A PARTIAL EQUILIBRIUM ANALYSIS OF GLOBAL FERTILIZER SUPPLY AND DEMAND

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 in Agricultural and Applied Economics

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by
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MAY 2014

APPROVAL FORM

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

A PARTIAL EQUILIBRIUM ANALYSIS
OF GLOBAL FERTILIZER SUPPLY AND DEMAND

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ACKNOWLEDGEMENTS

This thesis would not have been possible without the support of my family, friends, co-workers, and mentors. I would like to give a special thank you to Dr. Patrick Westhoff, Dr. John Kruse, and Dr. Bill Wiebold for serving on my thesis committee and providing valuable insight that has helped me finish this thesis.

I would also like to give a huge thank you to my fiancé, Jillian. Without your editing expertise and your kind and understanding heart, I would be lost. The home-cooked meals that you have provided for me when I was stuck at the office and the support you have given me have been a blessing.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ii

TABLE OF CONTENTS iii

LIST OF ILLUSTRATIONS v

ABSTRACT vi

- INTRODUCTION 1
- INDUSTRY OVERVIEW 5
  - General Fertilizer Industry Overview 5
  - Nitrogen Fertilizer Overview 12
  - Phosphorus Fertilizer Overview 16
  - Potassium Fertilizer Overview 18
- LITERATURE REVIEW 21
  - Demand Literature 21
  - Supply Literature 27
- THEORETICAL ASPECTS OF SUPPLY AND DEMAND 30
  - Profit Maximization – Derived Demand 30
  - Profit Maximization – Supply 33
- DATA DISCUSSION 37
  - Demand Data 37
  - Supply Data 39
  - Exogenous Variables 40

Prices 40

Data Adjustments 49

MODEL SPECIFICATION 50

Supply Specifications 50

Demand Specifications 54

Solving the Model 56

BASELINE RESULTS 58

Supply 58

Demand 60

Fertilizer Prices 64

FERTILIZER MARKET SCENARIOS 72

Scenario 1 – Natural Gas Price Shock 72

Scenario 2 – U.S. Ammonia Farm Price Tax 74

Scenario 3 – Decrease in U.S. Corn Area 77

SUMMARY AND CONCLUSIONS 81

Future Research 82

Conclusion 84

REFERENCES 85

APPENDIX A 91

APPENDIX B 107

LIST OF ILLUSTRATIONS

Figure 1.1 - 2011 World Nitrogen Fertilizer Use 9

Figure 1.2 – 2011 World Nitrogen Fertilizer Production 9

Figure 1.3 – 2011 World Phosphorus Fertilizer Use 10

Figure 1.4 – 2011 World Phosphorus Production 10

Figure 1.5 – 2011 World Potassium Fertilizer Use 11

Figure 1.6 – 2011 World Potassium Production 11

Figure 1.7 – Global Natural Gas Prices 16

Figure 1.8 – Potash Fertilizer Production Flow-Diagram 19

Figure 3.1 – Own-Price Elasticities of Demand for Nitrogen, Phosphorus, and Potassium 28

Figure 3.2 – Output Price Elasticities of Demand for Nitrogen, Phosphorus, and Potassium 29

Figure 5.1 – U.S. and Canada Industrial Natural Gas Prices 43

Figure 5.2 Global Port Ammonia Prices 48

Figure 5.3 Global Port DAP/MAP Prices 48

Figure 5.4 Global Port Potash Prices 49

Figure 7.1 – U.S. Ammonia Profit Margin 65

Figure 7.2 – U.S. DAP Profit Margin 67

Figure 7.3 – U.S. Potassium Chloride Price 68

Figure 7.4 – U.S. Nitrogen Fertilizer Supply and Demand 69

Figure 7.5 – U.S. Phosphorus Fertilizer Supply and Demand 70

Figure 7.6 – U.S. Potassium Fertilizer Supply and Demand 71

Figure 8.1 – 10% Increase of North American Natural Gas Prices 73

Figure 8.2 – 10% Tax on U.S. Farm-Level Ammonia Prices 75

Figure 8.3 – Sustained 10% Decrease of U.S. Corn Acreage from WAEES Baseline Levels 77

ABSTRACT

Prices of nitrogen and phosphorous fertilizer spiked between 2008 and 2012. A partial equilibrium model of global nitrogen, phosphorus, and potassium fertilizer markets is constructed that is capable of producing a baseline of economic variables against which the impacts of various alternative scenarios can be evaluated. A 10% tax on farm-level nitrogen fertilizer in the United States would decrease domestic use in 2013 by 2.2%, suggesting that a very high tax might be required to obtain large reductions in nitrogen fertilizer use. A 10% increase to North American natural gas prices resulted in a long-run decrease in U.S. nitrogen fertilizer production of 2.4%, and long-run decreases in production in foreign markets of 0.1%. A 10% decrease in U.S. corn acreage was projected to reduce U.S. nitrogen, phosphorus, and potassium fertilizer use by 4.1%, 3%, and 2.5% in 2013, respectively, leading to moderate decreases in fertilizer prices and smaller reductions in domestic production.

CHAPTER ONE

INTRODUCTION

The purpose of this research is to develop an economic model of nitrogen, phosphorus, and potassium (NPK) supply and use in the U.S. and other selected countries for market and policy analysis. This model will produce a baseline of economic variables that can be used in combination with scenario analysis to better understand the implications of potential changes in government policies and market conditions.

Countries of interest for this study are Canada, China, India, Russia, and the United States. A “Rest of World” (ROW) region completes a global model. Each of these countries was identified as being a top five producer or consumer of at least one fertilizer nutrient. Future research could expand upon this model by adding additional countries to increase the level of detail.

Objectives:

1. Provide baseline estimates of nitrogen, phosphorus, and potassium supply and demand variables
3. Estimate fertilizer prices in modeled countries
4. Analyze impacts of policy changes and modifications to model assumptions
    A. Sustained 10% increase in North American natural gas prices from 2013 to 2030

B. Sustained 10% tax on U.S. farm-level ammonia prices from 2013 to 2030

C. Sustained 10% decrease of U.S. corn acreage from 2013 to 2030

A large unknown is the responsiveness of farmers to fertilizer and commodity prices. If unresponsive, as recent literature would suggest, then a lower price for fertilizer may not cause application rates to react strongly. Employing a partial equilibrium model using up to date market information and elasticities from fertilizer market studies will produce a snapshot of the future that can provide useful insight for analyzing policy options and changes in market factors.

One such policy issue revolves around the contention that farmers over-apply fertilizers used in the production of agricultural commodities. The farmer's nutrient application decision is subject to uncertainty in weather (Babcock 1992). When rainfall, temperature and other conditions are optimal, plants have higher yield potential than under average or poor growing conditions. Plants are able to utilize higher levels of nutrients under such conditions. Given the weather related uncertainty, it is economically optimal for producers to apply more nutrients than would be necessary under normal conditions in order to avoid applying suboptimal levels if conditions become more favorable for crop growth. When fertilizer is relatively cheap, producers will rationally choose to apply more fertilizer than plants can use under normal or poor weather conditions and nutrient run-off and leaching can become increasingly prevalent. Therefore, a policy targeted at reducing this behavior may be considered by policy makers.

A commonly researched remedy to this problem is a tax aimed at adjusting the farmer's application rate decision. When nutrients are over-applied relative to yield potential or applied prior to rain, there is an increased risk of nutrient running off into streams or leaching into groundwater. Fertilizer run-off can damage the ecosystem of rivers and bodies of water further downstream from the source of pollution. The Environmental Protection Agency (EPA) believes that fertilizer use in the United States has contributed to hypoxia in the Gulf of Mexico and that improved fertilizer management can help to reverse this damage (EPA 2007). Dead zones, such as the one found in the Gulf of Mexico, are caused by increased levels of nitrogen and phosphorus in the water, two major nutrients used as inputs in farming. The United States Geological Survey (USGS) estimates that more than 70% of this pollution comes from agricultural sources (EPA 2014). Heightened levels of nitrogen and phosphorus can allow the formation of algal blooms that reduce the level of oxygen in the water making the habitat unsuitable for many forms of marine life. A policy aimed at reducing nutrient over-application would help reduce unintentional pollution.

Output from the model created for this thesis will be used to produce estimates of supply and demand variables and prices for nitrogen, phosphorus, and potassium fertilizers from 2013 to 2030. Performing scenario analysis and comparing resulting model output to this baseline yields important information to decision makers and can help individuals better understand the effects of both policy decisions and other factors that can affect fertilizer supply and demand. While not performed as part of this thesis research, linking this model of fertilizer markets to a larger system of partial equilibrium models would show the effects of changes in the fertilizer sector on other commodity markets. Additional information about how these changes in fertilizer markets can affect a broader range of commodity markets can help individuals make more informed decisions.

When used in combination with other agricultural crop models, output from this fertilizer model can be used to enhance the accuracy of crop cost of production estimates. For instance, two outputs from this fertilizer model are the nitrogen application rate per acre of corn and the price of ammonia. With some manipulation of the units of both variables, the two can be multiplied to get the portion of the cost of production that can be attributed to nitrogen fertilizer use. This process can be replicated for the remaining nutrient varieties and utilized in estimating the expected net returns that drive crop supply decisions in crop market models. This is one example of how a fertilizer model can be used in combination with other agricultural models.

Constructing the model for this thesis requires an understanding of the fertilizer industry, a review of relevant previous literature, a theoretical background, and available sources of data. The model for this thesis was assembled in order to test the effects of relevant policy options and examine the effects of other factors on supply and demand in fertilizer markets. Each of these issues has implications on how a model is structured and directly affects the way the model responds to changes in the market. Subsequent chapters will describe these issues in fine detail, as well as results of the baseline projections and analysis of alternative scenarios.

CHAPTER TWO

INDUSTRY OVERVIEW

The goal of this chapter is to give an overview of the global fertilizer industry with a specific focus on the United States. The first section will explore the fertilizer industry as a whole and subsequent sections will look more closely at individual nutrient industries.

General Fertilizer Industry Overview

Global fertilizer producers provide key inputs for agricultural crop production. Fertilizer use has allowed for increased yields of agricultural commodities adding to the farmer's ability to feed the planet. While fertilizers are generally categorized by major nutrient type, many combinations of NPK nutrients are achievable and can be purchased by the farmer to fit specific soil requirements. As technology has advanced over time, farmers have become more efficient in their use of fertilizers. The most efficient users can distribute nutrients to the soil based on specific requirements for each acre rather than applying fertilizer at a flat rate across an entire field.

For farmers in the United States and abroad, nitrogen fertilizers are applied in the largest quantities accounting for about 61% of global fertilizer use and 59% of fertilizer use in the United States in 2011. The remainder of fertilizer use in the United States is split between phosphorus and potassium at 20% and 21%, respectively. Global consumption is similarly distributed with phosphorus accounting for 22% of global use and potassium 17%. While each nutrient is very important for production of agricultural commodities, the majority of the focus on policy analysis and industry discussion for this thesis will be on nitrogen fertilizer markets (FAO 2014).

New production facilities are costly to build and take a significant amount of time to complete. Greenfield projects are those that are built in a location where there was not a fertilizer facility previously. Brownfield projects are built where preexisting infrastructure such as railways can be reutilized. Since certain infrastructure can be reused, these two types of building projects may have different total costs of production.

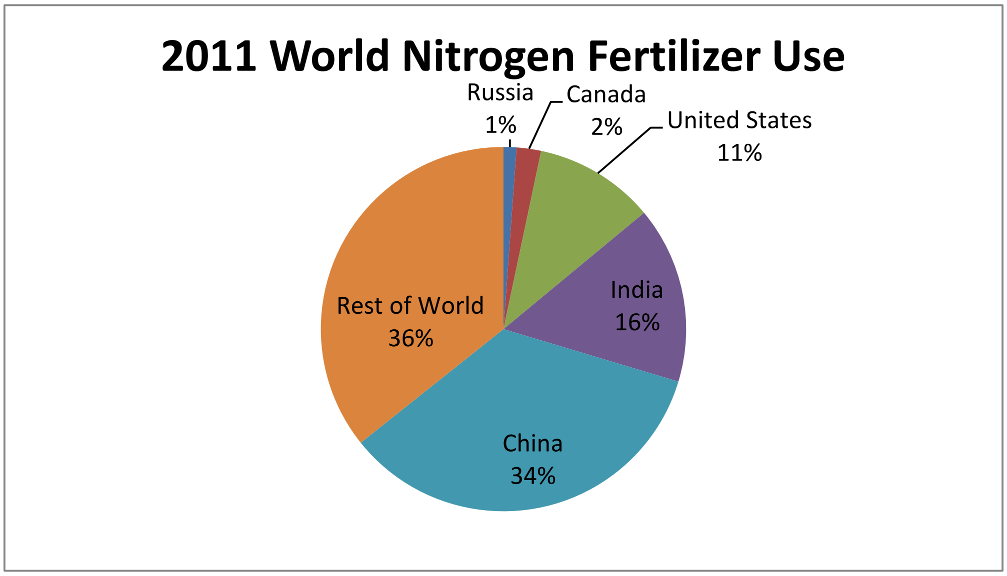
A greenfield ammonia facility with a capacity of one million metric nutrient tons costs between 1.8 billion and 2 billion dollars to construct (PotashCorp 2013a). To put this into perspective, in 2011, global production of nitrogen fertilizers, by nutrient weight, was 110.5 million metric tons (FAO 2014). This means that to expand global production potential of nitrogen fertilizers by less than 1% would require an investment of around 2 billion dollars. Similarly, a phosphate facility of the same capacity requires estimated costs of 2.1 billion to 2.3 billion dollars, and a potash facility with a capacity of 2 million metric nutrient tons is estimated to cost 4.7 billion to 6.3 billion dollars (PotashCorp 2013a). A discussion of why these costs differ will be included in further detail in the following overview sections.

Considering the presence of high industry concentration and the significant investment required to build a new production facility, it is reasonable to assume that there are high barriers to entry in both the fertilizer industry itself and in the individual nutrient markets. These barriers to entry may allow firms to maintain positive economic profits as potential entrants into the market may be unable to afford the costs of building a facility large enough to compete with the lower average fixed costs associated with larger production facilities.

Fertilizer application rates per hectare in the United States and most high-income countries are high and relatively stable. If this pattern continues, any significant future demand growth in countries like the U.S. would have to come from increases in crop acreage rather than increases in application rates. Alternatively, shifts from crops that have lower nutrient requirements (soybeans) to crops that are more nutrient dependent (corn) will also result in increased fertilizer demand. In Russia and the ROW, where application rates are much lower, there may be room for demand growth from increases in application rates (Rosas 2012). Additional demand growth may come from industrial uses other than fertilizer use. According to FAO (2014) data, non-fertilizer nutrient use accounted for 31% of nitrogen, 67% of phosphorus, and 40% of potassium nutrients consumed in the United States in 2011. While these uses are relatively large for the U.S., non-fertilizer use for the majority of countries is missing from the Food and Agricultural Organization (FAO) dataset. Non-fertilizer uses of nutrients include applications in housing construction and explosives for nitrogen, detergents and cleaners for phosphorus, and water softeners and food products for potassium (PotashCorp 2014d).

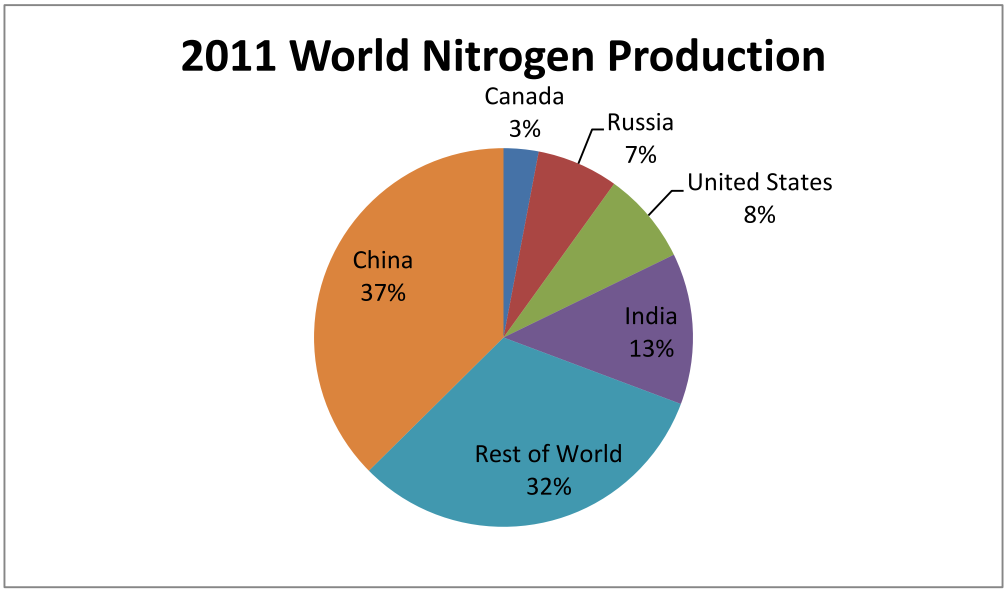
Corn requires the largest amount of each of the three nutrients, accounting for the use of 47% of nitrogen fertilizers, 44% of phosphorus fertilizer, and 45% of potassium fertilizers in the U.S. (FAO 2014). Globally, 64% of nitrogen, 60% of phosphorus, and 51% of potassium fertilizers were consumed by Canada, China, India, Russia, and the United States with the remaining portions accounted for by the Rest of World (FAO 2014). Similarly, 63% of nitrogen, 68% of phosphorus, and 61% of potassium nutrients were produced by the same set of included countries (FAO 2014). Additional countries of importance that are not included in this model are Indonesia, Pakistan, Brazil, Belarus, Germany and other countries of the European Union, and Australia. The five modeled countries were identified as being either in the top five producers or consumers of at least one nutrient in 2011. Pie graphs summarizing fertilizer consumption and production can be seen below.

Figure 1.1 - 2011 World Nitrogen Fertilizer Use



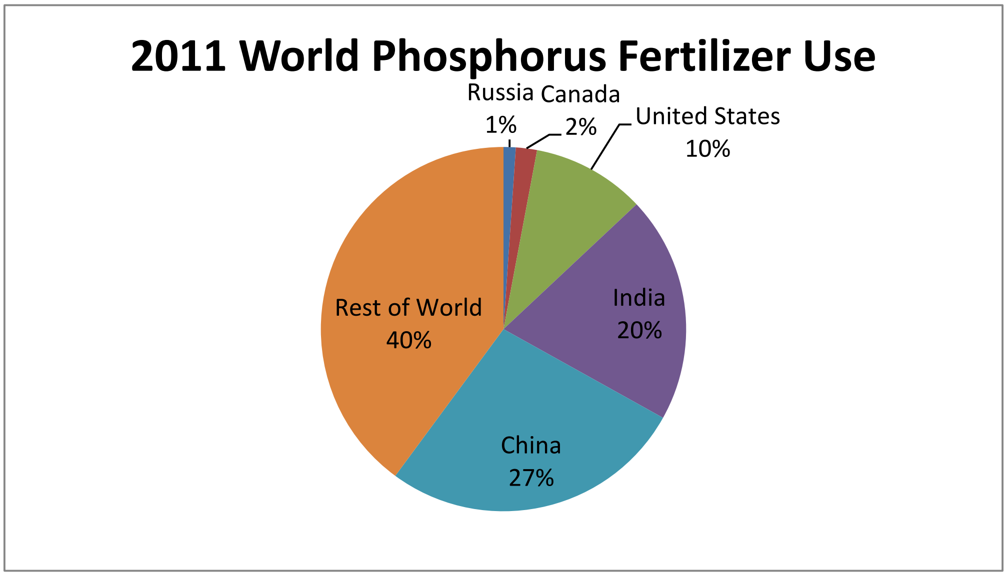
Source: FAO 2014

Figure 1.2 – 2011 World Nitrogen Production



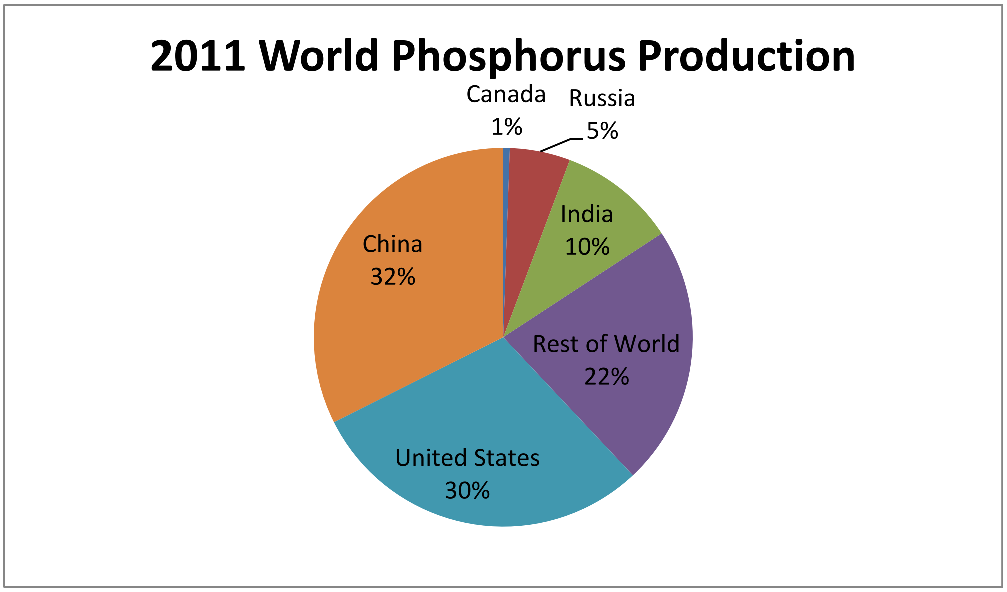
Source: FAO 2014

Figure 1.3 – 2011 World Phosphorus Fertilizer Use



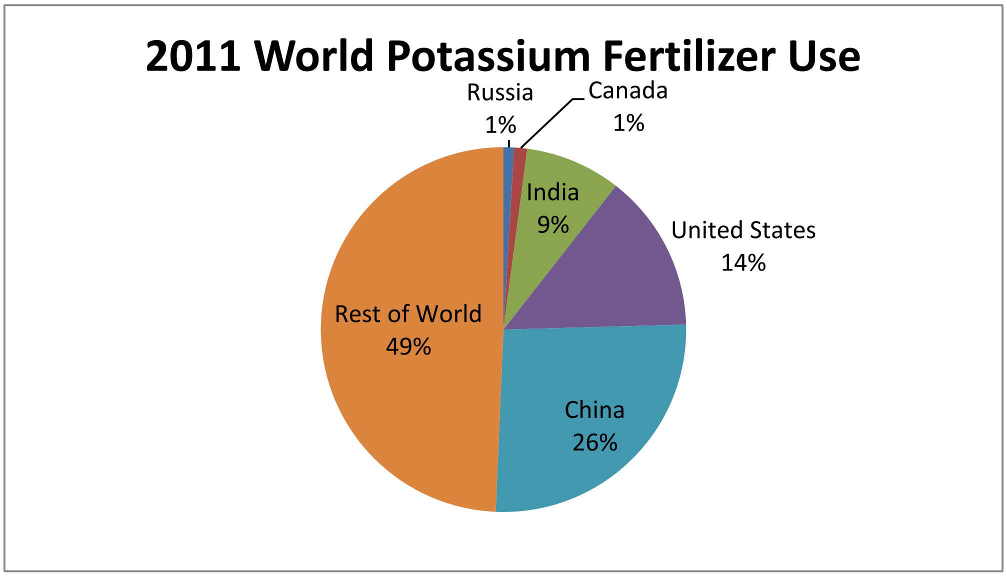
Source: FAO 2014

Figure 1.4 – 2011 World Phosphorus Production



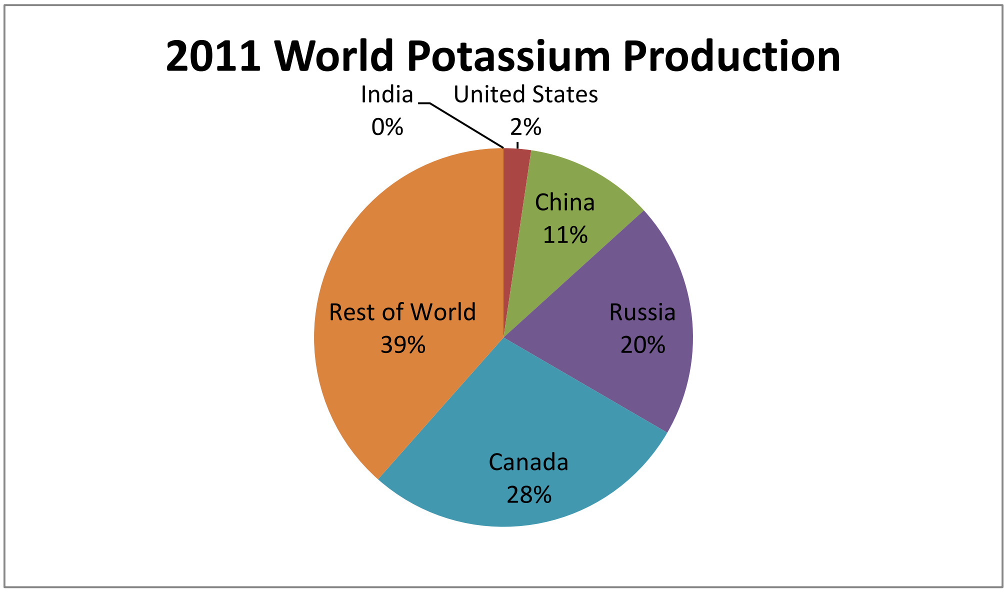
Source: FAO 2014

Figure 1.5 – 2011 World Potassium Fertilizer Use



Source: FAO 2014

Figure1.6 – 2011 World Potassium Production



Source: FAO 2014

Nitrogen Fertilizer Overview

Nitrogen is the main fertilizer nutrient consumed globally, accounting for 61% of total fertilizers consumed in 2011, measured by nutrient tons (FAO 2014). Ammonia can be directly used as a nitrogen fertilizer itself in the form of anhydrous ammonia or further developed into urea, ammonium nitrate, or Urea-Ammonium Nitrate. It is synthesized from natural gas and elemental nitrogen from the atmosphere. Natural gas is the main input for nitrogen fertilizer production and makes up approximately 70 to 85 percent of the cost of producing ammonia (PotashCorp 2013b). A strong physical relationship in production means that one might expect to find a correlation between the price of natural gas in the United States and the domestic price of ammonia.

When ammonia prices are high relative to natural gas prices, the high profitability of ammonia production should encourage increased use of existing capacity and could induce new investment in plant capacity. In a perfectly competitive market new competitors would enter the market until economic profits (which consider all relevant costs, not just short-run variable costs) are reduced to a level close to zero. However, the high profitability of ammonia production in recent years is consistent with arguments that U.S. fertilizer markets have high barriers to entry, perhaps caused by the high capital cost and long time frames associated with building new plant capacity in an industry with some characteristics of a non-competitive market structure. Despite high industry concentration, many smaller firms are able to operate in the industry, implying that barriers to entry are not so high as to preclude all competition. Additionally, U.S.

fertilizer producers must compete with many producers in other parts of the world (IFDC 2013). Therefore, it is unlikely that high levels of long-term profits can be sustained in the nitrogen fertilizer industry. In the long run, one would expect margins between ammonia prices and natural gas costs to be narrower than they were between 2008 and 2012. If recent high profits were maintained, they would incentivize the full use of existing capacity, the expansion of capacity by existing firms and perhaps new entrants into the market.

Building a new ammonia production facility takes a minimum of three years from initial planning to production (PotashCorp 2014a). For new capacity to be built and ready to come online in 2012, planning would have had to start before 2009 when the profit margin was much lower. Given the time it takes to plan and construct a new plant, an increase in expected profits will only translate into increased plant capacity after a several year lag.

There is evidence that additional investment has taken place during this period of high profitability. The International Fertilizer Development Center (IFDC) provides a data series of current and planned capacity for ammonia, phosphoric acid, and potash that highlights new production facilities that will become operational over the next several years (IFDC 2013). This information is used in constructing capacity projections in the model developed for this thesis.

Using the IFDC database, it was found that the top five North American (Canada and U.S.) ammonia producers accounted for 70% of nameplate capacity in 2013 (IFDC 2013).

These companies were CF Industries (US) with 28%, Agrium (CA) with 13.8%, Koch Industries Company (US) with 10.7%, PCS Nitrogen Fertilizer L.P. (US) with 10.5%, and Canadian Fertilizers Ltd. (CA) with 7% of total North American ammonia capacity (IFDC 2013).

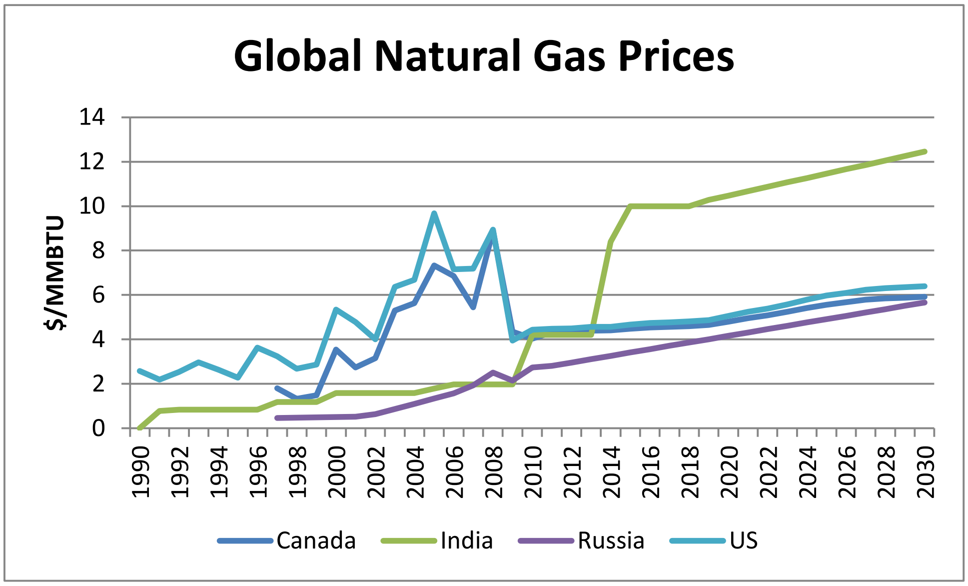
A significant shift in the U.S. natural gas market occurred in 2009 due to a decline in consumption of 1.8% as a result of the economic recession and increased production of natural gas domestically (EIA 2011). This prompted natural gas prices to drop from the high of $9.65 per million BTU seen in 2008 (EIA 2014). Natural gas prices dropped by 56% in 2009 but recovered 10% by 2012 (EIA 2014). The 2012 price for natural gas in the United States was $4.50 per million BTU (EIA 2014). The Russian natural gas export price, taken from International Monetary Fund, was nearly three times higher than the U.S. price at $11.98 per million BTU in 2012 (IMF 2014a). Similarly to prices in the United States, Canadian natural gas prices have also declined. Canadian natural gas prices were $8.88 per million BTU in 2008 and had declined 55% to $4.03 by 2010 (EIA 2010). While natural gas prices in the U.S. and Canada saw a sharp decline in 2009, prices in other parts of the world have seen differing trends in prices. In contrast to U.S. gas prices, Russian natural gas prices dropped by a much smaller amount of 15% in 2009, with a 27% recovery in 2010 (EIA 2010). Domestic natural gas prices in Russia were the cheapest of included countries with a price of only $2.74 per million BTU in 2010 (EIA 2010).

The natural gas price for use in nitrogen fertilizer production in India is highly regulated. Natural gas prices for use in fertilizer production fall under the Advanced Pricing Mechanism (APM) of India (Infraline Energy n.d.). While APM prices were historically low, recent prices have been revised to a point where they are closer to spot market prices (Infraline Energy n.d.). An increase in APM natural gas prices for fertilizer use was scheduled to occur in April 2014. Indian APM prices in 2013 were $4.2 per million BTU and will be increased to $8.4 per million BTU in 2014, an increase of 100% (Infraline Energy n.d.).

While natural gas is the main feedstock for producing nitrogen fertilizers in the other modeled countries, approximately 75% of nitrogen fertilizer was produced from coal in China, in 2010 (IETD 2013). However, because a coal price for China was not found, the Australian coal price has been used as a proxy. Approximately 1.5 metric tons of coal is required to produce one metric ton of ammonia (China Coal Research Institute 2011). Australian coal prices saw a significant increase of 93% in 2008, followed by a 46% decrease in 2009 (The World Bank 2014). A smaller spike in prices occurred in 2011 when Australian coal prices increase by 23%, but prices returned close to the 2010 level, decreasing 21% in 2012 (The World Bank 2014).

Retail ammonia markets in the U.S. showed a decreasing price trend with a drop of 20% in 2009 and a subsequent drop of around 21% in 2010, compared to the 56% decrease in natural gas prices in 2009 (USGS 2014a). However, retail ammonia prices returned to 2009 levels by 2012. Rising commodity prices may account for the rebound in ammonia prices in spite of continued low prices for natural gas (WAEES 2012b). The 2012 U.S. wholesale ammonia price was $634 per metric ton (USGS 2014a).

Figure 1.7 – Global Natural Gas Prices



Sources: Natural Gas Prices for the U.S., Canada, and Russia (EIA 2010), Compiled sources for India

Phosphorus Fertilizer Overview

Globally, phosphorus fertilizers are the second most common type of fertilizer. China is the world's largest producer of phosphorus fertilizer accounting for 32% of production in 2011, followed closely by the United States at 30%. Russia, India, and Canada make up an additional 16% of global production (FAO 2014). Phosphorus fertilizers come in two major varieties, diammonium Phosphate (DAP) and monoammonium phosphate (MAP). DAP and MAP fertilizers are produced from sulfuric acid, phosphate rock, and ammonia. These two types of fertilizer differ in their ratios of the three inputs. DAP has a higher nitrogen content but less phosphorus than MAP. Other phosphorus fertilizers (such as superphosphate) are produced using different production techniques, not all of which involve the use of ammonia. Phosphate rock is mined in the form of ore and is reacted with sulfuric acid to produce phosphoric acid (PotashCorp 2011). Similar to ammonia for nitrogen fertilizers, phosphoric acid is the main building block for producing many phosphorus based fertilizers.

The U.S. phosphorus fertilizer industry is highly concentrated with the top four firms controlling approximately 90% of nameplate capacity in 2013 (IFDC 2013). These four firms are Mosaic Company with 46.6%, PCS Phosphate Company Inc. at 24%, and CF Industries Inc. at 10.6%, and J.R. Simplot Company at 8.6% of nameplate capacity (IFDC 2013). Capacity expansion takes three to four years to construct a new 1 million metric ton P_2O_5 plant (PotashCorp 2013a). Costs of increasing capacity are estimated to be higher for phosphorus than for ammonia, possibly because the costs of constructing a phosphate rock mine, a sulfuric acid plant, and a phosphoric acid plant are included in this estimate. Phosphoric acid is 60% P_2O_5. Therefore 1 million metric tons of P_2O_5 is equivalent to 1.7 million metric tons of phosphoric acid. With global phosphoric acid capacity for 2011 of approximately 52 million metric tons, an additional 1.7 million metric tons would increase global capacity by a little over 3%. As in the ammonia market, high levels of profitability would be expected to lead to investment in capacity that would eventually translate into increased production and more normal rates of profit.

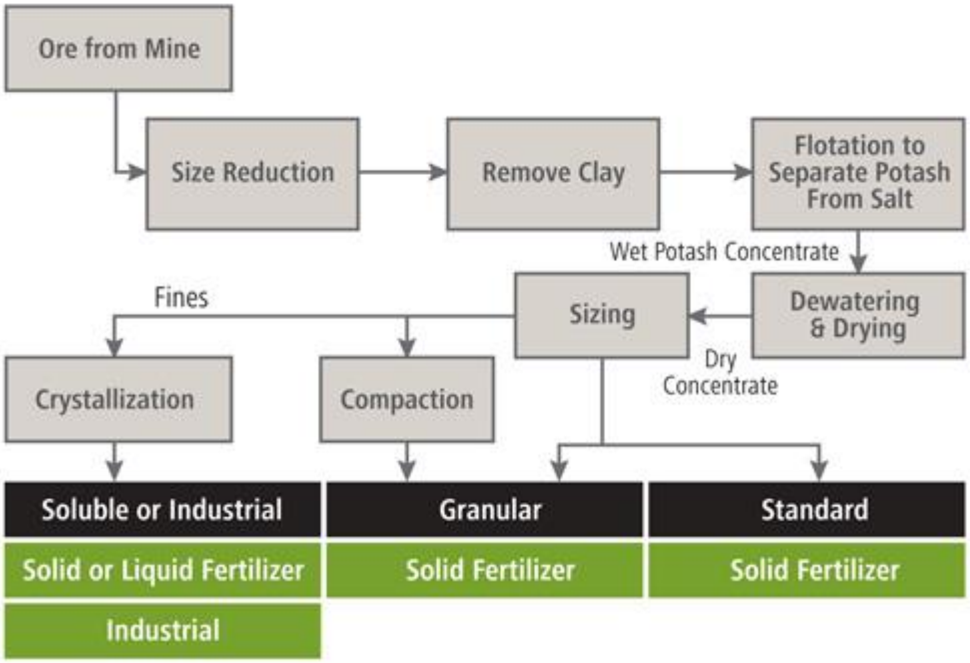
U.S. DAP prices saw major volatility in 2007 when the yearly average price increased from $320 per metric ton to nearly $750 per metric ton, an increase of over 130% (NFDC n.d.). By 2009 prices had plunged back to $384 per metric ton, perhaps due in part to a 10% increase in global phosphorus production (NFDC n.d.; FAO 2014). Lower demand in 2008 may have also pushed prices lower in 2009. The U.S. accounts for 10% of phosphorus fertilizer use behind China with 27%, and India with 20% of global consumption (FAO 2014). Russia and Canada account for only 1% and 2% of phosphorus fertilizer consumption, respectively (FAO 2014).

Potassium Fertilizer Overview

In 2011, the United States controlled approximately 2% of global potassium fertilizer production (FAO 2014). Canada is the world's largest producer accounting for 28% of global production in 2011 (FAO 2014). The North American potassium fertilizer industry is highly concentrated with the top four firms controlling approximately 98.4% of nameplate capacity in 2013 (IFDC 2013). These four firms are Mosaic (CA/US) with 45.9%, PotashCorp (CA) with 41.9%, Agrium (CA) with 7.3%, and Intrepid Mining LLC (US) with 3.3% of North American nameplate capacity in 2013 (IFDC 2013). Although the U.S. produces a small portion of total potassium fertilizers, the United States is the second largest consumer accounting for 14% of global fertilizer consumption in 2011 (FAO 2014). Potassium fertilizer is consumed in the form of potassium chloride, also known as potash. Potash is mined directly from ore deposits making the production process significantly different than that of nitrogen and phosphorus fertilizers.

After potash is extracted from a mine it must go through processing as summarized in the Figure 1.8.

Figure 1.8 – Potash Fertilizer Production Flow-Diagram



Source: PotashCorp 2014c

Contrary to production costs of phosphorus and nitrogen fertilizers, production of potassium fertilizer does not require a single major input like natural gas or phosphoric acid. Instead, variable production costs for potash come mainly from mining costs (e.g. fuel costs) and electricity and labor inputs required to power refinement facilities throughout the production process.

Construction of a two million metric ton potash mine takes a minimum of seven years to complete at a cost of 4.7 to 6.3 billion dollars (PotashCorp 2013a). Global potash production capacity in 2011 was 47 million metric tons (IFDC 2013). Construction of a 2 million metric ton mine would be equivalent to a 4.2% increase in global capacity in 2011 (IFDC 2013). As with both nitrogen and phosphorus, it is likely that there are significant barriers to entry into the potash market.

Russia accounts for an additional 20% of total potassium fertilizer production (FAO 2014). Two groups of producers dominate the global potassium fertilizer industry. The first is Belarusian Potash Co., a partnership between Belaruskali of Belarus and Uralkali of Russia. The second group is Canpotex Ltd., an exporting entity that sells potash for PotashCorp and Agrium in Canada, and Mosaic in the United States. These two groups controlled approximately 70% of global production in 2013 (Marotte 2013). In July of 2013, Uralkali announced they would end an agreement that formerly limited supply of potassium fertilizers out of Russia (Fedorinova 2013). Following the announcement, stock prices for companies producing potassium fertilizer dropped due to the expected increase in supply. Uralkali has announced intent to increase output by 24% for 2014 which equates to around two million metric tons of potash. This expansion in production is equal to 6% of 2011 global potassium fertilizer production. If this additional supply were to come online, it would put downward pressure on potash prices, and farmers would respond by consuming more of the nutrient in 2014 (Clark 2013). Uralkali has also made it clear that they expect to see world potash prices 25% lower in 2014 than in 2013 (Marotte 2013).

CHAPTER THREE

LITERATURE REVIEW

Because of time and data constraints no attempt will be made to use econometric methods to estimate the parameters of the model developed in this thesis. Instead, parameters for this model will rely heavily on the results of previous estimation. Particular parameters of interest are fertilizer demand elasticities with respect to both fertilizer input prices and commodity output prices. Parameters used to drive model equations are synthetically derived from these elasticities. While some adjustments are made to estimates from previous literature to better match observed data and ensure plausible model behavior, the values from previous literature serve as strong priors for this study.[1] This chapter summarizes relevant previous works that have contributed to the estimation of fertilizer market relationships.

Demand Literature

In the United States, much effort has been made to estimate the effects of changes in fertilizer prices on crop demand for fertilizer. Studies vary in many ways including the crops studied, level of nutrient aggregation, covered nutrient types, estimation period, equation functional form, and regression technique. These factors lead to widely varying estimates of elasticities and other important differences across the studies. In addition to research focusing on the U.S., an attempt has been made to assemble elasticity studies for China, Canada, India, Russia, and other countries. As is evident in the

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[1] Elasticity values used in the model can be found in Appendix B.

literature review below, there is an absence of research for Russia and Canada. Only a single study was identified for Indian fertilizer markets, and only one study that covers South and Southeast Asia.

Heady and Yeh (1959) estimated demand functions of fertilizer for an aggregated crop group for each of the individual nutrient types in the United States. Two demand functions were used to estimate the responsiveness of fertilizer use to nutrient prices. Key differences between these two equations were the variables included in estimation. In the first equation, two groups of cash receipts were utilized, and in the second a lagged average crop price index was included. The first approach was applied to each of the three endogenous fertilizer categories to produce nutrient-specific elasticity estimates.

The authors found that farmers had an inelastic response in their nutrient application rate decisions with respect to a fertilizer price index. While they did not estimate the response for different crops, they did find estimates for each of the three nutrients. Nitrogen and phosphorus fertilizers were estimated to have the most responsiveness with elasticities close to -0.45 followed by potassium at -0.4. Elasticities were also calculated with respect to crop cash receipts. These measures were 0.8, 0.58, and 0.88 for nitrogen, phosphorus, and potassium, respectively. Thus, the results suggested that fertilizer use might be more sensitive to output prices than input prices.

Gunjal et al. (1980) estimated demand functions of fertilizer for five crops in the United States. The study used a dataset spanning from 1952 to 1976, a period over which fertilizer consumption expanded significantly. Differing from the earlier work of Heady and Yeh, Gunjal et al. estimated fertilizer demand by crop but did not split fertilizer by nutrient type due to differences in data availability. Crops included in estimation were wheat, soybeans, cotton, feed grains, and tobacco.

The authors discovered elasticities with respect to fertilizer prices for feed grains and wheat of -0.9 and -0.99, but found slightly more inelastic responses for soybeans and cotton at -0.62 and -0.31, respectively. The elasticity estimate for feed grains with respect to fertilizer prices was calculated using a ratio of output prices to fertilizer prices so the inverse of this estimate, or 0.9, is the output price elasticity. Output price elasticity was also calculated for wheat and was found to be inelastic at 0.42.

Roberts and Heady (1982) estimated nine equations of fertilizer demand in the United States using data from 1952 to 1976. Attempts to include all cross-price effects in a single equation were unsuccessful, perhaps due to high multicollinearity among the fertilizer prices. The authors assembled application rates for nitrogen, phosphorus, and potassium for three crops and for each state. These values were then aggregated to the national level. The three crops covered in this study were corn, wheat, and soybeans. To estimate these equations the authors used seemingly unrelated regressions. Roberts and Heady suggested that while price elasticities were important, other factors such as technology and farming practices may affect application rate more than the price of nutrients.

Roberts and Heady estimate larger elasticities for corn than for wheat and soybeans. The fertilizer own-price elasticity values for corn for nitrogen, phosphorus, and potassium were -1.15, -1.13, and -1.3, respectively. These results are similar to those found by Gunjal et al. but are quite a bit larger than estimates found earlier by Heady and Yeh. Additional elasticities were estimated at -0.23 (N), -0.74 (P), and -0.24 (K) for wheat and -0.29 (N), -0.82 (P), and -0.96 (K) for soybeans. Note that the studies cited so far all estimated parameters using data for the period when fertilizer use was expanding rapidly.

For the United States, Zelaya (1991) estimated a model of fertilizer supply and demand using data from 1964 to 1988. This study had broader coverage than previous research. Crops covered in Zelaya's model were corn, soybeans, wheat, and cotton. An "other crops" category was also included. Estimating fertilizer demand relationships for these crops produced useful elasticities for both input and output prices. In equations where either input prices or output prices did not perform well, a ratio of the two prices was used. Zelaya found that fertilizer demand for the observed crops in the United States was relatively unresponsive to changes in fertilizer prices. The author also compiled a list of other relevant studies that estimated fertilizer demand elasticities. However, Zelaya provides a much more extensive group of estimates in his 1991 thesis than previous authors (Figures 3.1 & 3.2).

Denbaly and Vroomen (1992) used dynamic error-correction models to estimate demand elasticities of nitrogen, phosphorus, and potassium for corn in the United

States. Consistent with the majority of the other studies examined here, Denbaly and Vroomen estimated inelastic responses in fertilizer demand with respect to nutrient prices for corn, both in the short-run and the long-run. The study used data from 1964 to 1989 to estimate responsiveness. The authors argue that a dynamic model is more appropriate for estimating corn fertilizer demand than a static one and suggest that this sort of estimation leads to higher statistical significance of regression estimates. Short-run elasticities for corn with respect to the price of nitrogen, phosphorus, and potassium fertilizers were -0.21, -0.25, and -0.19, respectively. Long-run elasticities were more responsive at -0.41 (N), -0.37 (P), and -0.31 (K).

Garcia and Randall (1994) estimated cost-functions to compute input demand elasticities in order to analyze the consequences of fertilizer policy on corn and wheat in the U.S., France, and England. U.S. data for this estimation spanned from 1975 to 1989. The authors found that combined NPK fertilizer demand for wheat and corn was inelastic with wheat being more elastic than corn in the United States. Hicksian elasticities, which hold crop output constant, for wheat and corn were -0.34 and -0.06. The authors also found inelastic responses for France and England. As this is an aggregated nutrient category, these elasticity estimates are less useful for utilization in this synthetic model, but the inelastic results stay consistent with most of the other studies.

Williamson (2011) estimated the elasticity of the application rate of nitrogen for corn in the United States using the Agricultural Resource Management Surveys from 2001 and

2005. The author used cross-sectional methods and instrumental variables to estimate the effects of nitrogen prices on demand. Williamson found elasticity values between -1.67 to -1.87 for corn which are quite high compared to other studies examined. Williamson includes some unique measures of distance in his estimation of nutrient demand. Additionally, the estimated fertilizer demand equations included factors such as whether farmers used soil testing, whether farmers irrigated, farmer education, and many other relevant variables. Williamson also addressed the issue of over application of nitrogenous fertilizers in the U.S. and discussed the policy implications of a tax scenario on nitrogen fertilizers. It is not unusual for cross-sectional analysis to generate different estimates than time-series approaches, and there are questions about the appropriateness of applying parameters from cross-sectional analysis in projection work such as that conducted in this thesis.

Dholakia and Majumdar (1995) estimated the total NPK fertilizer demand elasticity in India using a data set from 1966 to 1992. The authors estimated an inelastic response, with respect to a weighted combined NPK fertilizer price, of -0.28 for an aggregate “all crops” category. These results support a claim that fertilizer demand in India is inelastic to prices, similar to observations of fertilizer demand in the United States from other studies.

Li et al. (2011) calculated partial factor productivity (PFP) of nitrogen fertilizer for corn, wheat, and rice for the South and Southeast Asia region. This region is of interest as it includes both India and China, two of the five countries included in the global NPK model for this thesis. The authors then used these PFP measures to estimate nitrogen fertilizer application rates and attempt to find optimum nitrogen use. In doing this, the authors ultimately calculated nitrogen fertilizer demand elasticities with respect to input prices for the region. Resulting elasticity estimates for each of the three commodity groups were negative and inelastic, with wheat (-0.17) being the most responsive and corn (-0.11) being the least responsive to the price of nitrogen.

Supply Literature

In addition to elasticities for demand side equations, attempts were made to identify previous research discussing the specification of supply side equations in fertilizer and similar markets.

Kruse et al. (2007) discussed the implications of a biofuel policy extension in the United States. Rather than directly estimating production of biofuels in this study, they elected to break production into two pieces -- capacity and capacity utilization. Due to the long lifespan of production facilities and the time needed to construct a facility, multiple lags of a net return variable were used in estimating plant capacity. A term was also included in capacity specification to account for retiring plants in the industry. The utilization rate equation is a function of only the current period net returns. Additionally, the utilization rate equation is specified in logistic form to guarantee that estimated capacity use remains between zero and 100% of capacity. The product of these two variables was used to obtain forecasted values of production.

There are some holes remaining in this literature review. Fertilizer market studies for Russia and Canada are missing as no relevant studies have been found for these two countries. In order to produce a forecast for these countries, studies for other modeled countries are used as a guide. Different estimation periods, observed country, and commodity and nutrient aggregation lead to differences in elasticity magnitudes.

Table 3.1 – Own-Price Elasticities of Demand for Nitrogen, Phosphorus, and Potassium Inputs

Own-Price Elasticities of Demand for Nitrogen, Phosphorous, and Potassium Nutrient Inputs							
Study	**Region**	**Data Period**	**Commodity**	**Own-Price Elasticities**			**Variable Notes**
				N	**P**	**K**	
Heady and Yeh (1959)	U.S.	1910 - 1956	**All Crops**	-0.449	-0.448	-0.403	Fertilizer Price Index
Gunjal et al. (1980)	U.S.	1952 - 1976	**Feed Grains**	**ALL NPK:**	-0.9		Fertilizer Index / Feed Grains Price
	U.S.		**Wheat**	**ALL NPK:**	-0.99		Fertilizer Price Index
	U.S.		**Soybeans**	**ALL NPK:**	-0.62		Fertilizer Price Index
	U.S.		**Cotton**	**ALL NPK:**	-0.31		Fertilizer Price Index
Roberts and Heady (1982)	U.S.	1952 - 1976	**Corn**	-1.148	-1.131	-1.298	Nutrient Prices
	U.S.		**Wheat**	-0.232	-0.737	-0.236	Nutrient Prices
	U.S.		**Soybeans**	-0.293	-0.824	-0.956	Nutrient Prices
Zelaya (1991)	U.S.	1964 - 1988	**Corn**	-0.1297	-0.1045	-0.0755	Nutrient Prices
	U.S.		**Wheat**	-0.4554	-0.0747	-0.1033	Nutrient Prices
	U.S.		**Soybeans**	-0.0968	-0.1150	-0.0485	Nutrient Prices
	U.S.		**Cotton**	-0.0783	-0.2440	-0.2729	Nutrient Prices
	U.S.		**Other Crops**	-0.3049	-0.3167	-0.3201	Nutrient Prices
Denbaly and Vroomen (1992)	U.S.	1964 - 1989	**Corn - S.R.**	-0.21	-0.25	-0.19	Nutrient Prices
			Corn - L.R.	-0.41	-0.37	-0.31	Nutrient Prices
					Hicksian	**Marshallian**	
Garcia and Randall (1994)	U.S.	1975 - 1989	**Wheat**	**ALL NPK:**	-0.3383	-0.8758	Weighted Fertilizer Price
	U.S.		**Corn**	**ALL NPK:**	-0.0602	-0.954	Weighted Fertilizer Price
	France		**Wheat**	**ALL NPK:**	-0.0771	-1.0511	Weighted Fertilizer Price
	France		**Corn**	**ALL NPK:**	-0.0798	-1.1516	Weighted Fertilizer Price
	England		**Wheat**	**ALL NPK:**	-0.5227	-1.0901	Weighted Fertilizer Price
Williamson (2011)	U.S.	2001 & 2005	**Corn**	-1.67 to -1.87			Nitrogen Prices
Dholakia and Majumdar (1995	India	1967 -1992	**All Crops**	**ALL NPK:**	-0.28		Ratio of Fertilizer to Output Prices
Li et al. (2011)	S. and E. Asia	1980 - 2008	**Corn**	-0.11			Corn Price
	S. and E. Asia		**Rice**	-0.16			Rice Price
	S. and E. Asia		**Wheat**	-0.17			Wheat Price

Figure 3.2 – Output Price Elasticities of Demand for Nitrogen, Phosphorus, and Potassium Inputs

Output Price Elasticities of Demand for Nitrogen, Phosphorous and Potassium Nutrient Inputs

Study	Region	Data Period	Commodity	Output Price Elasticities			Variable Notes
				N	P	K	
Heady and Yeh (1959)	U.S.	1926 - 1959	**All Crops**	0.804	0.579	0.881	Cash Receipts
Gunjal et al. (1980)	U.S.	1952 - 1976	**Feed Grains**	**ALL NPK:**	0.9		Feed Grains Price / Fertilizer Index
	U.S.		**Wheat**	**ALL NPK:**	0.42		Lagged Wheat Price
Roberts and Heady (1982)	U.S.	1952 - 1976	**Corn**	1.053	0.592	0.633	Lagged Corn Price
	U.S.		**Wheat**	0.312	0.432	0.417	Lagged Wheat Price
	U.S.		**Soybeans**	0.065	0.504	0.015	Lagged Soybean Price
Zelaya (1991)	U.S.	1964 - 1988	**Corn**	0.1752	0.0647	0.0755	Composite Price
	U.S.		**Wheat**	0.0617	0.0681	N/A	Composite Price
	U.S.		**Soybeans**	0.0968	0.1399	0.0485	Lagged Market Price
	U.S.		**Cotton**	0.2307	0.1216	0.2729	Target Price
	U.S.		**Other Crops**	0.3049	0.3167	0.3201	Lagged Corn Price

CHAPTER FOUR

THEORETICAL ASPECTS OF SUPPLY AND DEMAND

The purpose of this chapter is to summarize key features of economic theory that form the foundation for the global fertilizer model. The theory discussed in this chapter will represent the derivation of supply and demand under the assumption of a perfectly competitive market. There is some evidence to suggest that the fertilizer industry has elements of an oligopoly market structure, but there are also features that suggest a competitive market structure. Even though the industry may not fit the competitive model in every respect, it has been assumed that the consequences of deviating from a perfectly competitive model would be small. The validity of this assumption could be evaluated by future research in order to determine the extent to which noncompetitive behavior in fertilizer markets might lead to results that differ from the predictions of a competitive model.

Profit Maximization – Derived Demand

In a perfectly competitive market, farmers are assumed to be price takers when it comes to both the prices they pay for inputs and the price they receive for their output. The individual producer is seen as a price taker because no single participant can affect output prices in a perfectly competitive market by changing their production decision.

Producers maximize profits by choosing an optimum level of production. In order to achieve this optimum level of production, an optimum set of inputs must be employed.

By solving the producer's profit maximization problem, one can acquire input demand equations. In general, the input demand equation for a specific input should be a function of the output price, the own input price, and the prices of other inputs.

The theory represented here will demonstrate an "n" input, one output case of profit maximization. In the case of this thesis, farmers' input demand equations for a single commodity output include such inputs as fuel, land costs, prices of other nutrients, and chemical costs. The theory discussed here has been adapted from Henderson and Quandt's (1980), *Microeconomic Theory: A Mathematical Approach*.

The individual's profit function is the difference between revenues gained by selling output, and the cost of producing that output.

$$\pi = TR - TC \qquad (4\text{-}1)$$

Substituting in $TR(x) = p*f(x_1, \ldots, x_n)$, and $TC(x) = (r_1x_1 + \ldots + r_nx_n)$ yields

$$\pi = pf(x_1, \ldots, x_n) - \sum_{i=1}^{n}(w_i x_i) \qquad (4\text{-}2)$$

Where:

p = Output price

x_i = Quantity of input i

w_i = Price of input i

In this form it can be seen that profit is a function of the output price, inputs, and input prices. As input quantities are the only choice variable, profits are maximized with respect to input variables. Differentiating equation (4-2) with respect to inputs yields the following First-Order Conditions of profit maximization.

$$\frac{\delta\pi}{\delta x_1} = pf_1 - w_1 = 0 \qquad (4\text{-}3)$$

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$$\frac{\delta\pi}{\delta x_n} = pf_n - w_n = 0 \qquad (4\text{-}4)$$

The first term in each equation represents the value of the marginal product of the respective input. The second term in each equation represents the marginal cost of each input, or the additional cost of employing one additional unit of the respective input. These equations can be re-written as follows to reveal an important maximization requirement.

$$pf_1 = w_1 \qquad (4\text{-}5)$$

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$$pf_n = w_n \qquad (4\text{-}6)$$

These equations show that in order for a producer to maximize profits, additional units of input will be employed until the marginal increase in total revenue added by the next unit of input is equal to the cost of employing that additional unit of input. From this point one can solve for input demand equations.

$$x_1^* = f(w_1,\ldots,w_n, p) \qquad (4\text{-}7)$$

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$$X_n^* = f(w_1,\ldots, w_n, p) \qquad (4\text{-}8)$$

Here, theory demonstrates that in the most general form, prices of complement and substitute inputs should be included in input demand equations. Due to a lack of estimates of the cross-price effects, input demand equations specified in this thesis contain only the own input price and output price. The prices of other nutrients and of other inputs such as fuel, chemicals, and labor costs could have small effects on application rates. Most previous research suggests that any cross-price effects are likely to be small, and they are not considered in this analysis.

In application, one property of input demand equations that must hold is homogeneity of degree zero. One way to ensure that this property will hold, is to deflate all prices in the model. In the model, this is done by deflating input and output prices by the gross domestic product (GDP) deflator.

Profit Maximization – Supply

The derivation of a firm's supply curve starts from the same initial point and under the same profit maximization assumptions that were used to derive input demand as shown below.

$$\pi = TR(y) - TC(y) \tag{4-9}$$

where TR(y) is total revenue and TC(y) is the total cost of producing the level of output y. To maximize profits given the optimum output level (y*), equation (4-9) is differentiated with respect to y.

$$\frac{d\pi}{dy} = MR(y*) - MC(y*) = 0 \tag{4-10}$$

Equation (4-10) can be rewritten as

$$MR(y*) = MC(y*) \tag{4-11}$$

Equations (4-10) and (4-11) imply that a profit maximizing firm will always produce at an output level where marginal revenue equals marginal costs. Producers in a perfectly competitive industry take output prices as given. Therefore total revenue can also be written as follows.

$$TR(y) = Py \tag{4-12}$$

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

$$MR(y*) = P \tag{4-13}$$

Equation (4-13) shows that the revenue gained from selling a unit of output is always equal to the price of that output, given the assumptions of a competitive market. Substituting equation (4-13) into (4-11) shows that the marginal cost of producing the last unit of output should also be equal to the given output price.

$$P = MC(y*) \tag{4-14}$$

A profit maximizing firm will produce at an output level where marginal cost is equal to the price received for selling an additional unit of output. Therefore, a firm treats its marginal cost curve as its supply curve because at any given output price the output level can be found by equating marginal cost to output price. The supply curve follows the portion of the marginal cost curve for levels of output where marginal cost is above average variable costs. At levels of output below average variable costs a firm would choose to produce nothing. For this reason, at all levels of output below the point where marginal cost is equal to the output price the supply curve will be equal to zero. The optimal quantity supplied (q_s*) is a function of the optimal input choices.

$$q_s* = f(x_1*, \ldots, x_n*) \tag{4-15}$$

By substituting in for input demand equations, equation (4-15) can be rewritten as a function of input prices and the output price.

$$q_s* = f(w_1, \ldots, w_n, p) \tag{4-16}$$

While the theoretical derivation for capacity and capacity utilization will not be demonstrated here, it is important to note that these results can be derived from the basic profit maximization problem presented above. The theoretical construction of these variables can be attributed to Houck, Ryan, and Subotnik (1972). Application of this theory is also found in a paper by Kruse et al. (2007) which examines the economic impacts of biofuels subsidies. Capacity was modeled with a significant lagged structure to reflect the idea that investment in production takes time. The number of lagged variables included in the capacity equation is a direct result of the average number of years required to complete the construction of a fertilizer production facility.

CHAPTER FIVE

DATA DISCUSSION

This fertilizer model is a global partial equilibrium model that focuses on the countries of Canada, China, India, Russia, and the United States. To make the model solution a global one, a Rest of World region has been aggregated to account for all other countries. Partial equilibrium models employ both exogenous and endogenous data to produce a forecast. The process of acquiring data is very important as collected data directly impact model results. The following section discusses exogenous and endogenous variables and data adjustments that were made in the development of this global fertilizer model.

Demand Data

The primary source of data for this model is the Food and Agricultural Organization Statistics Division (FAOSTAT) (FAO 2014). Demand variables used from this source include domestic consumption[2], non-fertilizer use, and exports. The FAOSTAT fertilizer dataset covers a ten year period from 2002 to 2011. Fertilizer use, non-fertilizer use, domestic consumption, and imports are in units of thousand nutrient metric tons.[3]

Application rates for nitrogen, phosphorus, and potassium for various countries were taken from the Center for Agricultural and Rural Development (CARD) at Iowa State

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[2] FAO's "domestic consumption" is re-termed as "fertilizer use" in this thesis because FAO treats non-fertilizer use separately. In other words, the summation of fertilizer and non-fertilizer uses will be referred to as domestic consumption for this thesis from here on.

[3] Nutrient tons of nitrogen measure the nutrient value of nitrogen in nitrogen-containing fertilizers.

University (ISU) (Rosas 2012). The CARD dataset includes corn, soybeans, rapeseed, and cotton. To calculate application rates for the observed period, the researchers started with some known initial application rate level for each variable. Application rate values for the remainder of the period were calculated by adjusting the application rate in the previous year by a growth factor. Nutrient use per hectare for wheat and rice were taken from the Food and Agricultural Policy Research Institute (FAPRI) at ISU (FAPRI 2011). The U.S. Department of Agriculture Economic Research Service (USDA ERS) provides U.S. application rates for corn, cotton, soybeans, and wheat but has missing data for various years (ERS 2013). As the CARD dataset is more complete only wheat application rates are utilized from the ERS source. The use of multiple data sources creates the potential for inconsistencies in the data, but there appears to be no other practical alternative. When years of data are missing, values are interpolated or additional sources are found to fill in these missing data. Application rate data are in terms of nutrient kilograms per hectare.

Application rate data are available for the period of 1990 to 2010 from CARD, and from 2000 to 2012 from FAPRI ISU. ERS application rate data span the period of1964 to 2012 with various years missing depending on the commodity.

The portion of fertilizer use that can be attributed to corn, soybeans, rapeseed, cotton, wheat, and rice can be obtained by multiplying area harvested for each commodity, taken from Production, Supply and Distribution Online (PSD), by respective nutrient application rates and summing these values. “Other crop” demand in the model is calculated by subtracting this value from total fertilizer use.

Supply Data

FAOSTAT is the primary data source for the supply side of this model. Supply variables used from FAOSTAT include production and imports. FAOSTAT fertilizer data cover a ten year period from 2002 to 2011. Both production and imports are in thousand nutrient metric tons.

In addition to FAO data, nutrient production capacity data were taken from the International Fertilizer Development Center (IFDC) (IFDC 2013). This variable is available at the plant, country, and region levels. Country level capacity represents the maximum amount of nutrient production that a country is able to achieve in a year. Nameplate capacity is not always fully utilized, so the capacity utilization rate is defined as the ratio of production to nameplate capacity for each year. Capacity data from IFDC are available from 1998 to 2012 for nitrogen and phosphorus fertilizers and 1996 to 2012 for potassium fertilizer. IFDC also provides a forecast of capacity expansion out to 2016 that serves as a guideline for calibrating capacity projections in this model. IFDC also estimates an “indefinite” level of capacity that is an estimate of eventual capacity in the future. Units of capacity variables are thousand nutrient tons, and capacity utilization rates are simple percentages between zero and 100.

Exogenous Variables

This section summarizes exogenous variables, other than input prices, that are used as explanatory variables in model equations. The majority of exogenous data, excluding prices, were taken from baseline models that were developed at the World Agricultural Economic and Environmental Services (WAEES).

Commodity prices used in input demand equations come from the WAEES baseline and cover the period of 1980 to 2030 (WAEES 2012b). Farm level commodity prices were used for corn, wheat, soybeans, cotton, rapeseed, and rice for each modeled country. All farm level prices are in local currency per metric ton of a given commodity. Producer Price Indices for electricity and wages were taken from WAEES cost of production models for use in potassium capacity equations for Canada, China, India, and the United States (WAEES 2012a). Macroeconomic variables including consumer price indices and the GDP deflator were also taken from the WAEES macro model (WAEES 2013). Macroeconomic variables originate from the International Monetary Fund (IMF) for years 1980 to 2018 with WAEES forecasts to 2030 (IMF 2014b).

Prices

The input prices examined here are the key drivers behind cost of production for nitrogen and phosphorus fertilizers. Cost of production measures are used in combination with fertilizer output prices to calculate net returns. This measure of profitability is used to simulate capacity expansion paths and the capacity utilization rate that are ultimately used to determine future production of fertilizer. Fertilizer output prices are also important drivers of individual crop nutrient demand equations. These facts make price data among the most important to get right. However, prices are often some of the hardest variables to acquire. When entire price series or specific years of data are missing, assumptions must be made in order to allow for model simulation. These assumptions may include using a price from a different country as a proxy, interpolating for missing values, combining price data from multiple sources, and extending a series based on available information. Additional sources of prices can be obtained from proprietary sources, but at a substantial monetary cost.

Below are discussions of data sources for input and output prices as well as assumptions that were made for each modeled country.

Input Prices

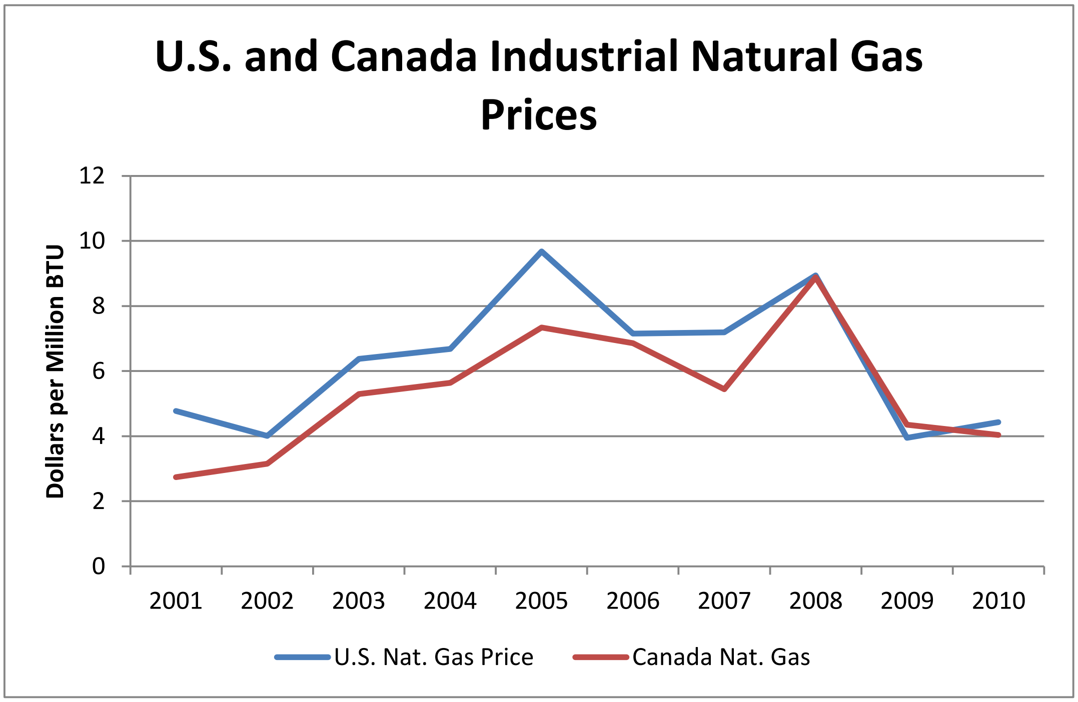
United States

Price information for the United States is the most complete of modeled countries. Natural gas prices for industrial use in the U.S. are taken from the Energy Information Administration (EIA) (EIA 2014). This price series is available from 1990 to 2013 with a forecast provided by EIA out to 2032. Phosphate rock prices come from the U.S. Geological Survey over the period of 1991 to 2012 (USGS 2014b). Values of this variable for the forecasted period have been estimated as a function of the U.S. crude oil price (The World Bank 2014) and the DAP output price in U.S. markets. This specification reflects the notion that phosphate rock has value primarily as an input for phosphorus fertilizer production, so its price is likely to be related to the price of phosphorus fertilizer. U.S. FOB Tampa sulfur prices were compiled from Nexant and Sulfur Information Services (Nexant 2009; Sulfur Information Services 2012). The FOB Tampa sulfur price is available from these sources from 1996 to 2012 with a forecast from Sulfur Information Services through 2017. Nexant estimates are applied to extend sulfur price projections to 2030. Due to data availability constraints, the Tampa FOB sulfur price was used as a proxy for sulfur prices in other modeled countries.

Canada

Natural gas prices for Canada are taken from EIA and are available from 2001 to 2010. However this series, unlike the U.S. price series from the same source, does not come with estimated values for the forecasted period (EIA 2010). North American natural gas markets are tightly linked with the two price series having a correlation value of 0.9 (Figure 5.1). Given the historical similarities it is a reasonable assumption that the price series will take similar paths into the future. For this reason the Canadian natural gas price is linked to the U.S. natural gas price using a price linkage equation to provide a forecast for the series out to 2030. The series is also backcast to 1997 using the same procedure. In the absence of a Canadian phosphate rock price, the U.S. phosphate rock price is used for Canada.

Figure 5.1 – U.S. and Canada Industrial Natural Gas Prices



Source: EIA 2014

China

As mentioned in the overview chapter, approximately 75% of China's ammonia is produced from coal rather than using natural gas. Due to data availability issues no China coal price was available, and the Australian coal price was used in its place (The World Bank 2014). While it would be ideal to have the Chinese coal price, it is better to use some other coal price as a proxy than to use a natural gas price that might not accurately represent the variable costs of producing nitrogen fertilizers in China. The Australian coal price series is available from 1980 to 2013 and is extended to 2030 by fitting a trend. The world phosphate rock price from The World Bank is used for China (The World Bank 2014). This price series is available from 1980 to 2012. For model simulation purposes, the world phosphate rock price was estimated as a function of the Brandt crude oil price from The World Bank and the DAP price in China to provide a forecast to 2030 (The World Bank 2014; NDRC 2014).

India

Natural gas prices for India are compiled from Infraline, the International Energy Agency (IEA), and a paper published by Harsh Kanani (Infraline Energy n.d.; Corbeau 2010; Kanani 2011). This series covers the period from 1991 to 2013. Natural gas pricing for fertilizer use in India falls under the Administrated Pricing Mechanism (APM). APM prices were historically much lower than natural gas prices in other modeled countries except for Russia, but recent policy changes have pushed Indian to levels closer to these other countries. Expected APM policy changes will double the APM price of natural gas in 2014, and is expected to increase further to $10 per million BTU in 2015 (FAI 2014; The Times of India 2013). For the forecasted period, prices are held flat at the 2015 level out to 2019 as Indian APM policy seems to follow a pattern of being revised approximately once every five years. For 2020 forward a trend based on historical data was used to forecast the remaining years of data. The same phosphate rock price used for China was also used for India.

Russia

Natural gas prices for Russia are also taken from EIA and are available from 2001 to 2010 (EIA 2010). A trend was fit to extend this series to 2030. The same World phosphate rock price used for China and India is used for Russia.

Rest of World

The ROW natural gas price used for this model is the Russian natural gas border price in Germany which was obtained from British Petroleum (BP 2013). This price series is available from 1985 to 2013 and is extended to 2030 through a price linkage to the domestic natural gas price in Russia. The two Russian natural gas prices have a correlation of approximately 0.88. The Russian export price was selected as Russia is the largest exporter of natural gas, accounting for approximately 26% of pipeline exports in 2012(BP 2013). This price was selected as it should accurately reflect Russian export policies that adjust the price paid by importing countries. The phosphate rock price used for the ROW is the same as the price that was used for China, India, and Russia.

Output Price Data

United States

Farm level prices for ammonia, DAP, and potash in the United States were obtained from the ERS (ERS 2013). Each prices series is available from 1980 to 2013. The March price was used as it represents fertilizer costs closest to the time of application (April prices were used between 1986 and 2008). Port ammonia and potash prices come from the United States Geological Survey (USGS) for 1991 to 2012 (USGS 2014a; USGS 2014c). The U.S. DAP port price was taken from the National Fertilizer Development Centre (NFDC) of Pakistan and PotashCorp to form a combined series spanning from 1995 to 2011 (NFDC n.d.; PotashCorp 2014c).

Canada

The Canadian farm level ammonia price comes from the Statistics and Data Development Branch, Alberta Agriculture and Rural Development (Alberta Agriculture and Rural Development 2012). A port price for ammonia has not been obtained for Canada, so the farm level price is used in place of a port price. The farm level ammonia price is available from 1983 to 2012. The Canadian MAP farm price is from the same source with data available from 1980 to 2012. The Vancouver FOB spot price for Canada was taken from The World Bank for years 1980 to 2012 (The World Bank 2014).

China

All nutrient prices for China were gathered from the Price Department of the China's National Development and Reform Commission, National Cost of Production Data (NDRC 2014). From this source implied prices were derived for urea, DAP, and potash from 1998 to 2012. The urea price from this source was used in place of an ammonia price for China.

India

For each nutrient group, fertilizer prices in China were used in the absence of Indian fertilizer prices. While this is not an ideal solution, an assumption was required to produce projections.

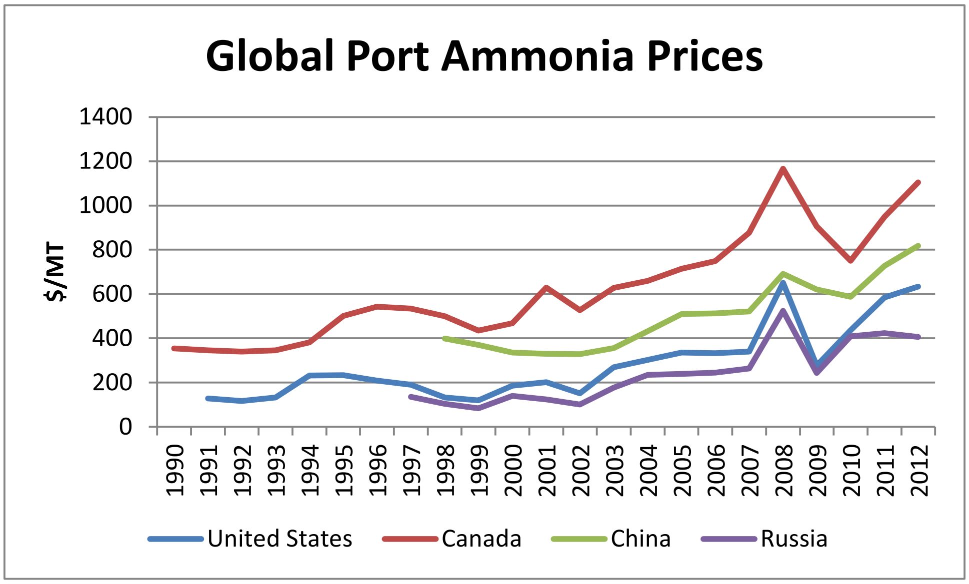
Russia

Russian ammonia prices were compiled from Yara International Historical Data and ICIS monthly reports for years 1997 to 2012 (Yara 2012; ICIS 2014). Potash and DAP prices for Russia were not available so China fertilizer prices were used in the absence of better options.

Rest of World

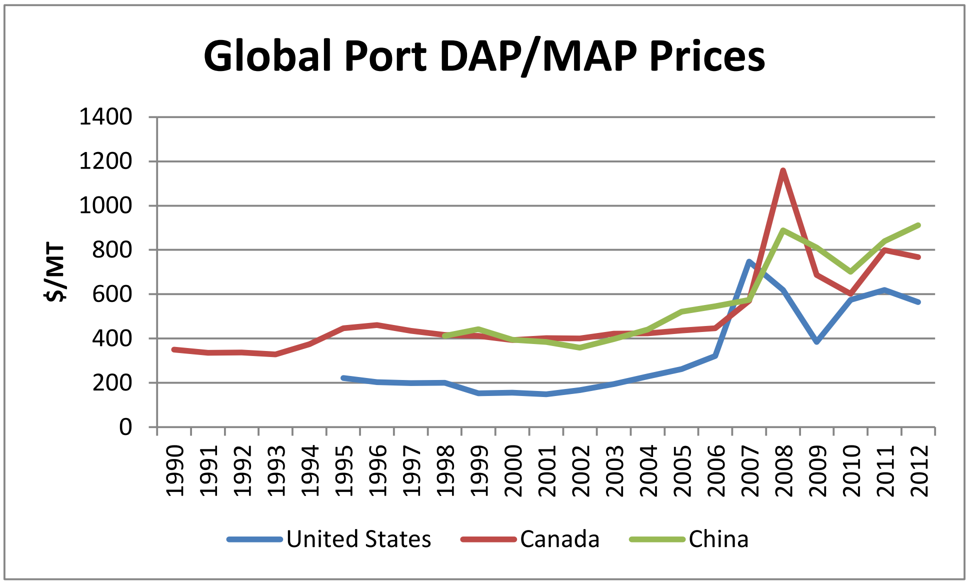
Chinese prices were selected to represent ROW prices for this global fertilizer model. These prices were chosen as they should represent the closest approximation of output prices in ROW countries of the available sources. Fertilizers in the United States and Canada have significantly lower costs of production than other countries around the world. For this reason, prices in these countries were not selected to represent ROW price levels.

Figure 5.2 Global Port Ammonia Prices



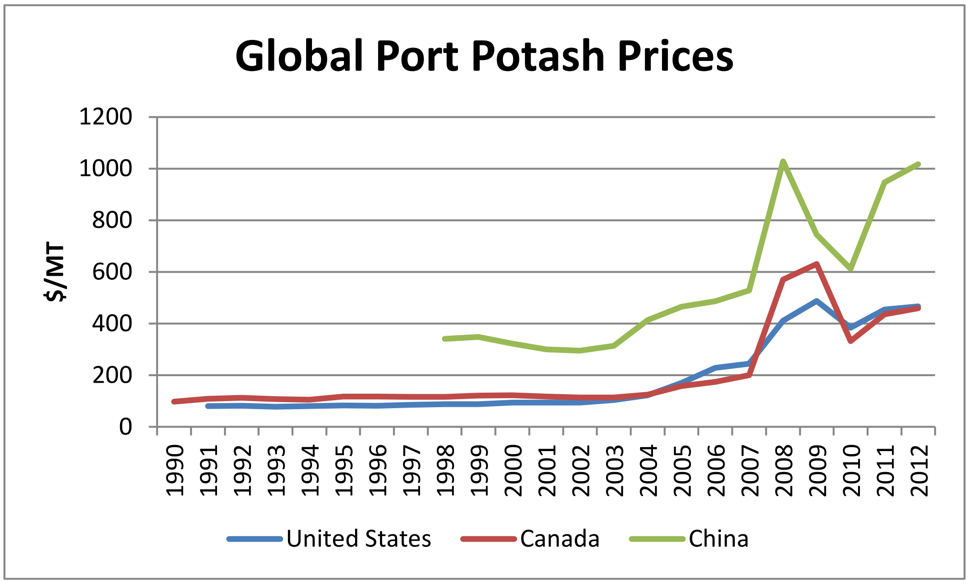
Sources: Listed in country sections above (CA prices are farm-level)

Figure 5.3 – Global Port DAP/MAP Prices



Sources: Listed in country sections above (CA prices are MAP farm-level prices)

Figure 5.4 – Global Port Potash Prices



Sources: Listed in country sections above (CA prices are farm-level)

Data Adjustments

To begin the model building process, data were gathered from the sources listed above. Different sources come with varying degrees of reliability and must be checked for errors and inconsistencies. For prices compiled from multiple sources, attempts were made to collect sources with overlapping time periods to ensure consistency of the prices series. Supply and demand variables from FAOSTAT were tested by checking the supply and demand balance of the dataset. A residual demand category was calculated to account for statistical discrepancies. IFDC capacity numbers were also adjusted to always be at least 101% of reported FAOSTAT production figures so that capacity utilization rates in the data set are always less than 100%. In addition to problems of inconsistency of data sources, there may be cases where actual production capability exceeds nameplate capacity.

CHAPTER SIX

MODEL SPECIFICATION

In order to assess the impacts of various fertilizer scenarios that would be relevant to policy makers and industry participants, baseline estimates for supply and demand variables must be developed. This effort uses partial equilibrium modeling techniques to develop a baseline model that is capable of such an endeavor. The sections below will discuss supply and demand equation specifications for nitrogen in the United States. Important differences in specification for phosphorus and potassium will be explained after each nitrogen equation is discussed. Due to the high level of similarity between nutrients, not all equations will be discussed for each nutrient.

Supply Specifications

On the supply side of the model there are three behavioral equations and one identity equation. Capacity, capacity utilization, and imports are behavioral equations while the production equation is an identity. Due to unique relationships between imports, exports, and the net trade position equation, imports will be discussed along with the other two trade variables in a later section of this chapter.

Ammonia Capacity = $f\,[(\mathrm{ENR}_{N\text{-}US} / \text{GDP Deflator}_{US})_{t,\, t-1,\, t-2,\, t-3,\, t-4,\, t-5,\, t-6}, \text{Capacity}_{t-1}, \text{Trend}_t]$

Important in supply side equations are expected net returns (ENR) of nitrogen, phosphorus, and potassium fertilizers. $\mathrm{ENR}_{N\text{-}US}$ is the expected net returns for ammonia in the United States. ENR for ammonia is calculated by taking the wholesale price of one metric ton of ammonia in a given year and subtracting the variable costs of producing that quantity of ammonia in the same year. As discussed, natural gas accounts for the majority of the variable costs of producing ammonia. Cost of production for ammonia in the United States was calculated by multiplying the price of natural gas per million BTU in the United States by the quantity of natural gas needed to produce one metric ton of ammonia (32.7 million BTU, according to Huang 2007).

The ammonia capacity equation was specified using a significant lagged structure due to the long investment period required to construct ammonia production facilities. Model parameters suggest that net returns from three years ago have the largest impact on capacity, reflecting the approximate time required to take a plant from the planning stage to operation. ENR for the current period and for the first and second lagged periods are also relevant as projects can either be cancelled or delayed if higher costs of production or lower output prices reduce potential profitability of new construction. Longer lags are also included, as some plants take more than three years to complete.

Initial calibration efforts suggested that the short-run elasticity of capacity with respect to ENR must be fairly small to be consistent with observed data and to generate plausible simulation results. The lifespan of an ammonia production facility is stated as being around 20 to 25 years, with plants often staying in production beyond this stated lifespan (Dekker 2001). Available information suggests that production facilities are not retired with any meaningful frequency, so the equation does include a variable to represent plant retirement.[4] To reflect the long lifespan of fertilizer plants and the fact that nameplate capacity does not decrease for a given plant over time, future capacity will largely be a function of capacity available today. For this reason lagged capacity was also included as an important driver of future capacity. By placing a high coefficient on this variable, close to 0.9, the modeled expansion path matches observed behavior and implies that long-run capacity is far more price responsive than capacity is in the short run, consistent with typical investment behavior.

Phosphoric Acid Capacity = $f\ [(ENR_{P\text{-}US} / \text{GDP Deflator}_{US})_{t,\ t-1,\ t-2,\ t-3,\ t-4}, \text{Capacity}_{t-1}]$

This equation is relatively similar to the ammonia capacity equation with fewer lagged terms as a reflection of the three to four year period required to build a phosphate plant. ENR for all countries except for Canada are calculated using DAP fertilizer prices as the indicator output prices. For Canada, the MAP price is used in the absence of a DAP price. Phosphorus fertilizer in the form of DAP was chosen for ENR calculations as the majority of phosphorus fertilizers consumed globally are in the DAP form (IPNI n.d.). ENR for DAP are calculated by taking the price of one metric ton of DAP and subtracting costs of production. Costs of production of DAP and MAP were calculated in the same way ammonia costs of production were calculated. Inputs needed to produce one metric ton of DAP (MAP) include approximately 1.81 (1.88) short tons of phosphate rock, 0.485 (0.585) short tons of sulfur, and 0.25 (0.16) short tons of ammonia (PotashCorp 2014b).

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[4] Meaningful, in this case, is defined as being relevant given the time frame of the model.

Potassium Chloride Capacity = f [(Port Price$_{\text{K-US}}$ / GDP Deflator)$_{\text{t, t-1}}$, Average(Port Price$_{\text{K-US, t-6,7,8}}$ / GDP Deflator$_{\text{t-6,7,8}}$), PPI Electricity$_{\text{K-US, t-7}}$ / GDP Deflator$_{\text{US, t-7}}$, PPI Wages$_{\text{K-US, t-7}}$ / GDP Deflator$_{\text{US, t-7}}$, Capacity$_{\text{t-1}}$, Trend$_{\text{t}}$]

The capacity equation for potassium chloride was specified differently than capacity for the other two nutrients due to differences in nutrient production processes. Instead of using expected net returns for potassium, selected potassium fertilizer production costs and revenues enter into the equation separately. Producer Price Indices (PPI) for wages and electricity serve as cost drivers in the capacity equation. Revenues in the form of the potassium chloride port price are used in place of ENR variables found in capacity equations for nitrogen and phosphorus.

Ammonia Capacity Utilization = f [ENR$_{\text{N-US, t}}$ / GDP Deflator$_{\text{US, t}}$] (Logistic Form)

Unlike capacity equations, capacity utilization equations only contain ENR in the current period. Capacity utilization is specified using a logistic functional form to keep the simulated values between zero and 100%. Fertilizer industries may operate below 100% of nameplate capacity for a number of reasons. Unfavorable fertilizer prices, high domestic input cost, and maintenance requirements may force less efficient facilities to operate below maximum capacity, or even temporarily halt production altogether.

The capacity utilization equation for potassium fertilizers contains the deflated potassium chloride port price and the same PPI variables as used in the capacity equation. Phosphorus capacity utilization is specified in the same manner as the ammonia capacity utilization equation.

Ammonia Production = Ammonia Capacity * Ammonia Capacity Utilization

Rather than estimating production directly, the model developed here calculates production as the product of capacity and the capacity utilization rate.

Demand Specifications

Demand side equations include application rates for corn, soybeans, wheat, cotton, rapeseed, and rice. Additionally, an “other crops” fertilizer use category, fertilizer use identity, non-fertilizer use equation, domestic consumption identity, and residual balance category are used to provide a forecast for the demand side of nutrient markets.

Application rate equations are very similar across crop varieties and nutrient categories. For this reason, only the corn application rate equation is discussed.

Corn Nitrogen Fertilizer Use per Acre = f [(Farm $\text{Price}_{\text{Corn-US}}$ / GDP Deflator $_{\text{US}}$) $_{\text{t-1}}$, Farm $\text{Price}_{\text{N-US, t}}$ / GDP $\text{Deflator}_{\text{US, t}}$]

The nitrogen application rate for corn is specified as being a function of the lagged corn farm price, and the current period retail level ammonia price. Higher ammonia prices should reduce nitrogen fertilizer consumption, given the expected downward sloping factor demand curves. When planting decisions are made, farmers do not yet know what the price of corn will be at harvest time. However, the price of corn in the previous year is known, and is used in this model as a proxy for the price expected by corn producers. The relationship between commodity output prices and nutrient use is positive as a higher output price should encourage higher levels of fertilizer use.

Other Crops Nitrogen Fertilizer Use = f [Trend, Farm Price$_{N\text{-}US,\,t}$ / GDP Deflator$_{US,t}$]

Use of nitrogen fertilizers by crops not modeled separately is specified as a function of a simple trend and the real farm level ammonia price in the current period. Prices for all commodities that would make up the other crops category were not available. A positive trend term is consistent with the observed data, and could reflect changes in both area for non-modeled crops and changes in per-hectare application rates. The other crops category includes vegetables, other grains and oilseeds, sugar beets, and other crops not explicitly broken out in the model. Rice use is modeled for China and India, but not for other countries. Initial regression estimation was performed on this equation with elasticity values adjusted in the case of poor model performance or incorrect signs on coefficients.

Nitrogen Fertilizer Use = Corn Nitrogen Use Per Acre * Corn Harvested Area + Soybean Nitrogen Use Per Acre * Soybean Harvested Area + … + Other Crops Nitrogen Use

Nitrogen fertilizer use is the summation of the individual demands from each crop. Nitrogen demand from each crop is calculated by taking individual crop application rates and multiplying those values by area harvested for the same crop. Summing across individual crop demands and other crops demand yields total nitrogen fertilizer use.

Nitrogen Non-Fertilizer Use = f [Trend, Farm Price$_{N\text{-}US,\,t}$ / GDP Deflator$_{US,t}$]

As discussed previously, nutrient use can come from industrial sources outside of the agricultural industry. This equation is specified using the same variables as the other crops nitrogen use equation but with different elasticities. As with the other crops use equation, initial regression estimation was performed for this variable and elasticity values were adjusted in the case of poor model performance or to ensure signs on coefficients that matched theoretical expectations.

Nitrogen Domestic Consumption = Nitrogen Fertilizer Use + Nitrogen Non-Fertilizer Use

The domestic consumption identity is simply the summation of the two major demand categories.

Nitrogen Net Imports = Domestic Consumption – Production – Residual

In the case of ammonia, the U.S. is a net importer. The net trade equation reflects a simple accounting identity; if there are no stocks, net trade should simply be the difference between domestic production and consumption. To ensure this accounting identity holds, a residual term must be added to account for any statistical discrepancies. This residual term is held constant in the projection period.

Solving the Model

In order for the model to produce a forecast, a few additional steps must be completed. Acquiring a model solution requires the use of an equilibrator. An equilibrator is a mechanism that solves for chosen world market clearing prices. U.S. port prices for each nutrient group were the equilibrating prices for this model. Prices in other modeled countries and prices at different marketing levels are connected through price linkage equations. International port prices are linked to the U.S. equilibrating port price. U.S. farm level prices are linked to U.S. port prices.

The world net trade position is calculated as the sum of the trade positions from the five modeled countries and the ROW region. As the World net trade position changes, the equilibrating price in the model adjusts by a percentage of the change in this position. Prices are increased if world imports exceed world exports, and prices are reduced if world exports exceed world imports. As equilibrating prices adjust, price linkage equations allow prices in other countries to adjust accordingly, and as these prices shift, modeled equations adjust to new prices levels. The process iterates until the world net trade position is equal to zero, corrected for a fixed assumed difference between world exports and imports, based on observed historical data discrepancies. When this process is complete, the model has achieved equilibrium.

The equilibrium solution is unique, and is dependent on the current and historical values of exogenous variables and model parameters. A model solution is called a baseline and can be used to test shocks and scenarios on the model. By comparing the model before and after a shock has been performed one can assess model performance and test the effects of changes in policy and other market factors.

CHAPTER SEVEN

BASELINE RESULTS

A baseline level of modeled variables was constructed in order to determine the effects of relevant shocks and scenarios. A global partial equilibrium model was synthetically constructed using elasticity estimates from various other studies in order to produce the baseline model forecast. Forecasted results are available to 2030. Important model simulation results will be discussed below, accompanied by summary figures of U.S. data at the end of this chapter. Discussion here will focus on fertilizer markets in the United States while data for all modeled countries can be viewed in Appendix A.

Supply

IFDC estimates of capacity expansion to 2017 were used to calibrate capacity estimates for the baseline forecast (IFDC 2013). IFDC also provides a long-run estimate of future capacity that the model utilizes as a guideline for capacity in 2030. IFDC estimates suggest that capacity will increase or stay relatively flat for each of the three nutrient groups within each of the modeled countries and the aggregated ROW region. Larger declines in prices would be expected in the forecast if long-run IFDC estimates were more aggressively pursued in place of current more restrained assumptions (IFDC 2014).

Nitrogen Fertilizer Supply

The model estimates that U.S. nitrogen fertilizer capacity will increase approximately 53% by 2030 at an average rate of around 2.3% per year. This translates into an increase in U.S. nitrogen fertilizer production of 38%. Production is estimated to increase less than capacity over the same period due to a decrease in the capacity utilization rate in response to lower ammonia prices. Nitrogen fertilizer capacity in Canada is projected to remain flat in the forecast period while capacity in China, India, Russia, and ROW are forecasted to increase by approximately 62%, 37%, 31%, and 24%, respectively. These results vary largely due to differences in expected capacity expansion paths that have been estimated by IFDC. Expansion in capacity ultimately results in an estimated 39% increase in World nitrogen fertilizer production by 2030.

Phosphorus Fertilizer Supply

IFDC capacity estimates suggest that phosphate capacity in the U.S. will see only a small increase in the near future. Model projections of U.S. phosphate capacity are set to increase approximately 5% by 2030. Capacity utilization is expected to stay stable, resulting in projected increases in U.S. phosphate production of 3%. Phosphate production in China, India, and ROW are forecast to increase by around 20%, 24%, and 33% by 2030, respectively. As was the case for nitrogen fertilizers, differences here are a direct implication of differences in expectations in IFDC capacity forecasts across countries. Total World production of phosphorus fertilizers is estimated to increase by approximately 17% by 2030.

Potassium Fertilizer Supply

U.S. potash capacity accounted for only 3% of total world capacity in 2011 (FAO 2014). The model estimates an increase in U.S. potash capacity of around 13% by 2030. Potash capacity expansion in other countries and ROW are estimated to increase more significantly, excluding India where potassium fertilizers are not produced. Aligning model forecasts with IFDC estimates of potash capacity expansion for Canada, China, Russia, and ROW resulted in increases of 72%, 49%, 47%, and 18%, respectively. The model forecasts an increase in world potassium fertilizer production of approximately 34%.

Demand

Unlike supply side projections, which are strongly influenced by capacity expansion path estimates from IFDC, demand projections cannot rely on a similar benchmark, so must be based on model equations and judgments about likely future trends.

Nitrogen Fertilizer Demand

In the U.S., nitrogen fertilizer use increased by approximately 8% from 2002 to 2011. In response to lower forecasted ammonia prices, the model estimates an increase in fertilizer use of approximately 15% between 2011 and 2030. Exogenous commodity prices during the same period see a small downward trend which puts downward pressure on fertilizer application rates. Similarly, total crop area in the U.S. for included crop varieties is projected to decrease slightly from the high levels seen in 2012 but is projected to remain higher than 2011 levels. If recent trends continue, then non-fertilizer and other crop use will be the source of future increases in consumption.

Breaking down U.S. nitrogen fertilizer use by the individual crops reveals that the largest increases in projected use during the forecast period come from the other crops category. Historically, the majority of the increase in fertilizer use came from corn production. However, in the forecast period, fertilizer demand from corn is projected to be almost flat, decreasing around 4% by 2030. Application rates of nitrogen on corn stay relatively flat in the forecast period, so most of the decrease in nitrogen fertilizer demand comes from small decreases in corn area. Nitrogen fertilizer use from wheat and soybeans are projected to increase by 8% and 6% respectively. Demand for cotton is projected to decrease by 10% while demand from rapeseed is projected to more than double by 2030, but start from a very small initial level.

Non-fertilizer use of nitrogen in the U.S. increased 27% between 2002 and 2011 (FAO 2014). Non-fertilizer use continues to increase in the forecasted period ending 25% higher by the end of the period than it was in 2011. World total nitrogen fertilizer demand, including both fertilizer and non-fertilizer uses, is projected to increase 36% by 2030 with the majority of demand growth to come from China, India, and the ROW.

Nitrogen domestic consumption in China is projected to increase more rapidly than projected growth in production of the separately modeled crops. The historical data used for this analysis suggests a rapid increase has occurred in use by non-modeled crops, and the projections show this rate of growth increasing. Increases in ammonia capacity, and production in China have generally matched increases in the amount of fertilizer consumed domestically. Historically, production and domestic consumption had a correlation of 0.98.[5] While correlation does not imply causality, it is likely that some causal relationship exists between production and the amount of fertilizer consumed domestically in the short-run, as the country has been reluctant to trade fertilizer. For this reason, large estimated increases in China ammonia capacity and production were modeled to reflect this relationship and in turn, caused proportionate increases in ammonia consumption domestically. As Chinese fertilizer markets evolve and domestic consumers are no longer able to increase consumption as quickly, it is possible that China will become more likely to export a higher percentage of nitrogen production. Total fertilizer demand in China increases 71% during the forecast period.

Phosphorus Fertilizer Demand

Projections for U.S. phosphorus fertilizer markets suggest fertilizer use increases of 5% in the forecast period. Expected changes in fertilizer demand for phosphorus are much smaller than for nitrogen fertilizer demand. From 2002 to 2008 phosphate fertilizer use in the U.S. decreased by approximately 16%, but from 2008 to 2011 demand recovered by 22%. Non-fertilizer use in the U.S. accounts for the majority of domestic consumption. Reported non-fertilizer use nearly quadrupled from 2002 to 2008, but in the following year dropped 21% and by 2011, had not fully recovered to 2008 levels, raising some questions about the reliability of the reported data. For this reason, a more

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[5] The correlation between ammonia production and other crops demand had a value of 0.97 for the same period. This category accounted for the majority of the increases in demand in the historical period. Non-fertilizer use is not reported for China. Therefore, some of the increase in the other crops demand category could have come from unreported non-fertilizer sources.

modest increase of around 9% was projected for this variable in the forecast period. The combined effect on domestic consumption was a projected increase of 8%.

Of the remaining countries, China, India, and the ROW make up the majority of remaining Global demand for phosphorus fertilizers. Projections for China, India, and ROW show increases in fertilizer use of 19%, 7%, and 26% by 2030, respectively. Non-fertilizer use of phosphorus fertilizers is not reported for these countries. Total world phosphorus demand is projected to increase 16% in the forecast period.

Potassium Fertilizer Demand

Of the major fertilizer nutrients, potassium is the least consumed in the United States. Historically, potassium fertilizer consumption was relatively stable until 2008 and 2009 when use dipped temporarily before returning roughly to 2007 levels by 2010. By 2011, potassium fertilizer use had increased 28% above the trough of 2009. For the forecasted period the model projects growth in potassium fertilizer use of 9%. Data on non-fertilizer use in the U.S. suggest growth from 2002 to 2008 of 250%. However, FAO data for non-fertilizer use of potassium are a cause for concern; in 2009 the category had a value of zero, which seems implausible. For the forecast period, non-fertilizer use was projected to grow 29%. The combined effect on total domestic consumption of potassium was an increase of 17% by the end of the forecast period.

Reported potassium fertilizer use in China saw more significant changes, historically, than U.S. As in the U.S., the reported annual changes have been erratic; in 2011 alone, reported potassium fertilizer use in China increased 42% over the level in 2010 after back-to-back decreases in 2008 and 2009. For the forecast period, potassium fertilizer use in China is estimated to increase approximately 26%. ROW and India fertilizer use are projected to increase 42% and 40% respectively. Total world domestic consumption of potassium fertilizers was projected to increase 32% by 2030.

Fertilizer Prices

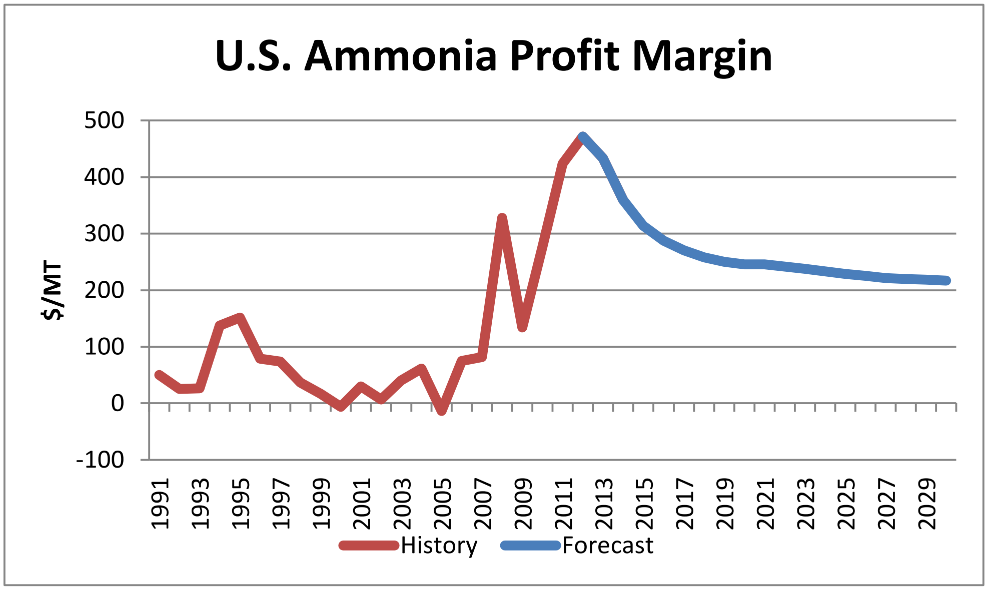
For each nutrient group an output price was chosen to represent revenues gained from the sale of fertilizer output and the costs paid by farmers to employ units of fertilizer inputs. Ammonia was selected for nitrogen, diammonium phosphate for phosphorus, and potassium chloride (potash) for potassium fertilizers. The following discussion is of U.S. prices only, with other prices in tables available at the end of chapter five.

Nitrogen Fertilizer Prices

The period from 2008 to 2012 experienced the highest average annual prices of ammonia in the United States. This was despite natural gas prices dropping by more than 50% in 2009 and remaining approximately 50% lower than 2008 levels until 2012. Ammonia prices also experienced a drop in 2009 of 58%. Prices recovered, and by 2012 ammonia prices were within 3% of the highs of 2008 while natural gas prices were still far below 2008 levels. Due to high output prices, and low variable costs of production, calculated average profit margins during the period of 2008 to 2012 were more than six times larger than the average for the preceding 17 years.

Some justification of high ammonia prices may come from a capacity shortage issue. However, as capacity responds to the high level of profitability in the industry, these margins should tend toward the historical average. How quickly this happens depends on how quickly capacity is able to react. Given barriers to entry in fertilizer markets, expected paths of exogenous natural gas prices, and trends in endogenous variables discussed above, Figure 7.1 indicates why margins are likely to decline from recent levels.

Figure 7.1 – U.S. Ammonia Profit Margin



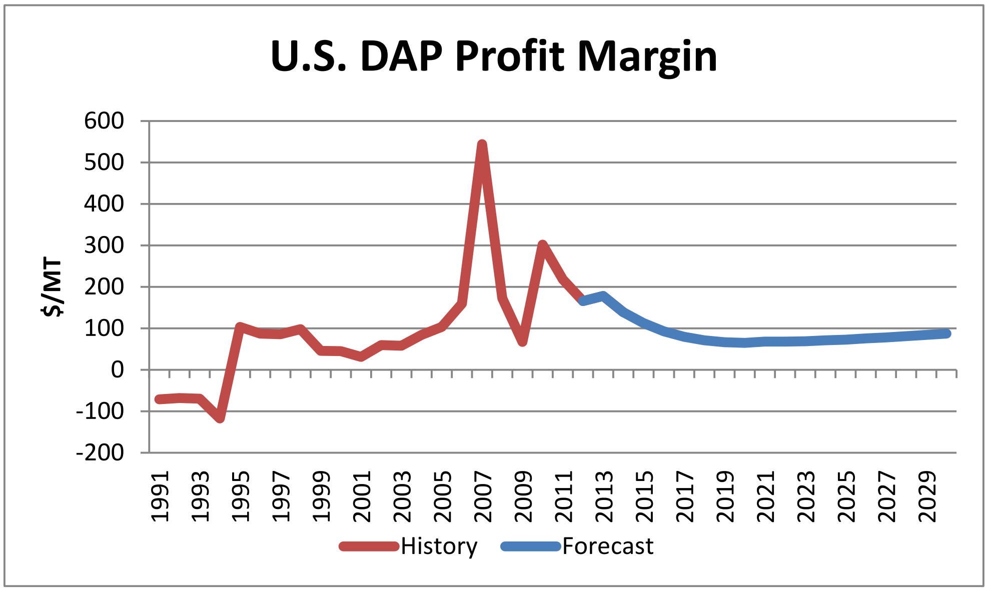
Source: Natural Gas Prices (EIA 2010), Ammonia Price History (USGS 2014a), Ammonia Price Forecast (Model Results)

Ammonia profit margins are expected to come down from the high levels seen in 2012. Initially, this occurs rapidly as planned capacity comes on line, especially in China, where IFDC reports significant planned increases in capacity for 2014 and 2015.

Phosphorus Fertilizer Prices

Ammonia markets were not the only fertilizer market to see high profit margins in recent years. Phosphorus markets also saw large spikes in 2007 and 2010. In 2007, DAP profit margins were seven times larger than the average from 2000 to 2006 and nearly fourteen times larger than the average from 1991 to 2006. However, a combination of high ammonia and sulfur prices in 2008 forced DAP profit margins back toward the historical average. In 2009, higher phosphate rock prices put downward pressure on profit margins but significantly lower sulfur and ammonia prices outweighed this effect, resulting in higher profit margins in 2009. In 2010, phosphate rock prices came down significantly while ammonia prices had not yet reached their second peak. This allowed profit margins for DAP to increase further in 2010. Ammonia prices in the following year increased to a point where profit margins returned to a level that was closer to historical averages. Figure 7.2 is one depiction of what could happen to DAP margins in the coming years.

Figure 7.2 – U.S. DAP Profit Margin



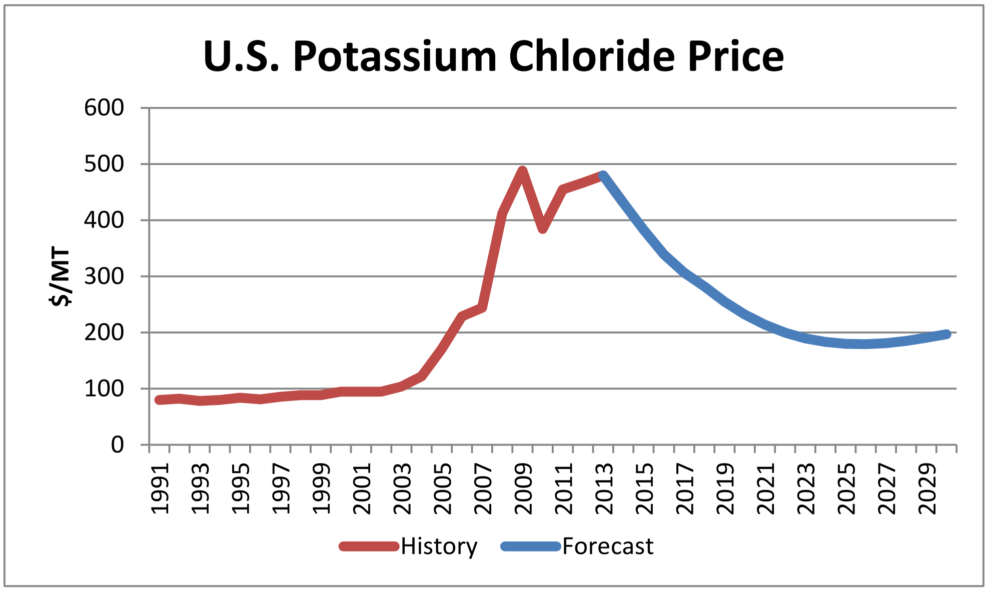
Source: Sulfur Price (Nexant 2009; Sulfur Information Services 2012), Ammonia Price (USGS 2014a; Steiner Model), Phosphate Rock (USGS 2014b), DAP Price Historical (NFDC n.d.; PotashCorp 2014), DAP price forecast (Model Results)

Phosphorus profit margins are likely to tend towards historical averages in the forecast period. As with ammonia, many different assumptions were tested for phosphorus fertilizer markets including how quickly to allow capacity to expand.

Potassium Fertilizer Prices

Much like the other two nutrient groups, potassium fertilizers experienced a run-up in prices from 2008 to 2012 with the average price for the period being almost four times greater than the 1991-2007 period average. Figure 7.3 shows projected potassium chloride prices through 2030.

Figure 7.3 – U.S. Potassium Chloride Price



Source: KCl price history (USGS 2014c), KCl Price Forecast (Model Results)

As with both of the other nutrient categories, prices in potassium chloride markets are projected to return closer to historically observed levels. The decline assumes that market structure in the industry is sufficiently competitive that recent high prices and profitability cannot persist.

Figure 7.4 – U.S. Nitrogen Fertilizer Supply and Demand

United States Nitrogen Fertilizer Supply and Demand

	Units	2005	2012	2015	2030
	1000 Nutrient Tonnes				
Supply					
Capacity		9570	9712	11550	14419
Capacity Utilization (Implied)		86.9%	95.3%	90.7%	84.5%
Production		8317	9258	10476	12181
Imports		10414	9840	9509	9088
Total Supply		18731	19098	19985	21269
Demand					
Total Nitrogen Fertilizer Use		11014	12369	12514	12866
Corn Nitrogen Fertilizer Use		4441	5925	5631	5213
Wheat Nitrogen Fertilizer Use		1588	1525	1534	1545
Soybean Nitrogen Fertilizer Use		136	116	118	120
Rapeseed Nitrogen Fertilizer Use		51	107	135	128
Cotton Nitrogen Fertilizer Use		317	344	278	277
Other Crops Nitrogen Fertilizer Use		4480	4352	4818	5582
Non Fertilizer Use		5444	5277	5990	6823
Domestic Consumption		16458	17646	18503	19689
Exports		2273	1452	1482	1580
Total Demand		18731	19098	19985	21269
Residual		0	0	0	0
	$US per Metric Tonne				
Fertilizer Prices					
Anhydrous Ammonia Port Price		335	634	482	447
Anhydrous Ammonia Farm Price		459	863	659	612
Urea Farm Price		332	554	427	397

Sources: 2005/2012 S&D data (FAO 2014), 2005/2012 Farm Ammonia Price (ERS 2013), 2005/2012 Ammonia Port Price (USGS 2014a), 2005/2012 Urea Farm Price (ERS 2013), Forecasted values (Model Results)

Figure 7.5 – U.S. Phosphorus Fertilizer Supply and Demand

United States Phosphorus Fertilizer Supply and Demand

Units	2005	2012	2015	2030
1000 Nutrient Tonnes				
Supply				
Capacity	11554	14327	14361	15127
Capacity Utilization (Implied)	99.0%	92.0%	91.6%	91.2%
Production	11439	13186	13151	13800
Imports	627	1151	1218	1294
Total Supply	12067	14337	14369	15093
Demand				
Total Phosphorus Fertilizer Use	4121	4157	4184	4167
Corn Phosphorus Fertilizer Use	1575	1855	1830	1734
Wheat Phosphorus Fertilizer Use	875	660	665	672
Soybean Phosphorus Fertilizer Use	437	384	393	396
Rapeseed Phosphorus Fertilizer Use	12	21	26	25
Cotton Phosphorus Fertilizer Use	137	118	98	99
Other Crops Phosphorus Fertilizer Use	1085	1120	1172	1241
Non Fertilizer Use	3586	7578	8090	8689
Domestic Consumption	7707	11735	12275	12857
Exports	4360	2602	2094	2237
Total Demand	12067	14337	14369	15093
Residual	0	0	0	0
$US per Metric Tonne				
Fertilizer Prices				
DAP Port Price	263	565	436	433
DAP Farm Price	334	800	598	595

Sources: 2005/2012 S&D data (FAO 2014), 2005/2012 Farm DAP Price (ERS 2013), 2005/2012 DAP Port Price (NFDC n.d.; PotashCorp 2011), Forecasted values (Model Results)

Figure 7.6 – U.S. Potassium Fertilizer Supply and Demand

United States Potassium Fertilizer Supply and Demand

	Units	2005	2012	2015	2030
	1000 Nutrient Tonnes				
Supply					
Capacity		1566	1485	1541	1670
Capacity Utilization (Implied)		76.7%	53.3%	52.5%	50.7%
Production		1200	791	809	846
Imports		6116	6574	6767	7753
Total Supply		7316	7365	7576	8599
Demand					
Total Potassium Fertilizer Use		4448	4397	4382	4629
Corn Potassium Fertilizer Use		1830	2023	1954	1886
Wheat Potassium Fertilizer Use		670	509	506	539
Soybean Potassium Fertilizer Use		656	747	758	793
Rapeseed Potassium Fertilizer Use		13	24	31	31
Cotton Potassium Fertilizer Use		195	161	132	139
Other Crops Potassium Fertilizer Use		1084	932	1002	1241
Non Fertilizer Use		2785	2822	3041	3786
Domestic Consumption		7233	7219	7423	8415
Exports		83	146	152	184
Total Demand		7316	7365	7576	8599
Residual		0	0	0	0
	$US per Metric Tonne				
Fertilizer Prices					
Potassium Chloride Port Price		171	467	383	197
Potassium Chloride Farm Price		270	713	583	316

Sources: 2005/2012 S&D data (FAO 2014), 2005/2012 Farm KCl Price (ERS 2013), 2005/2012 KCl Port Price (USGS 2014c), Forecasted values (Model Results)

CHAPTER EIGHT

FERTILIZER MARKET SCENARIOS

In order to test the reliability and responsiveness of the model to exogenous changes in policy and market conditions, the following shocks were imposed.

D. Sustained 10% increase of North American natural gas prices from 2013 to 2030

E. Sustained 10% tax on U.S. ammonia farm price from 2013 to 2030

F. Sustained 10% decrease of U.S. corn acreage from WAEES baseline from 2013 to 2030

Results will be assessed by comparing the equilibrium levels of model output after each shock to baseline levels. The analysis discussed here will focus on U.S. fertilizer markets.

Scenario 1 – Natural Gas Price Shock

The first shock imposed on the model is an increase in natural gas prices for North American markets. Natural gas prices in Canada and the United States are increased by 10% from 2013 to 2030. This shock could be viewed as a tax on natural gas or some other exogenous cause for an increase in natural gas prices.

Figure 8.1 – 10% Increase of North American Natural Gas Prices

Sustained 10% Increase of North American Natural Gas Prices from 2013 to 2030						
	2013	**2020**	**2030**	**2013**	**2020**	**2030**
	Baseline Levels			**Changes from Baseline**		
NA Nitrogen Fertilizer Production - Mil. MT	13.0	15.3	15.3	-0.4%	-1.4%	-2.4%
Non-NA Nitrogen Fertilizer Production - Mil. MT	107.2	129.6	140.6	0.0%	0.1%	0.1%
NA Nitrogen Domestic Consumption - Mil. MT	21.0	21.9	22.3	0.0%	-0.2%	-0.3%
Non-NA Nitrogen Domestic Consumption - Mil. MT	102.0	125.7	136.3	0.0%	-0.1%	-0.1%
U.S. Port Ammonia Price - $/MT	598	428	447	0.1%	0.9%	1.4%

Source: Model Results

As a direct implication of an increase in natural gas prices one would expect a decrease in production of nitrogen fertilizer in both the United States and Canada due to higher costs of production. In fact, immediate model impacts are decreases in capacity and the capacity utilization rate in North America, leading to decreases in production. The short-term combined production response is a decrease of about 0.4% in the two North American markets. In the long-run, after firms have enough time to fully adjust to lower net returns, North American production sees a 2.4% decrease from baseline levels.

Decreases in production immediately result in suppressed levels of exports. Imports are expected to increase in an attempt to satisfy domestic demand for nitrogen fertilizer. Upward pressure is applied to domestic prices of ammonia due to lower domestic availability of nitrogen fertilizers. U.S. ammonia prices are slated to increase by roughly 0.1% in 2013 and end approximately 1.4% higher than baseline projections in the long-run. Domestic consumption is significantly less responsive due to the inelastic nature of nitrogen fertilizer use, decreasing from baseline levels by less than 0.1% in the short-run and 0.3% in 2030 for North American markets.

Exports of nitrogen fertilizer elsewhere in the world are expected to increase in response to higher levels of imports desired by U.S. and Canadian nitrogen fertilizer markets as transmitted through higher ammonia prices. As a consequence of a higher level of exports, ammonia prices in the rest of the world increase, causing reductions in domestic consumption of 0.1% in 2030 for countries outside of the U.S. and Canada.[6] At the new levels of ammonia prices, production is expected to rise by 0.1% in 2030 for these countries. These are small proportional changes, but given the relative sizes of North American and other markets, the absolute changes in the rest of world necessarily balance the estimated changes in North American markets.

In addition to consequences for nitrogen, phosphorus markets also experience changes, as increases in the price of ammonia increases the cost of producing DAP fertilizer. This reduces net returns for phosphorus fertilizers, leading to lower levels of production than in baseline projections. Lower levels of production put upward pressure on DAP prices, which in turn result in decreased domestic consumption of phosphorus fertilizers for all countries in the model. However, these results are small as the effect on production costs derived from ammonia price increases is not large enough to change phosphorus production by a meaningful magnitude.

Scenario 2 – U.S. Ammonia Farm Price Tax

The second shock imposed on the model is an increase in the farm-level ammonia price in the United States. This price series is increased by 10% from 2013 to 2030. A nitrogen

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[6] It should be noted that “rest of the world” here is not meant to signify the ROW region as defined previously, but rather all countries other than the U.S. and Canada.

fertilizer tax is a commonly discussed policy option and has appeared many times in recent literature including the work of Rosas (2012) who examined a tax on N_2O emissions at CO_2 equivalence, and Berntsen et al. (2002) who looked at various nitrogen tax scenarios, among others (Rosas 2012; Berntsen 2002).

Figure 8.2 – 10% Tax on U.S. Farm-Level Ammonia Prices

Sustained 10% Tax on U.S. Farm-Level Ammonia Prices from 2013 to 2030						
	2013	2020	2030	2013	2020	2030
	Baseline Levels			Changes from Baseline		
U.S. Nitrogen Fertilizer Production - Mil. MT	9.6	12.2	12.2	-0.2%	-0.5%	-0.6%
Non-U.S. Nitrogen Fertilizer Production - Mil. MT	110.6	132.7	143.8	-0.1%	-0.1%	-0.1%
U.S. Nitrogen Fertilizer Use - Mil. MT	13.0	12.9	12.9	-1.6%	-1.1%	-1.0%
U.S. Non-Fertilizer Use - Mil. MT	5.5	6.4	6.8	-3.4%	-2.0%	-1.7%
U.S. Nitrogen Domestic Consumption - Mil. MT	18.5	19.3	19.7	-2.2%	-1.4%	-1.3%
Non-U.S. Nitrogen Domestic Consumption - Mil. MT	104.5	128.3	139.0	0.3%	0.1%	0.0%
U.S. Farm Ammonia Price - $/MT	815	586	612	-1.3%	-0.6%	-0.6%
Net Effect of Tax on Farm-Level Costs	-	-	-	8.7%	9.4%	9.4%
U.S. Port Ammonia Price - $/MT	598	428	447	-1.3%	-0.6%	-0.6%

Source: Model Results

The direct expected effects of an increase in farm ammonia prices in the United States are a decrease in the application rate of nitrogen for each crop and lower demand from the other crops category. Non-fertilizer use is also expected to decrease, resulting in an overall decrease in domestic consumption. In fact, the model captures a reduction in 2013 of 2.2%, and a 1.3% reduction from baseline levels in 2030. Of the individually modeled commodities, the largest changes in fertilizer demand come from corn and wheat. These commodities see respective decreases of 1.2% and 1.7% in 2013. Long-run effects are smaller with only a 0.8% reduction in corn nitrogen fertilizer use and a decrease of 1% in wheat nitrogen fertilizer use. Of the modeled crop varieties, these two crops account for the largest portion of nitrogen fertilizer consumed. For this reason, the largest absolute changes in fertilizer use should be expected to come from these commodities. The magnitudes of these projections seem reasonable given the inelasticity of fertilizer demand with respect to fertilizer prices. Non-fertilizer use in the U.S. is projected to see 3.4% reductions below baseline levels in 2013, but end only 1.7% below baseline projections in 2030.

In response to lower levels of domestic consumption, port and farm level ammonia prices of nitrogen fertilizers are expected to decrease from baseline levels by 1.3% in the short-run, resulting in a net tax effect of an 8.7% increase in farm-level fertilizer costs to producers. The long-run effect is a decrease of 0.6% from baseline levels. Basic economic theory would insist that a reduction in producer ammonia prices should result in a decrease in production of nitrogen fertilizer in the U.S. due to lower net returns. The model is consistent with this notion, projecting reductions in U.S. nitrogen fertilizer production of 0.2% in 2013 and by 2030, projecting values 0.6% below baseline levels. U.S. exports are expected to increase slightly. Cheaper domestic prices for fertilizer inputs in other countries around the world encourage additional consumption of nitrogen fertilizers in those countries. Also, a decrease in net returns causes production in countries outside of the U.S. to fall. Lower levels of production negatively impact exports. However, a combination of increases in foreign nutrient requirements and lower levels of foreign availability of nitrogen fertilizers results in increases in the level of fertilizer imports in these countries compared to the baseline case.

Scenario 3 – Decrease in U.S. Corn Area

The final shock imposed on the model is a 10% reduction in U.S. corn area from baseline levels in each year. In order to avoid imposing large swings in total crop area, soybean area is assumed to replace 80% of the reduction in corn area, with the remaining 20% of reduced area added to U.S. wheat. The majority of the weight was given to soybeans because crop rotation is common between corn and soybean acres as a part of standard soil conservation management practices (Roth 1996). No changes are assumed in land use in other countries. As with the first two shocks, the duration of the impact is from 2013 to 2030.

Figure 8.3 – Sustained 10% Decrease of U.S. Corn Acreage from WAEES Baseline Levels

Sustained 10% Decrease of U.S. Corn Acreage from WAEES Baseline from 2013 to 2030						
	2013	**2020**	**2030**	**2013**	**2020**	**2030**
	Baseline Levels			**Changes from Baseline**		
U.S. Nitrogen Fertilizer Production - Mil. MT	9.6	12.2	12.2	-0.2%	-0.7%	-1.0%
U.S. Phosphorus Fertilizer Production - Mil. MT	13.2	13.2	13.8	0.0%	-0.1%	0.0%
U.S. Potassium Fertilizer Production - Mil. MT	0.8	0.8	0.8	-0.1%	-0.1%	-0.1%
U.S. Nitrogen Fertilizer Use - Mil. MT	13.0	12.9	12.9	-4.1%	-3.6%	-3.4%
U.S. Phosphorus Fertilizer Use - Mil. MT	4.3	4.2	4.2	-3.0%	-2.8%	-2.7%
U.S. Potassium Fertilizer Use - Mil. MT	4.5	4.6	4.6	-2.5%	-2.2%	-2.2%
U.S. Port Ammonia Price - $/MT	598	428	447	-1.6%	-1.2%	-1.1%
U.S. Port DAP Price - $/MT	551	387	433	-1.3%	-0.8%	-0.8%
U.S. Port Potash Price - $/MT	480	232	197	-1.4%	-2.1%	-0.4%

Source: Model Results

Given the relative levels of demand for nitrogen, phosphorus, and potassium derived from the examined crops, a reduction in total nitrogen fertilizer use is expected to occur. While it is widely understood that the highest application rates of each fertilizer type are used on acres of corn, this fact can be more readily observed by looking at historical application rates data (Rosas 2012; ERS 2013). Nitrogen application rates per acre of soybeans were applied at an average of approximately 3% of the rate applied to corn over the observed period.[7] Using the same comparison for wheat, it was found that nitrogen fertilizer is applied at approximately 50% of the rate applied to corn. Phosphorus is applied to soybeans at an average of 25% of the rate applied to corn. Phosphorus fertilizers were applied to wheat at an average of approximately 73% of the rate applied to corn acres during the historical period. Potassium fertilizers were applied at approximately 40% and 64% of the rate applied to corn, on soybean and wheat acreage respectively. Lower levels of impact should be expected for phosphorus and potassium markets as application rates are much more similar between corn, wheat, and soybeans. These relationships result in smaller reductions in demand, given the proposed substitution.

Applying this knowledge would suggest an expected initial impact of reduced total fertilizer use of each nutrient, or a shift to the left by demand curves for nitrogen, phosphorous, and potassium fertilizers. Increases in soybean and wheat area should offset some portion of fertilizer use that was lost due to decreases in corn area, but use is expected to stay well below baseline levels. Model results are consistent with this intuition, with projected decreases from baseline levels of nitrogen fertilizer consumption in the U.S. of 4.1% in 2013 and smaller decreases of 3.4% in 2013. Phosphorus and potassium fertilizer use see decreases of 3% and 2.5% in the short-run, and end 2.7% and 2.2% below baseline levels in the long-run. Decreases in demand for

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[7] Farmers do not apply nitrogen to soybeans because they think that soybeans need nitrogen, but because there is nitrogen in DAP fertilizer.

nitrogen leads to lower prices in U.S. fertilizer markets and lower import quantities due to less fertilizer desired domestically. However, lower price levels encourage some additional non-fertilizer use with levels 0.6% above baseline projections in 2013 and long-run increases of only 0.2%.

Lower net returns cause domestic nitrogen production in the U.S. to decrease. Also, the decrease in prices domestically should make prices elsewhere in the world more attractive to U.S. producers and should result in increases in U.S. exports of nitrogen, phosphorus, and potassium fertilizer. The model projects decreases in U.S. port ammonia prices of 1.6% in 2013, and decreases of 1.1% in 2030 from baseline levels. Port prices for phosphorus and potassium fertilizers see similar decreases in the short-run of 1.3% and 1.4% respectively. Long-run impacts are smaller at a 0.8% reduction in phosphorus prices and 0.4% reductions in potassium port prices in the United States. Production of nitrogen fertilizer is expected to decrease from baseline levels of 0.2% in 2013 and 1% in 2030. Production of phosphorus and potassium fertilizers is expected to fall below baseline levels by less than 0.1% in 2030. As expected, the model projects decreases in imports into the U.S. and higher levels of exports.

The impacts on nitrogen, potassium, and phosphorous fertilizers markets for countries outside of the U.S. are small, but directional changes for these countries are as follows. In each of these markets it is expected that prices should decrease in response to a combination of lower prices in the U.S. and fewer net imports of fertilizers from U.S. markets. Lower prices in these countries are expected to encourage additional consumption of fertilizer inputs and lower levels of production due to the reduction in net returns. Because decreases in production leave domestic availability stifled, exports of fertilizers decrease from baseline levels, while imports increase to meet the requirements of additional quantities of fertilizer demanded domestically.

CHAPTER NINE

SUMMARY AND CONCLUSIONS

The purpose of this thesis was to construct a synthetic partial equilibrium model of global nitrogen, phosphorus, and potassium fertilizer markets that is capable of producing a baseline of economic variables against which the impacts of various alternative scenarios can be evaluated. The model is designed to be able to answer a diverse set of questions about the fertilizer industry that would be of interest to both policy makers and industry participants.

One of the main motivations for this study was the series of large spikes in ammonia prices that occurred in 2008, and again from 2010 to 2012. This run-up in prices led to highly abnormal profit margins for the industry when compared to historical averages.[8] Profit margins of DAP fertilizers also saw high levels during the period of 2007 to 2010. The model forecasts significant drops in price for each fertilizer type from the recent high levels. Most of this response is due to projected increases in fertilizer capacity, consistent with industry expectations, which ultimately results in increased production of fertilizers globally.

Changing selected model assumptions and re-solving the model yields estimates of market responses to changes in policies or market conditions, and is a good way to test the behavior of the model. The results of these shocks were found to be directionally

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[8] Profit margins for ammonia in the U.S. were calculated by subtracting the variable costs of producing ammonia derived from natural gas costs and subtracting this value from the port price in the U.S. DAP margins were calculated in similar fashion.

consistent with basic economic principles. Perhaps the most interesting of these shocks was a 10% tax on the farm price of ammonia in the U.S. which resulted in small reductions in nitrogen fertilizer use. Decreases in domestic use in 2013 of 2.2% were projected by the model in response to this shock, suggesting it might take a very high tax to obtain a large reduction in nitrogen fertilizer use. Additionally, a shock decreasing U.S. corn area and a positive shock to North American natural gas prices were examined.

This model attempts to expand upon the efforts of previous literature by including both capacity and capacity utilization equations to estimate fertilizer supply. Capacity is modeled with a significant lag structure to reflect the idea that investment takes time. The time frame to build a fertilizer production facility is quite long, with an ammonia plant taking the least time to construct at a minimum of 3 years. By specifying supply in this way, the model is able to distinguish the once potentially ambiguous changes in production as changes in the individual components. Reactions to a single period decrease in profit margins would put downward pressure on rates of capacity utilization but have only small effects on capacity itself.

Future Research

While the model constructed for this thesis was built to be a simple approximation of real world markets there are certain factors that could be added in order to improve the model's representation of fertilizer markets while maintaining model simplicity. This section looks at a few of the missing aspects of the model that could be considered when researchers examine this problem in the future.

This model assumes most key parameters, but if time and data permitted, it would beneficial to use econometric approaches to estimate supply and demand elasticities and other key parameters. Elasticity estimates for U.S. fertilizer demand were borrowed extensively from Harvey Zelaya’s 1991 thesis and need to be re-estimated based on more current information. Additionally, the literature provides only limited information about fertilizer supply and demand behavior for other countries. Acquiring such estimates for other countries, or estimating them directly, would also be a valuable improvement.

The timespan and quality of the datasets used for this thesis are likely insufficient for proper estimation. Proprietary sources for fertilizer prices are available at a significant cost, making these sources unavailable for this research. FAOSTAT reports that supply and demand variables in their database are collected directly from government sources. However, it is possible that proprietary sources of this data are available. Given the many concerns with the data used for this analysis, finding better and more consistent data should be a high priority for any future research.

The thesis model estimates supply and demand variables for the largest producers and consumers of fertilizers, but does not incorporate all countries that would be interesting to project separately. Future research could expand upon the model by breaking additional countries out of the Rest of World (ROW) category.

Conclusion

The real power of a partial equilibrium model is the ability to provide a quantitative analysis to answer various questions about the effects of changes in relevant economic variables, while requiring only minor modifications to the model. It is extremely important to assess the implications of policy options before they are implemented in order to understand both the positive and negative consequences of a proposed policy. Fertilizer industry participants would be interested in the expected effects of policy options and the implications of changes in other market factors that would impact fertilizer markets and could affect the profitability of their businesses. The global fertilizer model is capable of providing a portion of this analysis. Future research should attempt to expand upon the model in order to increase the analytical power of the model and provide more accurate estimates of market responses.

While the model developed here provides only one piece of the analysis of the fertilizer industry, connecting this model to a larger system of agricultural commodity models would allow researchers to assess the impacts that policy decisions and changes in market factors in the fertilizer industry would have on other agricultural commodity markets. It would also make it possible to evaluate a broader set of questions, such as how a change in farm policies or crop market conditions might affect everything from the price of corn to the production and use of nitrogen fertilizer.

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APPENDIX A

Supply and Utilization Tables

For each table, 2005 is a historical year while 2012 forward are model projections. Citations for individual components can be found in the data section of this thesis.

Canada Nitrogen Fertilizer Supply and Demand

	Units	**2005**	**2012**	**2015**	**2030**
	1000 Nutrient Tonnes				
Supply					
Capacity		4387	4480	4465	4422
Capacity Utilization (Implied)		70.9%	77.4%	72.5%	71.3%
Production		3109	3468	3237	3151
Imports		373	554	578	627
Total Supply		3483	4022	3815	3778
Demand					
Total Nitrogen Fertilizer Use		1777	2451	2523	2638
Corn Nitrogen Fertilizer Use		137	234	220	220
Wheat Nitrogen Fertilizer Use		599	624	637	621
Soybean Nitrogen Fertilizer Use		8	18	18	24
Rapeseed Nitrogen Fertilizer Use		296	678	710	735
Other Crops Nitrogen Fertilizer Use		736	897	938	1038
Non Fertilizer Use		0	0	0	0
Domestic Consumption		1777	2451	2523	2638
Exports		1706	1571	1292	1140
Total Demand		3483	4022	3815	3778
Residual		0	0	0	0
	$US per Metric Tonne				
Fertilizer Prices					
Anhydrous Ammonia Farm Price		715	1105	830	772

China Nitrogen Fertilizer Supply and Demand

	Units	2005	2012	2015	2030
	1000 Nutrient Tonnes				
Supply					
Capacity		29152	48886	65391	77293
Capacity Utilization (Implied)		96.1%	92.8%	91.7%	90.5%
Production		28015	45356	59945	69976
Imports		1015	334	351	441
Total Supply		29030	45690	60296	70418
Demand					
Total Nitrogen Fertilizer Use		28044	41471	55862	65607
Corn Nitrogen Fertilizer Use		4102	4952	5154	5030
Wheat Nitrogen Fertilizer Use		4131	4221	4455	4474
Soybean Nitrogen Fertilizer Use		491	367	402	361
Rapeseed Nitrogen Fertilizer Use		1050	1062	1104	1015
Cotton Nitrogen Fertilizer Use		1036	968	1145	1021
Rice Nitrogen Fertilizer Use		5590	5657	5887	5976
Other Crops Nitrogen Fertilizer Use		11644	24244	37715	47730
Non Fertilizer Use		0	0	0	0
Domestic Consumption		28044	41471	55862	65607
Exports		1037	4235	4451	4827
Total Demand		29081	45706	60313	70434
Residual		-51	-16	-16	-16
	$US per Metric Tonne				
Fertilizer Prices					
Urea Port Price		510	818	624	581

India Nitrogen Fertilizer Supply and Demand

	Units	2005	2012	2015	2030
	1000 Nutrient Tonnes				
Supply					
Capacity		11330	16030	18843	20019
Capacity Utilization (Implied)		99.0%	99.4%	97.2%	95.5%
Production		11218	15929	18324	19109
Imports		1390	3007	1388	2602
Total Supply		12608	18936	19712	21712
Demand					
Total Nitrogen Fertilizer Use		12724	17173	17941	19913
Corn Nitrogen Fertilizer Use		311	344	336	325
Wheat Nitrogen Fertilizer Use		2906	3663	3931	4005
Soybean Nitrogen Fertilizer Use		141	192	206	249
Rapeseed Nitrogen Fertilizer Use		473	586	624	581
Cotton Nitrogen Fertilizer Use		834	844	959	1247
Rice Nitrogen Fertilizer Use		4146	4483	4925	5144
Other Crops Nitrogen Fertilizer Use		3913	7061	6959	8361
Non Fertilizer Use		0	0	0	0
Domestic Consumption		12724	17173	17941	19913
Exports		10	28	36	64
Total Demand		12734	17201	17977	19977
Residual		-126	1735	1735	1735

Russia Nitrogen Fertilizer Supply and Demand

	Units	**2005**	**2012**	**2015**	**2030**
	1000 Nutrient Tonnes				
Supply					
Capacity		11056	11996	12647	15363
Capacity Utilization (Implied)		60.8%	65.3%	64.5%	60.9%
Production		6725	7828	8152	9362
Imports		42	16	16	16
Total Supply		6767	7844	8168	9378
Demand					
Total Nitrogen Fertilizer Use		863	1268	1352	1535
Corn Nitrogen Fertilizer Use		52	174	175	168
Wheat Nitrogen Fertilizer Use		458	453	503	532
Other Crops Nitrogen Fertilizer Use		354	641	674	836
Non Fertilizer Use		0	0	0	0
Domestic Consumption		863	1268	1352	1535
Exports		4892	5612	5852	6879
Total Demand		5755	6880	7204	8414
Residual		1011	964	964	964
	$US per Metric Tonne				
Fertilizer Prices					
Anhydrous Ammonia Port Price		240	407	429	403

Rest of World Nitrogen Fertilizer Supply and Demand

	Units	2005	2012	2015	2030
	1000 Nutrient Tonnes				
Supply					
Capacity		56377	66820	69407	82704
Capacity Utilization (Implied)		64.7%	53.8%	52.1%	51.0%
Production		36482	35977	36167	42164
Imports		18800	23450	25871	27901
Total Supply		55282	59427	62038	70065
Demand					
Total Nitrogen Fertilizer Use		34162	38932	42057	48400
Corn Nitrogen Fertilizer Use		5414	6141	6280	6239
Soybean Nitrogen Fertilizer Use		164	228	232	263
Rapeseed Nitrogen Fertilizer Use		75	166	188	218
Cotton Nitrogen Fertilizer Use		379	501	388	364
Other Crops Nitrogen Fertilizer Use		28129	31896	34969	41316
Non Fertilizer Use		1214	672	761	860
Domestic Consumption		35376	39604	42818	49260
Exports		16025	17695	17092	18677
Demand		51401	57299	59910	67937
Residual		3881	2128	2128	2128

Canada Phosphorus Fertilizer Supply and Demand

	Units	2005	2012	2015	2030
	1000 Nutrient Tonnes				
Supply					
Capacity		345	345	343	336
Capacity Utilization (Implied)		80.6%	71.7%	68.5%	68.0%
Production		278	247	235	228
Imports		478	549	582	626
Total Supply		756	796	817	855
Demand					
Total Phosphorus Fertilizer Use		693	757	779	815
Corn Phosphorus Fertilizer Use		37	62	58	58
Wheat Phosphorus Fertilizer Use		172	184	186	180
Soybean Phosphorus Fertilizer Use		28	49	51	66
Rapeseed Phosphorus Fertilizer Use		66	148	152	158
Other Crops Phosphorus Fertilizer Use		389	315	331	353
Non Fertilizer Use		0	0	0	0
Domestic Consumption		693	757	779	815
Exports		63	38	39	40
Total Demand		756	796	817	855
Residual		0	0	0	0
	$US per Metric Tonne				
Fertilizer Prices					
MAP Port Price		436	768	571	568

China Phosphorus Fertilizer Supply and Demand

	Units	2005	2012	2015	2030
	1000 Nutrient Tonnes				
Supply					
Capacity		12360	17845	19291	21747
Capacity Utilization (Implied)		99.0%	93.2%	87.9%	81.4%
Production		12238	16636	16957	17698
Imports		1255	310	297	230
Total Supply		13493	16946	17253	17928
Demand					
Total Phosphorus Fertilizer Use		13140	12036	12431	12768
Corn Phosphorus Fertilizer Use		649	845	876	857
Wheat Phosphorus Fertilizer Use		1846	1965	2058	2040
Soybean Phosphorus Fertilizer Use		417	302	338	312
Rapeseed Phosphorus Fertilizer Use		351	351	359	332
Cotton Phosphorus Fertilizer Use		379	359	410	351
Rice Phosphorus Fertilizer Use		1855	2018	2052	2061
Other Crops Phosphorus Fertilizer Use		7643	6195	6338	6815
Non Fertilizer Use		0	0	0	0
Domestic Consumption		13140	12036	12431	12768
Exports		435	4935	4848	5186
Total Demand		13574	16971	17279	17953
Residual		-82	-25	-25	-25
	$US per Metric Tonne				
Fertilizer Prices					
DAP Port Price		522	911	714	711

India Phosphorus Fertilizer Supply and Demand

	Units	2005	2012	2015	2030
	1000 Nutrient Tonnes				
Supply					
Capacity		4133	4986	6041	6362
Capacity Utilization (Implied)		99.0%	98.2%	94.6%	89.2%
Production		4093	4895	5716	5677
Imports		1145	2797	2523	2986
Total Supply		5237	7692	8239	8662
Demand					
Total Phosphorus Fertilizer Use		5210	7523	8068	8485
Corn Phosphorus Fertilizer Use		76	103	101	97
Wheat Phosphorus Fertilizer Use		1098	1757	1837	1804
Soybean Phosphorus Fertilizer Use		143	246	254	301
Rapeseed Phosphorus Fertilizer Use		164	223	243	236
Cotton Phosphorus Fertilizer Use		414	534	585	739
Rice Phosphorus Fertilizer Use		1271	1516	1775	1817
Other Crops Phosphorus Fertilizer Use		2045	3144	3273	3491
Non Fertilizer Use		0	0	0	0
Domestic Consumption		5210	7523	8068	8485
Exports		11	17	19	25
Total Demand		5221	7540	8087	8510
Residual		16	152	152	152

Russia Phosphorus Fertilizer Supply and Demand

	Units	**2005**	**2012**	**2015**	**2030**
	1000 Nutrient Tonnes				
Supply					
Capacity		2802	3168	3178	3121
Capacity Utilization (Implied)		98.7%	87.0%	83.7%	80.7%
Production		2766	2757	2659	2520
Imports		2	19	21	30
Total Supply		2768	2776	2680	2550
Demand					
Total Phosphorus Fertilizer Use		347	433	471	506
Corn Phosphorus Fertilizer Use		17	48	49	46
Wheat Phosphorus Fertilizer Use		183	222	252	274
Other Crops Phosphorus Fertilizer Use		147	163	170	186
Non Fertilizer Use		0	0	0	0
Domestic Consumption		347	433	471	506
Exports		2242	2857	2723	2558
Total Demand		2589	3290	3194	3064
Residual		179	-514	-514	-514

Rest of World Phosphorus Fertilizer Supply and Demand

	Units	2005	2012	2015	2030
	1000 Nutrient Tonnes				
Supply					
Capacity		15044	16272	18994	22067
Capacity Utilization (Implied)		66.3%	65.4%	62.6%	61.0%
Production		9979	10642	11899	13467
Imports		10010	11798	11744	13190
Total Supply		19989	22440	23643	26657
Demand					
Total Phosphorus Fertilizer Use		16016	17684	18518	19885
Corn Phosphorus Fertilizer Use		1857	1946	2025	2028
Soybean Phosphorus Fertilizer Use		1226	1621	1773	2103
Rapeseed Phosphorus Fertilizer Use		23	40	45	54
Cotton Phosphorus Fertilizer Use		127	168	126	115
Other Crops Phosphorus Fertilizer Use		12783	13909	14549	15585
Non Fertilizer Use		0	0	0	0
Domestic Consumption		16016	17684	18518	19885
Exports		3340	3667	4035	5682
Total Demand		19357	21350	22553	25567
Residual		632	1090	1090	1090

Canada Potassium Fertilizer Supply and Demand

	Units	2005	2012	2015	2030
	1000 Nutrient Tonnes				
Supply					
Capacity		13340	14547	16540	24045
Capacity Utilization (Implied)		60.5%	69.7%	68.6%	66.9%
Production		8073	10139	11345	16086
Imports		16	22	22	21
Total Supply		8089	10161	11366	16107
Demand					
Total Potassium Fertilizer Use		329	368	380	446
Corn Potassium Fertilizer Use		48	79	75	82
Wheat Potassium Fertilizer Use		32	32	31	32
Soybean Potassium Fertilizer Use		19	36	38	52
Rapeseed Potassium Fertilizer Use		42	97	102	114
Other Crops Potassium Fertilizer Use		187	124	133	166
Non Fertilizer Use		0	0	0	0
Domestic consumption		329	368	380	446
Exports		7760	9704	10898	15572
Total Demand		8089	10072	11277	16018
Residual		0	89	89	89
	$US per Metric Tonne				
Fertilizer Prices					
Potassium Chloride Port Price		158	459	369	185

China Potassium Fertilizer Supply and Demand

Units	2005	2012	2015	2030
1000 Nutrient Tonnes				
Supply				
Capacity	1464	4337	4961	6068
Capacity Utilization (Implied)	84.4%	92.8%	90.2%	84.2%
Production	1236	4025	4476	5111
Imports	5893	3487	3722	5033
Total Supply	7129	7512	8197	10144
Demand				
Total Potassium Fertilizer Use	7161	7283	7973	9946
Corn Potassium Fertilizer Use	113	95	104	117
Wheat Potassium Fertilizer Use	242	214	219	217
Soybean Potassium Fertilizer Use	66	37	42	40
Rapeseed Potassium Fertilizer Use	90	65	69	69
Cotton Potassium Fertilizer Use	63	43	49	42
Rice Potassium Fertilizer Use	1741	1598	1598	1616
Other Crops Potassium Fertilizer Use	4846	5231	5892	7844
Non Fertilizer Use	0	0	0	0
Domestic Consumption	7161	7283	7973	9946
Exports	45	204	199	173
Total Demand	7206	7487	8172	10119
Residual	-77	25	25	25
$US per Metric Tonne				
Fertilizer Prices				
Potassium Chloride Port Price	466	1017	834	509

India Potassium Fertilizer Supply and Demand

	Units	2005	2012	2015	2030
	1000 Nutrient Tonnes				
Supply					
Capacity		0	0	0	0
Capacity Utilization (Implied)		0.0%	0.0%	0.0%	0.0%
Production		0	0	0	0
Imports		2764	2844	3225	3939
Total Supply		2764	2844	3225	3939
Demand					
Total Potassium Fertilizer Use		2414	2512	2892	3598
Corn Potassium Fertilizer Use		24	28	30	33
Wheat Potassium Fertilizer Use		194	329	338	335
Soybean Potassium Fertilizer Use		27	42	44	54
Rapeseed Potassium Fertilizer Use		27	31	35	37
Cotton Potassium Fertilizer Use		137	151	168	219
Rice Potassium Fertilizer Use		769	936	1072	1091
Other Crops Potassium Fertilizer Use		1235	996	1207	1831
Non Fertilizer Use		0	0	0	0
Domestic Consumption		2414	2512	2892	3598
Exports		0	29	30	39
Demand		2414	2542	2923	3637
Residual		350	302	302	302

Russia Potassium Fertilizer Supply and Demand

	Units	**2005**	**2012**	**2015**	**2030**
	1000 Nutrient Tonnes				
Supply					
Capacity		7202	7865	8770	10846
Capacity Utilization (Implied)		99.0%	96.3%	94.1%	87.7%
Production		7131	7572	8249	9514
Imports		21	9	10	15
Total Supply		7152	7581	8259	9529
Demand					
Total Potassium Fertilizer Use		226	279	296	317
Corn Potassium Fertilizer Use		11	33	36	38
Wheat Potassium Fertilizer Use		75	76	86	92
Other Crops Potassium Fertilizer Use		140	169	174	187
Non Fertilizer Use		0	0	0	0
Domestic Consumption		226	279	296	317
Exports		5719	5717	6378	7627
Total Demand		5945	5995	6674	7944
Residual		1207	1585	1585	1585

Rest of World Potassium Fertilizer Supply and Demand

	Units	2005	2012	2015	2030
	1000 Nutrient Tonnes				
Supply					
Capacity		18403	20581	21436	24266
Capacity Utilization (Implied)		75.4%	64.4%	64.1%	63.4%
Production		13884	13264	13735	15377
Imports		13358	15980	16972	19654
Total Supply		27242	29244	30707	35031
Demand					
Total Potassium Fertilizer Use		12686	15487	16918	21320
Corn Potassium Fertilizer Use		1444	1448	1508	1566
Soybean Potassium Fertilizer Use		1114	1285	1296	1498
Rapeseed Potassium Fertilizer Use		26	43	48	58
Cotton Potassium Fertilizer Use		53	70	53	51
Other Crops Potassium Fertilizer Use		10050	12641	14012	18148
Non Fertilizer Use		683	297	357	516
Domestic Consumption		13369	15784	17275	21836
Exports		12489	12402	12374	12137
Demand		25858	28186	29649	33973
Residual		1384	1058	1058	1058

APPENDIX B

Model Elasticities

Own-Prices Elasticities Used in the Model

Country	Category	N	P	K
United States	Corn	-0.13	-0.10	-0.08
	Soybeans	-0.11	-0.14	-0.12
	Rapeseed	-0.13	-0.14	-0.27
	Cotton	-0.10	-0.12	-0.15
	Wheat	-0.20	-0.14	-0.14
	Other Crops	-0.30	-0.15	-0.20
	Non-Fertilizer Use	-0.40	-0.20	-0.20
Canada	Corn	-0.12	-0.12	-0.25
	Soybeans	-0.10	-0.18	-0.20
	Rapeseed	-0.15	-0.10	-0.20
	Wheat	-0.20	-0.15	-0.15
	Other Crops	-0.10	-0.15	-0.20
China	Corn	-0.11	-0.12	-0.25
	Soybeans	-0.10	-0.18	-0.20
	Rapeseed	-0.15	-0.10	-0.20
	Cotton	-0.11	-0.05	-0.05
	Wheat	-0.17	-0.15	-0.15
	Rice	-0.16	-0.15	-0.15
	Other Crops	-0.40	-0.03	-0.30
India	Corn	-0.12	-0.12	-0.25
	Soybeans	-0.25	-0.18	-0.20
	Rapeseed	-0.05	-0.10	-0.20
	Cotton	-0.15	-0.05	-0.10
	Wheat	-0.20	-0.15	-0.15
	Rice	-0.20	-0.15	-0.15
	Other Crops	-0.10	-0.10	-0.20
Russia	Corn	-0.12	-0.12	-0.25
	Wheat	-0.12	-0.15	-0.15
	Other Crops	-0.20	-0.10	-0.05
ROW	Corn	-0.12	-0.20	-0.08
	Soybeans	-0.10	-0.35	-0.05
	Rapeseed	-0.15	-0.20	-0.10
	Cotton	-0.15	-0.05	-0.10
	Other Crops	-0.20	-0.20	-0.30
	Non-Fertilizer Use	-0.30		-0.35

Output Price Elasticities Used in the Model

Country	Category	N	P	K
United States	Corn	0.17	0.06	0.08
	Soybeans	0.05	0.08	0.05
	Rapeseed	0.15	0.10	0.27
	Cotton	0.15	0.10	0.14
	Wheat	0.15	0.05	0.08
Canada	Corn	0.17	0.17	0.10
	Soybeans	0.10	0.08	0.10
	Rapeseed	0.15	0.10	0.10
	Wheat	0.06	0.06	0.15
China	Corn	0.17	0.17	0.10
	Soybeans	0.10	0.08	0.10
	Rapeseed	0.15	0.10	0.10
	Cotton	0.16	0.23	0.23
	Wheat	0.06	0.06	0.15
	Rice	0.06	0.06	0.15
India	Corn	0.17	0.17	0.10
	Soybeans	0.10	0.08	0.10
	Rapeseed	0.14	0.10	0.10
	Cotton	0.23	0.23	0.23
	Wheat	0.06	0.10	0.15
	Rice	0.06	0.06	0.15
Russia	Corn	0.17	0.17	0.10
	Wheat	0.13	0.06	0.15
ROW	Corn	0.17	0.17	0.08
	Soybeans	0.10	0.08	0.05
	Rapeseed	0.15	0.10	0.10
	Cotton	0.23	0.23	0.23

Nitrogen Net Return Supply Equation Elasticities Used in the Model

Country	Category	ENR t	ENR t-1	ENR t-2	ENR t-3	ENR t-4	ENR t-5	ENR t-6
United States	Capacity	0.002	0.0015	0.003	0.015	0.003	0.0025	0.002
	Capacity Utilization	0.42						
Canada	Capacity	0.002	0.0015	0.001	0.01	0.009	0.007	0.0055
	Capacity Utilization	0.7						
China	Capacity	0.002	0.0015	0.003	0.015	0.004	0.0035	0.0025
	Capacity Utilization	0.1						
India	Capacity	0.0015	0.001	0.002	0.025	0.01	0.0035	0.0025
	Capacity Utilization	0.5						
Russia	Capacity	0.002	0.0015	0.001	0.001	0.0035	0.007	0.0055
	Capacity Utilization	0.5						
ROW	Capacity	0.001	0.001	0.001	0.004	0.002	0.002	0.001
	Capacity Utilization	0.5						

Potassium Supply Elasticities Used in the Model

Country	Category	KCl Price	KCl Price t-1	Average ENR t-6 to t-8	PPI Electricity t-7	PPI Wages t-7
United States	Capacity	0.0012	0.001	0.005	-0.01	-0.01
	Capacity Utilization	0.5			-0.1*	-0.05*
Canada	Capacity	0.0025	0.0015	0.03		-0.1
	Capacity Utilization	0.5				-0.15*
China	Capacity	0.006	0.005	0.01	-0.05	-0.05
	Capacity Utilization	0.5			-0.1*	-0.1*
Russia	Capacity	0.0025	0.0015	0.01		
	Capacity Utilization	0.5				
ROW	Capacity	0.002	0.001	0.005		
	Capacity Utilization	0.1				

* Denotes elasticities for year t in PPI columns

Phosphorus Net Return Supply Elasticities Used in the Model

Country	Category	ENR t	ENR t-1	ENR t-2	ENR t-3	ENR t-4
United States	Capacity	0.001	0.001	0.0015	0.003	0.003
	Capacity Utilization	0.1				
Canada	Capacity	0.005	0.001	0.001	0.002	0.0015
	Capacity Utilization	0.6				
China	Capacity	0.003	0.002	0.003	0.006	0.006
	Capacity Utilization	0.5				
India	Capacity	0.01	0.03	0.02	0.07	0.06
	Capacity Utilization	0.5				
Russia	Capacity	0.001	0.0015	0.002	0.01	0.01
	Capacity Utilization	0.2				
ROW	Capacity	0.001	0.001	0.001	0.004	0.03
	Capacity Utilization	0.5				

Long-run capacity elasticites

Country	N	P	K
United States	0.41	0.14	-0.26
Canada		0.05	-2.20
China	0.13	0.25	-0.53
India	0.27	2.11	
Russia	0.43	0.04	0.20
ROW	0.15	0.37	0.27