the largest importer in 2007 (Huang 2009). Fertilizer prices increased along with most other commodity prices in the 2008 price spike but promptly returned to pre-spike levels in 2009 (Figure 2.3). The ammonia price has been well above the natural gas price since 2009, possibly due to a combination of strong demand and limited supply (Figure 2.3). These high profit margins helped U.S. nitrogen producers stay competitive against imports and has motivated an increase in capacity by firms in the market (PotashCorp 2014). According to the IFDC (2013), capacity for ammonia has risen by 8 percent for the period 2011 to 2014 and is project to increase an additional 9 percent by 2016.

However, these relatively low natural gas prices are not projected to last by the U.S. EIA. According to the EIA's Annual Energy Outlook (2013), several factors are expected to contribute to a rise in natural gas prices. The two main uses of natural gas in the U.S. are electric power generation and industrial use. In both sectors, natural gas is projected to retain around 33 percent of the market share, each. In the power generation sector, natural gas has been gaining shares of electric power generation over coal. For a few months in 2012, natural gas-fired generation plants were more economically feasible to run than coal plants, resulting in a near tie for the largest share of total electricity generation. Coal's power generation share is also in jeopardy of further restriction from policies aimed at reducing greenhouse gas emissions. Coal is expected to regain some of the lost market by 2020; however, coal's share is projected to fall to 45 percent while natural gas rises to 30 percent by 2040. Natural gas use in the industrial sector is projected by the EIA to increase by 16 percent from 2011 to 2025, while use for heavy-duty freight transportation and gas-to-liquid production of diesel fuels is expected to account for 6 percent of production by 2040, up from essentially 0. The EIA also expects the U.S. to become a net exporter of natural gas by 2019. Domestic production is projected to increase by 1.3 percent annually which will outpace domestic consumption for the foreseeable future. Most of the projected growth in U.S. exports consists of pipeline exports to Mexico with further contribution from declining imports of natural gas from Canada (EIA 2013a).

In summary, the EIA (2013a) expects a rise in the cost of developing new incremental production needed to support the continued growth in natural gas consumption and exports. The depletion of resources in inexpensive areas leads producers to basins where recovery of the gas is more difficult and expensive. Overall, Henry Hub natural gas spot prices are expected to increase by 2.4 percent annually until 2040 (EIA 2013a).

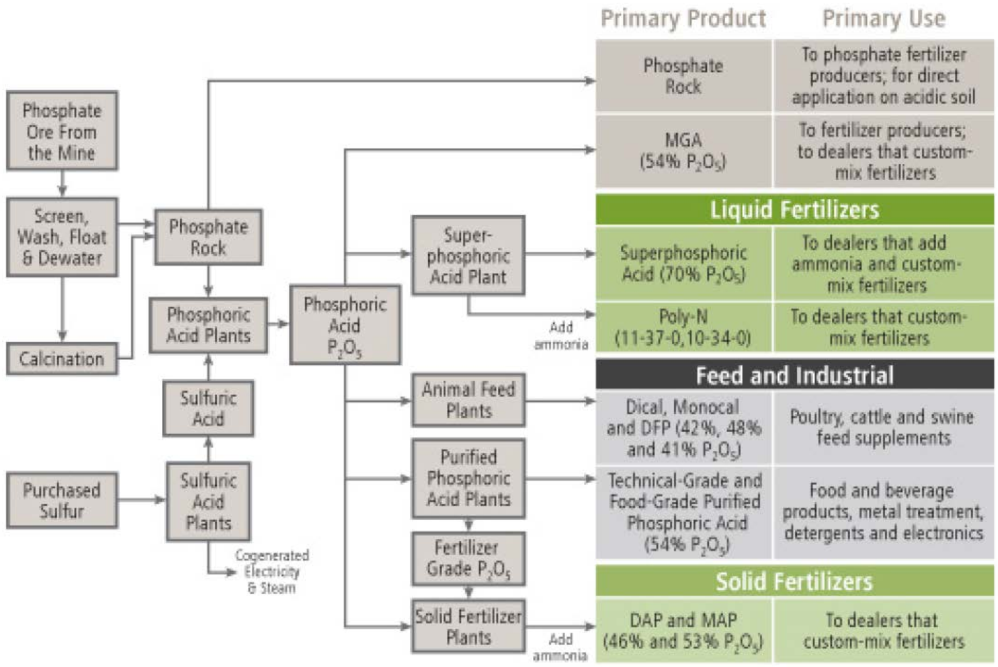
Phosphate Sector

Phosphate fertilizers are the main source phosphorus, crucial to photosynthesis, speeding maturity and reproduction, and increasing yield in plants. Phosphorus is also vital to muscle contraction, growth, maintenance and repair in animals and is used in many industrial products.

Phosphate fertilizer production begins in underground ore deposits. Phosphate rock is mined, and then dissolved in a mixture of phosphoric and sulfuric acids. This results in production of additional phosphoric acid, which is the feedstock for most fertilizer, industrial and feed phosphate products. Figure 2.4 gives a visual representation of the phosphate production process.

Potash Corp (2014) suggests that around 90 percent of global phosphoric acid is used as a fertilizer. MAP and DAP are the most common solid phosphate fertilizers used by farmers. Grains account for 44 percent of world phosphate use, and fruits and vegetables account for 18 percent according to PotashCorp (2014). Due to the production of phosphate intensive crops like fruits and vegetables, over 60 percent of all phosphates are consumed in Asia where these crops are grown. China alone accounts for approximately 40 percent (PotashCorp 2014).

Figure 2.4: Phosphate Flow Chart



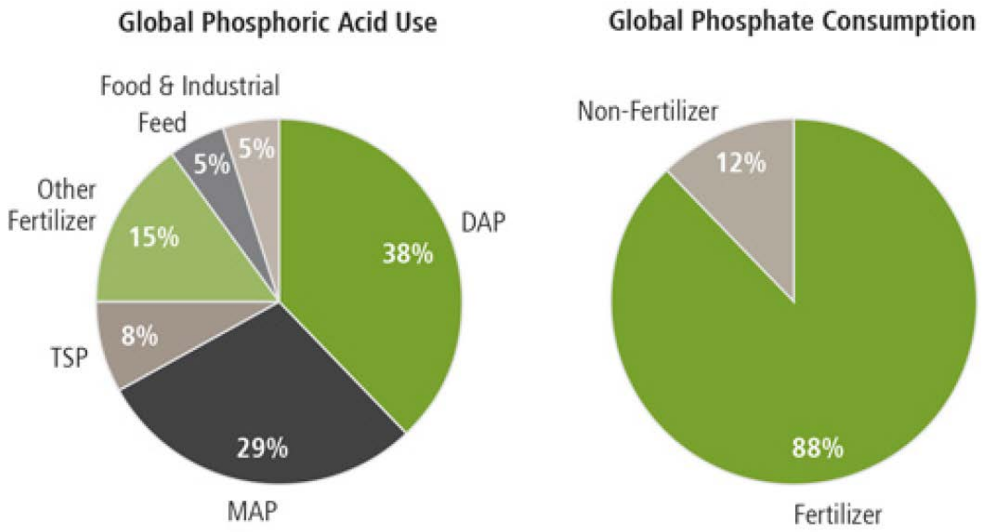
Source: PotashCorp 2014

Industrial phosphate products include soft drinks, food additives, metal treatment, detergents and cleaners. Phosphate is also used as a supplement in beef, poultry and pork rations and in the aquaculture industry.

PotashCorp (2014) also points out that only a few geographic areas offer substantial quantity and quality sources of phosphate. Approximately 75 percent of known global reserves are located in Morocco and Western Sahara. U.S. deposits are only responsible for 2 percent of global production and are located in Florida, North Carolina and Idaho (PotashCorp, 2014).

Morocco is responsible for supplying around half of the global trade and the majority of phosphate exporters are located in Africa (PotashCorp 2014). Europe and India are large importers accounting for over half of global imports (PotashCorp 2014).

Figure 2.5: Global Phosphate Use



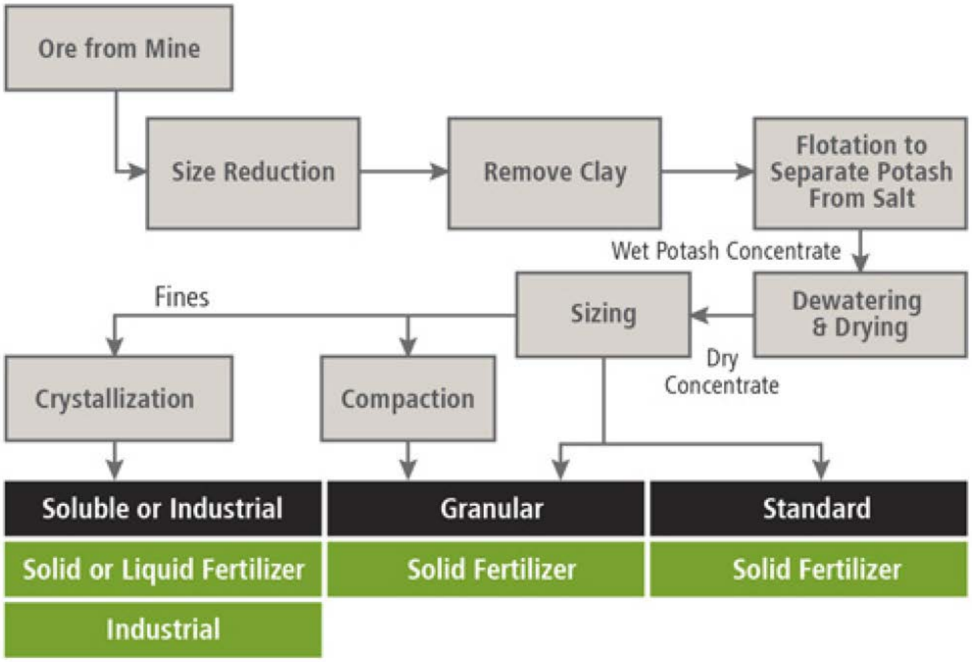
Source: PotashCorp 2014

Over the past decade, according to PotashCorp (2014), North American MAP and DAP production has been reduced by 35 percent as a result of increased competition in the export market. Despite this, the U.S. remains an important phosphate supplier to key markets such as Latin America, India and Canada (PotashCorp 2014).

Potash Sector

Potassium chloride, commonly called potash, is mined from ore deposits or extracted from salt lakes or seas. Nearly 80 percent of global potassium chloride capacity is provided by conventional underground mines (PotashCorp 2014). The remainder is obtained in solution mines or by harvesting natural brines from bodies of water, typically using solar evaporation. Potash production does not involve the use of a main input like the nitrogen or phosphate production process. Rather, variable production costs arise from either the mining or refinement process in the form of fuel, electricity and labor inputs (Steiner 2014). The diagram below outlines the process of potash production.

Figure 2.6: Potash Flow Diagram



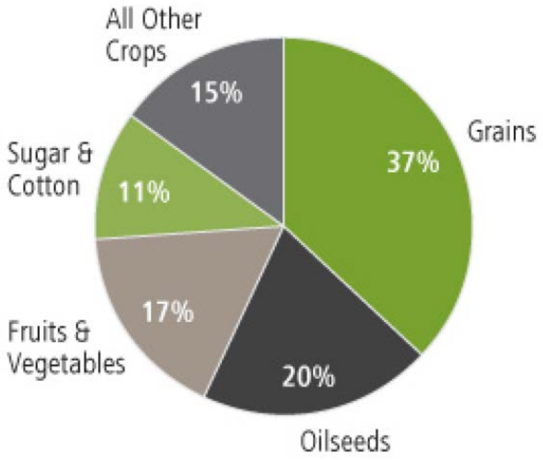
Source: PotashCorp 2014

Potash is used on a wide variety of crops in the agricultural sector. Over half of the potash used worldwide is applied to corn, wheat, rice, oilseed and sugar crops (PotashCorp 2014). Fruits and vegetables are important users of potash fertilizers. The remainder is used by crops such as palm, rubber, cotton, coffee and cocoa.

According to PotashCorp (2014), approximately 90 percent of potash in the world is applied as a fertilizer. The remaining 10 percent is used in the livestock sector as a feed supplement or in the industrial sector in water softeners, food products, soaps, de-icers, batteries, drilling muds and pharmaceuticals (PotashCorp 2014).

There are only a few major sources of reliable potash production. PotashCorp (2014) states that Canada controls 36 percent of world capacity and almost half of known global reserves. Russia controls around 35 percent of additional reserves. There are other known deposits; however, securing an economically mineable deposit in a country with both political stability and infrastructure availability can present significant challenges to building new capacity (PotashCorp 2014).

Figure 2.7: World Potash Use by Crop



Source: PotashCorp 2014

The U.S. has imported a majority of its supply historically from Canada. According to the ERS (2013a), more than 85 percent of potash supply was from imports in 2011. Because domestic production capacity is limited and has generally declined over time, any increase in potash demand must be met by imports (ERS 2013a).

Fertilizer Use and Price in U.S. Agriculture

Fertilizers are a vital input in the production of crops used for food, feed, fiber, and fuel. In the United States, many forms of the primary macronutrients nitrogen phosphate and potassium are applied to agricultural commodities. Adequate supply and crops bred to utilize these available nutrients have contributed to record production from increased yields.

Huang (2009) gives a thorough analysis of fertilizer price trends for the past 5 decades. Data for this period is provided by the ERS (2013b) and can be viewed in Figure 2.8. During the 60s and 70s fertilizer use was expanding rapidly as farmers began switching to high-yield crop varieties and hybrids that responded favorably to intensive fertilization. Driven by global demand for grains, U.S. consumption of fertilizers peaked in the early 80s as seen in Figure 2.8. Huang (2009) then indicated that use began to decline as government programs removed cropland from production in response to decreased grain demand. The late 80s saw consumption begin an upward trend, likely as a result of an increase in planted corn acres. Volatile fertilizer use ensued in the early 2000s as increasing energy input costs drove nutrient prices higher. High material costs, production cutbacks and decreasing imports of fertilizers prompted record fertilizer prices from 2007 to 2009, resulting in reduced consumption in 2010 (Huang 2009). Increased plantings and high commodity prices in 2011 and 2012 are the likely cause of the increase in fertilizer use to pre-2007 levels (Figure 2.8).

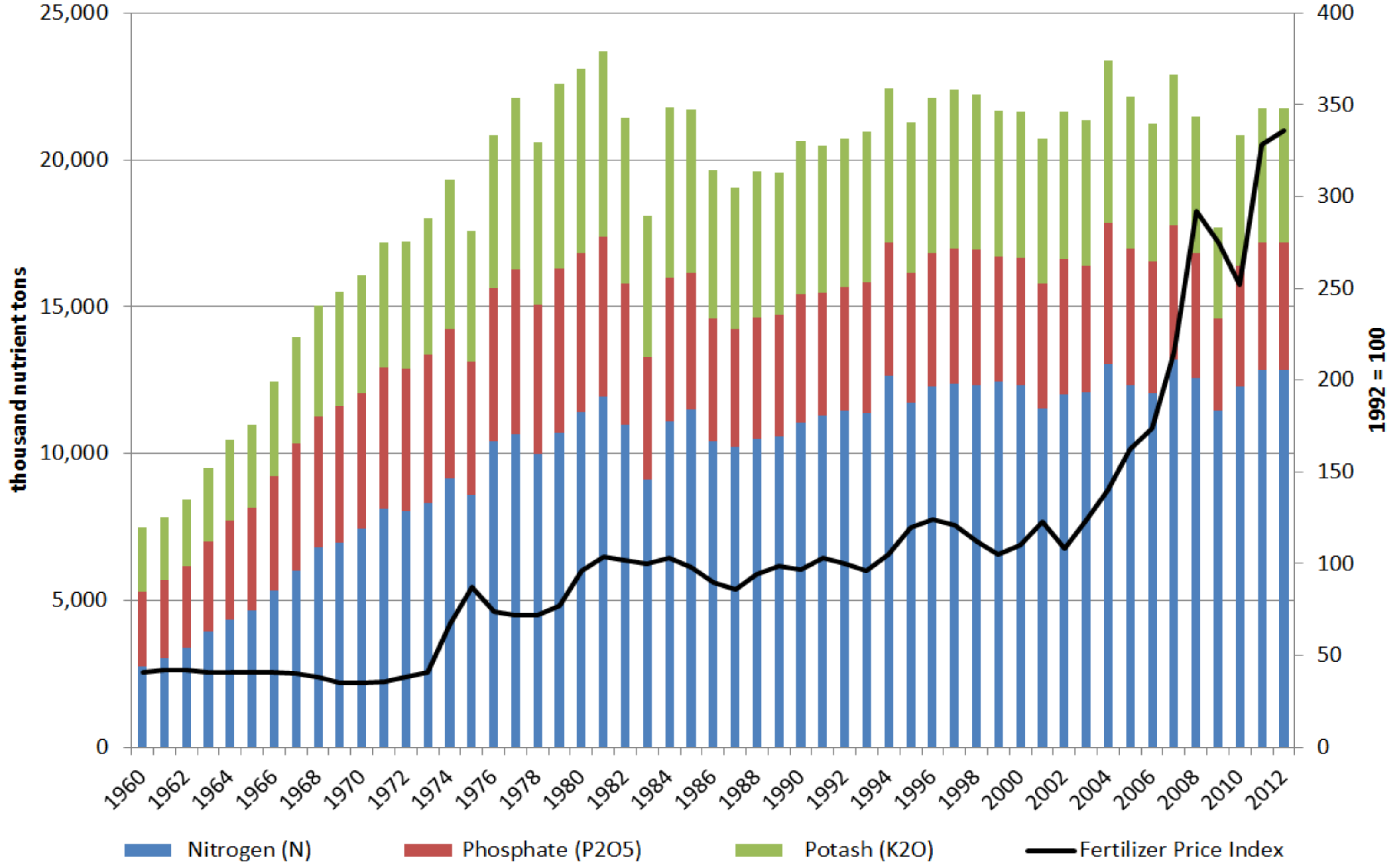
Nitrogen fertilizer use has expanded faster than phosphate and potash because of the development of high-yielding varieties that are more responsive to NH_3. According to the ERS (2014), common forms of nitrogen fertilizer and their nutrient content are anhydrous ammonia (82%), urea (46%), ammonium-nitrate (33%) and ammonium-sulfate (21%). Phosphate fertilizers include monammonium phosphate (MAP, 52%), diammonium phosphate (DAP, 46%), phosphoric acid (54%) and superphosphoric acid (74%). Potassium muriate (61%), potassium sulfate (50%) and potassium nitrate (44%) make up common options for potash (ERS, 2014). These nutrients are commonly used separately or mixed into solutions and applied to a field all at once. Fertilizer application typically occurs in the spring and fall for most major crops.

There has been evidence presented by (Ribaudo et al. 2011) and Sheriff (2005) that suggests farmers commonly over-apply fertilizer from an agronomic perspective. One hypothesis contends that uncertainty in weather and soil conditions leads producers to over-apply nutrients as a "safety net" approach. Optimistic yield goals are set based on optimum weather conditions, thus adequate fertilizer is applied to ensure that the needed amount to obtain these yields is available. However, optimal conditions are rare, resulting in heavy fertilization a majority of the time (Ribaudo et al. 2011, Sheriff 2005). This observation has motivated many studies on the effectiveness of policy intervention to reduce environmental effects of heavy fertilization that might serve long run profit motives rather than short run agronomic needs.

The adoption of global positioning system (GPS) mapping and variable rate technology (VRT) might be able to combat this inefficiency. By gathering information during field operations, farmers can adjust the application of inputs to satisfy specific crop needs (Schimmelpfennig and Ebel 2011). This additional information can lead to better informed management decisions by crop producers.

Agricultural practices have evolved over time and must be considered when specifying model equations and evaluating elasticities. Farmers are no longer in the fertilizer adoption phase, so the need for lagged application rates and technology trends might have lessened. Producers are now closer to the yield-maximizing point on the production function suggesting that fertilizer demand elasticities could be lower now than they were in the past. Increased supply of information for decision making supports the assumption that a farmer is a profit-maximizing producer.

Figure 2.8: Nutrient Use and Price in the U.S.



Source: PotashCorp 2014

III: LITERATURE REVIEW

In the pursuit of agricultural supply functions, many studies have been conducted on the various factors of production in the agricultural sector. These factors include purchased inputs such as seed, machinery, chemicals and fertilizer. Estimates of the demand and supply elasticities for these factors are invaluable to market analysts and policy makers. Because there is sufficient aggregate consumption and price series data for the U.S., fertilizer has been the focus of many demand analyses. Consumption of fertilizer in the U.S. approximately tripled in the 1940's and 50's prompting studies by Griliches (1958) and Heady and Yeh (1959) among others. These studies focused on the fertilizer demand elasticities with respect to fertilizer input prices and commodity output prices, offering a common reference for future analysis. While a few studies have been made on the supply side, a majority of the literature for fertilizer is the analysis of demand.

Demand Literature

While there were previous studies, this literature review begins with two journal articles: the first by Zven Griliches and the latter by Earl Heady and Martin Yeh. The framework developed in these articles is referenced by many future studies on fertilizer demand. The model framework consisted of the amount of fertilizer applied in the U.S. for agriculture as a function of the fertilizer own-price (input cost) and the price of agricultural commodities (output price). Other variables were included to represent additional market factors, but these two variables became the foundation from which many modern studies stemmed.

Griliches (1958) analyzed demand at the national level for the period 1911 to 1956. His study measured the consumption of fertilizer in terms of the total quantity of nutrient tons of nitrogen, phosphate and potash applied in the U.S. as an aggregate. The model used to represent demand was divided into a long run demand function and an adjustment equation. The demanded quantity of fertilizer was a function of price paid per plant nutrient divided by an index of prices received by farmers for all crops in the same year. The inclusion of an adjustment factor arises from the idea that farmers do not immediately change their fertilizer application practices in the current period.

While this seems plausible, the inclusion of an adjustment factor might not be as applicable to modern agricultural practices. The use of yield monitors, GPS mapping and variable rate technology allows farmers to vary the rate of fertilizer application within one field. Lagged effects would also not be as great in the aggregate. Griliches' estimated price elasticities are listed with elasticities from all other reviewed studies at the end of this chapter.

Heady and Yeh (1959) estimated demand functions for fertilizer nutrients in the United States for the period 1910 to 1956. Their goal was to express demand elasticity relative to own-price, crop prices and other factors of production including advancement of technology and total acreage of cropland. The fertilizer price at the time of planting is used as the input price and the crop price for the previous year is used as a proxy for output price expectation. An expectation of price is used because farmers do not know the harvest price at the time of fertilization. Technological advancement in application practices, fertilizer quality and knowledge of fertilizer is represented by a trend variable.

The coefficient for total acreage of cropland was negative in the estimated demand equations indicating that fertilizer is a substitute for additional cropland acres. The idea, per the authors, is that farmers that have taken acreage out of production due to control programs make up for the difference by applying more fertilizer to increase yields on the remaining acres. Elasticities for these variables were estimated in the aggregate, by individual nutrient and for different regions in the U.S.

The results for the individual nutrient demand equations are presented in the following chart:

Figure 3.1: Heady and Yeh (1959) Nutrient Total Demand Elasticities

Demand for tons of fertilizer consumed w.r.t:	N	P	K
Fertilizer price index	-0.449	*-0.448	-0.403
Cash receipts from farming $_{t-1}$	*0.804	0.579	*0.881
Total acreage of cropland	-1.691	*-2.368	-1.294
Time	*0.207	0.079	*0.217

* = significant at 5% level

Here, the demand with respect to own-price is inelastic and similar among all three nutrients. The demand elasticities for nitrogen and phosphate are almost identical for the fertilizer price variable. According to the authors, the difference in the demand for phosphate arises from the greater extent of use of this nutrient on hay ground.

In 1980 Gunjal, Roberts and Heady estimated separate demand functions for five crops in the U.S. Ordinary least squares methods were used for the period 1952-1976. The five crops analyzed were feed grains, wheat, soybeans, cotton and tobacco. Feed grains were an aggregate category that consisted of corn, grain sorghum, oats and barley. With fertilizer expenditures per acre as the dependent variable, the explanatory variables included fertilizer own-price, per acre farm income, lagged dependent variable, trend and farm physical assets. The value of land and buildings and the annual average values of machinery and commodity stocks owned by farmers were included in farm physical assets. Elasticities listed in the study are displayed in the following chart:

Figure 3.2: Gunjal, Roberts, Heady (1980) Fertilizer Demand Elasticities

	Feed Grains	Wheat	Soybeans	Cotton	Tobacco
gross farm per acre income$_{t-1}$	0.29			0.19	0.65
farm physical assets	1.33	0.31	0.70		
fertilizer price index	-0.90	-0.99	-0.62	-0.31	-0.53
price of crop$_t$		0.42			
price of crop$_{t-1}$	0.90				

According to the authors, farmers with inventories of feed grains, wheat and soybeans can use these assets to obtain loans to pay for input costs such as fertilizer. Like Griliches, the authors also included a lagged dependent variable in their model estimation because farmers might not make the full adjustment to long run equilibrium in one year due to habit persistence. However, this term was only significant in the soybean model. It was also noted that the same explanatory variables were not significant in all the crop functions. This observation “implies that all types of farmers, producing different crops, may not respond to the same variables or may not consider the same type of economic variables while making their fertilizer-purchasing decisions” (p. 113).

According to the authors, the fertilizer demand elasticities with respect to fertilizer price are less elastic for cotton and tobacco because they are strictly cash crops and are grown in areas known for high application rates. The elasticity for soybeans is likely inelastic because it is a legume which requires little nitrogen. Wheat and feed grains have a higher elasticity because the Corn Belt region had recently seen the most increase in fertilizer use. Lagged per-acre gross income, rather than crop prices, might have been significant for cotton and tobacco because they have significant variations in yield. These results suggest that farmers growing different crops might respond with varying degrees to the same economic factor.

Two years later, Roberts and Heady (1982) did a similar analysis for corn, wheat and soybeans. For the period 1952 to 1976, separate demand equations were estimated for nitrogen, phosphate and potassium fertilizers for each crop. The authors used the following framework for the demand equations in the model:

$$AC_{ij} = a_0 + a_1 PR_j + a_2 PR_i + a_3 DIV_i + a_4 T + u_{ij}$$

where AC_{ij} is the quantity of nutrient *j* per harvested acre of crop *i*, PR_j is the price of nutrient *j*, PR_i is the price of crop *i* lagged one period, DIV_i is the number of acres diverted from production of crop *i*, T is a time trend, u_{ij} is the stochastic disturbance and $a_0 - a_4$ are the estimated parameters. The time trend is used to represent technological advancements. Their estimated demand elasticities at the variable means for nitrogen, phosphate and potash per harvested acre of corn, wheat and soybeans are as follows:

Figure 3.3: Roberts and Heady (1982) Fertilizer Demand Elasticities

Dependent Variable	PR_j	PR_i	DIVi	T
Corn-N	-1.148	1.053	0.046	0.784
Corn-P	-1.131	0.592	0.037	0.887
Corn-K	-1.298	0.633	-0.013	0.845
Wheat-N	-0.232	0.312	0.001	1.213
Wheat-P	-0.737	0.432	0.010	0.726
Wheat-K	-0.236	0.417	-0.009	0.549
Soybean-N	-0.293	0.065		2.113
Soybean-P	-0.824	0.504		0.815
Soybean-K	-0.956	0.015		1.461

According to the authors, nutrient application rates per acre on corn had similar own price elasticities for each nutrient. Variances in the same elasticities for wheat were greater, but it cannot be concluded that they are different statistically. Phosphate and potash rates are similar for soybeans. Nitrogen is much lower because soybeans are legumes and need little additional nitrogen. This study found significantly higher own-price elasticities for fertilizers applied to corn than the previous studies found. The predominately positive elasticities for fertilizer rate per acre with respect to acres diverted from production supports the idea that farmers will substitute more fertilizer for fewer acres in production.

Another notable aspect of this study was the reasoning for differences in fertilizer application rate elasticities of demand. The idea presented by the authors was nitrogen, phosphate and potash have different characteristics of depletion in the soil and this causes farmers to treat each nutrient differently. Nitrogen is highly leachable and the applied nutrient is typically used up in one crop year. Phosphate is fixed in the soil and is only removed by plant use. Potassium is similarly fixed but not to the same degree as phosphate. Therefore, a percent of the extra phosphate or potassium applied can be assumed to be available for the next crop year. These properties might cause farmers to apply these nutrients differently from one year to the next, resulting in varying elasticities of demand.

The final two studies included in the demand segment offer alternative approaches to finding demand equations than the previous studies' methods. They are provided in order to compare the demand elasticities produced by varying methods.

In 1993, Denbaly and Vroomen published a study using dynamic error-correction models to analyze fertilizer nutrient use. With data from 1964 to1989, the authors used cointegration to estimate models for nitrogen, phosphate and potash use on corn.

The authors argue that "the demand response to a change in relative input prices may be dispersed over more than one period, giving rise to differences in short and long run own and cross price elasticities" (p. 204). It is also suggested that the use of a dynamic model leads to higher statistical significance of regression estimates when compared to a static model. In the short run, the own-price elasticity of demand for nitrogen, phosphate and potash were -0.21, -0.25, and -0.19, respectively. In the long run, the same elasticities were -0.41, -0.37 and -0.31, respectively.

In 1994, "A Cost Function Analysis to Estimate the Effects of Fertilizer Policy on the Supply of Wheat and Corn" by authors Roberto J. Garcia and Alan Randall was published. Marginal costs were derived from estimated cost functions by crop for U.S. and French wheat and corn, and English wheat. The U.S. data collection period spanned from 1975 to 1989. Estimation procedures included a three-input (energy, fertilizer and capital) translog cost function that was estimated simultaneously with two cost share equations using seemingly unrelated regression techniques. The partial derivative of the fertilizer demand function with respect to the fertilizer price produced the own-price Hicksian fertilizer demand elasticity. The Marshallian elasticity of demand was also calculated as the sum of the substitution effect (Hicksian elasticity) and the output effect. The authors found the Hicksian and Marshallian fertilizer own-price elasticities of demand for corn to be -0.06 and -0.95, respectively. For wheat they were -0.34 and -

0.88, respectively. In addition to the marginal cost elasticities, the marginal cost function was used to determine supply side responses including the fertilizer price elasticity of supply. The own-price elasticities for fertilizer supplied to corn and wheat were 0.75 and 0.63, respectively.

Simultaneous Supply and Demand Literature

The next three studies analyzed the fertilizer industry by estimating partial equilibrium econometric models. Domestic U.S. fertilizer supply and input demand equations were estimated by Gyawu et al. (1984) and Zelaya (1991) in order to assess the impact of changes in relevant policy instruments and other economic variables. Going a step further, Steiner (2014) used synthetic equations to develop a global fertilizer model to understand better policy implications domestically and abroad.

Gyawu, Debertin, Jones and Pagoulatos (1984) developed a model of the U.S. fertilizer industry with equations representing the supply, demand, price, imports and exports of fertilizer products. The data consisted of aggregate nutrients and specific products in order to show the relationships of various forms of fertilizer.

The supply of fertilizers was expressed as a function of the own price and the prices of inputs used in production. Thus variables were included for natural gas, labor and electricity for nitrogen, while labor and electricity were used for phosphate and potash production. These functions also used a time trend to account for investments in fixed factors.

The derived demand for fertilizer by farmers was specified as a function of crop and input prices. The U.S. corn price was used as a proxy because corn production is the largest user of fertilizer nutrients. Rather than include a time trend for technological shifts, the authors used total acreage planted of 20 principle crops, claiming this variable contains a strong trend component as well as economic meaning. The use of substitute and complementary input prices were excluded due to a high degree of correlation and the potential for bias.

Import and export quantity equations were dependent upon the fertilizer price adjusted by an exchange rate and factors that influences output levels. For nitrogen, these influencing factors included the natural gas price and the amount of land in production.

These authors developed reduced form equations from a simultaneous equation model for the three macronutrients. Impact multipliers and structural elasticities derived from the system were used as the basis for comparison and analysis. The estimated elasticities for nutrient demand and imports are given in Figure 3.4. Elasticities for production and exports were not given.

Figure 3.4 Model Elasticities, Gyawu et al 1984

Explanatory Variables	N	P	K
Dependent Variable: Applied NPK			
Own Price	-0.300	-0.087	-0.782
Acreage Planted of 20 crops	3.593	3.686	4.126
Farm Price of Corn	0.334	0.132	0.091
Dependent Variable: Import Quantities			
Net Farm Income	0.100	0.214	0.097
Acreage Planted of 20 crops	2.627	3.900	3.187
Natural Gas Price	0.428		
Phosphate Rock Price		-0.308	
Wage Rate, Chemical Industries			0.774

The inelasticity with respect to the price terms in the nutrient demand equations was consistent with previous works. However, the elasticities found with respect to acreage planted seem high. The implication of the 3.59 elasticity of applied nitrogen with respect to total area is that a 1 percent increase in total area causes a 3.59 percent increase in nitrogen use. An estimate near unit-elasticity would seem more plausible. The elasticity of imports with respect to total acreage planted was also highly elastic, implying a dramatic increase in imports with an increase in acres. The import elasticities with respect to domestic fertilizer input prices were positive, except for phosphate rock, indicating if the input prices increase, then it might be cheaper to import nutrients from low-cost producing areas. The authors noted that the coefficient for phosphate rock had the wrong sign.

In 1991, Harvey Zelaya conducted another econometric analysis of the supply and demand of U.S. fertilizers. Zelaya empirically estimated fertilizer input demand equations for corn, wheat, soybeans, cotton and other crops, as well as, domestic fertilizer supply equations for nitrogen, phosphate and potassium in the aggregate. He computed structural parameters and elasticities to create a simultaneous framework that could analyze future supply, demand, price trends and relevant policy instruments.

Supply equations were specified for each nutrient using profit maximizing theory of the firm and knowledge of the industry. Similar to Gyawu et al., the production of fertilizers was expressed as a function of output and input prices. Zelaya also included time trends to represent technological advancement and lagged production because fertilizer plants and mines cannot adjust capacities completely in the current period.

Zelaya specified demand equations similarly, using input prices, output prices and other various factors of production. In this model, an equation for application rates was developed for each of the three macronutrients on corn, soybeans and wheat acres.

Cotton and other crops were aggregated separately in their own total use categories. The production factor variables included in these equations are listed in Figure 3.7. Zelaya also includes the application rates of some nutrients as explanatory variables for other nutrients. The signs on these coefficients were positive, implying complementary relationships.

The equation parameters were estimated using ordinary least squares and two-stage least squares techniques. Elasticities were then calculated at the means of the data for all variables. Figure 3.5 and 3.6 list all elasticities for demand and supply with respect to fertilizer and crop prices. All of these elasticities had the correct signs and were inelastic.

A partial equilibrium model of the global fertilizer market was constructed in 2014 by Matthew Steiner. This model simultaneously solved for supply and demand quantities in leading fertilizer countries and regions to find a market clearing world price for nitrogen, phosphate and potash. The goal of the study was to provide a baseline of economic variables that could be compared to various scenarios. Canada, China, India, Russia and the United States were the countries of interest and a rest of world category was used to complete the global model. Synthetic values that relied heavily on previous studies were used as parameters in the demand and supply equations.

On the supply side of the model there were three behavioral equations: capacity, capacity utilization and imports. Expected net returns was the price term in the capacity equations which also utilized a lagged structure to account for the time needed to construct additional production facilities. A similar structure was used for ammonia and phosphorus. The potash equation used input and output prices separately. Producer price indices for wages and electricity reflect production costs. There was no lagged variable in the potash capacity equation.

The capacity utilization equations for ammonia and phosphorus were also similar among the 3 markets. The price driver was the expected net returns in the current period to reflect adjustments of output below capacity levels. The capacity utilization equation for potassium fertilizers contains the deflated potassium chloride port price and the same producer price indices as used in the capacity equation. These equations were in logistic form. Production for each nutrient was equal to capacity multiplied by the capacity utilization term, a value between 0 and 1.

Steiner constructed equations for application rates on corn, soybeans, wheat, cotton, rapeseed, rice and an “other crops” category to estimate the demand for crop use in each country. A fertilizer use identity, non-fertilizer use equation, domestic consumption identity, and residual balance category are used to complete the total demand for fertilizer products for each nutrient.

The same functional form is used for each crop and nutrient category in the application rate equation. An example is the form used for the nitrogen application rate for corn:

$$Corn\ N\ Fertilizer\ Use\ per\ Acre = f\left(\frac{Farm\ Price\ Corn_{US,t-1}}{GDP\ Deflator_{US,t-1}}, \frac{Farm\ Price\ N_{US}}{GDP\ Deflator_{US}}\right)$$

Higher prices of fertilizer reduce the amount of fertilizer applied while higher crop prices result in greater application rates. Crop prices are not known at the time of application; therefore, prices from the previous period were used as a proxy.

The other crop category equation used a positive trend and the nutrient price as explanatory variables. This equation represents vegetables, other grains and oilseeds, sugar beets, and other crops not explicitly defined in the model. However, rice is broken out for China and India.

The total fertilizer use identity equation is the sum of the application rates multiplied by the harvested acres for each crop plus the other crop category. This total equals the amount of each fertilizer applied to crops in the specified country. The total domestic consumption of a nutrient is found by adding the non-fertilizer use to the fertilizer use total. Non-fertilizer use specification uses the nutrient farm price and a trend as explanatory variables. This form is the same across all nutrients.

Trade for a country is represented by a net import equation. The net trade is determined by an accounting identity: the domestic production and the residual subtracted from domestic consumption. The residual term was added to account for any statistical discrepancies and is held constant through the projection period.

An equilibrator was used to solve for world clearing market prices. The U.S. port prices for each nutrient group were solved for and linked to prices in other countries at different marketing levels. The model solution depends on current and historical values of exogenous variables and model parameters. The model was projected out to 2030 in this study. The initial simulation represented the baseline case. The author identified alternative model simulation scenarios to test how different assumptions affected these markets by comparing the new simulation results to the baseline.

Three scenarios were imposed on the model by Steiner to examine their effects on the market and test the reliability and responsiveness of the model. The shocks were a sustained 10 percent increase in North American natural gas prices, a sustained 10 percent tax on U.S. ammonia farm price and a 10 percent decrease of U.S. corn acreage from 2013 to 2030. The increase to natural gas prices resulted in a long run decrease in U.S. nitrogen fertilizer production of 2.4 percent, and long run decreases in production in foreign markets of 0.1 percent. The tax on nitrogen fertilizer in the United States would decrease domestic use in 2013 by 2.2 percent. A reduction of U.S. nitrogen, phosphorus, and potassium fertilizer use by 4.1 percent, 3.0 percent, and 2.5 percent in 2013, respectively, was the result of the decrease in U.S. corn acreage.

The previously discussed studies often focused on demand, with only a minority including supply and endogenous fertilizer prices. No study has been identified that went so far as to trace out the effects of natural gas price and other input changes on fertilizer supply, fertilizer markets more broadly and agricultural commodity markets. This study will attempt to measure the impacts of these changes on crop prices, planted acres and net farm returns.

Figure 3.5: Own-Price Elasticities of Supply

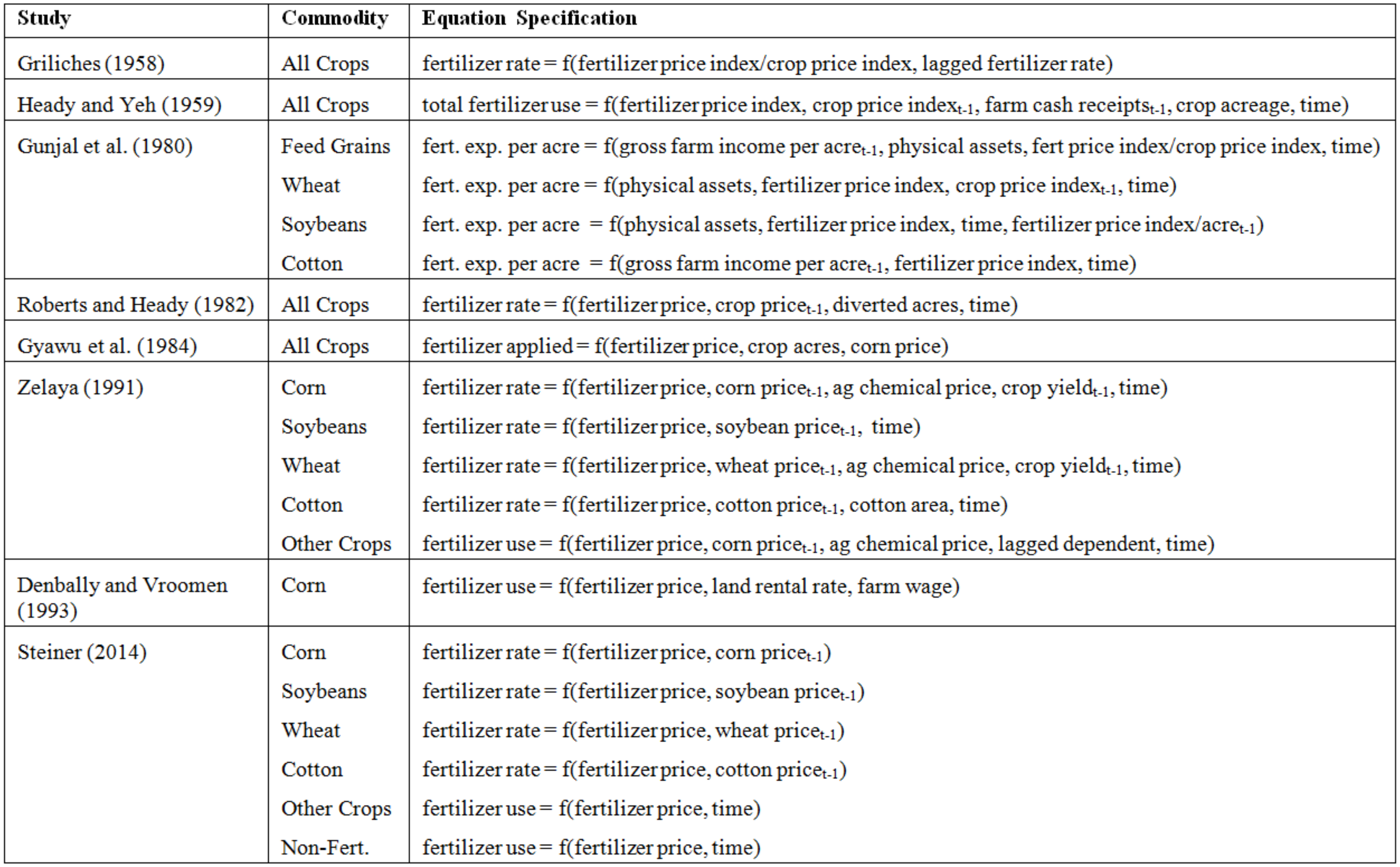
Study	**Data Period**	**Functional Form**	**Net Return Elasticities**		
			N	**P**	**K**
Zelaya (1991)	1964-1988	Production	*0.1300	*0.7000	*0.0800
Garcia and Randall (1994)	1975-1989	Supply (corn)	ALL NPK:	*0.7500	
		Supply (wheat)		*0.6265	
Steiner (2014)		Capacity	0.0020	0.0010	*0.0012
		Lag 1	0.0015	0.0010	*0.0010
		Lag 2	0.0030	0.0015	
		Lag 3	0.0150	0.0030	
		Lag 4	0.0030	0.0030	
		Lag 5	0.0025		
		Lag 6	0.0020		
		Capacity Utilization	0.4200	0.1000	*0.5000

*Own-price elasticities (as opposed to net return)

Figure 3.6: Own-Price and Output Price Elasticities for NPK Nutrient Inputs

Study	Data Period	Commodity	Own-Price Elasticities			Output Price Elasticities		
			N	P	K	N	P	K
Griliches (1958)	1911-1956	All Crops	ALL NPK:	-0.500				
Heady and Yeh (1959)	1910-1956	All Crops	-0.449	-0.448	-0.403	0.804	0.579	0.881
Gunjal et al. (1980)	1952-1976	Feed Grains	ALL NPK:	-0.900		ALL NPK:	0.900	
		Wheat		-0.990			0.420	
		Soybeans		-0.620				
		Cotton		-0.310				
Roberts and Heady (1982)	1952-1976	Corn	-1.148	-1.131	-1.298	1.053	0.592	0.633
		Soybeans	-0.293	-0.824	-0.956	0.065	0.504	0.015
		Wheat	-0.232	-0.737	-0.236	0.432	0.432	0.417
Gyawu et al. (1984)	1960-1980	All Crops	-0.300	-0.087	-0.782	0.334	0.132	0.019
Zelaya (1991)	1964-1988	Corn	-0.130	-0.105	-0.076	0.175	0.065	0.076
		Soybeans	-0.097	-0.115	-0.049	0.097	0.140	0.049
		Wheat	-0.455	-0.075	-0.103	0.062	0.068	
		Cotton	-0.078	-0.244	-0.273	0.231	0.122	0.273
		Other Crops	-0.305	-0.317	-0.320	0.305	0.317	0.320
Denbally and Vroomen (1993)	1964-1989	Corn – S.R.	-0.210	-0.250	-0.190			
		Corn – L.R.	-0.410	-0.410	-0.310			
Garcia and Randall (1994)	1975-1989	Corn	ALL NPK:	-0.954		ALL NPK:	0.511	
		Wheat		-0.876			0.330	
Steiner (2014)		Corn	-0.130	-0.100	-0.080	0.170	0.060	0.080
		Soybeans	-0.110	-0.140	-0.120	0.050	0.080	0.050
		Wheat	-0.200	-0.140	-0.140	0.150	0.050	0.080
		Cotton	-0.100	-0.120	-0.150	0.150	0.100	0.140
		Other Crops	-0.300	-0.150	-0.200			
		Non-Fert.	-0.400	-0.200	-0.200			

Figure 3.7: Demand Equation Specifications



Study	Commodity	Equation Specification
Griliches (1958)	All Crops	fertilizer rate = f(fertilizer price index/crop price index, lagged fertilizer rate)
Heady and Yeh (1959)	All Crops	total fertilizer use = f(fertilizer price index, crop price index$_{t-1}$, farm cash receipts$_{t-1}$, crop acreage, time)
Gunjal et al. (1980)	Feed Grains	fert. exp. per acre = f(gross farm income per acre$_{t-1}$, physical assets, fert price index/crop price index, time)
	Wheat	fert. exp. per acre = f(physical assets, fertilizer price index, crop price index$_{t-1}$, time)
	Soybeans	fert. exp. per acre = f(physical assets, fertilizer price index, time, fertilizer price index/acre$_{t-1}$)
	Cotton	fert. exp. per acre = f(gross farm income per acre$_{t-1}$, fertilizer price index, time)
Roberts and Heady (1982)	All Crops	fertilizer rate = f(fertilizer price, crop price$_{t-1}$, diverted acres, time)
Gyawu et al. (1984)	All Crops	fertilizer applied = f(fertilizer price, crop acres, corn price)
Zelaya (1991)	Corn	fertilizer rate = f(fertilizer price, corn price$_{t-1}$, ag chemical price, crop yield$_{t-1}$, time)
	Soybeans	fertilizer rate = f(fertilizer price, soybean price$_{t-1}$, time)
	Wheat	fertilizer rate = f(fertilizer price, wheat price$_{t-1}$, ag chemical price, crop yield$_{t-1}$, time)
	Cotton	fertilizer rate = f(fertilizer price, cotton price$_{t-1}$, cotton area, time)
	Other Crops	fertilizer use = f(fertilizer price, corn price$_{t-1}$, ag chemical price, lagged dependent, time)
Denbally and Vroomen (1993)	Corn	fertilizer use = f(fertilizer price, land rental rate, farm wage)
Steiner (2014)	Corn	fertilizer rate = f(fertilizer price, corn price$_{t-1}$)
	Soybeans	fertilizer rate = f(fertilizer price, soybean price$_{t-1}$)
	Wheat	fertilizer rate = f(fertilizer price, wheat price$_{t-1}$)
	Cotton	fertilizer rate = f(fertilizer price, cotton price$_{t-1}$)
	Other Crops	fertilizer use = f(fertilizer price, time)
	Non-Fert.	fertilizer use = f(fertilizer price, time)

IV: THEORETICAL ASPECTS OF SUPPLY AND DEMAND

The basic theory and methods involved in the derivation and construction of an econometric model will be discussed in this chapter. The specification of this model of the fertilizer industry is based on empirical estimation, prior research and knowledge of the industry. Relevant variables and economic relationships influencing the fertilizer industry are made apparent within the model structure.

Derived Demand

According to the profit maximization assumptions in a perfectly competitive market, the firm's supply curve is derived from the profit function. The demand for an input used in production depends on the demand for the final product. The production of crops in the United States involves the combination of plant nutrients (nitrogen, phosphates and potash) with other production inputs to produce crops. Nutrient derived demand functions can be estimated assuming a perfectly competitive market, in which farmers are considered price takers in both input and output markets. In this study, it is also assumed that market participants behave rationally according to profit maximization assumptions (Roberts and Heady 1982, Steiner 2014, Zelaya 1991).

In general, the demand for an input depends on:

1. the price of the output to be produced,
2. the price of the input,
3. the price of substitute or complement inputs,
4. the parameters that describe the technical transformation of inputs into output and
5. the quantities of fixed factors.

Given these conditions, the farmer's profit function (π) is expressed as revenues minus costs, where revenues are stated in terms of the product price and the underlying production function. The costs are the sum of input quantities times their respective prices.

$$\pi\ (x_i) = p_y\ \times f(x_1, x_2, \dots\ , x_n) - \textstyle\sum_{i=1}^{n} p_i\, x_i \quad (4.1)$$

where

P_y is the output price,

P_i is the price of the i^th factor,

f represents the production function and

x_i is the quantity of the i^th factor.

The partial derivatives of the profit function, with respect to the input quantities, are then set equal to zero in accordance with the first-order conditions for profit maximization:

$$\frac{\delta\pi}{\delta x_1} = \ p_y f_1 - p_1 = 0 \quad (4.2)$$

.

.

.

$$\frac{\delta\pi}{\delta x_n} = \ p_y f_n - p_n = 0 \quad (4.3)$$

Equations 4.2 and 4.3 express the marginal physical product of the i^th input. 4.2 can be expressed as

$$p_y f_i = \ p_i \quad (4.4)$$

which is another way to express the first-order conditions. This also indicates that additional units of input will be utilized until the marginal cost of using that input equals the marginal increase in the firm's total revenue. Equation 4.4 can also be expressed as

$$f_i = \frac{p_i}{p_y} \quad (4.5)$$

which indicates that the marginal physical product of the ith input equals the input-output price ratio.

These equations are solved simultaneously to obtain the derived demand functions:

$$x_1 = f(p_y, p_1, p_2, \dots, p_n) \quad (4.6)$$

.

.

.

$$x_n = f(p_y, p_1, p_2, \dots, p_n) \quad (4.7)$$

Equations 4.6 and 4.7 represent the derived demand for the ith input expressed as a function of the output price (p_y) and the input prices (p_1, p_2,…, p_n). It is assumed that the second-order conditions are satisfied.

Using the structure outlined here, the derived demand for a particular nutrient is a positive function of the product price and a negative function of its own price. Theory would suggest the inclusion of prices for complement and substitute inputs. However, due to small cross-price effects and the risk of multicollinearity indicated by other studies (Roberts and Heady 1982, Steiner 2014), other input prices were not explicitly included in this study.

Supply

The same profit maximization assumptions are used to derive a firm's supply curve. This approach will assume perfect competition even though some observers argue that there might be non-competitive behavior in this industry. The profit function is expressed in terms of the output level y, or

$$\pi = TR(y) - TC(y) \quad (4.8)$$

TR(y) is total revenue and TC(y) represents the total cost to the firm at the y level of output. As before, the profit function is differentiated and set equal to zero in accordance with first-order conditions at optimal output, y*:

$$\frac{d\pi}{dy} = MR(y*) - MC(y*) = 0 \quad (4.9)$$

This equation can be rewritten as:

$$MR(y*) = MC(y*) \quad (4.10)$$

These equations imply that a profit maximizing firm will choose a level of output where marginal revenue is equal to the marginal costs. In a perfectly competitive market, firms are assumed to be price takers, therefore:

$$TR(y) = Py \quad (4.11)$$

where P is the output price and y is the level of output. Differentiating with respect to y yields

$$MR(y*) = P \quad (4.12)$$

Substituting equation 4.12 in 4.10 results in:

$$P = MC(y*) \quad (4.13)$$

Thus, a profit maximizing firm will produce an output level at which price is equal to the marginal cost associated with producing that particular level. As a result, a firm's marginal cost curve will be its supply curve because a firm will always produce at a level where the marginal cost equals the price of the output. The firm's supply curve is therefore limited to the portion of the marginal cost curve for output greater than or equal to the average variable cost. A firm will choose to stop production at levels below the average variable costs curve, in the short run. The optimal quantity supplied is dependent upon the output and input prices. In other words,

$$y* = f(p, w_1, w_2, \dots, w_n) \quad (4.14)$$

where y* is the optimum quantity supplied, p is the output price and w is the price of inputs. It is assumed that the second-order conditions are satisfied.

V: EQUATION SPECIFICATIONS

Demand Equations

In addition to the theory presented, prior research and the knowledge of the industry have provided a framework for specifying input demand equations for fertilizer. Though prices might be significant in determining nutrient application rates, there are other influences on farmers' decisions.

Technological advancement in the agricultural sector including hybridization, genetic modification, increased irrigation, adoption of GPS precision technology and fertilizer product diversification have all caused shifts in the agricultural production function over time (Roberts and Heady 1982). Multiple studies have used a time trend to represent the influence of technological shifts over time. Heady and Yeh (1959) warn against using a time trend as a "catch all" but argue that its use is warranted in this situation.

In addition, agricultural practices have evolved over time and must be considered in model specification. It could be suggested that farmers are no longer in the adoption phase with fertilizer, so the need for lags and trends has lessened. Therefore, this study avoids the use of a time trend and instead uses the crop yield lagged one period to attempt to represent the influence of technological advancements in agricultural production. It is assumed that a majority of technological advancements will be captured by the resulting increase in crop production yields. Additionally, "the nutrient requirements of a current corn crop are also based, in part, on the plant-available nutrients existing in the soil, and past cropping practice can influence these nutrients" (Riboudo et al. 2011, p. 75).

Therefore, it is assumed that farmers will try to replenish the nutrients used by the crop production of the previous year. Additional nutrients would be utilized by a crop with a higher yield. The more nutrients the previous crop used, the higher the need to replenish nutrients the following year. These effects are assumed to be constant over time and are captured by including the one-period lag of the yield variable.

Crop area is another common variable used in fertilizer demand equations. Heady and Yeh (1959) observed a possible substitution effect between cropland area and fertilizer use, noting that many have hypothesized that farmers will make up for diverted acres by applying more fertilizer. Roberts and Heady (1982) postulated that government acreage control programs cause farmers to apply some of the resources they might have used on diverted acres on their remaining land. This study includes harvested acres for each respective crop as an explanatory variable for fertilizer application rates.

Finally, since crop prices are unknown at the time fertilizer nutrients are applied, application decisions must be based on an expected price. A majority of previous studies such as Roberts and Heady (1982), Zelaya (1991), and Steiner (2014) use crop prices lagged one period as a proxy for farmers' expectations. This study uses expected crop prices from the FAPRI-MU model to represent the expected crop price used for fertilizer application decisions.

Using these concepts, nutrient demand equations were specified for nitrogen, phosphate, and potash for corn, soybeans, wheat and cotton. Each equation for each crop and nutrient uses a similar functional form. The equation for the rate of nitrogen applied to corn will be used as an example:

$$NCRRATE = f(\frac{NPRFRM}{ECRUS}, CRSHAR, CRSYLD_{t-1})$$

where NCRRATE is the rate of nitrogen in pounds applied to an acre of corn, NPRFRM is the farm price of anhydrous ammonia, ECRUS is the expected corn price in dollars per bushel, CRSHAR is corn area harvested in acres and $CRSYLD_{t-1}$ is the corn yield in bushels per acre lagged one period. An equation was also specified for the percent of acres fertilized for each crop and nutrient. The equation for the percent of corn acres fertilized with nitrogen will be used as an example:

$$NCRPCT = f(\frac{NPRFRM}{ECRUS}, CRSHAR, TREND)$$

where NCRPCT is the percent of corn acres fertilized with nitrogen and TREND represents a time trend.

An “other’ crops category was similarly specified for crops such as barley, oats, peanuts, rice, sorghum, sugarcane, sugar beets, sunflowers and hay. The amount of nitrogen use on other acres is specified as

$$NOCUSE = f(\frac{NPRFRM}{SUMPRW_{t-1}})$$

where NOCUSE is the amount of nitrogen use on other acres and $SUMPRW_{t-1}$ is the lagged sum of the relevant crop prices, all on or converted to a per bushel basis, weighted by the percent of the respective crop’s share of total harvested area for the “other” crops. The specification of this equation is the same for each nutrient. Crops included in the data category for “other” crops were not specifically listed by the ERS. The included crops were chosen because they are explicitly included in the FAPRI-MU models. This method omits some crops that are included in the data category from the ERS.

Equations were also estimated for the industrial use of each nutrient. Difficulty arose in fitting equations to this data series likely because it was calculated as a balance between supply and demand by FAOSTAT (2014). This method of calculation would cause a majority of any error in data reporting to accumulate in this category. As a result, only the fertilizer price term is included in each equation:

$$NINDUSE = f\left(\frac{NPRFRM}{PDCGNP}\right)$$

where NINDUSE is the amount of nitrogen nutrients dedicated to industrial use and PDCGNP is a gross domestic product deflator. Both phosphate and potash had the same structure for their non-agricultural use equations.

Supply Equations

Supply equations for nitrogen, phosphates and potash were created relying heavily on the theoretical reasoning discussed in the previous chapter and knowledge of the fertilizer industry. The specified nitrogen production equation was

$$NPROD = f(\frac{NPRFRM}{PPIGASW}, NPROD_{t-1})$$

where NPROD is the amount of nitrogen produced in the U.S., NPRFRM is the farm price of nitrogen fertilizer, PPIGASW is the producer price index of gas fuels and $NPROD_{t-1}$ is the quantity of nitrogen produced in the previous period. PPIGASW is used as a proxy for the U.S. natural gas price, the main feedstock for nitrogen fertilizers. Because it takes 3 years on average to build ammonia production facilities (PotashCorp 2014), production cannot completely adjust for relative price changes in the current period. Therefore, the lagged production is included in the equation to represent investment behavior in plant construction and retirement.

Similarly, phosphate production was represented by

$$PPROD = f(\frac{PPRFRM}{PPIMINW}, PPROD_{t-1})$$

where PPROD is the amount of domestic phosphate fertilizer produced, PPRFRM is the farm price of phosphate fertilizer, PPIMINW is a producer price index for nonmetallic minerals and $PPROD_{t-1}$ is phosphate production from the previous period. PPIMINW is used as a proxy for the U.S. sulfur price because sulfuric acid is a major feedstock in phosphate production. Again, the lagged production is included to represent long term capacity adjustment.

Potash production was specified as

$$KPROD = f(\frac{KPRFRM}{PPIELPW}, KPROD_{t-1})$$

where KPROD is the domestic production of potash, KPRFRM is the farm price of potash fertilizer, PPIELPW is an index for the cost of electric power and $KPROD_{t-1}$ is the production of potash lagged one period. PPIELPW is included because it is a major cost of production of potash according to Steiner (2014). The lagged dependent variable is also included in this production equation to capture the effects of investment behavior in mine construction and retirement.

Because other input prices are not included in the specified production equations, there are omitted variables. This omission can bias parameters as, for example, own-price effects can be too small or input price effects can be too large during estimation.

Next, trade equations for nitrogen, phosphates and potash were also specified relying heavily on the literature, knowledge of the industry and economic theory. Net trade equations were estimated for each of the nutrients. Because the U.S. is a net importer of nitrogenous fertilizers, a net imports equation for nitrogen was specified as

$$NNIMP = f(NPRFRM \times AGEXCHR, NNIMP_{t-1})$$

where NNIMP is the net imports of nitrogen nutrient tons, NPRFRM is the farm price of nitrogen fertilizers, AGEXCHR is the U.S. agriculture weighted exchange rate in real terms and $NNIMP_{t-1}$ is the net nitrogen imports in the previous period. An exchange rate is used to adjust the U.S. fertilizer farm price to an estimate of a foreign fertilizer prices in all the trade equations. The lagged dependent variable is included to represent capacity adjustment of foreign production. Alternatively, the U.S. is a net exporter of phosphate fertilizers. Therefore, the phosphate trade equation was

$$PNEXP = f(PPRFRM \times AGEXCHR)$$

where PNEXP is the net exports of phosphate fertilizers and PPRFRM is adjusted by AGEXCHR. Just as with nitrogen, the U.S. is a net importer of potash. The potash trade equation is specified as

$$KNIMP = f(KPRFRM \times AGEXCHR)$$

where KNIMP is the net imports of potash fertilizers and KPRFRM is adjusted by AGEXCHR.

In order to create a simultaneous framework, five equations for each nutrient were created to link input demand and supply equations. On the demand side, an equation to calculate the total nutrient use on each crop was specified:

$$NCRUSE = NCRRATE \times NCRPCT \times CRSPLT$$

where NCRUSE is the total use of nitrogen fertilizers on corn in nutrient tons, NCRRATE is the rate of nutrient pounds per acre applied to corn, NCRPCT is the percent of corn acres fertilized with nitrogen and CRSPLT is the total acres of corn planted. This identity is the same across nutrients and crops. Next, a sum of the total nutrient used for agricultural purposes was calculated using the equation:

$$NAGUSE = NCRUSE + NSBUSE + NWTUSE + NCTUSE + NOCUSE$$

where NAGUSE is the total domestic use of nitrogen applied as fertilizer. NCRUSE, NSBUSE, NWTUSE and NCTUSE are the total amount of nitrogen applied to corn, soybean, wheat and cotton acres, respectively. NOCUSE is the total amount of nitrogen applied to the “other” crops category. This equation was also identical across nutrients and crops. To close the system of equations, the identities for nutrients were

$$NPROD + NNIMP = NAGUSE + NINDUSE$$

$$PPROD = NPEXP + PAGUSE + PINDUSE$$

$$KPROD + NKIMP = KAGUSE + KINDUSE$$

for nitrogen, phosphate and potash, respectively.

Each nutrient sector has 10 domestic demand equations, 1 domestic supply equation, 1 trade equation and 6 identities including the market-clearing equation. In all, the system has 30 demand equations, 3 supply equations, 3 trade equations, and 18 identities.

VI: EMPIRICAL RESULTS

Equations were estimated for production, demand and trade of each nutrient. Demand equations included the rate of fertilizer applied to each crop, the percent of acres fertilized and industrial use. Production and net trade equations were also estimated for nitrogen, phosphates and potassium. The estimation procedures relied on prior research, economic theory and knowledge of the industry.

Data Discussion

Two sources were used in the absence of an all-inclusive source for supply and demand fertilizer data. The statistics division of the Food and Agricultural Organization of the United Nations (FAOSTAT) provided supply and use quantities. Crop specific agricultural use data and nutrient prices were available from the Economic Research Service (ERS) of the United States Department of Agriculture (USDA). Other agricultural and macro variables were gathered from the Food and Agricultural Policy Research Institute at the University of Missouri (FAPRI-MU).

Annual production, import, export and non-fertilizer use quantities for the U.S. were drawn from the FAOSTAT database. This is the same source used in the recent study by Steiner (2014). The data were available for the period 2002-2012. According to FAOSTAT, the data are gathered from questionnaires, national sources or from the United Nations Commodity Trade Statistics Database (COMTRADE) reporters. The non-fertilizer data category is obtained as a balance. The data are given in metric nutrient tons for nitrogen, phosphate and potash totals and converted short nutrient tons for this study. Import and export quantities were differenced to obtain net imports for nitrogen and potash and net exports for phosphate in this study.

Crop specific fertilizer application and price data were gathered from the ERS. Percentage of acreage treated and rates of application for nitrogen, phosphate and potash are available. The U.S. averages for these data series were available for corn, soybeans, wheat and cotton. The percentage of acreage treated is given as the percentage of a specific crop acreage receiving a particular nutrient and the rate of application is given as fertilizer nutrient used on each crop in pounds per fertilized acre. This information was collected directly from growers by National Agricultural Statistics Service (NASS) surveys. These data are available for the period 1964-2012; however, certain years are missing for each crop. After 2003, surveys were conducted on a rotating schedule resulting in gaps in the data. These missing data are interpolated by the ERS but only data during survey years were used for estimation in this study.

The total U.S. consumption of each plant nutrient is also given by the ERS and is broken out into total use on corn, soybeans, wheat, cotton and other for 1960-2010. These data, except for the “other” category, are also determined by survey. The “other” category includes all other fertilizer nutrients used for agricultural purposes. According to the ERS, estimates for other crop use are determined by subtracting the plant use of the four selected crops from total domestic use of each plant nutrient.

Fertilizer price data are also available from the ERS. The national average farm prices in the month of April or March for the main forms of fertilizer are provided for the period 1960 to 2013. For this study, the anhydrous ammonia, super-phosphate and potassium chloride price were used as a proxy for each prospective nutrient price. These forms of fertilizer contain the highest nutrient content per pound of fertilizer product. NASS surveys were also the source for these data.

Macroeconomic and crop specific variables were collected from the FAPRI-MU database. Expected prices, farm prices, planted acreages, harvested acreages and yields of U.S. agricultural crops were used in the model and for estimation. The expected crop price is calculated using futures price data and adjustments based on known information at the time planting decisions occur. Farm price, acres and yields are annual data collected from NASS for the historical period and projected to the year 2030. The projections for agricultural markets were prepared using market information available in January of 2015. The macroeconomic variables included a GDP deflator and producer price indices for all commodities, gas fuels, non-metallic minerals, electric power, and employment cost. The projections of these variables are based on January 2015 forecasts by IHS Global Insight.

In order to represent technological change, two time trends were utilized. The first is a simple linear trend, the second a logarithmic trend. When included as a single variable, all prices were deflated by the producer price index for all commodities to convert them to real terms. All fertilizer quantity data were converted to nutrient short tons.

Estimation Results

Model equations for each nutrient were empirically estimated for production, application rates, percent acres fertilized, other crop use, industrial use and trade. These

36 equations were estimated using the ordinary least squares technique. All equations, except percent acres fertilized, were assumed to be linear in functional form. In order to force projected values between 0-100 percent for the percentage of acres fertilized, a logit functional form was assumed. Coefficients were included based on previously mentioned theory and specifications. In this study, more weight was put on economic reasoning and knowledge of the industry rather than statistical fit. Results from the estimation are presented in Figures 6.1 - 6.6.

A majority of the results for application rates and percent acres fertilized were in line with economic reason and previous studies. Sixty of the 89 explanatory variables were significant at the 10 percent level and adjusted R^2 values range from 0.12 to 0.93.

All input-output price ratio coefficients for the demand equations have the correct signs except for NWTRATE and KCTPCT. The coefficient for KCTPCT was not significant at the 10 percent level suggesting the possibility that the effects of the price ratio are statistically no different than zero. The P-value for the price ratio coefficient in the NWTRATE equation was 0.04, indicating reasonable significance. Nonetheless, these results contradict the assumptions of profit maximization.

Most of the coefficients for harvested crop acres are positive, which contradicts the land-fertilizer substitution effect suggested by Heady and Yeh (1959) and Roberts and Heady (1982). This observation could be explained by the expansion of farmers into marginal areas of crop production. If these marginal areas are less suitable for production and require additional fertilizer, then an expansion of total crop acres could lead to an increase in application rates or percent of acres fertilized in the aggregate.

A majority of the application rate equations agree with the assumption of a positive relationship between the rate of application and the crop yield from the previous period. The exceptions are PCTRATE and KCTRATE. Nine of the 12 coefficients for yield are significant at the 10 percent level. This estimated impact of yield would do little to disprove the notion that a lagged yield variable captures the effects of technological advancement and perceived nutrient needs.

Interestingly, results from 7 of the 12 percent fertilized equations indicated a negative relationship between the percent of acres fertilized and a time trend. This relationship could be explained by the adoption of yield monitoring, global positioning system (GPS) mapping and variable-rate technology (VRT) use in agricultural production. Yield monitoring could help farmers identify areas of fields that require less fertilizer. Then, using GPS mapping and VRT, the farmer could opt to not apply fertilizer to certain areas (Schimmelpfennig and Ebel 2011). These effects could lead to the negative relationship observed in this study between the percent of acres fertilized and a time trend.

For the coefficients with the correct signs, all application rate elasticities with respect to the price ratio are similar to results from recent studies and within economic reason. All of the input-output price ratio elasticities are inelastic as opposed to the more responsive values found by earlier studies during rapid agricultural expansion. This could indicate that U.S. crop producers are now closer to the yield-maximizing point on the production function and, as a result, are less responsive to input and output prices than in the past.

The elasticities for application rates per acre with respect to crop areas, ranging from -0.03 to 0.71, were all inelastic unlike Heady and Yeh (1959) but similar to Gunjal et al. (1980) and Zelaya (1991). The effect of area on the average application rate is likely to be small, these estimates notwithstanding, because a marginal change in total area is unlikely to affect the average application rate. The elasticities with respect to lagged crop yield ranged between -0.29 and 1.23. Zelaya (1991) found demand elasticities for application rates per acre on corn and wheat with respect to lagged yields to be 0.69 and 2.66, respectively.

The coefficients for the "other" crop categories also had the correct signs. The own-price elasticities ranged from -0.18 to -0.27 which is within Steiner (2014) and Zelaya's (1991) combined range of -0.15 to -0.32. While all of these coefficients were significant at the 10 percent level, the low adjusted R^2 values indicate that only a small portion of the dependent variable variance is explained by the included explanatory variables. This occurrence is most likely because these are residual categories which could lead to an accumulation of error.

The industrial use data series were also residual categories and, thus, also had low adjusted R^2 values for the regression results. Industrial use for all 3 nutrients was inelastic with elasticities ranging from -0.34 to -0.45. Steiner (2014) was the only other reviewed study to give elasticities for industrial use and these ranged from -0.20 to -0.40. Only the coefficient in the phosphate equation was considered statistically significant in this study.

A production equation was also estimated for each nutrient as specified in the previous chapter. Only the coefficient for lagged production was found to be statistically significant in the nitrogen equation. The elasticities with respect to own-price, natural gas price and lagged production were 0.06, -0.06 and 0.91, respectively. In the phosphate equation, the elasticities with respect to own-price, the mineral price index and lagged production were 0.05, -0.05 and 0.69, respectively. These coefficients were also statistically significant at the 10 percent level. Only the coefficient for lagged production was significant in the potash production equation. The elasticities for potash price, the electric power price index and lagged production were 0.11, -0.11 and 0.72, respectively. Long run production elasticities with respect to own-price were calculated to be 0.67, 0.16 and 0.39 for nitrogen, phosphate and potash, respectively.

Coefficients were also estimated for the 3 specified trade equations. These coefficients were all inelastic and had P-values of 0.00. The adjusted R^2 values ranged from 0.45 to 0.91. The exchange rate adjusted own-price elasticities for net nitrogen imports, phosphate exports and imports of potash were 0.71, -0.62 and 0.22, respectively.

Figure 6.1: Nitrogen Demand, OLS Estimates

Variable	Coefficient	P-value	Elasticity
Dependent Variable: NCRRATE		**Adjusted $R^2 = 0.65$**	
Intercept	37.19	0.03	
NPRFRM/ECRUS	-0.22	0.00	-0.19
CRSHAR	0.81	0.01	0.44
CRSYLD$_{t-1}$	0.51	0.00	0.44
Dependent Variable: NSBRATE		**Adjusted $R^2 = 0.47$**	
Intercept	-0.43	0.89	
NPRFRM/ESYUS	-0.06	0.23	-0.13
SBSHAR	0.07	0.27	0.23
SBSYLD$_{t-1}$	0.54	0.00	0.92
Dependent Variable: NWTRATE		**Adjusted $R^2 = 0.76$**	
Intercept	-45.84	0.00	
NPRFRM/EWTUS	0.12	0.04	0.16
WHSHAR	0.41	0.00	0.42
WHSYLD$_{t-1}$	1.96	0.00	1.23
Dependent Variable: NCTRATE		**Adjusted $R^2 = 0.17$**	
Intercept	56.08	0.00	
NPRFRM/ECTUS	-0.003	0.75	-0.02
CTSHAR	0.41	0.54	0.06
CTSYLD$_{t-1}$	0.04	0.01	0.28
Dependent Variable: NCRPCT		**Adjusted $R^2 = 0.77$**	
Intercept	-1.96	0.00	
NPRFRM/ECRUS	-0.01	0.00	
CRSHAR	0.01	0.49	
TREND	1.52	0.00	
Dependent Variable: NSBPCT		**Adjusted $R^2 = 0.33$**	
Intercept	-0.20	0.74	
NPRFRM/ESYUS	-0.004	0.22	
SBSHAR	0.03	0.00	
TREND	-0.75	0.01	
Dependent Variable: NWTPCT		**Adjusted $R^2 = 0.93$**	
Intercept	-6.12	0.00	
NPRFRM/EWTUS	-0.004	0.15	
WHSHAR	-0.004	0.26	
TREND	2.08	0.00	
Dependent Variable: NCTPCT		**Adjusted $R^2 = 0.43$**	
Intercept	-1.44	0.01	
NPRFRM/ECTUS	-0.0002	0.66	
CTSHAR	0.07	0.01	
TREND	0.55	0.00	

Figure 6.2: Phosphate Demand, OLS Estimates

Variable	Coefficient	P-value	Elasticity
Dependent Variable: PCRRATE			**Adjusted R^2 = 0.12**
Intercept	64.54	0.00	
PPRFRM/ECRUS	-0.16	0.02	-0.24
CRSHAR	0.07	0.61	0.08
CRSYLD$_{t-1}$	0.05	0.35	0.09
Dependent Variable: PSBRATE			**Adjusted R^2 = 0.61**
Intercept	18.86	0.00	
PPRFRM/ESYUS	-0.18	0.14	-0.14
SBSHAR	0.34	0.00	0.44
SBSYLD$_{t-1}$	0.39	0.06	0.28
Dependent Variable: PWTRATE			**Adjusted R^2 = 0.22**
Intercept	23.98	0.00	
PPRFRM/EWTUS	-0.05	0.30	-0.10
WHSHAR	0.12	0.05	0.21
WHSYLD$_{t-1}$	0.21	0.04	0.21
Dependent Variable: PCTRATE			**Adjusted R^2 = 0.43**
Intercept	68.99	0.00	
PPRFRM/ECTUS	-0.01	0.17	-0.07
CTSHAR	-0.24	0.48	-0.06
CTSYLD$_{t-1}$	-0.03	0.00	-0.29
Dependent Variable: PCRPCT			**Adjusted R^2 = 0.43**
Intercept	2.97	0.00	
PPRFRM/ECRUS	-0.01	0.00	
CRSHAR	0.00	0.74	
TREND	-0.19	0.30	
Dependent Variable: PSBPCT			**Adjusted R^2 = 0.46**
Intercept	0.18	0.74	
PPRFRM/ESYUS	-0.01	0.09	
SBSHAR	0.03	0.00	
TREND	-0.71	0.01	
Dependent Variable: PWTPCT			**Adjusted R^2 = 0.85**
Intercept	-3.18	0.00	
PPRFRM/EWTUS	-0.002	0.49	
WHSHAR	-0.01	0.05	
TREND	1.03	0.00	
Dependent Variable: PCTPCT			**Adjusted R^2 = 0.04**
Intercept	-0.46	0.35	
PPRFRM/ECTUS	-0.00002	0.97	
CTSHAR	0.04	0.09	
TREND	0.02	0.91	

Figure 6.3: Potash Demand, OLS Estimates

Variable	Coefficient	P-value	Elasticity
Dependent Variable: KCRRATE		**Adjusted R^2 = 0.57**	
Intercept	26.12	0.02	
KPRFRM/ECRUS	-0.26	0.01	-0.21
CRSHAR	0.44	0.02	0.38
CRSYLD$_{t-1}$	0.35	0.00	0.49
Dependent Variable: KSBRATE		**Adjusted R^2 = 0.72**	
Intercept	-13.10	0.13	
KPRFRM/ESYUS	-0.31	0.28	-0.11
SBSHAR	0.83	0.00	0.71
SBSYLD$_{t-1}$	1.28	0.01	0.59
Dependent Variable: KWTRATE		**Adjusted R^2 = 0.21**	
Intercept	35.99	0.00	
KPRFRM/EWTUS	-0.21	0.03	-0.26
WHSHAR	0.08	0.54	0.11
WHSYLD$_{t-1}$	0.24	0.26	0.21
Dependent Variable: KCTRATE		**Adjusted R^2 = 0.74**	
Intercept	66.12	0.00	
KPRFRM/ECTUS	-0.01	0.24	-0.06
CTSHAR	-0.14	0.77	-0.03
CTSYLD$_{t-1}$	-0.02	0.16	-0.16
Dependent Variable: KCRPCT		**Adjusted R^2 = 0.65**	
Intercept	3.70	0.00	
KPRFRM/ECRUS	-0.01	0.00	
CRSHAR	0.00	0.67	
TREND	-0.59	0.00	
Dependent Variable: KSBPCT		**Adjusted R^2 = 0.45**	
Intercept	-0.62	0.24	
KPRFRM/ESYUS	-0.01	0.02	
SBSHAR	0.02	0.00	
TREND	-0.34	0.17	
Dependent Variable: KWTPCT		**Adjusted R^2 = 0.21**	
Intercept	-2.20	0.00	
KPRFRM/EWTUS	-0.002	0.25	
WHSHAR	0.003	0.26	
TREND	0.16	0.03	
Dependent Variable: KCTPCT		**Adjusted R^2 = 0.66**	
Intercept	0.90	0.07	
KPRFRM/ECTUS	0.0004	0.34	
CTSHAR	0.01	0.47	
TREND	-0.49	0.00	

Figure 6.4: Nitrogen Equations, OLS Estimates

Variable	Coefficient	P-value	Elasticity
Dependent Variable: NPROD		**Adjusted R^2 = 0.83**	
Intercept	392	0.69	
NPRFRM/PPIGASW	247	0.31	0.06
NPROD1	0.90	0.00	0.91
Dependent Variable: NNIMP		**Adjusted R^2 = 0.91**	
Intercept	-1711	0.00	
NPRFRM*AGEXCHR	10.13	0.00	0.71
NIMP$_{t-1}$	0.45	0.00	0.43
Dependent Variable: NOCUSE		**Adjusted R^2 = 0.05**	
Intercept	4804	0.00	
NPRFRM/SUMPRW$_{t-1}$	-3.73	0.08	-0.22
Dependent Variable: NINDUSE		**Adjusted R^2 = 0.02**	
Intercept	4341	0.00	
NPRFRM/PDCGNP	-4.43	0.15	-0.34

Figure 6.5: Phosphate Equations, OLS Estimates

Variable	Coefficient	P-value	Elasticity
Dependent Variable: PPROD		**Adjusted R^2 = 0.55**	
Intercept	2692	0.09	
NPRFRM/PPIMINW	137	0.09	0.05
PPROD$_{t-1}$	0.69	0.00	0.69
Dependent Variable: PNEXP		**Adjusted R^2 = 0.75**	
Intercept	7309	0.00	
PPRFRM*AGEXCHR	-7.52	0.00	-0.62
Dependent Variable: POCUSE		**Adjusted R^2 = 0.17**	
Intercept	1708	0.00	
PPRFRM/SUMPRW$_{t-1}$	-0.06	0.01	-0.27
Dependent Variable: PINDUSE		**Adjusted R^2 = 0.23**	
Intercept	2022	0.00	
PPRFRM/PDCGNP	-6.81	0.00	-0.39

Figure 6.6: Potash Equations, OLS Estimates

Variable	Coefficient	P-value	Elasticity
Dependent Variable: KPROD		**Adjusted R^2 = 0.70**	
Intercept	195	0.46	
KPRFRM/PPIELPW	98	0.67	0.11
$KPROD_{t-1}$	0.69	0.00	0.72
Dependent Variable: KNIMP		**Adjusted R^2 = 0.45**	
Intercept	3852	0.00	
KPRFRM*AGEXCHR	4.70	0.00	0.22
Dependent Variable: KOCUSE		**Adjusted R^2 = 0.29**	
Intercept	2080	0.00	
$KPRFRM/SUMPRW_{t-1}$	-0.08	0.00	-0.18
Dependent Variable: KINDUSE		**Adjusted R^2 = 0.00**	
Intercept	909	0.04	
KPRFRM/PDCGNP	-3.39	0.32	-0.45

VII: BASELINE RESULTS

The baseline projection is a 15-year outlook for the 3 fertilizer nutrients given an assumed market context. The results will be the point of comparison for the scenarios discussed the next chapter. The baseline was estimated using the previously specified partial equilibrium model structure and estimated equations for the 3 fertilizer markets. The majority of the elasticities used in the fertilizer model came from the estimation in this study. In order for profit maximization assumptions to hold for the baseline values, estimated equations that included coefficients with incorrect signs were replaced with synthetic equations. In these equations, the incorrect coefficients were adjusted to match elasticities from previous studies or assumed to be 0.

The fertilizer model developed in this study was then linked to the FAPRI-MU agricultural commodities model system. FAPRI-MU uses this system to provide detailed projections and policy analysis for major agricultural markets including grains, oilseeds, livestock, dairy and biofuel commodities. Linking the fertilizer model to the FAPRI-MU system allows changes in fertilizer production input prices to affect agricultural producer profit margins, production decisions and, thus, commodity prices.

The fertilizer model is linked to the FAPRI-MU system in two distinct ways: variables that flow into the fertilizer model from the FAPRI-MU system, and variables that flow out of the fertilizer model and into the FAPRI-MU system. The variables the flow into the fertilizer model include the expected price, planted area, harvested area and yield of corn, soybeans, wheat and cotton. Prices of barley, oats, peanuts, rice, sunflowers, sorghum, hay, sugar beets and sugar cane also flow into the fertilizer model.

The fertilizer prices are that are generated from the fertilizer model flow back into the FAPRI-MU system. The fertilizer model and the FAPRI-MU system are then set to solve simultaneously for the market clearing commodity and fertilizer prices, providing the baseline. Projected results, estimated to 2025, are discussed in this chapter.

Agricultural Commodities

Agricultural commodity results come from the FAPRI-MU system. Variables of interest in this study were crop prices, planted area and net returns per acre for corn, soybeans, wheat and cotton.

Figure 7.1: Baseline Results for Agricultural Commodities

	Units	2010-12 average	2015	2020	2025
Corn					
Farm Price	dollars per bushel	6.10	3.79	4.17	3.77
Net Returns	dollars per acre	525	296	355	293
Area Planted	million acres	92.5	88.5	91.3	90.4
Soybeans					
Farm Price	dollars per bushel	12.73	9.19	10.31	9.54
Net Returns	dollars per acre	381	246	301	269
Area Planted	million acres	76.6	84.3	84.1	84.3
Wheat					
Farm Price	dollars per bushel	6.90	5.12	5.81	5.29
Net Returns	dollars per acre	194	110	136	109
Area Planted	million acres	54.1	54.8	54.5	54.9
Cotton					
Farm Price	dollars per pound	0.81	0.60	0.65	0.66
Net Returns	dollars per acre	298	107	122	100
Area Planted	million acres	12.4	9.6	9.2	9.4

Source: Model Results

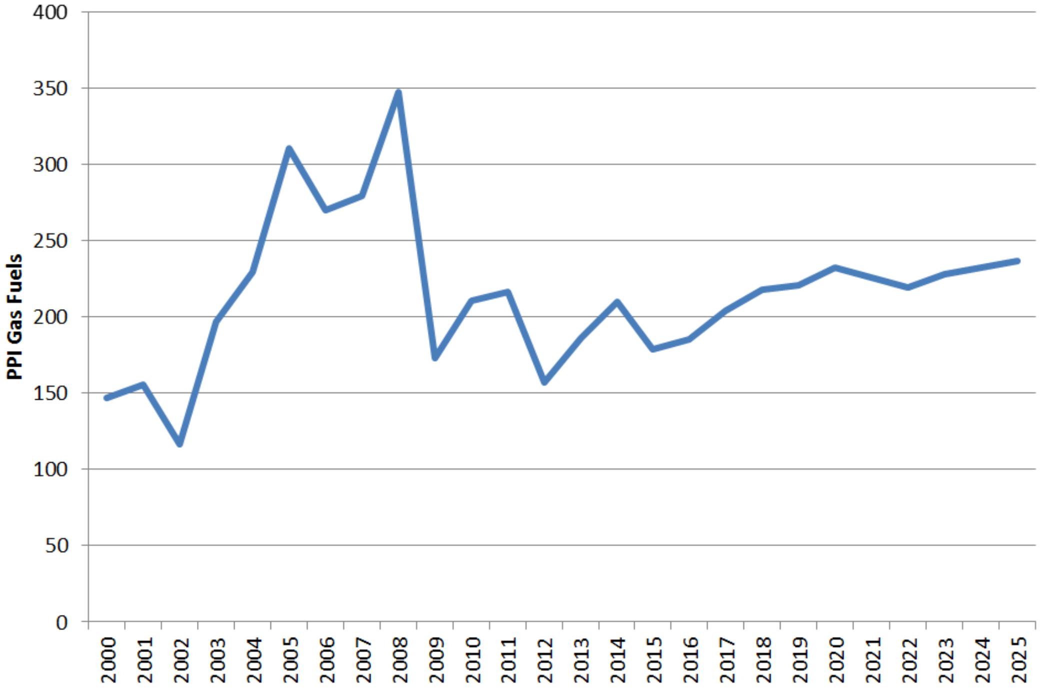
The baseline shows a decrease in crop prices in the projection period, down from the average high from 2010 through 2012. Corn, soybean, wheat and cotton farm prices are projected to decrease by 38, 25, 23 and 19 percent, respectively, by 2025. Net returns per acre for each crop also decrease by 44, 29, 44 and 66 percent, respectively, during the projection period. Because soybean returns are projected to decrease the least, it appears that some acres are shifted from corn and cotton to soybeans. Soybean acres are expected to increase by 10 percent while corn and cotton acres are projected to fall by 2 and 24 percent respectively. No significant change is expected in planted wheat area.

Nitrogen Sector

A summary of baseline values for the nitrogen sector is given in Figure 7.3. Production is expected to increase from the historical average by 156,000 nutrient tons by 2015, but then is projected to decrease by 564,000 tons or 6 percent. The decline in production is likely a result of weaker fertilizer demand from the agricultural sector and rising projected natural gas prices as shown in Figure 7.2. Net imports are predicted to increase by 2025 by 1,323,000 tons or 15 percent. Thus, the U.S. is expected to import almost 55 percent of its total supply by 2025.

These supply results are contradictory to a projected increase in production of 32 percent and decrease in net imports of 13 percent by Steiner (2014). There are two likely reasons this difference could have occurred. The first is the lack of capacity data in this study. Steiner (2014) uses capacity projections from the International Fertilizer Development Center. According to Steiner (2014), U.S. nitrogen capacity is expected to increase 48 percent from 2012 to 2025. This large increase in capacity likely caused production to rise along with it. The second reason is the potential difference in crop price projections at the time each study was conducted. It is possible that the crop price projections Steiner included in his dataset were more optimistic than those used here, resulting in a higher demand for nitrogen fertilizers. A higher nitrogen price due to this higher demand could have kept nitrogen production returns high enough to expand capacity.

Figure 7.2: Producer Price Index for Gas Fuels



Source: FAPRI Database

On the demand side, total agricultural use of nitrogen fertilizer is expected to increase from historical levels as use on corn, wheat and other crops are projected to rise. Corn and wheat fertilizer use increases are partially due to an expansion in the application rate on corn and the percent acres fertilized of wheat, respectively. On the other hand, soybean and cotton fertilizer use is expected to decline. These results are not surprising because of the forecasted decrease in crop prices. A decrease in the output (crop) price has a negative impact on fertilizer application rates, the percent of acres fertilized and the number of acres planted. A reduction in each of these 3 variables has a negative effect on the total use of fertilizer on a crop. As the output price decreases, there is less incentive for a farmer to apply fertilizer. However, because corn accounts for approximately half of total nitrogen used in agriculture, an overall increase in total use can be expected. As a result, total agricultural use of nitrogen is expected to increase during the projection period.

Figure 7.3: Nitrogen Supply and Use

	2010-12 average	2015	2020	2025
Supply	(Thousand nutrient tons)			
Production	9258	9414	8997	8694
Net Imports	9108	9389	10103	10431
Total Supply	18365	18803	19099	19126
Demand				
Total Agricultural Use	12874	13213	13505	13380
Corn Use	6126	6087	6481	6381
Soybean Use	143	157	150	141
Wheat Use	1507	1608	1630	1651
Cotton Use	437	316	306	324
Other Crop Use	4661	5045	4937	4882
Non-agricultural Use	5491	5590	5595	5746
Total Demand	18365	18803	19099	19126
	(Dollars per ton)			
Anhydrous Ammonia Farm Price	677	686	748	759

2010-12 Source: FAO 2015 (Supply and Non-fert. Use), ERS 2012 (Agricultural Uses and Price); 2015-2030 Source: Model Results

Anhydrous ammonia prices are projected to increase by $82 per ton or 12 percent from the historical average by 2025. An average annual growth rate in price of 1 percent annually is expected from 2015 to 2025. The projected prices are, however, projected to decline from the highs observed in recent years. According to NASS surveys, the average U.S. price per ton of nitrogen was $851 in 2014. The model shows a 19 percent decline in price from this value the following year.

Phosphate Sector

Selected baseline values for the phosphate sector are given in Figure 7.4. Domestic production of phosphate is projected to slightly increase from the 2010-2012 average by 265,000 ton decline from 2015 to 2025, an overall increase of only 2 percent. No major changes are expected to affect domestic production in the near future.

Phosphate fertilizer demand is projected to slightly increase by 2025. An increase of 9 percent is expected for total agricultural use by 2020 before falling back to historical levels by 2025. Some individual crop uses are projected to decline while others increase for the period. Corn use is projected to decline the most during the projection period with a predicted fall of 12 percent. A 5 and 22 percent drop is anticipated to occur in soybean and cotton use, respectively. The exception is the predicted rise of wheat use and other crop use by 28 and 24 percent, respectively. The fertilizer application rate for wheat remains flat throughout the projection period while the percent acres fertilized and wheat acres planted increase, resulting in a net increase in total wheat use. Conversely, either one or a combination of these factors is expected to decline for corn, soybeans and cotton.

A discrepancy in the data is observed while analyzing the baseline values for phosphate non-fertilizer use. FAOSTAT (2014) data from 2008 to 2012 show that industrial use accounts for over half of all phosphate consumption in the U.S. On the other hand, PotashCorp (2014) states that industrial use only makes up 12 percent of global use. The non-fertilizer use category in the FAOSTAT (2014) dataset is calculated as a balance, raising suspicions about the reliability of the data. As a result, the non-fertilizer use might account for an inflated share of total phosphate use in this model.

Net exports are estimated to remain steady during the projection period. The drop in phosphate price in 2015 results in an additional 58,000 tons of exports compared to the historical average. Steiner (2014) also shows slightly declining U.S. exports from 2015 to 2030, which are in line with the results from this study.

Figure 7.4: Phosphate Supply and Use

	2012	2015	2020	2025
Supply	(Thousand nutrient tons)			
Production	14733	15497	15162	14998
Demand				
Total Agricultural Use	4258	4651	4590	4361
Corn Use	1896	1779	1817	1655
Soybean Use	587	632	600	556
Wheat Use	495	620	624	631
Cotton Use	139	108	103	108
Other Crop Use	1141	1513	1446	1412
Non-agricultural Use	8710	9022	8995	9176
Net Exports	1766	1824	1577	1461
Total Demand	14733	15497	15162	14998
	(Dollars per ton)			
Super-Phosphate Farm Price	602	570	630	643

2010-12 Source: FAO 2015 (Supply, Exports, Non-fert. Use), ERS 2012 (Agricultural Uses and Price); 2015-2030 Source: Model Results

Short term relief to the super-phosphate farm price is expected in 2015 followed by a gradual increase to near 2012 levels by 2025. The price is projected to decline 5 percent in the short term but rise 7 percent in the long run. Again, this short term drop is likely partly due to reduced demand for fertilizers caused by weak agricultural commodity prices.

Potash Sector

Baseline values are listed for the potash sector in Figure 7.5. Compared to nitrogen and phosphate, domestic potash production accounts for a relatively small share of total potash supply. Domestic production is projected to increase by 40 percent by 2025, nearing pre-2008 levels. The majority of U.S. supply is imported from nearby Canada. Net imports are only expected to increase by 2 percent, only losing a small share of total supply to production.

Figure 7.5: Potash Supply and Use

	2010-12 average	2015	2020	2025
Supply		(Thousand nutrient tons)		
Production	852	1109	1207	1189
Net Imports	6342	6395	6497	6500
Total Supply	7194	7504	7703	7689
Demand				
Total Agricultural Use	4559	4790	4931	4776
Corn Use	2023	1679	1839	1711
Soybean Use	840	1158	1175	1152
Wheat Use	95	135	129	125
Cotton Use	206	164	156	160
Other Crop Use	1396	1654	1633	1627
Non-agricultural Use	2634	2714	2772	2912
Total Demand	7194	7504	7703	7689
		(Dollars per ton)		
Potassium Chloride Farm Price	586	588	614	599

2010-12 Source: FAO 2015 (Supply, Exports, Non-fert. Use), ERS 2012 (Agricultural Uses and Price); 2015-2030 Source: Model Results

The largest increase in demand during the projection period is estimated to come from non-fertilizer use. Again, this data series might include error; however, it accounts for a much smaller share of total demand than in the phosphate sector. Total agricultural use is predicted to rise by 5 percent by 2025. The model estimation shows that soybean, wheat and other crop use will be the main drivers behind this increase. Corn and cotton crop categories are expected to decrease.

The potassium chloride farm price also follows a similar path to nitrogen and phosphate prices. Prices are expected to increase by $13 per ton or 2 percent by 2025. NASS surveys indicate a 2014 potash price per ton of $601. This model exhibits a 2 percent reduction by 2015. The decrease is likely attributable to expansion in domestic production, increased imports and weak fertilizer demand.

VIII: MARKET SCENARIOS

Market scenarios are used to test the responsiveness of the model to exogenous changes. The process involves changing an exogenous variable, allowing the model to solve for a new set of values then comparing the new values to the baseline. The following shocks were introduced into the model:

1. Sustained 10 percent increase in the natural gas price proxy from 2015 to 2025;
2. Sustained 10 percent increase in the sulfur price proxy from 2015 to 2025; and
3. Sustained 10 percent increase in the electric power price index from 2015 to 2025.

The shocks are independent, not additive, so the results are presented separately. The shocked variables were chosen because they are the main inputs in the production of each fertilizer nutrient. By shocking each variable by the same percentage, end results in the fertilizer industry and agricultural markets can be compared across scenarios.

The shocks reflect an increase in the price of the input in the U.S. only. This key assumption results in trade effects that will tend to moderate the impact, responding only to changes in the U.S. fertilizer price. If the scenarios were conducted using global fertilizer input shocks, trade effects would change along with the U.S. quantity and price impacts shown below.

Natural Gas Price Shock

The first scenario was an increase in the gas fuels price index to represent an increase in natural gas prices. This variable was increased by 10 percent from 2015 to 2025. Results are shown in Figure 8.1.

This price shock directly increased the cost of production for nitrogen fertilizers, causing a backward shift in the nitrogen supply curve. This shift resulted in a 0.7 percent decrease in annual production of nitrogen from the baseline in the short run and a 3.9 percent decrease in the long run. The production of nitrogen decreased at an increasing rate during the projection period because of the inclusion of the lagged dependent variable in the production equation, effectively simulating long-term capacity adjustments.

Lower domestic availability of nitrogen fertilizers caused the nitrogen farm price to move higher than the baseline. This increase in fertilizer price induced an approximate 1.3 percent increase in nitrogen imports which offset almost half of the reduction in domestic production. If the nitrogen import elasticity with respect to nitrogen price is actually higher than the estimation in this study, it would be possible to for the imports to offset the reduction in production. In this event, smaller effects on the nitrogen price would be expected.

The higher fertilizer price also reduced the quantity demanded in both the agricultural and industrial sectors. A combination of a reduction in application rates and percent acres fertilized caused a decrease in use of nitrogen on all the crop categories. Not surprisingly, the largest decrease in use was for soybeans. Because soybeans are a legume and do not gain much benefit from nitrogen applications, an increase in the nitrogen price caused the largest percent decrease in application of nitrogen on soybeans. A majority of the nitrogen applied to soybean acres is in the form of MAP and DAP mixed fertilizer. The reduction in nitrogen use could be explained by a switch to the application of fertilizers that only contain phosphate. Corn, wheat and cotton all have higher yield responses to nitrogen, suggesting their demands might be more inelastic. Due to the overall inelastic behavior of nitrogen fertilizer users, total agricultural use of nitrogen fell below baseline values by 0.14 percent in the short run and 0.71 percent by 2025. Industrial use also decreased by similar percent values.

Effects of the price shock were also observed in the agricultural crops market. Corn, wheat and cotton planted areas were all reduced likely because of reduced expected net returns. Again, corn, wheat and cotton are intensive users of nitrogen fertilizers meaning an increase in the nitrogen price would have a larger increase in the cost of production for these crops. Soybean returns are more immune to this increase and, thus, exhibit a relatively higher expected net return than the other crops. Because planted acres are positively related to expected net returns, U.S. producers shifted production acres from corn, wheat and cotton to the seemingly more profitable soybeans.

However, in this scenario, U.S. crop producers might have overreacted to the expected profits. Because of the increase in acres dedicated to soybeans, the model generated more soybean production causing a reduction in the soybean farm price. Vice versa, producers of corn, wheat and cotton observed higher farm prices per bushel as a result of lower production from the reduction in planted area. Thus, a 10 percent increase in the natural gas price culminated in projection period average changes of 0.05, -0.04, 0.01 and 0.01 percent in farm price per bushel for corn, soybean, wheat and cotton baseline values, respectively.

Net returns per acre decreased for each crop category as a result of the 10 percent increase in domestic natural gas price. By ultimately increasing the cost of production per acre for each crop, the price shock decreased the net returns for corn, soybeans, wheat and cotton by an average of -0.20, -0.08, -0.26 and -0.42 percent, respectively. A summary of absolute and percent changes from baseline values as a result of this shock are displayed in Figure 8.1.

Additional observations and conclusions were drawn from the scenario results. First, impacts of the shock were very small in the crop sector. Changes in crop prices were never over a penny per bushel and net returns per acre deviations were always under a dollar per acre. This is most likely caused by a combination of the small fertilizer price response and inelastic tendencies in U.S. agricultural markets. Second, small effects were noticed in the markets for phosphate and potash in response to this shock. No direct cross-price effects are included in the fertilizer demand equations; therefore, the movements must have been triggered by changes in the agricultural sector. Soybeans and a majority of the agricultural products included in the other crops category use a relatively high rate of phosphate and potash fertilizers. During the scenario, model results showed that while phosphate and potash use on corn, wheat and cotton decreased, an increase occurred in soybean and other crop use. This was likely due to the shift in acres from corn, wheat and cotton to soybeans. The subsequent increase in use on soybeans and other crops outweighed the effects of the others, which resulted in a higher level of total agricultural demand for phosphate and potash. This brought about a slight increase in the price for phosphate and potash fertilizer as a result of a domestic natural gas price increase.

Figure 8.1: Natural Gas 10% Price Shock Results, Changes from Baseline Values

		2015	2020	2025	2015	2020	2025
Supply			(thousand nutrient tons)			(percent)	
Production		-66	-252	-338	-0.70%	-2.80%	-3.89%
Net Imports		37	146	198	0.39%	1.45%	1.90%
Total Supply		-29	-106	-140	-0.16%	-0.55%	-0.73%
Demand							
Total Agricultural Use		-19	-69	-95	-0.14%	-0.51%	-0.71%
Corn Use		-12	-41	-57	-0.19%	-0.63%	-0.89%
Soybean Use		-1	-2	-3	-0.36%	-1.42%	-2.07%
Wheat Use		-2	-8	-11	-0.12%	-0.47%	-0.67%
Cotton Use		-1	-2	-3	-0.18%	-0.62%	-0.78%
Other Crop Use		-4	-16	-22	-0.08%	-0.33%	-0.45%
Non-fertilizer Use		-10	-37	-45	-0.19%	-0.67%	-0.78%
Total Demand		-29	-106	-140	-0.16%	-0.55%	-0.73%
			(dollars per ton)				
Anhydrous Ammonia Farm Price		4	14	19	0.530%	1.908%	2.478%
Corn							
Area Planted	(acres)	-15919	-34851	-37105	-0.018%	-0.038%	-0.041%
Farm Price	(¢/bushel)	0.09	0.20	0.23	0.024%	0.048%	0.061%
Net Returns	($/acre)	-0.11	-0.77	-1.03	-0.037%	-0.218%	-0.351%
Soybeans							
Area Planted	(acres)	11882	22301	21642	0.014%	0.027%	0.026%
Farm Price	(¢/bushel)	-0.22	-0.37	-0.52	-0.024%	-0.036%	-0.055%
Net Returns	($/acre)	-0.11	-0.24	-0.35	-0.046%	-0.079%	-0.128%
Wheat							
Area Planted	(acres)	-1160	-6355	-8199	-0.002%	-0.012%	-0.015%
Farm Price	(¢/bushel)	0.03	0.08	0.08	0.006%	0.013%	0.015%
Net Returns	($/acre)	-0.08	-0.36	-0.49	-0.077%	-0.267%	-0.443%
Cotton							
Area Planted	(acres)	-1262	-1937	-2410	-0.013%	-0.021%	-0.026%
Farm Price	(¢/pound)	0.005	0.009	0.011	0.008%	0.014%	0.017%
Net Returns	($/acre)	-0.12	-0.52	-0.71	-0.108%	-0.428%	-0.709%

Source: Model Results

Sulfur Price Shock

The next scenario was a 10 percent increase in the producer price index for minerals from 2015 to 2030. The producer price index for minerals is used as a proxy for a sulfur price; the main feedstock in phosphate production.

Similar to the natural gas scenario, the sulfur price shock increased the cost of domestic production for phosphate nutrients. In this market, domestic production was only reduced by about 1 percent in the long run. There are no imports in this market to make up for the loss of production. Phosphate fertilizer prices were consequently driven up by the reduction in supply.

In response to the higher phosphate price, the model projected lower quantities for agricultural use, non-fertilizer use and net exports. In this scenario, agricultural use declines by a greater percentage than the change observed in the nitrogen sector. This difference suggests that phosphate agricultural demand is more elastic than that of nitrogen. The higher phosphate application rate elasticities with respect to the fertilizer price estimated in this study (Figure 6.2) would add credence to this hypothesis. Higher elasticities of demand for non-agricultural use and exports help keep the phosphate price increase slightly lower than that observed in the nitrogen market.

Almost identical directional changes to the previous scenario are observed in the agricultural commodities market as a result of this shock. This occurrence contradicts the explanation given for the shift to soybean acres because, in this market, soybeans use phosphate fertilizers just as intensively as the other crops. Alternatively, there is evidence to suggest that a combination of two factors leads to the acreage shift in the model. First, soybean phosphate use drops the most out of all the crops in response to the price shock, indicating a more elastic response. Second, the cost of phosphate application on soybeans only accounts for 6 percent of total variable costs per acre (ERS 2013). The combination of these two effects could mitigate the effects of an increase in phosphate prices on soybean net returns, relative to corn, wheat and cotton.

Figure 8.2: Sulfur 10% Price Shock, Changes from Baseline Values

		2015	2020	2025	2015	2020	2025
Supply			(thousand nutrient tons)			(percent)	
Production		-67	-162	-168	-0.44%	-1.07%	-1.12%
Demand							
Total Agricultural Use		-22	-53	-59	-0.47%	-1.16%	-1.34%
Corn Use		-13	-30	-33	-0.71%	-1.65%	-2.01%
Soybean Use		-4	-9	-9	-0.62%	-1.46%	-1.67%
Wheat Use		-1	-3	-4	-0.21%	-0.53%	-0.60%
Cotton Use		0	0	0	-0.21%	-0.46%	-0.46%
Other Crop Use		-4	-11	-12	-0.27%	-0.74%	-0.83%
Non-fertilizer Use		-25	-56	-53	-0.27%	-0.63%	-0.58%
Net Exports		-21	-52	-56	-1.14%	-3.33%	-3.85%
Total Demand		-67	-162	-168	-0.44%	-1.07%	-1.12%
			(dollars per ton)				
Super Phosphate Farm Price		6	14	15	0.98%	2.23%	2.27%
Corn							
Area Planted	(acres)	-3931	-4742	-2774	-0.004%	-0.005%	-0.003%
Farm Price	(¢/bushel)	0.025	0.040	0.040	0.007%	0.009%	0.011%
Net Returns	($/acre)	-0.078	-0.238	-0.208	-0.026%	-0.067%	-0.071%
Soybeans							
Area Planted	(acres)	4058	5186	4804	0.005%	0.006%	0.006%
Farm Price	(¢/bushel)	-0.082	-0.031	0.024	-0.009%	-0.003%	0.002%
Net Returns	($/acre)	-0.083	-0.137	-0.119	-0.034%	-0.045%	-0.044%
Wheat							
Area Planted	(acres)	-946	-3639	-4246	-0.002%	-0.007%	-0.008%
Farm Price	(¢/bushel)	0.013	0.036	0.047	0.003%	0.006%	0.009%
Net Returns	($/acre)	-0.076	-0.193	-0.196	-0.069%	-0.141%	-0.179%
Cotton							
Area Planted	(acres)	-1383	-1315	-1351	-0.014%	-0.014%	-0.014%
Farm Price	(¢/pound)	0.005	0.006	0.007	0.009%	0.009%	0.010%
Net Returns	($/acre)	-0.098	-0.297	-0.310	-0.092%	-0.243%	-0.308%

Source: Model Results

The changes in response to the price shock were even less in this scenario than in the nitrogen scenario mainly because phosphate costs per acre are roughly half of the amount paid for nitrogen on average (ERS 2013). The inelasticity in the agricultural crop sector is also to blame for the weak response. In this scenario, net returns for corn, soybeans, wheat and cotton were diverted from the baseline by an average of -0.055, -0.041, -0.130 and -0.214 percent, respectively, in response to a 10 percent increase in the sulfur price.

Electric Power Shock

The final scenario consisted of a sustained 10 percent increase in the producer price index for electric power. This shock is meant to directly raise the cost of production for potash fertilizers in the U.S. Because domestic production makes up such a small portion of U.S. supply, the effects are expected to be small compared to nitrogen and phosphate.

The reduction in production in this scenario was between the changes for nitrogen and phosphate with a long run decline of over 2 percent from the baseline. The resulting price increase drives up imports of potash by 0.14 percent in 2025. This trade response is much lower than the change observed in the nitrogen market because the nitrogen net import equation is much more elastic with respect to own price.

The overall reduction in supply pushes the potash fertilizer price higher than the values projected in the baseline. The agricultural and industrial sectors react by reducing their demand for potash. The demand response in this market is the lowest of the 3 scenarios. Agricultural and industrial use are projected to fall from baseline values by less than half a percent in 2025. The potassium chloride price is expected to increase by less than half a percent from baseline levels during the projection period.

Figure 8.3: Electric Power 10% Price Shock, Changes from Baseline Values

		2015	2020	2025	2015	2020	2025
Supply			(thousand nutrient tons)			(percent)	
Production		-10.8	-29.6	-29.7	-0.98%	-2.45%	-2.50%
Net Imports		3.0	8.7	8.8	0.05%	0.13%	0.14%
Total Supply		-7.8	-20.9	-20.9	-0.10%	-0.27%	-0.27%
Demand							
Total Agricultural Use		-5.7	-15.4	-16.0	-0.12%	-0.31%	-0.33%
Corn Use		-3.6	-9.6	-9.9	-0.21%	-0.52%	-0.58%
Soybean Use		-1.4	-4.0	-4.2	-0.12%	-0.34%	-0.37%
Wheat Use		-0.2	-0.6	-0.6	-0.15%	-0.46%	-0.50%
Cotton Use		-0.1	-0.2	-0.1	-0.05%	-0.10%	-0.09%
Other Crop Use		-0.4	-1.1	-1.1	-0.02%	-0.06%	-0.07%
Non-fertilizer Use		-2.1	-5.5	-5.0	-0.08%	-0.20%	-0.17%
Total Demand		-7.8	-20.9	-20.9	-0.10%	-0.27%	-0.27%
			(dollars per ton)				
Potassium Chloride Farm Price		0.98	2.76	2.73	0.17%	0.45%	0.46%
Corn							
Area Planted	(acres)	-1083	-2174	-1905	-0.001%	-0.002%	-0.002%
Farm Price	(¢/bushel)	0.007	0.015	0.017	0.002%	0.004%	0.004%
Net Returns	($/acre)	-0.014	-0.062	-0.056	-0.005%	-0.017%	-0.019%
Soybeans							
Area Planted	(acres)	464	534	648	0.001%	0.001%	0.001%
Farm Price	(¢/bushel)	-0.013	0.008	0.025	-0.001%	0.001%	0.003%
Net Returns	($/acre)	-0.020	-0.040	-0.033	-0.008%	-0.013%	-0.012%
Wheat							
Area Planted	(acres)	259	1399	1237	0.000%	0.003%	0.002%
Farm Price	(¢/bushel)	0.001	-0.001	-0.001	0.000%	0.000%	0.000%
Net Returns	($/acre)	-0.003	-0.008	-0.005	-0.003%	-0.006%	-0.005%
Cotton							
Area Planted	(acres)	-592	-729	-692	-0.006%	-0.008%	-0.007%
Farm Price	(¢/pound)	0.002	0.003	0.003	0.004%	0.004%	0.004%
Net Returns	($/acre)	-0.019	-0.082	-0.084	-0.018%	-0.067%	-0.083%

Source: Model Results

A similar phenomenon occurs in the agricultural crop markets in this scenario as well. This observation can again be explained by high elasticities and low fertilizer cost of production share for soybeans. As a result, the price shock in this scenario provokes a change of -0.014, -0.011, -0.005 and -0.056 percent from the baseline for corn, soybean, wheat and cotton net returns, respectively.

IX: SUMMARY AND CONCLUSION

Summary

The motivation for this study was the uncertainty following great price volatility observed in recent years. Factors like falling natural gas prices might have had an effect on U.S. agricultural commodity markets. Previous studies, which have mainly focused on demand, have rarely analyzed the supply and demand of fertilizer simultaneously. This study endeavored to estimate and link a model of the U.S. fertilizer industry to an agricultural commodities model in order to quantify important relationships. More specifically, the performed objectives of this study were the specification of an econometric model of the fertilizer markets using economic theory, knowledge of the industry and prior research. Second, coefficients and elasticities were estimated for production, use and trade of each nutrient. By linking the developed model to the FAPRI-MU system, baseline values for key fertilizer and agricultural commodity variables were projected to the year 2025. Finally, these baseline values were compared to the results of 3 different scenarios in order to analyze the relationship between fertilizer production costs and key agricultural variables.

To accomplish these goals, an overview of the fertilizer industry was provided. This overview provided information that was useful in equation specification. For instance, sources indicated that the main inputs for production of nitrogen, phosphate and potash are natural gas, sulfuric acid and electric power, respectively. These sources also showed that the U.S. domestically produces around half of its nitrogen supply while the remainder is provided by imports. The U.S. is a net exporter of phosphate while it imports the majority of its potash supply from Canada. Shifting focus to demand, crop varieties with high yield responses to fertilizer applications are the main users of each nutrient. Historically, it has been suggested that farmers tend to over-apply fertilizers, but the adoption of GPS mapping and variable rate technologies might be curbing this behavior. All of these factors bear significant implications in the specification of applied economic model equations.

Reviews of previous fertilizer studies and economic theory also contributed to specification. The literature review focused on the specification of demand and supply equations and their estimated elasticities. It was generally found that the demand for fertilizers is inelastic with respect to own and input price. The production of nutrients was also found to be inelastic with respect to input and output prices. The elasticities given in the reviewed studies provided a valuable reference point to compare the estimation results from this study. The review of the theory behind derived and factor demand also aided in the selection of explanatory variables in the model and gave an indication of the correct coefficient sign in some cases.

The combination of the industry, literature and theoretical reviews provided direction for the specification and estimation of each structural equation in the model. Each equation was estimating using ordinary least squares regression techniques. In all, the fertilizer model has 30 demand equations, 3 supply equations, 3 net trade equations, and 18 identities which solve simultaneously for the market clearing price of nitrogen, phosphate and potash. This model was linked to the FAPRI-MU system and solved to produce a baseline of key agricultural variables from 2015 to 2025.

The responses of the model to fertilizer production input price shocks were examined in an attempt to quantify relationships between the fertilizer production costs and fertilizer prices, crop prices, crop net returns per acre and area planted in the U.S. The conclusions drawn from these results are discussed later in this chapter.

Limitations

This study attempts to supplement the efforts of previous analysis by re-estimating demand and supply equations. However, no estimation procedure is ever perfect. Consequently, the limitations of the assumptions, methods and conclusions of this study must be considered.

First, evidence exists that the assumption of a competitive market structure for fertilizer production might be inaccurate. Barriers to entry in the market might exist due to limited reserves, high industry concentration and significant capital requirements. The high profit margins maintained by firms in the nitrogen industry in recent years also point to the presence of these barriers.

Additional limitations arise from the statistical methods used for parameter estimation in this study. According to Roberts and Heady (1982) ordinary least squares techniques might not produce efficient estimates because of autocorrelation and multicollinearity risks within the data. The authors specifically noted the possibility of high correlation of nutrient and crop prices. The presence of these relationships in the data would violate the least squares assumptions. Thus, there is a chance the parameters used in this study are inefficient estimators.

Certain methods in the model specification used in this study were also a cause for concern. Not every variable suggested by economic theory was included in the specified equations, either due to a lack of data or poor estimation results. This could have led to the absence of important market relationships within the model. Poor estimation results also required the use of borrowed parameters from previous studies in some cases.

Finally, unreliable data might have added further weaknesses to model performance. Questions of reliability arose from discrepancies between and within the fertilizer data sources used in this study. The discrepancies indicate the possible existence of error in the data, increasing the risk of errors in the study results.

Conclusions

This study has still produced some useful results. There are limitations, as noted in the text, but certain findings could be relevant to decision makers in business and government. First, input and output price elasticities of demand for fertilizer nutrients were estimated to be inelastic, reinforcing and updating the findings of previous studies by testing these relationships over more recent survey data. Differences in elasticities among specific nutrients and crops led to unique responses in the agricultural commodities market for each scenario.

Simulation model results were used to find small impacts of domestic fertilizer input costs on U.S. agricultural commodity markets. In the natural gas scenario, a 10 percent increase in the domestic natural gas price changed the farm price of corn, soybeans, wheat and cotton by 0.05, -0.04, 0.01 and 0.01 percent, respectively. The second scenario showed a 10 percent rise in the U.S. price of sulfur cause the same farm prices to adjust by 0.009,   -0.003, 0.006 and 0.09 percent, respectively. Lastly, the crop prices changed by 0.003, 0.001, -0.0001 and 0.004 percent, respectively, as a result of a 10 percent domestic electricity price surge in the third scenario. Scenario results indicate that an increase in domestic fertilizer production costs might cause agricultural producers to shift production acres from crops with intensive fertilizer usage to other alternatives. This observation could provide insight for environmental policy makers. For example, attempts to reduce the amount of fertilizer usage in the U.S. might take the form of a tax or cost imposed on domestic fertilizer manufacturers that is tied to their key input purchases.

The small to nearly nonexistent effect a change in domestic fertilizer production costs has on fertilizer usage and agricultural commodity markets found in this study suggest that such a policy effort would not be effective. In terms of policy implications, this low responsiveness demonstrates that a large domestic fertilizer input price change would be required to invoke changes in the agricultural sector. This finding also attests to the inelasticity of demand for fertilizer, supporting the common notion that U.S. agricultural production is highly dependent on fertilizer use.

That being said, the results also show that these demands are not unresponsive. For example, by comparing the percent change in agricultural use to the percent change in fertilizer price in each of the scenarios, the elasticity of demand might be approximated as -0.29 for nitrogen, -0.59 for phosphate, and -0.72 for potash. These numbers could be useful for fertilizer market studies that seek aggregate elasticities of demand.

Further Research

This study attempted the ambitious feat of quantifying relationships between the 3 major fertilizer markets and 4 agricultural commodity markets. While much care was given to the choice of methods and estimation, there is much room for improvement. Future research on this subject could enhance the model's representation of fertilizer markets and their effects on agriculture.

Data quality is one vital area of improvement. While unavailable for this study because of significant costs, proprietary sources of fertilizer quantity and price data do exist. Given the concerns with data used in this study, future research could make a serious effort to utilize these sources for more consistent and reliable datasets.

Efforts could also be made to remedy the other previously mentioned limitations of this study. Additional emphasis on parameter estimation methods would add validity to model results. The model structure itself could also be altered to represent more accurately the fertilizer industry. For example, additional data might allow for the estimation of domestic production capacity and utilization equations similar to Steiner's (2014).

Future research could also expand these ideas into a model representation of global fertilizer markets. A global model, linked to crop models as in this study, would more accurately depict relationships between foreign fertilizer market implications and agricultural commodity markets.

WORKS CITED

Denbaly, M., & Vroomen, H. (1993). Dynamic Fertilizer Nutrient Demands for Corn: A Cointegrated and Error-Correcting System. *American Journal of Agricultural Economics, 75*(1), 203-209.

Economic Research Service. (2013). *Fertilizer Use and Markets.* United States Department of Agriculture. Retrieved from http://www.ers.usda.gov/topics/farm-practices-management/chemical-inputs/fertilizer-use-markets.aspx

Economic Research Service. (2013). *Fertilizer Use and Price.* United States Department of Agriculture. Retrieved from http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx

Economic Research Service. (2014). *Fertilizer Imports/Exports.* United States Department of Agriculture. Retrieved from http://www.ers.usda.gov/data-products/fertilizer-importsexports.aspx

FAOSTAT. (2014). *FAOSTAT Database.* Food and Agriculture Organization of the United Nations, Statistics Division. Retrieved from http://faostat3.fao.org/home/E

Follett, J. R., Follett, R. F., & Herz, W. C. (2010). Environmental and Human Impacts of Reactive Nitrogen. *Advances in Nitrogen Management for Water Quality*, 1-37.

Food and Agricultural Policy Research Institute. (2015). *U.S. Baseline Briefing Book Projections for Agricultural and Biofuels Markets.* University of Missouri, Division of Applied Social Sciences.

Garcia, R. J., & Randall, A. (1994, May). A Cost Function Analysis to Estimate the Effects of Fertilizer Policy on the Supply of Wheat and Corn. *Review of Agricultural Economics, 16*(2), 215-230. Retrieved 9 6, 2014, from http://www.jstor.org/stable/1349464

Griliches, Z. (1958). The Demand for Fertilizer: An Economic Interpretation of a Technical Change. *Journal of Farm Economics, 40*(3), 591-606.

Gunjal, K. R., Roberts, R. K., & Heady, E. O. (1980). Fertilizer Demand Functions for Five Crops in the United States. *Southern Journal of Agricultural Economics, 12*(2), 111-116.

Gyawu, E., Debertin, D. L., Jones, L. D., & Pagoulatos, A. (1984). *An Econometric Analysis of the Fertilizer Industry in the U.S.* University of Kentucky, Department of Agricultural Economics. Retrieved from http://EconPapers.repec.org/RePEc:ags:ukyaer:159488

Heady, E. O., & Yeh, M. H. (1959, May). National and Regional Demand Functions for Fertilizer. *Journal of Farm Economics, 41*(2), 332-348. Retrieved 2 6, 2014, from http://www.jstor.org/stable/1235160

Huang, W. (2007). *Impact of Rising Natural Gas Prices on U.S. Ammonia Supply.* Economic Research Service, United States Department of Agriculture. Retrieved from http://www.ers.usda.gov

Huang, W. (2009). *Factors Contributing to the Recent Increase in U.S. Fertilizer Prices, 2002-2008.* Economic Research Service, United States Department of Agriculture. Retrieved from http://www.ers.usda.gov

International Fertilizer Development Center. (2013). *IFDC Capacity Data.* IFDC Surveys and Published Reports. Retrieved from http://www.ifdc.org/FertilizerStat_10413.pdf/

National Agricultural Statistics Service. (2015). *Statistics By Subject*. Retrieved from United States Department of Agriculture: http://www.nass.usda.gov/Statistics_by_Subject/index.php

PotashCorp. (2014). Overview of PotashCorp and its Industry. Retrieved from http://www.potashcorp.com/overview/upload/pdf/nutrients-section.pdf

Ribaudo, M., Delgado, J., Hansen, L., Livingston, M., Mosheim, R., & Williamson, J. (2011). *Nitrogen in Agricultural Systems: Implications for Conservation Policy.* Economic Research Service, United States Department of Agriculture.

Roberts, R. K., & Heady, E. O. (1982). Fertilizer Demand Functions for Specific Nutrients Applied to Three Major U.S. Crops. *Western Journal of Agricultural Economics, 7*(2), 265-278.

Schimmelpfennig, D., & Ebel, R. (2011). *On the Doorstep of the Information Age: Recent Adoption of Precision Agriculture.* Economic Research Service, United States Department of Agriculture.

Sheriff, G. (2005). Efficient Waste? Why Farmers Over-Apply Nutrients and the Implications for Policy Design. *Review of Agricultural Economics, 27*(4), 542-557. Retrieved 10 23, 2014

Steiner, M. P. (2014). *A Partial Equilibrium Analysis of Global Fertilizer Supply and Demand.* University of Missouri, Department of Agricultural and Applied Economics.

U.S. Energy Information Administration. (2011). *Review of Emerging Resources: U.S. Shale Gas and Shale Oil Plays.* U.S. Department of Energy. Retrieved from http://www.eia.gov/analysis/studies/usshalegas/pdf/usshaleplays.pdf

U.S. Energy Information Administration. (2013). *Annual Energy Outlook.* U.S. Department of Energy. Retrieved from http://www.eia.gov/forecasts/archive/aeo13/pdf/0383(2013).pdf

U.S. Energy Information Administration. (2013). *Natural Gas Annual.* U.S. Department of Energy. Retrieved from http://www.eia.gov/naturalgas/annual/

U.S. Energy Information Administration. (2014). *Effect of Increased Levels of Liquified Natural Gas Exports on U.S. Energy Markets.* U.S. Department of Energy. Retrieved from http://www.eia.gov/analysis/requests/fe/pdf/lng.pdf

Zelaya, H. A. (1991). *U.S. Fertilizers: An Econometric Analysis of Supply and Demand with Some Emphasis on Policy Evaluation.* University of Missouri, Department of Agricultural and Applied Economics.