

PRICE RELATIONSHIPS IN THE U.S. NITROGEN FERTILIZER INDUSTRY

by

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ABSTRACT

This study estimates the price dynamics in the U.S. nitrogen fertilizer industry, measures information flow efficiency in spatially separated fertilizer markets, and measures to what extent structural changes in corn and natural gas markets may have altered these price dynamics and information flow relationships. A vector error correction model is used to measure the short-run and long-run relationships between nitrogen fertilizer markets, natural gas markets, and corn markets. The results show that price information flows from the central market of New Orleans to inland regional markets. The efficiency of this information flow increased in the period after the Renewable Fuel Standards increased the demand for corn.

INTRODUCTION

Price is the fundamental mechanism in the classical economic model of supply and demand to summarize the relationship dynamics between producers and consumers. The price of a particular good or service serves as an economic signal that allows consumers and producers to allocate their scarce resources in a manner that maximizes their well-being. An important aspect that enables prices to serve as an efficient instrument for allocating resources is fast, unimpeded flow of information.

Assessing price dynamics in commodity markets can be particularly useful for understanding the efficiency of information flow (and overall market efficiency). This is because these products are homogeneously produced and consumed, they are marketed in many geographically separated markets, and those markets are highly competitive such that any economic advantages are quickly arbitrated away. This would particularly be the case for markets that are connected through the physical trade of those commodities. As such, if these markets operate in a long-run efficient manner, the prices of agricultural goods across these spatially-separated markets should be highly linked.

Empirically testing this hypothesis by studying price linkages in spatially-separated markets is important for understanding the economic landscape of specific agricultural markets and helping participants of these markets make more informed decisions about allocating resources in a Pareto efficient manner. If empirical results show that a market is inefficient, this may indicate the presence of information asymmetry or imperfect competition, resulting in socially non-optimal outcomes. This inefficiency could be addressed through public policy.

Nitrogen fertilizer is one of the most important agricultural inputs. It is marketed in spatially separated markets because of its use in agricultural production, which is geographically spread across the United States. There has been limited research into the spatial price transmission between regional nitrogen markets in the United States. Hu and Brorsen (2017) is the only study that measures spatial price relationships in this industry, but they only focus on one spatial relationship for one nitrogen fertilizer. This study measures spatial price relationships in the United States for four common nitrogen fertilizers and looks at how these spatial price relationships are affected by structural changes in the related vertical markets of natural gas and corn.

Measuring the spatial price relationships between regional markets and understanding how price shocks are transmitted around the country provides valuable information to both fertilizer and agricultural producers. Fertilizer producers who understand regional market linkages can better price their fertilizer and estimate regional demand. Agricultural producers may use insights about market linkages to better anticipate local price variation when making production and farm management decisions.

The U.S. nitrogen fertilizer industry is centered on the regional market of New Orleans, Louisiana. This is where the majority of domestic production occurs and also where a significant portion of imported nitrogen enters the United States. From New Orleans, fertilizer moves inland to be used in agricultural production. Therefore, price information also flows from New Orleans to inland regional markets. This study looks at the price dynamics for urea, urea ammonium nitrate (UAN), diammonium phosphate (DAP), and monoammonium phosphate (MAP) between New Orleans and the inland

regional markets of the Northern Great Plains (NGP), the Southern Great Plains (SGP), the Great Lakes (GL), and the Pacific Northwest (PNW). Regional, weekly price data for these nitrogen fertilizer from 1995 to 2010 were obtained from Green Markets.

A vector error correction model (VECM) is used to empirically measure price relationships in the U.S. nitrogen fertilizer industry. VECMs model the influence of both long-run and short-run factors affecting the price dynamics and transmission behaviors between markets. This provides a thorough understanding of how price information flows between both spatially-separated fertilizer markets and vertical markets that can affect the demand and supply of fertilizer. This study measures the spatial price relationships between the major fertilizer distribution center in the United States—New Orleans, Louisiana—and other inland regional markets, while controlling for price shocks from related vertical markets of corn and natural gas. These price relationships are measured before and after the structural changes in U.S. agricultural markets that began in 2007; specifically the 2005 and 2007 policies mandating the use of ethanol fuel and the acceleration of hydraulic fracturing technologies that impacted the production of natural gas.

The results show that price information does in fact flow from New Orleans to inland regions. The inland regional prices, NGP, SGP, GL, and PNW, adjust to shocks in the system, while NOLA does not. There was low price information flow from the vertical markets to the fertilizer markets, although the results show that natural gas had a greater effect on the price discovery process before the structural change, and corn had greater affect after the structural change. Lastly, this structural change resulted in a

greater efficiency of price information flow from New Orleans to the inland regional markets.

INDUSTRY BACKGROUND

During WWII, the U.S government invested in the facilities and technology to produce nitrogen, an important input to munition markets. In the postwar world, the need for bombs dwindled and instead, nitrogen was used to make fertilizer to satisfy a growing world population. The use of synthetic fertilizer and development of other agricultural techniques and technologies lead to the “Green Revolution”, which brought the world into the modern age of fertilizer (Hergert et al. 2017). Since then, it has grown into a global commodity, where thirty-seven percent of the total production is traded internationally (Dutkowsky, Brester, & Smith, 2014a).

The vast majority of fertilizer demand originates from commercial farms. Many farmers determine their nutrient needs by contracting specialists who analyze their soil characteristics, but expectations about crop quality, type, yield responses, and fertilizer prices also factor into each farmer’s decision as to what type and how much fertilizer they use. Most fertilizer products used by farmers contain three main plant nutrients: nitrogen, phosphate, and potassium. Micronutrients, like sulfur, iron, boron, copper, chloride, zinc, and manganese, are also present in fertilizer in varying amounts (Dutkowski et al., 2014). This study focuses specifically on nitrogen fertilizers, which accounts for about half of synthetic fertilizers use in the United States (USDA, ERS).

Overview of Nitrogen Fertilizer Production

Modern agricultural production uses nitrogen fertilizer to not only increase yields, but also maintain plant health on existing fields (FAO, 1981). Fertilizer adds inorganic nitrogen to the soil, which through the process of nitrification and with the help of bacteria, is transformed into a usable form by plants. Crops need to absorb sufficient amounts of nitrogen to facilitate photosynthesis, a building block to amino acids that is necessary for reproduction (International Plant Nutrition Institute, 2017). Modern yields would not be possible without the use of these additional nutrients, with many long-term studies determining the average percentage of annual yield attributed to fertilizer ranges from 30% to 60% in the United States (Stewart, 2005).

There are a variety of nitrogen fertilizers that are commercially available for agricultural use. As shown in Figure 1.1, the most common nitrogen fertilizers used in the United States and the ones looked at in this study are urea, urea ammonium nitrate (UAN), diammonium phosphate (DAP), and monoammonium phosphate (MAP). They accounted for an average of 71% percent of the total annual nitrogen consumption in the United States from 1988 to 2011.

The main input to each of these fertilizers is ammonia. Ammonia is a single nutrient fertilizer with the highest available concentration of nitrogen available on the market at 82%. Ammonia is produced through the Haber-Bosch Process. This exothermic chemical reaction uses nitrogen from the air, hydrogen from natural gas, a pressurized chamber, and an iron-based catalyst to produce liquid ammonia (International Plant Nutrition Institute, 2017). Natural gas accounts for about 72 to 85 percent of the

production costs of ammonia (Huang, 2007). Ammonia must be stored in pressurized tanks during transportation. It can also cause chemical burns if mishandled when applying it to a field (Shutske, 2005). Because of these risks, ammonia is frequently transformed into a variety of less volatile, safer products such as urea, UAN, MAP, and DAP.

Urea

Ammonia is combined with carbon dioxide to produce urea, the most widely used dry nitrogen fertilizer in the United States (USDA ERS, 2014). Urea contains about 46% nitrogen. While it contains relatively less nitrogen than ammonia, it is safer and easier to use because it is not as volatile and does not need to be stored in pressurized tanks during transportation. Urea is typically sold in prill or granular form, but can be mixed with irrigation water for a simpler application method (International Plant Nutrition Institute, 2017).

Urea Ammonium Nitrate

Urea and ammonium nitrate are combined to produce urea ammonium nitrate (UAN), a liquid fertilizer that contains nitrogen concentrations that typically range between 28% and 32%. UAN has favorable chemical properties that allow it to be mixed with various other nutrients, such as phosphorous and potassium, to meet farmers' custom needs. One common method of application is injecting UAN into the soil beneath the surface to avoid leaching, the loss of nitrogen from the soil due to rain and irrigation water (International Plant Nutrition Institute, 2017).

Diammonium Phosphate and Monoammonium Phosphate

DAP and MAP are multi-nutrient fertilizers that contain both nitrogen and phosphorous. Ammonia and phosphoric acid are combined to produce both of these fertilizers. DAP contains 18% nitrogen and 46% phosphate. MAP contains about 10% nitrogen and anywhere from 48% to 61% phosphate. The decision to use one or the other usually comes down to the relative amount of nitrogen needed in a certain farm's soil. (International Plant Nutrition Institute, 2017).

Nitrogen Fertilizer Consumption

Figure 1.2 shows that nitrogen represents about half of total plant nutrient consumption in the United States since the 1960s. The majority of nitrogen fertilizers are consumed for agricultural purposes. For example, 87% of ammonia production in the United States is used directly or indirectly for fertilizer (Vroomen, 2013). While all crops require nitrogen, some crops are more nitrogen-intensive. Two of the most nitrogen-intensive crops, corn and wheat, are also two of the most widely planted crops in the United States (USDA, ERS 2016).

Corn is the most nitrogen-intensive crop. Figure 1.3 shows corn producers are the largest consumers of nitrogen, using almost half the total supply in the United States. This nitrogen use has helped contribute (along with other technological improvements) to higher yields and production of corn in the United States. Figure 1.4 shows that acres planted of corn have remained relatively stable at an average of 87 million acres planted annually, while production has increase 1200% since 1936. Figure 1.5 shows that since

acres planted of corn has remained relatively stable over time, this increase in production is a result of higher yields.

While better production methods and seed technology can explain some of this increase in yields, nitrogen fertilizers were also important. Figure 1.6 show that fertilizers as a whole makes up the largest variable input cost for corn production. From 1996 to 2015, fertilizer accounted for an average of 37% of the total costs of producing corn on a representative acre in the United States. This value ranged from 25% to almost 50%, depending on the year.

Modern agricultural producers recognize the importance of nitrogen in crop production, but the optimal economic input use depends on the ratio of commodity (output) to input prices. Therefore, factors affecting commodity prices will lead to an adjustment in fertilizer use by farmers. For example, in the early 2000s, the Renewable Fuel Standards in the United States increased the demand and price for corn. These standards require that transportation fuel sold in the United States contain a minimum amount of renewable fuels, such as biofuel produced from corn (U.S Department of Energy, 2017). Higher prices lead to increased profit margins in agricultural production, encouraging producers to use more fertilizer to increase yields and therefore profits. Higher prices for commodities, like corn, shift out the demand for fertilizer, thereby increasing fertilizer prices (Acheampong and Dicks, 2012). These higher prices can make different production methods, such as variable rate application, more profitable (Gandonou and Dillon, 2007).

Overview of U.S. Fertilizer Distribution

As late as the 1980s, the United States was a net exporter of nitrogen fertilizer. Around that time, there were about fifty domestic firms with 113 plants producing ammonia, the foundation of all synthetic nitrogen fertilizers. There were significant changes in the domestic industry from 1980 to the 2000s (Kim et al., 2001). The domestic nitrogen fertilizer industry also became highly concentrated. By 2010, there were only 13 firms still in operation, producing 75% of the total domestic ammonia production (Humber 2014). The average size of plants also became larger during this period. The average production capacity per ammonia plant increased from 170.7 thousand tons per year in 1976 to 498.5 thousand tons per year in 2000. This provides evidence of economies of scale in the domestic nitrogen industry (Kim et al., 2001).

The highly concentrated domestic nitrogen fertilizer industry suffered in the early 2000s because of relatively high U.S. natural gas prices compared to foreign prices, given foreign exporters a competitive advantage over the domestic nitrogen industry (Government Accountability Office, 2003). These high prices resulted in a 25% decrease in domestic production of nitrogen in 2000. From 2001 to 2003, eight U.S. nitrogen fertilizer-manufacturing plants permanently closed. Therefore, to satisfy the continued demand for synthetic plant nutrients, U.S. fertilizer distributors began to import nitrogen fertilizer from countries that had lower natural gas prices and could produce nitrogen fertilizer at a lower cost (Government Accountability Office, 2003). This imported nitrogen satisfied about half the nitrogen consumed in the United States starting in the

early 2000s (Huang, 2007). Important trade partners for nitrogen fertilizers are Canada, Trinidad and Tobago, Russia, and a variety of Middle Eastern countries (Huang, 2004).

The reliance on imports continues today, but this is changing. In 2007, high natural gas production due to the introduction horizontal hydraulic fracking increased the domestic supply. This resulted in the producer price index for natural gas decreasing about 57% between 2007 and 2012 (PPI Energy and Chemicals Team, 2013). Lower domestic natural gas prices make U.S. nitrogen production more competitive. U.S. producers recognize this and new production plants in the cornbelt, like the Iowa Fertilizer Company's 3-billion dollar new plant, are starting to produce nitrogen fertilizer (Swoboda, 2017).

New Orleans as the U.S. Fertilizer Distribution Center

Most fertilizer plants are located near natural gas reserves, ensuring they have access to the main input needed to produce fertilizer (Dutkowsky, Brester, & Smith, 2014b). Figures 1.7 and 1.8 plot the location and production capacity of domestic ammonia processing facilities. Most of the domestic production is centered in the Gulf region around New Orleans. This is because firms here not only have access to relatively cheap natural gas, but also can take advantage of the Mississippi River to ship their fertilizer to inland regions. By 2022, New Orleans is projected to still be an important production area; however, new and expanded plants located in the U.S. cornbelt are expected to increase fertilizer production, which could affect how prices are transmitted around the country (Swoboda, 2017; Mitchell, 2017).

New Orleans is not only an important location for domestic production, but it is where the majority of imports enter the United States. This is for the same reason domestic producers build their plants there: cheap inland transportation provided by the Mississippi River. While there are no publicly-available data describing the actual amount of nitrogen imported through New Orleans, there are data on the value of these imports. For ammonia, urea, and UAN, figures 1.9, 1.10, and 1.11 show the port district of New Orleans was where the majority or a significant portion of nitrogen was imported into the United States. New Orleans is not always the top import location for ammonia or UAN, but other important locations include Tampa and Houston are still located in the Gulf region. The average value of imported fertilizer at New Orleans from 2003 to 2015 was \$1 billion, \$600 million, and \$100 million for urea, ammonia, and UAN, respectively.

From New Orleans, fertilizer products are shipped throughout the United States by barge, train, and truck to distribution centers and retailers, where they are sold to farm businesses. The Mississippi River is an important shipping route where large amounts of fertilizers can be moved to inland regions and at relatively lower costs to truck or train shipments. Typically, marine vessels and trains are the main transportation modes to move final fertilizer product from manufactures to retailers, warehouses, and terminals (Dutkowsky, Brester, & Smith, 2014d).

Large wholesalers can order entire unit trains of nitrogen. This gives them competitive prices and a short delivery time of about one week because distributors can fill an entire train with fertilizer and it can travel directly to wholesalers. Smaller

wholesalers must order by the car and face higher prices and potentially longer time until delivery. These deliveries take about one to five weeks to reach inland regions from New Orleans (Personal communication with a Montana fertilizer distributor, 2017). Any disruptions to the transportation system, such as flooding or drought on the Mississippi River or disruptions to rail shipments, are likely to affect the fertilizer supply and prices in inland regions (Dutkowsky, Brester, & Smith, 2014d). The shipment of fertilizer on marine vessels and trains is constant from quarter to quarter because retailers are storing it for later sale. They must estimate demand for fertilizer in order to have enough product on hand during periods like the fall applications of nitrogen in corn production. Trucks are only used during the high demand periods to move the fertilizer to their final destination at farms (The Fertilizer Institute, 2016).

Because New Orleans is the primary distribution center of nitrogen fertilizer in the United States, fertilizer wholesalers look to New Orleans prices to gauge how to price products at inland locations. In fact, some type of formula-based pricing is used for the entire nitrogen fertilizer industry in United States (Russ Miner, personal communication, 2017; Steve Keller, personal communication, 2017; Personal communication with a Montana fertilizer distributor, 2017). This means that the price at New Orleans is likely used as a base price for prices in many other U.S. regions. For example, the price in the Northern Great Plains might be the price at New Orleans plus any transportation or storage costs it took to move the fertilizer inland.

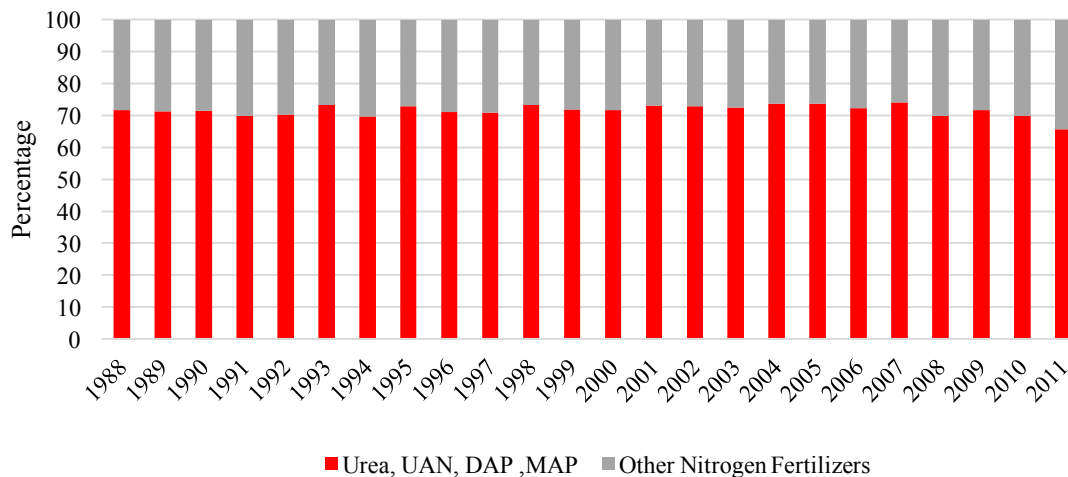
Steve Keller, the fertilizer sales manager at Morral Companies in Ohio, confirmed that the New Orleans market is used as a base price for nitrogen fertilizer sales around the

country. Two other fertilizer managers, both based in Montana, also confirmed this industry-wide practice (R. Miner, personal communication, January 2018; Anonymous, personal communication, January 2018). A fertilizer manager in Southeast Montana even added that Canadian producers look at the New Orleans market to price their nitrogen-based fertilizers (Anonymous, personal communication, January, 2018). Russ Miner cautioned that this practice might be disrupted as domestic manufacturing plants become more competitive compared to imports and build their plants in inland regions. This may affect the long-term price relationships between New Orleans and inland regions.

Chapter Takeaways

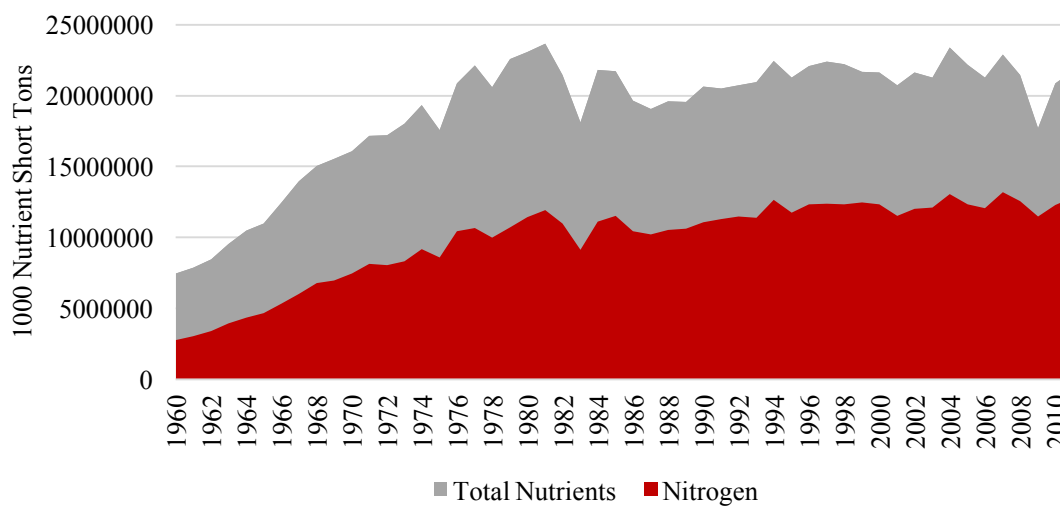
- Nitrogen fertilizers are one of the most important agricultural inputs, especially for corn production.
- Not only is New Orleans an important location for domestic production, but a significant port for fertilizer imports into the United States. From New Orleans, the fertilizer moves throughout the United States to be used in agricultural production.
- The nitrogen-based fertilizer industry around the United States bases their prices on the price at New Orleans.

Figure 1.1: Single and Multi-Nutrient Nitrogen Fertilizers in the United States from 1988 to 2011



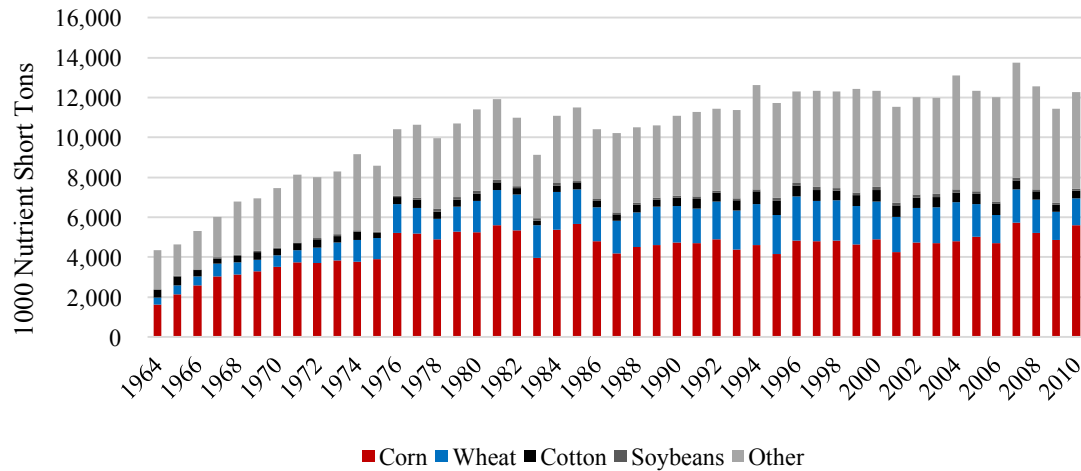
Source: USDA, Economic Research Service

Figure 1.2: U.S Consumption of Plant Nutrients from 1960 to 2011



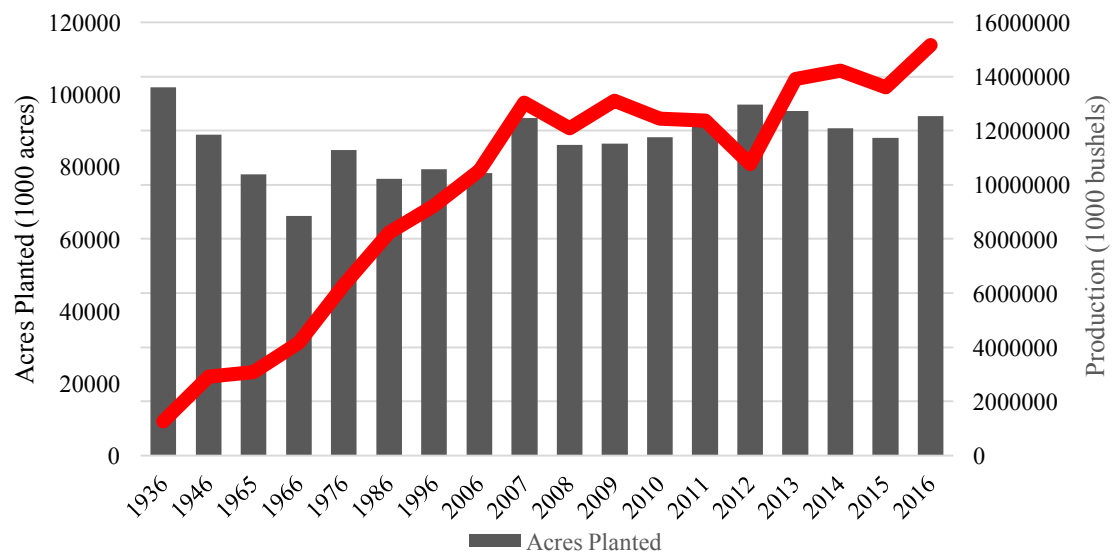
Source: USDA, Economic Research Service

Figure 1.3: Estimated U.S Nitrogen Use by Select Crops from 1964 to 2010



Source: USDA, Economic Research Service

Figure 1.4: Acres Planted and Production for Corn in the United States



Source: USDA, NASS, Crop Production 2016 Summary

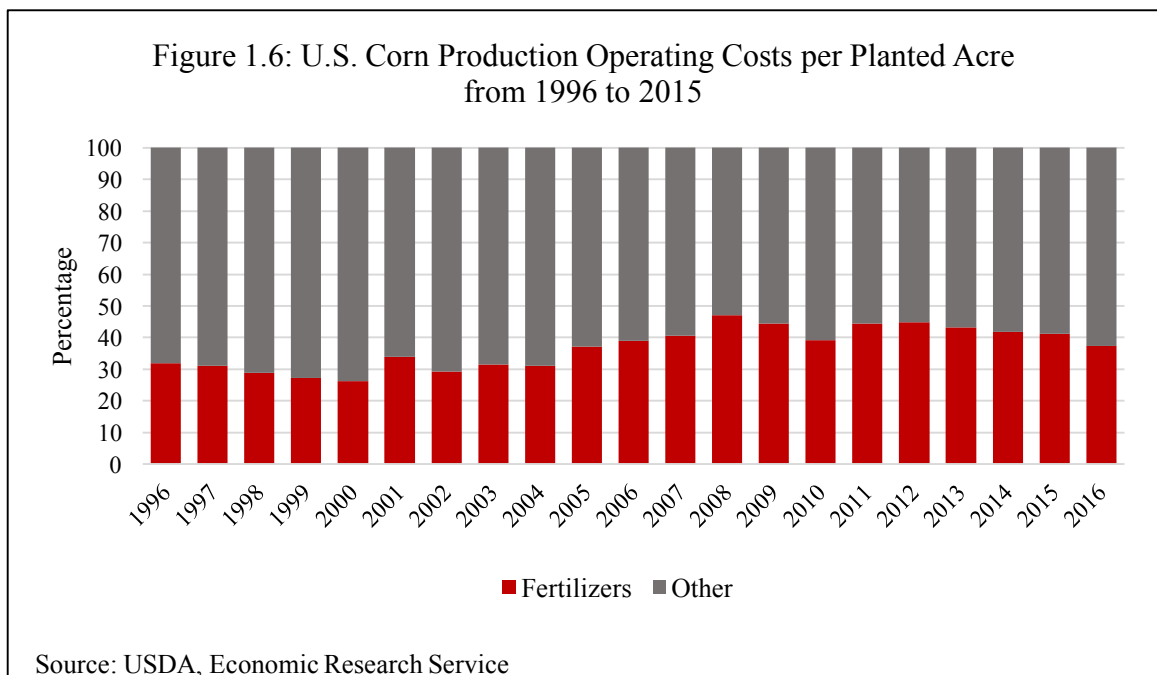
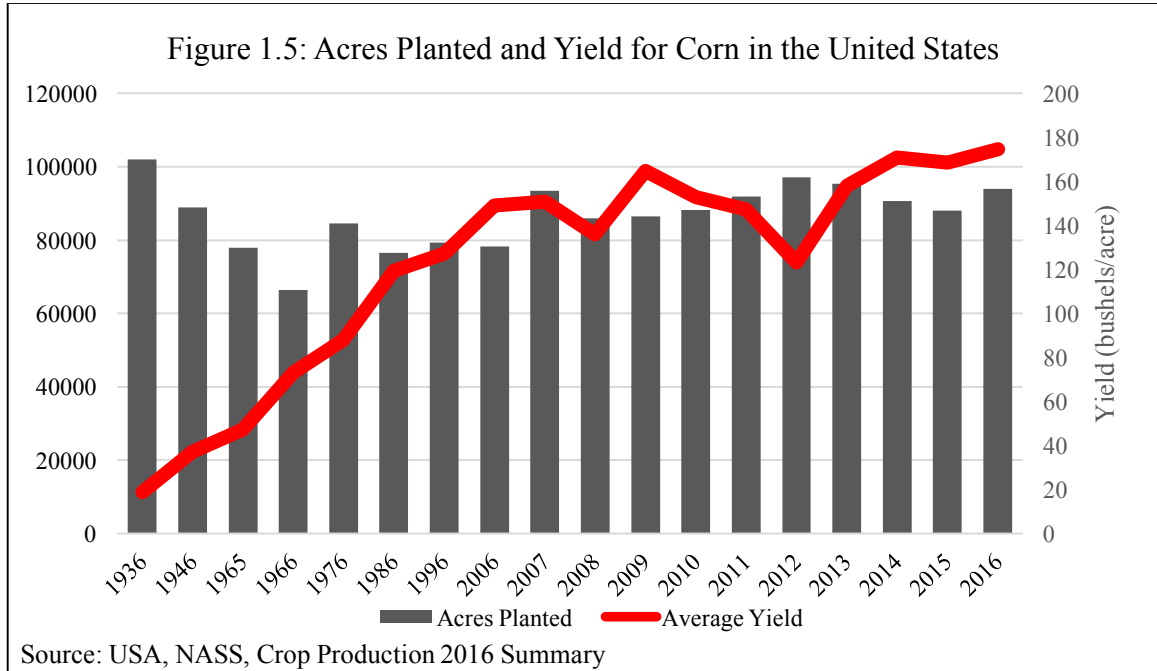
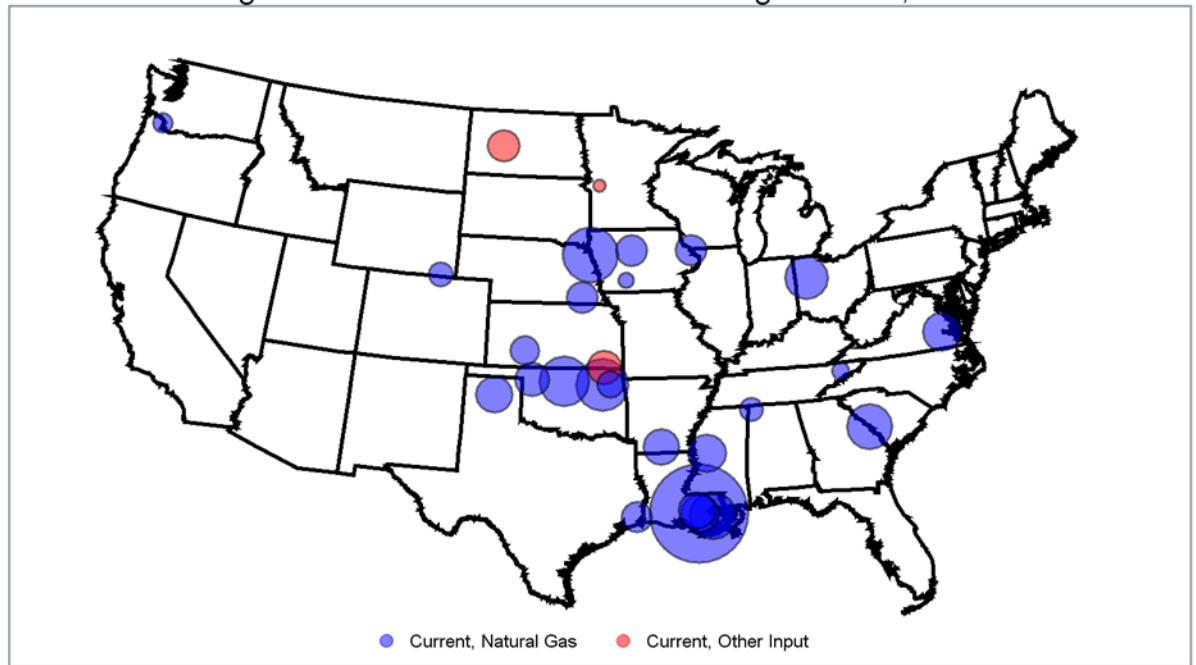
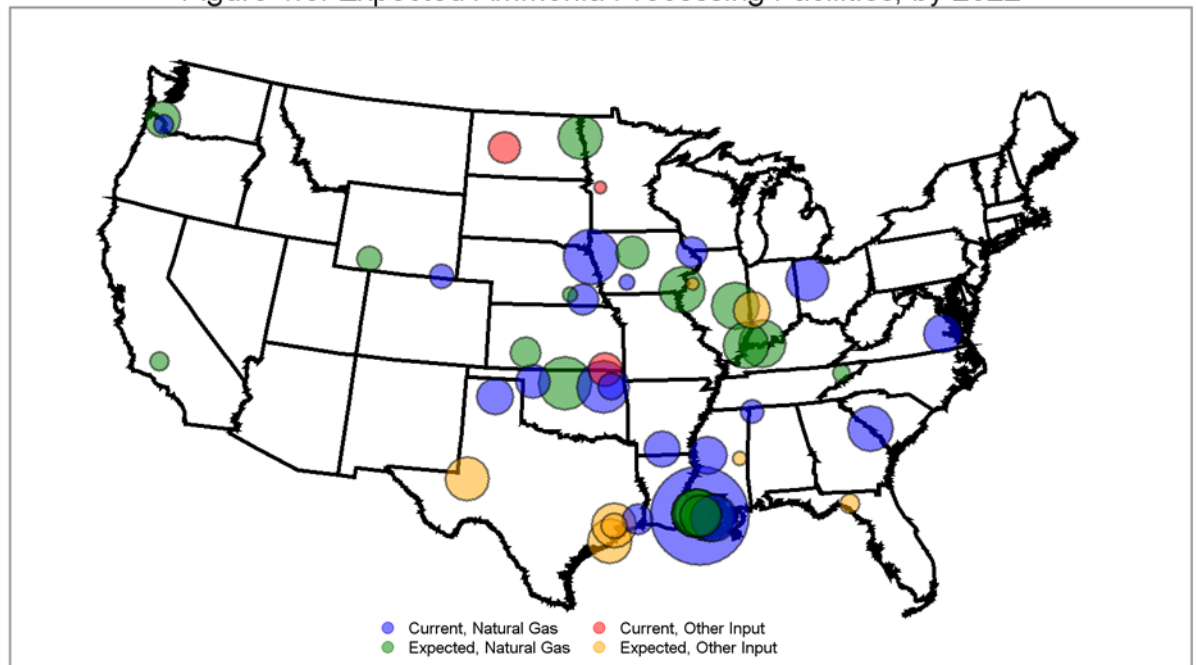


Figure 1.7: Current Ammonia Processing Facilities, 2017



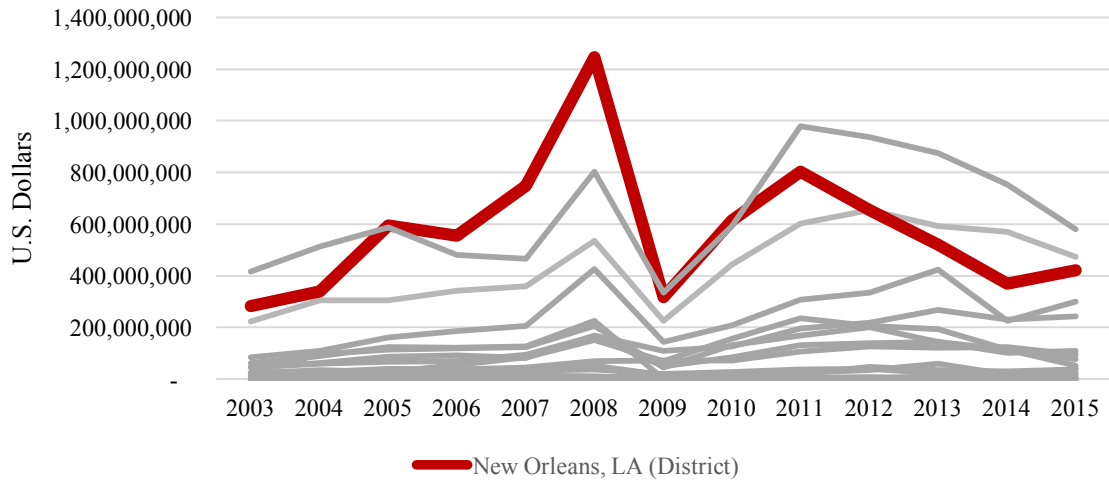
Source: Trever Brown, <http://ammoniaindustry.com>

Figure 1.8: Expected Ammonia Processing Facilities, by 2022



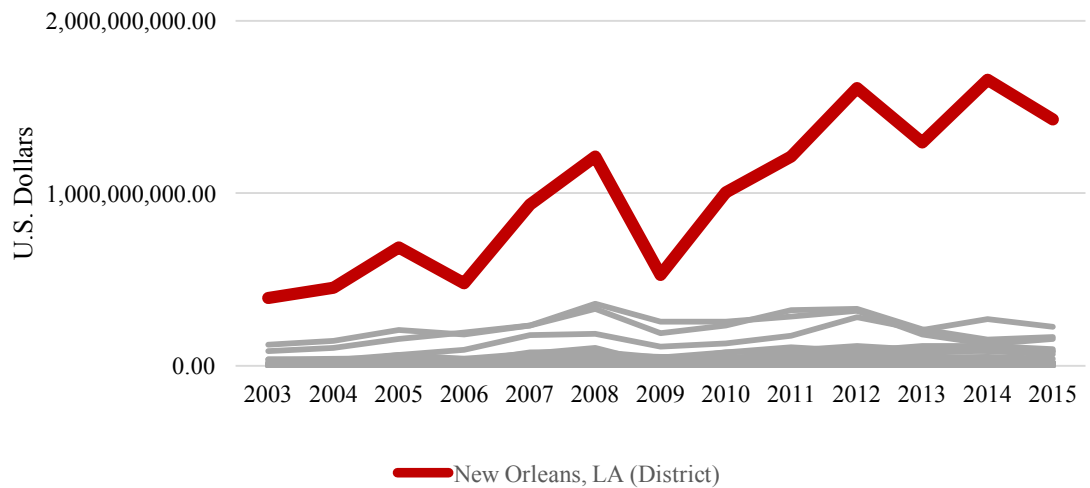
Source: Trever Brown, <http://ammoniaindustry.com>

Figure 1.9: Ammonia Imports by Port District from 2003 to 2015

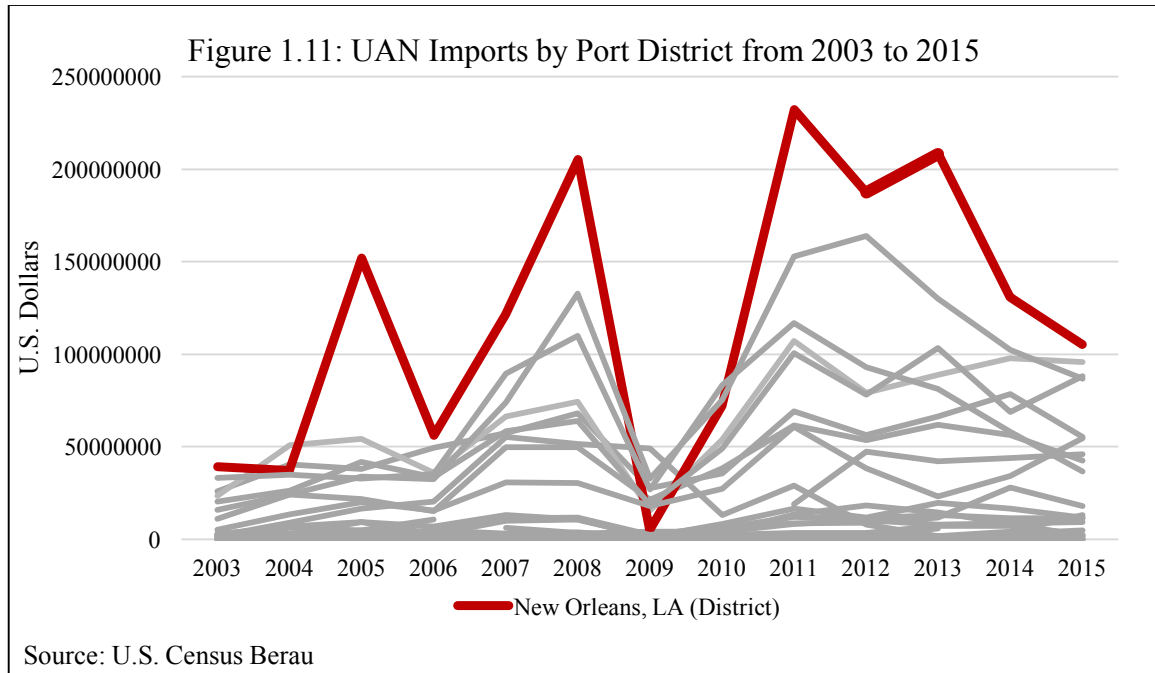


Source: U.S. Census Bureau

Figure 1.10: Urea Imports by Port District from 2003 to 2015



Source: U.S. Census Bureau



LITERATURE REVIEW

There has been limited economic research on the nitrogen fertilizer industry in the United States. This lack of literature does not reflect the importance of nitrogen in agricultural production or the importance of understanding the price dynamics of regional U.S. markets. Rather, it is due to the relative lack of price transparency and data availability, which can hinder empirical assessment. The limited research that does exist has focused on vertical price linkages, concentration of market power, and spatial price transmission of nitrogen fertilizers.

Vertical Price Linkages

Most of the literature on the nitrogen fertilizer industry focuses on its price discovery process. These studies describe and measure the vertical integration between nitrogen fertilizer, agricultural commodities, and natural gas markets. Studies that focus on this vertical integration describe possible structural changes in the markets, where the price discovery process of nitrogen switches between being heavily influenced by demand and supply-side factors. Learning about how price shocks are transmitted through the vertical market chain can help explain movements in nitrogen fertilizer prices, and how these price movements are transmitted regionally around the United States.

Price Discovery

One of the main factors used to explain nitrogen fertilizer price dynamics is natural gas, the main input to fertilizer production. It accounts for 72 to 85 percent of the production costs for ammonia, which itself is the foundation for all nitrogen fertilizers (Huang, 2007). Natural gas prices in the early 2000s were characterized by high volatility and an overall increasing trend. The price of natural gas ranged from \$2 to \$4 per mm Btu from 1985 to 1999. After this period until about 2006, prices ranged from \$3 to \$13 per mm Btu (Huang, 2007). This increase in natural gas prices in the early 2000s helps explain increases in nitrogen fertilizer prices during this same time. Huang (2007) performs a simple correlation analysis between U.S. ammonia and natural gas prices. He finds that the correlation between monthly ammonia and natural gas prices from 1985 to 1999 was 0.172. From 2000 to 2005, this correlation increased to 0.809.

In another analysis, Taylor & Koo (2006) provide further evidence of the relationship between ammonia and natural gas prices. They perform a regression to explain ammonia prices that include U.S. natural gas prices, crop index prices, and a dummy indicating the period after deregulation of natural gas in 1993. Their results indicate that from about 1960 to the early 1990s, the crop price index heavily influenced ammonia prices. After 1993, natural gas prices influence ammonia prices more possibly due to its deregulation. Their econometric method does not allow for casual interpretation though.

After 2007, natural gas price decreased due to the introduction of fracking (PPI Energy and Chemicals Team, 2013). This could have led to changes in the vertical price

relationships between natural gas and nitrogen fertilizers. Steve Keller, a fertilizer wholesaler, mentioned that industry participants no longer looked toward natural gas prices to gain information on price movements in nitrogen fertilizers.

While industry practices might signal changes in this price relationship, there is also empirical evidence that the vertical market linkages between natural gas and nitrogen prices changed in the late 2000s. Bushnell & Humber (2015) estimate the effect of Henry Hub natural gas prices on U.S. ammonia prices using pass-through regressions with a distributed lag specification. They also test their model for an unknown structural break. They find evidence for a structural break in their model around January 2010. Their results show that before January 2010, the pass-through rate of natural gas prices to ammonia prices was about 80%. After January 2010, the pass-through rate decreased to effectively zero, providing some evidence of a changed price-discovery process.

Sanyal et al. (2015) uses generalized autoregressive conditional heteroscedasticity models to explain volatility in various world fertilizer prices, including those for urea and DAP. In their models, natural gas and crude oil are two important explanatory variables they assume are exogenous. They also perform a sequential Bai-Perron test for structural breaks. They find structural breaks for urea in December 2006 and structural break for DAP in March 2007. They find that natural gas significantly effects urea prices from 1997 to 2006. When they reduce their sample from 2007 to 2012, natural gas still is significant in explaining urea prices, but has a lesser effect. The relationships between natural gas and urea prices is not significant in their sample from 1993 to 2012.

Evidence of the diminished importance of natural gas in the price discovery process of fertilizer raises the question: what factors are important after the potential structural break sometime in the late 2000s? Several studies have shown commodity prices, especially corn, might influence nitrogen prices more so in recent years due to increased demand for biofuels. After 2007, it might be that the variation in nitrogen prices are driven more by shifts in demand rather than supply because of the commodity boom caused by ethanol mandates. Beckman & Riche (2015) use an error correction model and a linear model with difference data to test the relationship between ammonia, natural gas, and corn prices. They test for a structural break and find evidence of one in June 2008, which they use as justification to create two subsamples. Before 2008, they find no evidence of cointegration between natural gas and ammonia, but natural gas still had a significant relationship in explaining ammonia prices in a linear model. After 2008, they find no statistical significant evidence of long term or short relationships between natural gas and ammonia prices. They do find evidence that corn futures price significant effect ammonia price in the post-2008 period.

Similar to Beckman & Riche (2015) other studies have looked at how commodity prices have influence fertilizer prices. Galbraith (2010) uses error correction models to test the effects of corn and natural gas futures price on ammonia and urea in two different periods; 2002 to 2005 and 2006 to 2009. He did not formally test for a structural break. From 2002 to 2005, he finds that natural gas had a larger effect on movements in ammonia prices. During the 2006 to 2009 period, corn future price had more of an impact on ammonia prices.

Etienne et al. (2016) uses a joint vector error correction model and generalized autoregressive conditional heteroscedasticity model to assess the long-run relationship and short-term price dynamics between U.S. ammonia, corn, and natural gas prices from 1994 to 2014. They find that for both the full sample and a sub sample from 2006-2014, there were significant short-term and long-run relationships between corn and ammonia prices. In the full sample, there was mixed evidence between significant relationship between natural gas and ammonia price. There was no significant relationship in the 2006-2014 relationships between natural gas and ammonia.

These studies show that the vertical integration of the nitrogen fertilizer market with commodity and natural gas markets is complex. Price relationships in these vertical markets seem to have changed due to the introduction of horizontal fracking and increase demand for biofuels, altering the price discovery process in nitrogen fertilizers. This is important to take into consideration when modeling spatial relationships around the United States. A price discovery process that changes could also alter long-term relationships between a central distribution hub and regional inland markets around the country, but have differential impacts across these markets.

Market Concentration

While demand and supply-side factors affect the price of nitrogen fertilizers in the United States, the actual structure of the market might play a role as well. As mentioned in the industry background section, the domestic fertilizer industry is highly concentrated. With few firms producing in the United States, they have more market power than if it

was a competitive industry. There may be asymmetric price adjustment because of this market power, where there are faster adjustments to input price increases rather than input price decreases.

There has been some evidence that there is asymmetric price adjustment. Galbraith (2010) found that ammonia prices responded almost instantaneously to natural gas price increases, while they had a delayed response to natural gas price decreases. Also, Beckman & Riche (2015) showed that a variable used as a proxy for market power (capacity of firms/number of firms) had a significant and positive relationship with ammonia prices. Heranadex & Torero (2010) perform a basic analysis of the effect of market concentration on a countries' urea price. They take a two-stage least square approach, using lagged market concentrations as an instrumental variable, to estimate the effect of the market power on price of urea. They find that countries with companies that have more market power tend to have higher urea prices.

Other studies have approached the question of market power effects on nitrogen prices by looking at specific events. Humber (2014) uses a structural vector autoregressive model that controls for demand and supply shocks to estimate the affect that a merger in 2010 between CF and Terra Industries, two large producers, had on nitrogen fertilizer prices. He forecasted a counterfactual price in a hypothetical market without the merger and their results indicated that the merger increased prices by 75%. However, the author acknowledges that he might not have been able to adequately control for increases in commodity prices, which might have led to an overestimate of the merger's effect.

Overall, it seems that nitrogen-based fertilizer producers have market power and some control over prices. The capital required for entry and economies of scale result in a highly concentrated nitrogen fertilizer industry. This concentration could affect the price discovery process for nitrogen fertilizers, especially after 2010 when the two largest nitrogen producers merged. The efficiency of spatial price transmission might differ depending on whether nitrogen prices are increasing or decreasing. This could also become more important in the near future as new domestic plants start to produce, which will decrease the United States reliance on imports.

Spatial Price Efficiency

Instead of measuring the vertical integration of the nitrogen fertilizer industry with agricultural and energy markets, some studies have looked at how spatial fertilizer markets are integrated with one another. Fertilizers, like many other commodities, are produced and consumed around the world. The global and national trade of fertilizer connects markets to one another, creating complex spatial price relationships. These relationships are often measured to determine the integration between markets, which can provide insights into the performance and efficiency of the domestic nitrogen market.

One of the main empirical problems faced when trying to measure efficiency and integration between markets is that there is usually a lack of data that describe the volume of fertilizer traded. Instead, the most readily available data are price data. Therefore, economists model spatial integration and efficiency by solely using the price data of two spatially-separated but economically-connected markets for a homogenous good. Early

studies focused on simple empirical strategies such as correlation analysis or linear regressions, but these failed to model the dynamic price relationships between markets because the prices are contemporaneously correlated. Therefore, economists started to use vector autoregressive models, which explain price movements from lagged prices (Fackler & Goodwin, 2001). Granger (1981) and Engle & Granger (1987) further improved these models by developing the idea of cointegration, long-term stationary relationships, between two-time series, which can be interpreted as an equilibrium relationship between the two markets.

Johansen (1995) extend this idea to a multivariate framework by describing a vector error correction model (VECM). VECMs are a variant of vector autoregressive models that include an error correction term from the cointegrated relationships. This error correction term measures how fast deviations from long-term equilibriums between two prices are corrected. This, along with short-term, lagged changes in both prices are used to explain how prices information is transmitted between the two markets. VECMs have been used to measure spatial price transmission in many agricultural markets. For example, Franken et al. (2011) measures the market integration of the U.S. hog industry and Acosta et al. (2013) measures spatial price transmission of milk from global to domestic markets.

While spatial price efficiency has been studied intensively in other commodities, there is only one paper that has looked at the U.S fertilizer industry. Hu & Brorsen (2017) looks at the spatial price transmission of urea between the Middle East-New Orleans market and the New Orleans-Arkansas River market. Using Vector Error

Correction Models (VECM) and Parity Bound Models (PBM), they find that there is relative low efficiency in the transfer of price information between all markets. There is more adjustment in domestic fertilizer prices than between domestic-international prices, which signifies that the domestic markets are more efficient. They also found that there was bidirectional causality between New Orleans and Arkansas River prices.

Hu & Brorsen only measure the price relationship between the New Orleans urea market and one inland regional urea market. This may not provide a complete understanding of the integration and efficiency of the U.S. nitrogen industry because price transmission behaviors may not be identical between New Orleans and different U.S. inland markets. To develop an understanding of how prices are transmitted around the country, this study measures the spatial price relationships between New Orleans, the Northern Great Plains, the Southern Great Plains, the Great Lakes, and the Pacific Northwest. This study also does not focus on one nitrogen fertilizer, but looks at urea, UAN, MAP, and DAP. Measuring the relationships and transmission of prices for these four fertilizers between these five regions will provide insights to the market performance of this industry.

Chapter Takeaways

- Nitrogen fertilizer markets are possibly integrated with corn and natural gas prices, but these relationships have often changed over the last 20 years.
- Market power might play a role in the price discovery process of nitrogen fertilizers, preventing efficient price transmission.

- Dynamic models that measure spatial price efficiency have been underutilized in the U.S. nitrogen fertilizer industry.

ECONOMIC MODEL

The objective of this study is to gain an understanding of market dynamics of the nitrogen fertilizer industry in the United States. That is, I seek to model the relationships between spatial markets and whether they changed over time due to structural changes in the price discovery process. Most of the economic literature on fertilizer markets has focused on the vertical integration of nitrogen fertilizer markets with corn and natural gas markets, but there is limited research on spatial price relationships in the U.S. nitrogen industry. While there is a general understanding of how nitrogen fertilizers move throughout the United States—from New Orleans to inland regions—there are no actual trade data of these movements. This lack of data makes it difficult to understand the market dynamics, but, as described in the preceding section, inferences about these dynamics can be gleaned from studying price variation in these markets.

Prices represent equilibrium conditions in markets and can serve as important signals for producers and consumers. In spatially separated markets that are connected through trade, the extent to which prices are linked offer important insights about the efficiency of information transfer between those markets. Therefore, understanding how price information is transmitted across the country could potentially help market participants make better decisions. Incomplete price transmission between markets might lead to inefficient outcomes and non-Pareto optimal allocation of nitrogen fertilizer in the United States. For example, fertilizer wholesalers that understand how price shocks are transmitted around the country can make informed decisions on how to price their fertilizer and where to sell it. In addition, identifying potential inefficiencies in

information transmission between markets could point to possible market failures, which may require public policy intervention.

Therefore, one way to gain an understanding market dynamics of the U.S. nitrogen fertilizer industry is to measure the integration between spatially separated markets while controlling for economic information provided by vertical markets. The law of one price provides the economic framework needed to understand how regional markets are connected and how price information is transmitted between them.

Law of One Price

The law of one price states that the price of a homogenous good sold in two spatially-separated but integrated markets should be equal after taking into account transaction costs associated with selling the goods between the markets. In regards to the U.S. nitrogen fertilizer industry, this means that regional prices of the same nitrogen fertilizer should be equal after accounting for transportation and storage costs. The implication of the law of one price is that there is a long-term equilibrium relationship between connected markets of the same good. Therefore, any deviations from this long-term equilibrium caused by demand or supply shocks should eventually be corrected.

The law of one prices is ensured by spatial arbitragers, who move goods between connected markets in response to price differences. For example, assume there are two separate markets for ammonia, market 1 and market 2, and that it can be traded between both markets. If the price in market 1, P_1 , is higher than the price in market 2, P_2 , then spatial arbitragers will move their ammonia to market 1 to take advantage of higher profit

opportunities. The movement of ammonia to market 1 will increase the supply in that market and will lead to a price decrease in market 1. This movement of ammonia between markets in response to price differences ensures the following relationship will hold:

$$P_1 - P_2 \leq T_{12} \quad (4.1)$$

where T_{12} is the transaction cost of selling ammonia between the two markets. Equation 4.1 states that the price difference between markets 1 and market 2 will be less than or equal transaction costs. Spatial arbitrage ensures an equilibrium relationship between markets 1 and 2.

Price Information Flow

The manner in which products and information flow in the U.S. nitrogen fertilizer industry allows New Orleans to be thought of as a central distribution market. New Orleans is not only the main location for domestic production, but it is where a majority of imported nitrogen enters the United States. The prices of nitrogen fertilizers here are representative of world nitrogen prices (after accounting for transportation costs) and these prices are the foundation to the price discovery process for domestic U.S. markets. Therefore, the average price at New Orleans is almost always expected to be less than the average price at inland locations for every fertilizer. This is consistent with the theory that New Orleans is the central market and the inland regions are “importing markets.” From New Orleans, the physical fertilizer is moved to inland regions by barges, trains, and trucks to be used for agricultural production.

If U.S. fertilizer markets are integrated, price information should at least flow from New Orleans to the rest of the country, and potentially from inland regions back to

New Orleans. Any shock to prices in New Orleans is likely to propagate out to the rest of the country. Regions that are geographically closer or more connected should have relatively quick adjustments in prices after a shock occurs in New Orleans. Regions that are less connected may not instantaneously reflect the shock in price at New Orleans. Since New Orleans is expected to lead the price discovery process, there may be an opportunity for market participants to use information about price changes in New Orleans to explain and predict price changes in their inland locations.

The law of one price is particularly useful to explain the dynamics of the U.S. nitrogen industry because both spatial arbitrage and formula-based pricing are important aspects. Therefore, in the context of the nitrogen industry, if markets are integrated and efficient, the law of one price states the following relationship should hold:

$$P_{IR} - P_{NOLA} \leq T_{IR, NOLA} \quad (4.2)$$

where P_{IR} is the price of a nitrogen fertilizer in an inland regions, P_{NOLA} is the price of a nitrogen fertilizer at New Orleans, and $T_{IR,NO}$ is the transaction of selling between the markets.

Spatial arbitrage opportunities are created by demand or supply shocks in spatially- separated markets. In talks with Russ Miner—a fertilizer wholesaler manager at Wilbur-Ellis in Great Falls, Montana—spatial arbitrage plays an important role in the price discovery process for smaller, local nitrogen-fertilizer markets. Fertilizer will move from regional fertilizer storage facilities in response to higher prices caused by local supply shortages. Arbitrageurs should restore the equilibrium relationship between these local nitrogen fertilizer markets. The speed at which equilibrium is restored will be could

be affected by transportation and storage factors such as the distance between the markets, the availability of train cars to move the fertilizer, the capacity of storage units in both markets that can safely contain the fertilizer. This speed at which equilibrium is restored might also be influenced by the degree of market power in each spatial market. This market power can cause asymmetric price information among market participants that prevents the discovery of a spatial arbitrage opportunities.

Formula-based pricing is another mechanism for the price discovery process in nitrogen fertilizer. Spatial arbitrage influences prices through the actual movement of goods, but formula-based pricing relays price information through industry practices. Creating fertilizer contracts is less costly to wholesalers and distributors when it is based on a simple formula using New Orleans prices as references. There are no negotiations, but rather, the price of a nitrogen-based fertilizer in region A, P_A , is determined through the following formula:

$$P_{NGP} = P_{NOLA} + \pi_{NGP} + \varepsilon_{NGP} \quad (4.3)$$

where P_{NO} is New Orleans price for fertilizer, π_{NGP} is represents transactions costs (transportation costs and storage costs), and ε_{NGP} is a specific plant's premium. While formula-based pricing plays a role in the transmission of price information around the United States, regional prices do not perfectly move together, which means there are other factors affecting the price discovery process. For example, it could be that certain plant managers might have market power, which allows them to add an additional premium to the price of their fertilizer.

Spatial arbitrage and formula-based pricing describe how price information is transmitted between regional markets in the United States. Theoretically, these two mechanisms should create equilibrium relationship between New Orleans and other regional U.S. markets, but these relationships need to be tested. The actual transmission of price information must be understood to learn about the market dynamics and efficiency in the U.S. nitrogen-based fertilizer industry.

Spatial Price Transmission

When measuring integration between regional nitrogen markets in the United States, there are two extremes. At one end, the regional markets are completely efficient and price information is perfectly transferred between these markets. At the other end, price shocks are not transferred at all. Fackler and Goodwin (2001) define market integration as the degree with which demand and supply shocks in one regional market are transmitted to another regional market. So, if in market 1 there is a shock, then the level of market integration between market 1 and market 2 can be thought of as the follow price transmission ratio, R_{12} :

$$R_{12} = \frac{\delta P_2 / \delta \varepsilon_1}{\delta P_1 / \delta \varepsilon_1} \quad (4.4)$$

where P_1 is the price in market 1, P_2 is the price in market 2, and ε_1 is the hypothetical shock in market 1. This ratio is the change in P_2 over the change in P_1 caused by the shock in market 1. A perfectly integrated market would have a price transmission ratio of 1, which indicates that there is perfect price information transmission between the two markets.

Market integration can also be thought of in the context of a simple regression between prices in market 1, P_1 , and market 2, P_2 :

$$P_{1t} = \beta_0 + \beta_1 P_{2t} + \beta_2 T_t + \varepsilon_t \quad (4.5)$$

where T_t is the transaction costs of selling between the two markets. If the markets are perfectly integrated, then $\beta_1 + \beta_2 = 1$ and $\beta_0 + \varepsilon_t = 0$. This means that the variation in P_1 is fully explained by P_2 and the transaction costs of selling between the two markets.

In this characterization, no other factors, such as market power, are represented. The linear regression is a simple model of market integration. To understand spatial integration and therefore the efficiency of regional markets, a model must incorporate not only the magnitude of price information transmission, but also the speed at which information is transmitted between two markets. In the case of the U.S. fertilizer industry, industry assessments and communications with stakeholders (discussed in detail in Chapter 1) suggest *a priori* expectations of an efficient information transmission speed of approximately one to five weeks, the time it typically takes to ship fertilizer from NOLA to inland locations.

Chapter Takeaways

- The analysis of price data alone can provide insights into the efficiency of U.S. nitrogen fertilizer market.
- The law of one price provide the economic framework for spatial price efficiency.

- Spatial integration can be thought of in two ways: the magnitude of information transmission between two separated markets and the time it takes this information to be transferred and incorporated in prices.

DATA

This study uses fertilizer price data from Green Markets, a private company that analyzes the global fertilizer industry. These data include weekly nominal FOB (free-on-board) prices from January 1995 to October 2015 for urea, UAN, MAP, and DAP in New Orleans, the North Great Plains, the Southern Great Plains, the Great Lakes, and the Pacific Northwest.¹ Figure 5.1 shows these regions, which are defined by Green Markets. Reported prices are based on transactions at least as large as a truckload (~22lbs), and represent prices at the producer's plant gate, terminal, or pipeline point. This means that these prices represent distributor level prices, and not retail prices that a farm would observe. All prices except UAN are on dollars per short ton. UAN prices are on a dollar per nutrient ton. All other data are collected for the time window that corresponds to the fertilizer price data.

Natural gas makes up a significant portion of the production costs of nitrogen fertilizer. Therefore, price of natural gas is used as a proxy for supply-side drivers in nitrogen prices. Weekly Henry Hub natural gas futures prices were obtained from CME Group using Quandl. As mentioned in the background section, corn producers are the largest consumers of nitrogen. Therefore, including these commodity prices can be a proxy for demand of nitrogen fertilizer. Corn nearby futures prices were obtained from the CME group using Quandl. Both futures prices are based on spot-month continuous contract calculations.

¹There are no price data for UAN in the Pacific Northwest. There are limited observations for certain regional prices for UAN, MAP, DAP, and urea, which can be seen in Table 1.

My empirical methodology requires a balanced time interval between observations. The models in this study use lagged prices as explanatory variables, so there can be no missing observations. There were 26 total missing observations around the holidays and cubic spline interpolation in SAS is used to estimate them. This method estimates missing prices based off the previous and subsequent weeks' prices. All data were converted to logarithmic form. Table 5.1 contains summary statistics for these data.

Additionally, because the Mississippi River is an important artery for barge transportation of nitrogen from New Orleans to inland markets, data on the river stage levels were collected to proxy for changes in transportation costs. Low water levels can decrease the amount of goods that barges can hold, which increase transportation costs. High water levels can prevent barges from safely moving on the river, similarly affecting costs. The river stage data were collected from rivergauge.com, which is administered by the U.S. Army Corps of Engineers. For many gauge sites on the Mississippi River, there are incomplete data and long periods of missing observations. Therefore, two river gauge sites were chosen for their mostly complete data and locations on the river. Camanche, IA, was chosen to represent the upper Mississippi River and Vicksburg, MS was chosen to represent the lower Mississippi river region.

There were missing observations, at times for as long as a week for both river gauge sites. To fill these observations, the average of the two nearest dates was calculated and used to fill the missing observation. There were not significant fluctuations in river stage levels in times when there were missing observations. Weekly observations were then created from the daily stage data so they could be used in the

empirical data analysis, and these weekly variables were then used to make a composite (average) weekly average between the two river sites to represent water levels on the entire river.

Data Description

Figures 5.2 to 5.5 show regional fertilizer prices for urea, DAP, UAN, and MAP seem to follow similar trends. The price at New Orleans is usually lower than inland regional prices, which provides some empirical evidence that New Orleans is the central market in the United States for nitrogen. Inland prices are on average higher, reflecting the transaction costs of moving the fertilizers from New Orleans to around the country.

Around 2008, there was a sharp increase in prices for every nitrogen fertilizer in all regions. Figures 5.6 and 5.7 show that this coincides with a sharp increase in corn prices due to ethanol mandates and a decrease in natural gas prices due to the introduction of fracking. Therefore, the period from 2007 to 2010 is a volatile time in the nitrogen fertilizer industry. An examination of the period before 2007 and the period after 2010 shows that a structural change occurred in this market. For example, there appears to be more volatility after 2010 in all nitrogen fertilizer prices than there was in the before 2007.

Between 2007 and 2010, information transmission efficiency is difficult to assess. Both input and demand markets related to the nitrogen fertilizer industry were transitioning, so market participants were unable to use historical information to make information decisions. These changes in the vertical markets also take longer to be

incorporated into fertilizer markets because of the high capital investment involved in fertilizer production and distribution. Lastly, because I use price data rather than realized traded volume data, it is difficult to measure the efficiency during this volatile period, especially since my empirical methods can be influenced by structural changes.

Because of these reasons, the data sample is divided into two subsamples: pre-2007 and post-2010. The price relationships between spatial nitrogen markets, corn markets, and natural gas markets can be measured in both of these subsamples. A comparison of the results of both these subsamples will provide intuition into how the price discovery process has changed and if this change influenced spatial price relationships in the nitrogen fertilizer industry.

Chapter Takeaways

- Weekly price data is used to estimate the price dynamics between New Orleans, inland regions, corn, and natural gas markets.
- Mississippi River levels are used as a proxy for supply-side transportation factors.
- The sample is split into the pre-2007 and post-2010 period.

Table 5.1: Summary Statistics

	N	Mean	Std Dev	Min	Max	Begin	End
Urea							
New Orleans	1,083	5.41	0.51	4.42	6.70	1995w1	2015w39
Northern Great Plains	1,083	5.56	0.48	4.68	6.76	1995w1	2015w39
Southern Great Plains	1,083	5.52	0.48	4.60	6.75	1995w1	2015w39
Great Lakes	1,083	5.59	0.48	4.66	6.77	1995w1	2015w39
Pacific Northwest	164	6.08	0.13	5.89	6.30	2012w33	2015w39
UAN							
New Orleans	581	2.00	0.31	1.34	2.76	2004w33	2015w39
Northern Great Plains	1,083	1.82	0.50	1.00	2.85	1995w1	2015w39
Southern Great Plains	1,083	1.73	0.50	0.89	2.77	1995w1	2015w39
Great Lakes	1,083	1.82	0.50	1.01	2.91	1995w1	2015w39
Pacific Northwest				Not Available			
MAP							
New Orleans	1,083	5.62	0.51	4.93	7.02	1995w1	2015w39
Northern Great Plains	355	6.22	0.19	5.75	6.51	2008w50	2015w39
Southern Great Plains	355	6.19	0.19	5.71	6.49	2008w50	2015w39
Great Lakes	355	6.23	0.18	5.75	6.50	2008w50	2015w39
Pacific Northwest	169	6.37	0.07	6.21	6.50	2012w28	2015w39
DAP							
New Orleans	1,083	5.59	0.51	4.89	6.99	1995w1	2015w39
Northern Great Plains	1,083	5.71	0.49	5.06	7.04	1995w1	2015w39
Southern Great Plains	1,083	5.68	0.49	5.02	6.99	1995w1	2015w39
Great Lakes	1,083	5.73	0.49	5.06	7.06	1995w1	2015w39
Pacific Northwest	137	6.36	0.05	6.32	6.47	2012	2015w39
Other							
Natural Gas	1,083	1.37	0.49	0.33	2.67	1995w1	2015w39
Corn	1,083	5.80	0.39	5.21	6.71	1995w1	2015w39
River Levels	1,083	16.83	6.44	5.09	35.95	1995w1	2015w39

Note: UAN = urea ammonium nitrate, MAP = monoammonium phosphate, DAP = diammonium phosphate, River levels= Mississippi River levels. All price data are in natural logarithmic form. Regional fertilizer price data is from Green Markets, futures prices come from CME, and river levels come for the U.S. Army Corps of Engineers

Figure 5.1: Green Market Regions for Fertilizer

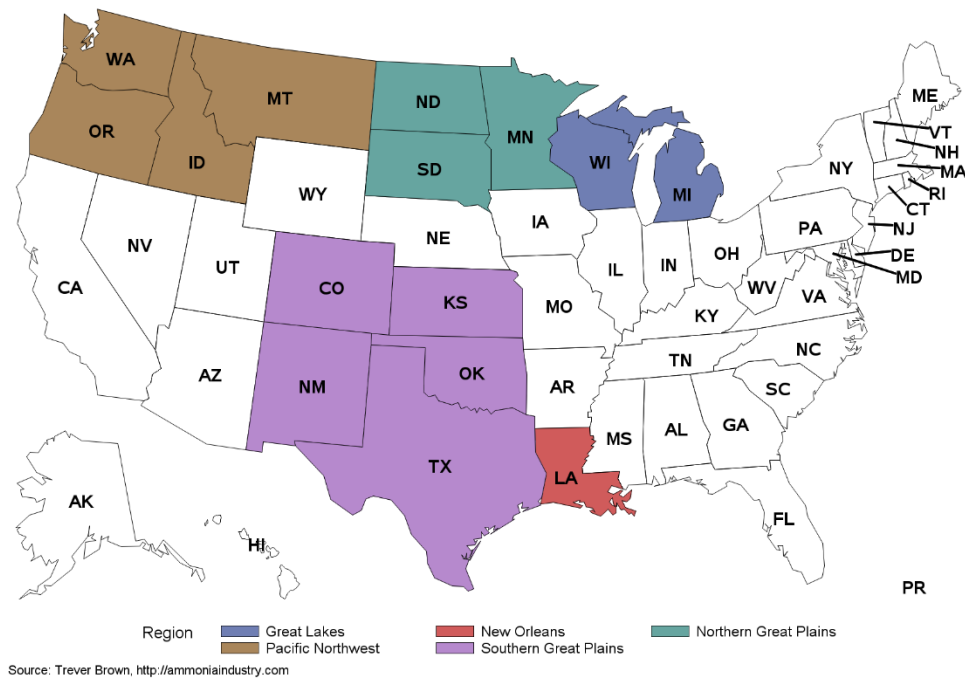


Figure 5.2: Price of Urea by Region from 1995 to 2015

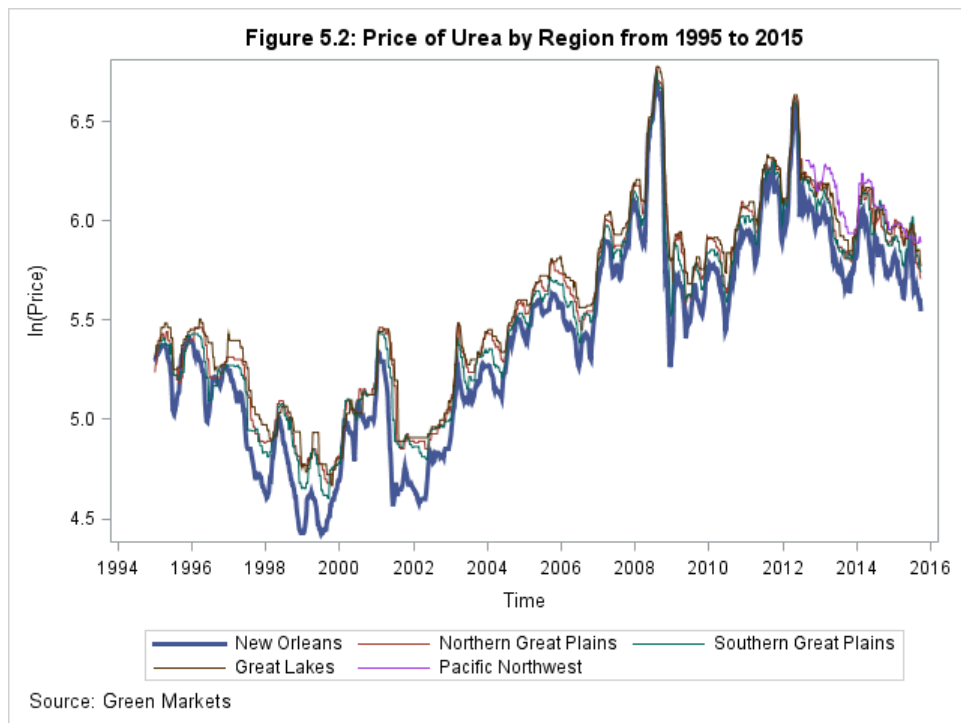
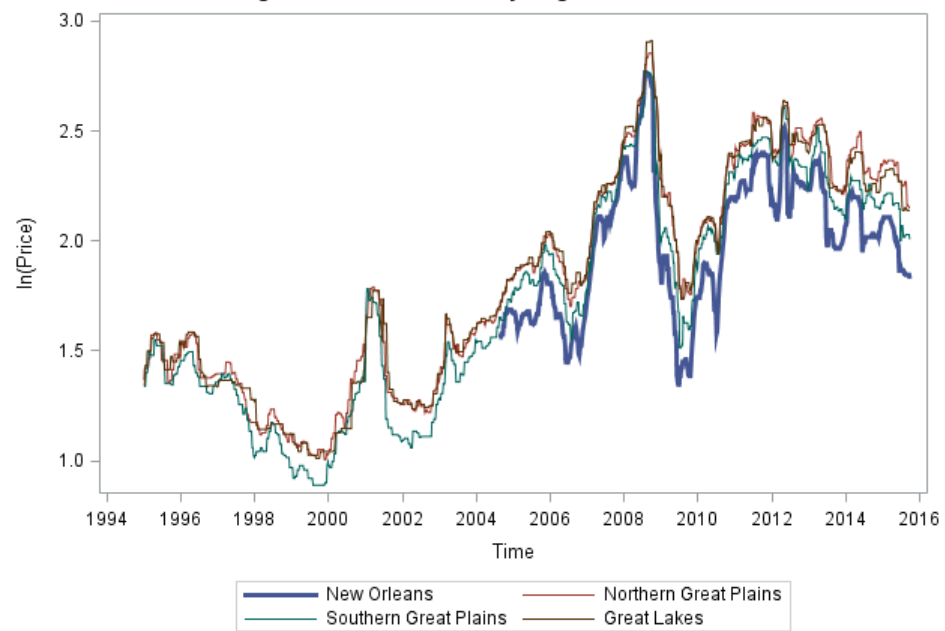
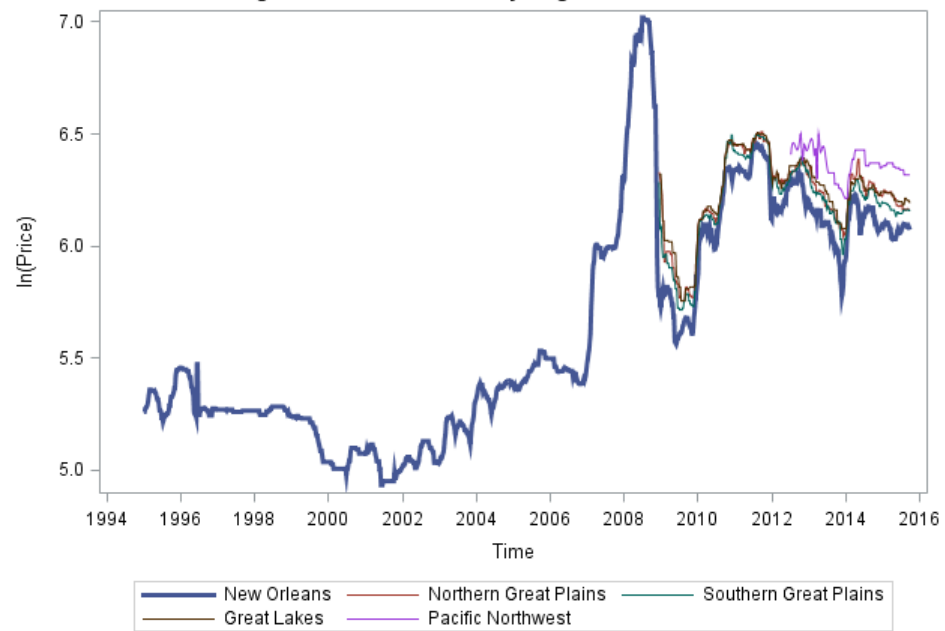
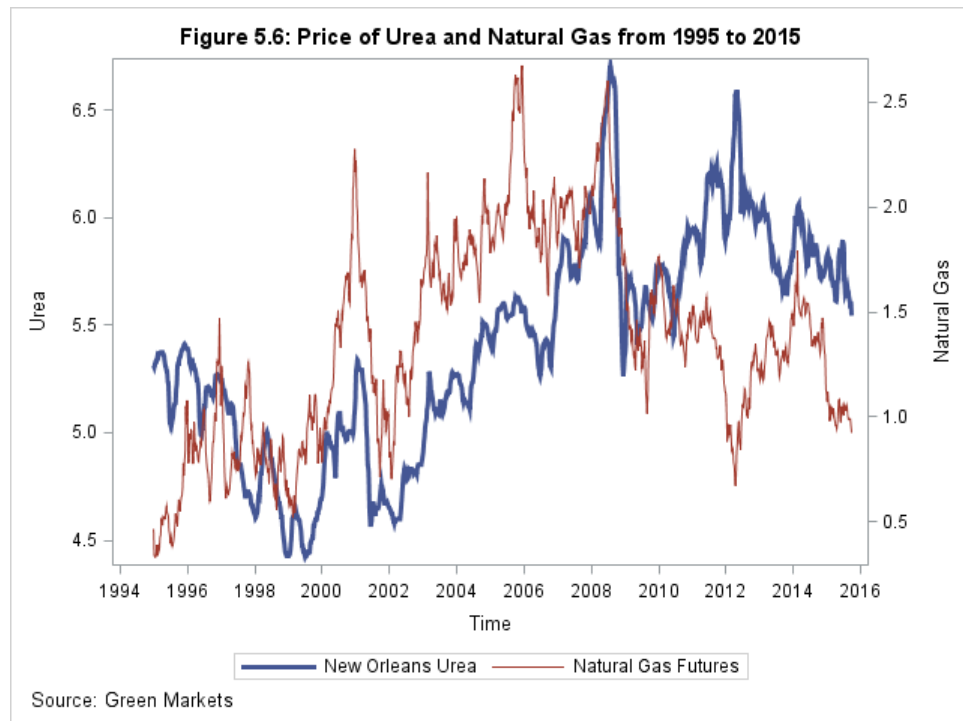
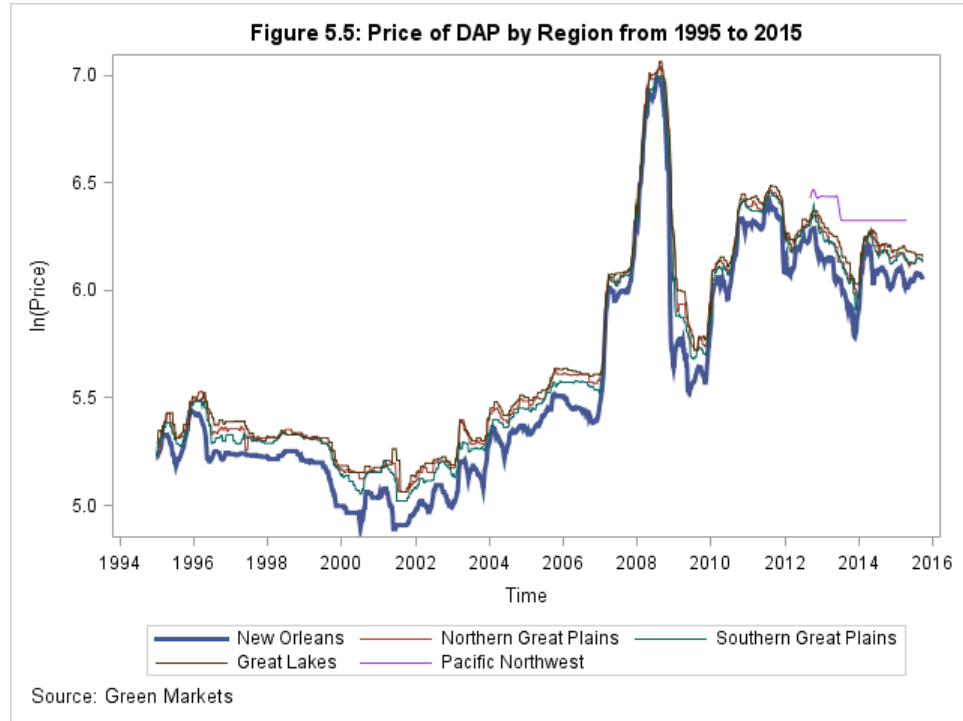
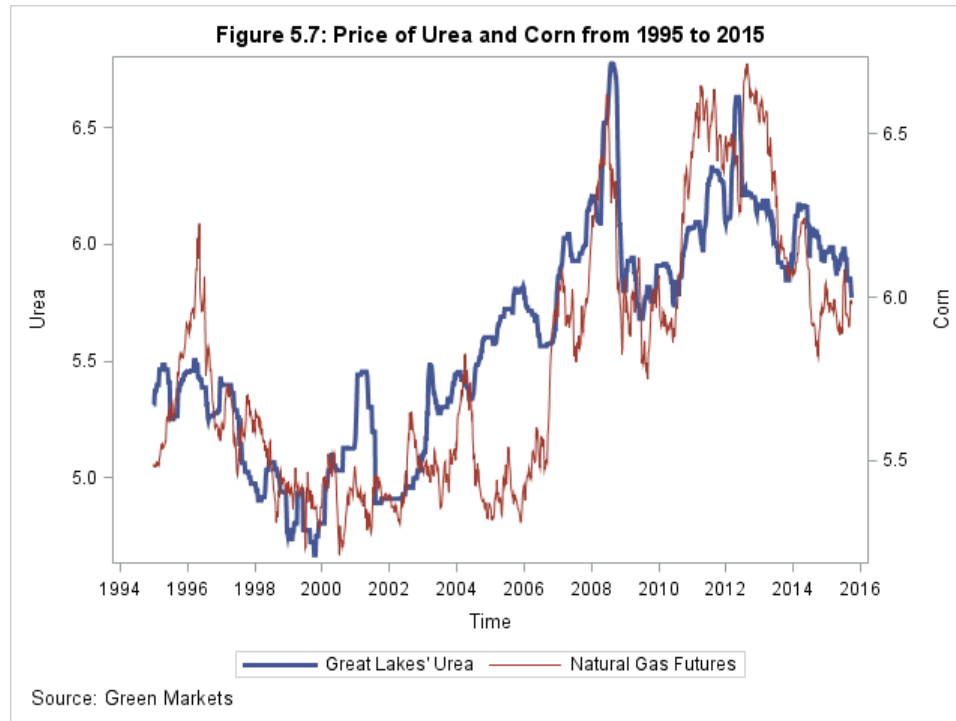


Figure 5.3: Price of UAN by Region from 1995 to 2015**Figure 5.4: Price of MAP by Region from 1995 to 2015**





ECONOMETRIC FRAMEWORK

This study uses a vector error correction model (VECM) to measure the price dynamics between regional fertilizer prices, corn futures prices, and natural gas futures prices. A VECM explains price changes using deviations from long-term equilibrium relationships, short-term lagged price changes, and various exogenous variables. This is a dynamic model that measures both the magnitude and speed of how price information moves between markets.

A VECM model is an adaption of a vector autoregressive model (VAR). A simple p th-ordered VAR process for can be expressed as follows:

$$Y_t = \delta + \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \dots + \Phi_p Y_{t-p} + u_t \quad (6.1)$$

where $Y_t = (Y_{1t}, Y_{2t}, \dots, Y_{kt})'$ is a k -dimensional vector of time series variables, Φ_i is $k \times k$ coefficient matrix, $\delta = (\delta_1, \delta_2, \dots, \delta_k)'$ is a vector of constant terms, $u_t = (u_{1t}, u_{2t}, \dots, u_{kt})'$ a vector of the residuals that follow a white noise process. The VAR model explains the variation in a price from its own and other lagged prices. The optimal number of lags is chosen from the corrected Akaike Information Criteria (AICC). By not using current variables, every explanatory variable can be considered weakly exogenous, and if the variables are stationary, the model will produce desirable estimators.

Stationarity means that the statistical characteristics of these prices, like the mean, variance, and autoregressive process, are constant through time. If the time series data are non-stationary (i.e., contain a unit root), then ordinary least squares (OLS) regressions will be spurious (Asteriou and Hall 2017). The augmented Dickey-Fuller test can be

used to check the stationarity of time series data. If the price data are stationary in levels, then it is considered to be integrated of order zero, $I(0)$, and OLS can be used. If the level price data are found to be non-stationary, then an OLS model might produce spurious regression results. One solution to non-stationarity is to first-difference the data. If the differenced price data are found to be stationary, then it is integrated of order one, $I(1)$. Asteriou and Hall (2007) explain that while differencing the data might achieve stationarity needed to model the relationship between variables over time, it does not provide an opportunity to estimate a unique long-term relationship, which is of interest in this study.

This econometric problem is overcome by exploiting long-term, stationary relationships between time series variables over time. Cointegration is when multiple $I(1)$ variables have a linear combination that itself is stationary, or $I(0)$. A simple way to represent the long-run, linear, and stationary relationship between time series variables is as follows:

$$\beta'Y_t = \varepsilon_t \quad (6.2)$$

where $\beta = (\beta_1, \beta_2, \dots, \beta_k)'$ and $Y_t = (Y_1, Y_2, \dots, Y_k)$. This linear combination represents the long-term, equilibrium relationships between k time series variables. β is called the cointegrating vector. The coefficients of β are usually normalized such that one of the elements of β equals one. This is done so the results can be economically interpreted. The presence of cointegration means that even though the variables might deviate in the short-run, economic forces will correct any deviations back to their equilibrium values in the long-run.

Empirically, cointegration can be tested for using the Johansen trace and eigenvalue tests for cointegration (Johansen, 1988). Johansen describes five separate cases that model the linear and stationary relationships between variables. These cases are slight variants of each other, including or removing trends and constants, so time series properties and economic theory should be used to determine which case best reflects the relationships between the variables.

If evidence of cointegration is found between time series variables, then the basic VAR model can be transformed into a VECM by using differenced lagged prices and adding the error correction term, $\beta'Y_{t-1}$, as an explanatory variable. This results in the following VECM(p) with $r(<k)$ cointegrating relationships:

$$\Delta Y_t = \delta + \alpha \beta' y_{t-1} + \sum_{i=1}^{p-1} \Phi_1 \Delta Y_{t-i} + u_t \quad (6.3)$$

where Δ is the difference operator, α and β are $k \times r$ matrices, and Φ_1 is a $k \times k$ matrix of parameters that represent the short term effects of lagged, differenced endogenous variables. The parameters are estimated with maximum likelihood estimation. The error correction term is βy_{t-1} , and α is the estimated parameter of that term, which represents the speed of adjustment (i.e., how fast deviations from the long term equilibrium are corrected). For example, if α_1 is estimated to be 0.5, then this can be interpreted as 50% of the deviation in Y_1 from equilibrium in period $t-1$ is corrected for by period t . β' will have different interpretations based on the economic relationships being measured.

Fertilizer Model Specification

The VECM framework can be extended to measure price relationships in the nitrogen fertilizer industry. Four endogenous variables are included when estimating each spatial relationship: the price of a fertilizer at New Orleans, the price of a fertilizer at an inland region, the price of the nearby corn futures contract, and the price of nearby natural gas futures contract. This specification of the VECM measures not only spatial price transmission, but also the price transmission between vertical markets. Including these vertical prices in the system allows for a more complete understanding of the price discovery process in the nitrogen fertilizer industry. It measures the relative influence that vertical markets have on the nitrogen fertilizer industry over time. The VECM that measures price transmission between New Orleans, a certain inland region, natural gas futures, and corn futures market is as follows:

$$\begin{aligned} \Delta P_t^{IR} = & \alpha_{IR} (P_{t-1}^{IR} - \beta_0 - \beta_1 P_{t-1}^{NOLA} - \beta_2 P_{t-1}^{CN} - \beta_3 P_{t-1}^{NG}) + \sum_{i=1}^p \pi_1^{IR} \Delta P_{t-i}^{IR} + \\ & \sum_{i=1}^p \pi_2^{IR} \Delta P_{t-i}^{NOLA} + \sum_{i=1}^p \pi_3^{IR} \Delta P_{t-i}^{CN} + \sum_{i=1}^p \pi_4^{IR} \Delta P_{t-i}^{NG} + \delta^{IR} X_t + u_{IR,t} \end{aligned} \quad (6.4)$$

$$\begin{aligned} \Delta P_t^{NOLA} = & \alpha_{NO} (P_{t-1}^{IR} - \beta_0 - \beta_1 P_{t-1}^{NOLA} - \beta_2 P_{t-1}^{CN} - \beta_3 P_{t-1}^{NG}) + \sum_{i=1}^p \pi_1^{NOLA} \Delta P_{t-i}^{IR} + \\ & \sum_{i=1}^p \pi_2^{NOLA} \Delta P_{t-i}^{NOLA} + \sum_{i=1}^p \pi_3^{NOLA} \Delta P_{t-i}^{CN} + \sum_{i=1}^p \pi_4^{NOLA} \Delta P_{t-i}^{NG} + \delta^{NOLA} X_t + u_{NOLA,t} \end{aligned} \quad (6.5)$$

$$\begin{aligned} \Delta P_t^{CN} = & \alpha_{CN} (P_{t-1}^{IR} - \beta_0 - \beta_1 P_{t-1}^{NOLA} - \beta_2 P_{t-1}^{CN} - \beta_3 P_{t-1}^{NG}) + \sum_{i=1}^p \pi_1^{CN} \Delta P_{t-i}^{IR} + \\ & \sum_{i=1}^p \pi_2^{CN} \Delta P_{t-i}^{NOLA} + \sum_{i=1}^p \pi_3^{CN} \Delta P_{t-i}^{CN} + \sum_{i=1}^p \pi_4^{CN} \Delta P_{t-i}^{NG} + \delta^{CN} X_t + u_t \end{aligned} \quad (6.6)$$

$$\Delta P_t^{NG} = \alpha_{NG} (P_{t-1}^{IR} - \beta_0 - \beta_1 P_{t-1}^{NO LA} - \beta_2 P_{t-1}^{CN} - \beta_3 P_{t-1}^{NG}) + \sum_{i=1}^p \pi_1^{NG} \Delta P_{t-i}^{IR} + \sum_{i=1}^p \pi_2^{NG} \Delta P_{t-i}^{NO LA} + \sum_{i=1}^p \pi_3^{NG} \Delta P_{t-i}^{CN} + \sum_{i=1}^p \pi_4^{NG} \Delta P_{t-i}^{NG} + \delta^{NG} X_t + u_t \quad (6.7)$$

Equations 6.4 to 6.7 show the VECMs that explain changes in a certain price with adjustments to lagged deviations from long-term equilibrium (α), short run changes in lagged differenced prices (π), exogenous variable like seasonal dummies and lagged Mississippi River levels (δ), and an error term.

The interpretation of the long-run parameters is not exactly straightforward. The estimated cointegrated relationships do not perfectly represent the law of one price (LOP) relationship between the New Orleans and inland regional market. Instead, it represents the general equilibrium between these spatial markets and the two vertical markets of natural gas and corn. This specification helps determine how the price discovery process has changed over time in the nitrogen fertilizer industry. Therefore, α measures how much of the deviation from equilibrium is corrected for in each period. It is a measure of how quickly a certain price will respond to restore the long-run equilibrium relationship between the other prices. Testing for the significance of α will show what prices are endogenous to the system, which will determine how price information is transmitted between the four prices. For example, if α_{IR} is the only significant speed of adjustment parameter, then the inland regional market is the only price to adjust to deviations from equilibrium in the system. This give an idea of how information is transmitted between spatial markets.

β , which is normalized to the inland regional price in every model, represents the long run price elasticity between the inland regional price and the other three prices. This

is a measure of how much of a shock in either the New Orleans market, the corn market, or the natural gas market is transmitted to the inland regional market. If there is perfect price transmission between one of these prices and the inland regional prices, then $\beta = 1$. β_1 represents the long-run, spatial price elasticity between New Orleans and a certain inland regions market. If $\beta_1 = 1$, then the spatial markets are perfectly efficient in the long-run.

This VECM is estimated for urea, UAN, MAP, and DAP in pre-2007 and post-2010 period, given that the data exists. For the sake of simplicity, the models are referred to by fertilizer type-inland region. For example, Urea-NGP refer to the VECM that measures the price relationships between NOLA's urea, NGP's urea, natural gas, and corn. After estimating each model, a variety of tests are performed to understand the short-term and long-term casual relationships in the U.S. nitrogen market.

Johansen Weak Exogeneity Test

The Johansen weak exogeneity test measures the significance of the speed of adjustment parameters, α . If there is no evidence to reject the null hypothesis that a certain $\alpha = 0$, then that price is considered weakly exogenous. For example, if the null hypothesis of $\alpha = 0$ is not rejected for natural gas, this means the price of natural gas does not adjust to any deviations from equilibrium. However, for example, if $\alpha = 0$ is rejected for the inland regional price, this means that in the long-run it is endogenously determined in the system. In other words, NOLA, corn, and natural gas prices cause the inland regional price in the long-run. Shocks in any of these three prices will cause the

inland regional price to adjust to restore the long-run equilibrium. Unfortunately, with the specification of the VECM in this study, the Johansen weak exogeneity test will not show if it is just one price, NOLA, corn, or natural gas, or a combination of them that is causing the inland regional prices in the long-run.

Granger Causality

The Johansen weak exogeneity test measures long-run casualty in cointegration analysis. However, in the short-run, prices may behave differently. For example, assume that the price of corn is found to be exogenous in the long-run. In other words, it does not adjust to deviations from equilibrium and the NOLA, inland region, and natural gas prices do not have a long-run causal relationship with corn. However, in the short run, it still might be the case that the NOLA, inland region, and natural gas prices cause the price of corn. Results like these would show that corn markets will not adjust to restore equilibrium in the long-run, but can still be influenced by short-run shocks in the fertilizer and natural gas markets.

Granger causality tests are used to determine the directional of price information flow between the spatial and vertical markets in the short-run (Granger, 1969). These tests determine if there is unidirectional or bidirectional causality of prices between two markets. For example, consider two markets for the same good, market A and market B, with prices P_A and P_B , respectfully. P_B is said to Granger-cause P_A if lagged prices in both markets can better predict P_A than just using lagged prices of P_A . Testing for Granger causality between regional fertilizer markets and vertical markets will help

determine how price information flows between markets in the short-run. These tests are used to determine if one price causes another price, something that is not possible with the Johansen weak exogeneity test.

Orthogonalized Impulse Response Analysis

Granger causality tests and the Johansen weak exogeneity test may not fully describe the interactions between regional markets and vertical markets because the dynamic responses depend on the interaction between the long-run relationships (α and β) and the short-run relationships (lagged prices). Impulse response analysis can tell a more complete story, where shocks (or impulses) can be applied to estimated VECM specifications, and the dynamic responses of each endogenous variable can be measured over time.

Typically, orthogonalized impulse response analysis is preferred over a simple impulse response analysis. With simple impulse response analysis, the response over time to a one-unit shock in one price holding all other prices constant is estimated. This analysis assumes that shocks in each price are independent from one another. Therefore, shocking one price, and setting the responses of the other prices equal to zero initially, may provide an unrealistic picture of the dynamic relationships between these markets because they are contemporaneously correlated. Instead, orthogonalized impulse response analysis looks at response of prices to shocks in the orthogonal or uncorrelated error terms. This standardized shock is equal to one standard deviation of the price whose error

is being shocked. So, if the impulse is applied to $u_{IR,t}$, this shock is equal to one standard deviation of P_t^{IR} .

The response to an orthogonalized impulse can be interpreted as the growth rate because the price data was transformed using natural logs. For example, consider an impulse to $u_{IR,t}$ and the impulse response of P_t^{NOLA} . The response of P_t^{NOLA} is the difference between the final observation of P_t^{NOLA} and the estimated price of P_{t+1}^{NOLA} after the shock. Since these prices are in logarithmic form, the difference represents the growth rate. It is important to note that when estimating the impulse response function in the VECM framework, the responses will not always converge to zero as they would in a VAR system. Instead, the shock might cause a price to converge to a new level, and the entire system will then adjust to restore the long-term equilibrium relationship between markets (Lutkepohl, 2004).

An understanding of the spatial relationships can be determined by looking at that the impulse responses to shocks in both NOLA and IR. The relative growth rates between these prices, and the time it takes to restore the equilibrium relationships provide information on how efficient information is transferred between NOLA and regional markets. Markets are considered to efficiently transmit information if equilibrium is restored in about 1 to 5 weeks after a shock, which is typically the transportation time between NOLA and inland regions and is, therefore, considered to be the *a priori* gauge for fertilizer market efficiency. Looking at the impulse responses in both subsamples will show how this efficiency has changed after the structural break in the agricultural production markets.

Chapter Takeaways

- The first step in this analysis is to test the data for unit roots and cointegration.
- Vector error correction models are used to model the price dynamics between the New Orleans, inland regional, corn, and natural gas markets
- Johansen weak exogeneity tests, Granger causality tests, and orthogonalized impulse response functions are used for further analysis of the dynamic price relationships between both spatial and vertical markets.

RESULTS

Unit Roots Test

The augmented Dickey-Fuller (ADF) test is used to check the stationarity of price data and Mississippi River stage levels in both in levels and differences for the pre-2007 and post-2010 periods. The null hypothesis of this test is non-stationarity. Therefore, a rejection of the null hypothesis provides evidence that the price series is stationary. The corrected Akaike Information Criteria is used to determine the lag length for each variable. The ADF test is performed using three separate specifications: zero mean, single mean, and trend. Appendix A provides the test statistics for every variable.

The ADF results indicate that fertilizer price levels, in both subsamples, are non-stationary. After differencing the fertilizer price data, ADF results provide evidence that the data is now stationary. This holds true for every differenced fertilizer price in both subsamples. Therefore, the fertilizer prices data are $I(1)$.

The non-fertilizer time series variables, natural gas futures, corn futures, and Mississippi River levels, are also tested for unit roots using the ADF test. For natural gas and corn futures prices, the ADF test indicates that the level data is non-stationary in both subsamples with one exception. The ADF trend specification for natural gas in the pre-2007 period indicates that it is stationary, but the autocorrelation function shows a slow decay. Therefore, natural gas is most likely non-stationary in levels in the pre-2007 period. After differencing natural gas and corn futures price, the ADF results shows the prices are stationary in both the pre-2007 and post-2010 periods. Lastly, the ADF results

indicate that the Mississippi River levels are stationary, which is a necessary assumption for its inclusion as an exogenous variable in the VECM.

Cointegration

After confirming that the fertilizer, natural gas, and corn prices are $I(1)$, the Johansen trace test under restriction is used to test for cointegration in both subsamples. The specification of this test assumes that there is no separate drift in the VECM, but a constant only enters through the error correction term. This is an appropriate characterization for price dynamics in the nitrogen fertilizer industry. The price at New Orleans and the price at an inland regional should follow the same trend, but be separated in levels due to transaction costs (i.e., the mean of those two prices should not be identical). The null hypothesis of this test is that there are at most r cointegrating vectors against the alternative hypothesis that there are more than r cointegrating vectors. So, a rejection of the null that $r=0$ means that there is evidence of more than one cointegrating vector. A subsequent test that fails to reject the null hypothesis that $r=1$ means that there is one cointegrating vector between the time series variables.

The results of the Johansen trace test under restriction are sensitive to the autoregressive order of the model. The lag lengths in this study are chosen based on the corrected Akaike Information Criteria (AICC) using the Proc Varmax procedure in SAS. The procedure estimates a portfolio of vector autoregressive models for the four endogenous variables in the model based on different lag lengths, and provides AICC values for these models. The model with the minimum AICC value is chosen because it

represents the best fitting model while using the fewest number of lags. Table 7.1 provides the estimated lag lengths for each model.

Tables 7.2 to 7.7 show the cointegration results. At the 5% significance level, there is evidence of one cointegrating vector ($r=1$) for almost every spatial model with some exceptions. There was no evidence for cointegration in the post-2010 models for MAP-NGP and MAP-GL.² For the UAN-NGP pre-2007 period, the p-value is 0.0476 and for the UAN-GL post-2010 model, the p-value is 0.0493. While this is not a clear “acceptance” of the null hypothesis ($r=1$), it is assumed that there is one cointegrating vector in both of these models. Since both other UAN-regional models and other non-UAN models in the same regions show that there is evidence of one cointegrating relationship, this does not seem like an unreasonable assumption. There are also no economic reasons to suggest the price relationships in these two regions in those periods are fundamentally different from other regions.³

² A reminder that the acronym “fertilizer-region” represents a specific VECM model. For example, MAP-GL refers to the VECM models that estimates the relationships between New Orleans’ MAP, Great Lakes’ MAP, natural gas, and corn prices.

³ One concern is whether there is sufficient data in each subsample (but primarily the post-2010 subsample) to minimize Type I and Type II errors when testing for cointegrating relationships. In the post-2010 period, there are approximately five years of data, which amounts to 300 observations. Multiple studies have simulated the small sample performance of the maximum likelihood cointegration method and found that there is good performance in the cointegration analysis if the sample size is between 100-500 observations (Mallory & Lence, 2010; Jacobson, 1995; Toda, 1995; Dhrymes & Thomakos, 1997). This is tested in this study by taking sub-samples of the post-2010 period. Table D1 to D3 show the cointegration, price elasticity, and speed of adjustment parameter results for different sized subsamples of the Urea-NGP model in the post-2010 period. A comparison between these restricted subsamples and the full post-2010 period show that one cointegrating vectors is always found. Estimates of the price elasticities and speed of adjustment parameters show that there are small sample distortions when using about 1.5 to 2.5 years of data, which amounts to 91 and 143 observations, respectfully. Since I am using about five years of data with 300 observations and the results are mostly consistent through subsamples, this provides evidence that I am adequately estimating the long-run relationships between prices in this study.

Urea

The discussion below focuses on long-term price elasticities, speed of adjustment parameters, Granger causality, and impulse response analysis for urea. Appendix B contains the short-run parameter estimates of each VECM. The VECM and tests were measured for Urea-NGP, Urea-SGP, Urea-GL in the pre-2007 period and for Urea-NGP, Urea-SGP, Urea-GL, and Urea-PNW in the post-2010 periods.

Price Elasticities

Table 7.8 contains the estimated long-run price elasticities between inland regional urea prices and the New Orleans' urea prices, natural gas prices, and corn prices. The long-run spatial price elasticity, between the inland regional market and NOLA, in the pre-2007 period is estimated to be approximately 0.8 for NGP-NOLA, SGP-NOLA, and GL-NOLA. This can be interpreted as 1% change in the price in New Orleans results in a 0.8% change in the price at either NGP, SGP, or GL in the long-run. In the post-2010 period, the price elasticities increase for all regions. The price elasticity is 0.95 for NGP-NOLA, 1.02 for SGP-NOLA, and 0.86 for GL-NOLA.⁴ This suggests that overall, the U.S. nitrogen industry has become more efficient. Price information is transmitted to a greater extent from New Orleans to around the country in the post-2010 period.

The vertical price elasticities are much lower than the spatial price elasticities. For example, the price elasticity in the Urea-NGP is 0.05 for corn. This means that a 1% increase in the price of corn leads to a 0.05% increase in the price of urea at NGP. Not

⁴ It should be noted that I do not test whether price elasticities between subsamples are statistically different from each other. This is an avenue for future research.

only are these price elasticities small in magnitude, not all have the expected sign. The price elasticity between natural gas and NGP urea is -0.03 in the post-2010 period. An increase in the price of natural gas should increase the price urea in NGP, as natural gas is the main input to urea. Overall, these vertical price elasticities indicated low transmission of information between the urea, corn, and natural gas markets in both periods. This means that shocks originating the vertical markets will not be transmitted to the fertilizer markets in the long-run.

Speed of Adjustment

Table 7.9 contains the estimated speed of adjustment parameters, (α), for each urea model in both subsamples. The Johansen weak exogeneity tests determine whether these parameters are statistically significant for each of the endogenous variables in the VECM; Appendix B shows these results. In the pre-2007 period for urea, the speed of adjustment parameters (α) for the inland regional prices are different from zero at the 5% significance level. The speed of adjustment parameters for the other prices are not significant, indicating that the inland regional markets have long-run relationships and adjust to deviations from equilibrium, while there are no adjustments in NOLA, corn, and natural gas markets. This is expected because NOLA is the leading spatial market, and regional markets should adjust to price shocks. In addition, natural gas and corn markets have other significant drivers in their own price discovery processes, so it is not surprising they are exogenously determined in the long-run.

Estimates of the speed of adjustment parameter are -0.13 for NGP, -0.19 for SGP, and -0.11 for GL in the pre-2007 period. This means that 13%, 19%, and 11% of the

deviation from equilibrium at period (t-1) is corrected for by period t in the NGP, SGP, and GL markets, respectively. There is weak evidence at the 10% statistical level that corn prices are endogenously determined in the Urea-NGP model in the pre-2007 period.

In the post-2010 period, the inland markets still adjust to deviations from equilibrium. NOLA significantly adjusts to deviations in both the Urea-SGP and Urea-NGP models, but not in the Urea-GL or Urea-PNW. Corn adjusts to deviations in the Urea-SGP, Urea-GL, Urea-PNW models. The total amount of adjustment is 0.42 (0.19+0.22) in NGP model, 0.43 in the SGP model, 0.38 in the GL model, and 0.16 in the PNW model.

Shocks to the equilibrium relationships between these prices are corrected for faster in the post-2010 period. In fact, there is evidence that NOLA and corn prices are endogenously determined in some regional models indicates the underlying price discovery process has changed. Instead of NOLA leading the spatial markets, there is more interplay with inland regional markets, where most of the nitrogen is consumed for agricultural production.

Granger Causality Test

Tables 7.10 shows the Granger causality tests between prices in the pre-2007 period. In this period, there is bidirectional causality between NOLA-NGP and NOLA-SGP at the 5% significance level. In the long-run, NOLA prices were exogenous to the system, but in the short-run, there is evidence that inland regional prices affect the NOLA market. There is unidirectional casualty between NOLA-GL, where NOLA granger causes GL, but GL does not granger cause NOLA. Table 7.11 shows the Granger

Causality Tests for the post-2010 period. There is bidirectional casualty between NOLA-SGP and NOLA-GL, but only unidirectional casualty between NOLA-NGP. NOLA granger causes NGP and PNW, but not the other way around.

In the pre-2007 period, natural gas also Granger causes all urea prices in the short-run. There is no evidence of Granger causality between urea and corn. In the post-2010 period, natural gas no longer has a short-run causal relationship with fertilizer prices, but instead, corn unidirectionally causes urea prices at the 5% significant level. This relationship does not hold for the PNW, but these results should be given less weight as there is only data for PNW urea prices starting in 2012. The fact that corn has short-run casual relationships in the post-2010 period, and natural gas does not, aligns with the fact that natural gas prices were low in this period due to fracking and corn prices were high due renewable fuel standards.

Impulse Response Analysis

Figures 7.1 to 7.8 show the impulse response functions for the urea models, where responses were estimated to orthogonal impulses in all four endogenous prices. The magnitudes of these shocks are in table 7.22.⁵ The only significant responses to impulses in the system were that of the inland regional fertilizer prices. Furthermore, these inland regional prices only reacted to orthogonalized impulses in the New Orleans prices, and

⁵ The magnitudes of the impulses for urea and DAP are not the same in the pre-2007 and post-2010 period. They are equivalent to one standard deviation of a certain price in a certain period. The fact that they are different complicates the comparison of the efficiency between subsamples. Simple impulse response analysis measures the same unit shock in both periods. These results are very similar to the orthogonalized impulse response analysis. Since orthogonalized impulse response analysis is preferred (see chapter 6), those are the results presented in this paper.

not to impulse in corn or natural gas. NOLA, natural gas and corn did not react to any shocks.

In the pre-2007 period, an orthogonalized impulse to NOLA urea prices results in a 5% growth of the NOLA price, which is reached in about 4-5 weeks. The inland regional prices respond to restore the equilibrium by increasing around 2.5%, reaching this new equilibrium levels in about 5-6 weeks. In the post-2010 period, there was a faster adjustment to the new equilibrium levels after an orthogonalized impulse in NOLA. NOLA prices respond by increasing around 5% for all regional model, reaching this equilibrium level in about 3 to 4 weeks. The regional prices reach the new equilibrium level that was about 5% higher than before the shock in about 4-5 weeks. This provides evidence in support of efficient flow of information from NOLA to inland regions. Additionally, the analysis suggest that those markets became slightly more efficient in the post-2010 period.

An orthogonalized impulse in the inland regional prices did not causes significant responses in the NOLA price. Instead, the regional prices adjusted to restore the original equilibrium relationship. In the pre-2007 period, it took around 5-6 weeks for the shock to dissipate for all regional prices. In the post-2010 period, the significant regional responses disappear in about 4-5 weeks. This provides evidence that NOLA is the leading market, and any shocks in the inland regional markets do not influence NOLA prices.

While the results of weak exogeneity and short-run causality may have differed from spatial model to spatial model and from year to year, the most important price relationship in these models was that between NOLA and the inland regions. So while

NOLA might have been statically found to be endogenous in the long-run, or have been caused in the short-run by a certain price, the actual magnitude of these casual relationships was small. This is also true for corn and natural gas. The only price that truly adjusts in these system is the inland regional price. The relative speed and magnitude of the transmission of this price information increased in the post-2010 model, possibly due to higher corn prices. Therefore, market participants can expect shocks to be transmitted from NOLA to inland regions faster in the post-2010 period.

DAP

The long-run elasticities, speed of adjustment parameters, Granger causality, and impulse response analysis for DAP are described below. The actual parameter estimates from the VECM of each regional model in both subsamples are in the appendix B. The VECM and tests were conducted for DAP-NGP, DAP-SGP, DAP-GL in both the pre-2007 and post-2010 periods.

Price Elasticity

Table 7.12 contains the long-run price elasticities between inland DAP markets and the NOLA market, corn market, and natural gas market. In the pre-2007 period, the long-run price elasticity was 0.85 for NOLA-NGP, 0.91 for NOLA-SGP, and 0.80 for NOLA-GL. In the post-2010 period, the long-run price elasticity was 0.87 for NOLA-NGP, 0.88 for NOLA-SGP, and 0.96 for NOLA-GL. There is mixed evidence that the price-elasticities increased between periods in the DAP models, unlike in urea. Once again, there is no way to determine if these estimates are statistically different from one

another, but overall in both periods, these are relatively high long-run price elasticities. Changes in the price at NOLA in the long-run are almost fully transmitted to inland regions in the long-run.

Similarly to urea, the long-run price elasticities between inland regional DAP prices and the vertical markets are close to zero. This indicates that in both subsamples, the long-run transmission of price information from vertical markets to the inland regions DAP markets is very low. Most of the vertical market price elasticities show the expected sign, except for corn in the pre-2007 DAP-SGP model and corn in the post-2010 DAP-GL model. However, the estimates are small and are not economically significant.

Speed of Adjustment

Table 7.13 contains the estimated speed of adjustment parameters, (α) , for each DAP model in both subsamples. The significance is determined from the Johansen's Weak Exogeneity test. At the 1% level, there is evidence that each inland regional price adjusts to deviations from equilibrium in the pre-2007 period. There is weaker evidence, at the 10% level, that corn prices are also endogenously determined and adjust to deviations in all DAP models. The total adjustment in pre-2007 period is 0.19 for the NGP-DAP model, 0.14 for the SGP-DAP, and 0.17 for the GL-DAP model. These are similar adjustments compared to urea in the pre-2007 period. The fact that all inland regional prices are endogenous show that the NOLA is the leading DAP market as well, but it is surprising that corn prices are endogenous in these models. The pre-2007 period

was before the price boom in corn, and there is no satisfactory explanation for these results.

In the post-2010 period, there are mixed results as to what prices significantly adjust to deviations. In the DAP-NGP model, both NOLA and NGP adjust to deviations with a total adjustment between the two markets being 0.46. In the SGP-DAP model, just SGP adjust to deviations with a speed of adjustment being 0.25. In the DAP-GL model, the NOLA, GL, and natural gas prices all adjust to deviations. There is a total adjustment of 0.41. It is surprising that natural gas prices are found to be endogenously determined in DAP-GL. Also, corn is no longer endogenous, possibly due to its higher prices in the post-2010 period. Overall, there is more adjustment in the post-2010 period than in the pre-2007 period. This indicates that there is a more efficient flow of price information in the post-2010 period, as markets faster adjust to restore long-term equilibrium relationships.

Granger Causality

Table 7.14 and 7.15 contain the Granger causality results. In the pre-2007 period, there are again mixed results between models. For the DAP-NGP model, there is bidirectional causality between NOLA and NGP. In the DAP-SGP and the DAP-GL models, only NOLA granger causes the inland regional prices. In the post-2010 models, there is evidence of bidirectional short-run casualty between NOLA and GL. For the DAP-NGP and DAP-SGP models, there is unidirectional granger causality where only NOLA affects the inland regional price. The inland regions never have a unidirectional casual relationships with NOLA, which provides evidence that NOLA is the leading

market in nitrogen fertilizer industry. There are no other patterns between either regions or subsamples.

There are also mixed results in terms of short-run casual relationships between regional models and vertical markets. In the pre-2007 DAP-NGP and DAP-SGP models, NOLA, NGP, and SGP all unidirectionally granger cause corn prices. In the post-2010 DAP-NGP and DAP-SGP model, there is bidirectional causality between both DAP prices and the corn. There is no causality between natural gas and DAP prices for both of these models in either period. In the pre-2007 DAP-GL model, there is bidirectional causality at the 10% significance level between corn and GL. In addition, this model finds evidence that NOLA causes natural gas prices. In the post-2010 DAP-GL model, there bidirectional causality between GL and corn prices. NOLA also granger causes corn prices. Lastly, natural gas is found to granger cause the NOLA price in the DAP-GL model, but not the GL price.

The granger causality results, along with the weak exogeneity tests, show that DAP has more of a relationship with corn in both periods than urea. An explanation for this is not determined. It is also interesting to note that there is no short-run causality with DAP and natural gas in the pre-2007 period, when natural gas prices were higher. This may be because DAP's price also depends on the price of phosphoric acid, another one of its inputs.

Impulse Response Functions

Figures 7.9 to 7.14 contain the impulse response functions for DAP. The magnitudes of each shock are in table 7.22. The prices of NOLA, corn, and natural gas do

not respond to impulses in the system. The only significant responses are in the regional fertilizer price, just like with urea. In the pre-2007 period, an orthogonalized impulse in the price of NOLA increases NOLA prices about 2% in each model. It takes 3 to 5 weeks for NOLA prices to reach this new equilibrium level. Regional prices respond by also increasing, but to a lesser extent. This shock results in around 1.5% increase in regional prices, which takes around 8 weeks to level off. This indicates relatively inefficient transfer of information because fertilizer can be moved from NOLA to inland regions in about 1 to 5 weeks. In the post-2010 period, the same shock to NOLA increases NOLA prices around 3%, taking 2-3 weeks to level off. Regional prices also increase in response to this shock about 1 to 1.5%, reaching these levels in 5-6 weeks. There is no discernable pattern between regions, but it seems that all prices reach their new equilibrium levels after a shock faster in the post-2010 period. This means that price information is transferred from NOLA to inland regions more efficiently in the post-2010 period.

Orthogonalized impulses in the regional market did not cause significant response in the NOLA. Instead, the shock in regional prices dissipated after a certain number of weeks. This indicates that NOLA is the leading DAP market, and shocks to prices in inland regions do not affect NOLA. In the pre-2007 period, responses to regional shocks become insignificant after 6 weeks. In the post-2010 period, the effects of these shocks disappear in about 5 weeks.

Once again, the fact that the inland regional prices are the only price to be significantly affected by shocks in other prices, and the only price to decrease after a

shock in its own price, indicates that it is truly the only endogenous variable in the system. While other prices are found to be endogenously determined, or had statically significantly significant short-run casual relationships with other prices, the economic significance of these relationships is small.

UAN

The long-run elasticities, speed of adjustment parameters, granger causality, and impulse response analysis for UAN are described below. The actual parameter estimates from the VECM of each regional model are in the Appendix B. The VECM and the subsequent tests are only conducted for post-2010 period for UAN-NGP, UAN-SGP, and UAN-GL because of a lack of data.

Price Elasticity

Table 7.16 presents the results of the long-term price elasticities between regional UAN prices and NOLA, natural gas, and corn. The long-term price elasticities in the post-2010 period between NOLA and inland regions is 0.94 for UAN-NGP, 1.01 for UAN-SGP, and 0.85 for UAN-GL. These estimates show that there is a relative high transmission of price information from NOLA to the inland regions, just like with urea and DAP. The shocks at NOLA are almost fully transmitted to the inland regions in the long-run, indicating efficient transmission of information.

The long-term price elasticities between the inland regions and the vertical markets are also low just like with urea and DAP. These vertical price elasticities also have negative signs in each spatial model, which goes against the economic intuition. An

increase in either natural gas or corn price should increase the price of UAN. While the significance of these cannot be test, they indicate a very low transmission of price information from the vertical markets to the inland regional markets.

Speed of Adjustment

Table 7.17 contains the speed of adjustment parameters for each UAN model in the post-2010 period. For every spatial model, the inland regional prices significantly adjusts to deviations from equilibrium. In the UAN-NGP and UAN-SGP models, NOLA also significantly adjusts to deviations from equilibrium. NOLA did not exhibit any adjustment in the UAN-GL model. Lastly, corn prices adjust to deviations in the UAN-SGP model. The total adjustment was 0.38 in the NGP-UAN model, 0.26 in the SGP-UAN model, and 0.31 in the GL-UAN model.

This is somewhat similar, if not a little lower adjustment, when compared to urea and DAP. Unfortunately, there are no comparisons that can be made to the pre-2007 estimates, preventing evidence that there is a more efficient flow of information in the post-2010 period than in the earlier period.

Granger Causality

The post-2010 period's Granger causality test results are reported in table 7.18. NOLA granger causes the inland regional price in the UAN-NGP and UAN-GL models. In the UAN-SGP, there is bidirectional causality between NOLA and SGP. Corn is found to granger cause both UAN prices in each model. There are no short-term casual relationships with UAN and natural gas in any of the models. This follows similar trend

in urea and DAP. In the pre-2007 period, natural gas had short-run casual relationships with urea prices, which unfortunately cannot be seen in the UAN models. The fact that natural gas has no short-run casual relationships in the post-2010 period provides evidence that natural gas did not have large effects on the price discovery process after fracking was introduced. In the post-2010, corn had more of an influence on the short-run price discovery process in urea, DAP, UAN, due to the greater demand for biofuel.

Impulse Response Functions

Figures 7.15-7.20 show the impulse responses of UAN. The magnitudes of the impulses are in table 7.22. The impulse response analysis was only available for the post-2010 period. The results are similar to urea and DAP. Corn and natural gas prices did not respond to any shocks, and the fertilizer prices did not respond to shocks in the vertical markets. A shock in NOLA results in about a 4% increase in NOLA prices, which reaches this new equilibrium level in about 3-4 weeks in each model. The inland regional prices take about 5 weeks to reach a level that was 3% higher than before the shock. The spatial markets are relatively efficient because the shock is transmitted to inland regions in about the time it takes for a fertilizer shipments to reach these regions from NOLA.

The results to an orthogonalized impulse in the regional prices vary by model. The shock increases NGP prices by 2%, but this shock disappears in 5 weeks. NOLA slightly increased, but the magnitude was close to zero and it disappeared after 2 weeks. The same results are found the in UAN-SGP model. SGP prices rose by 2%, but this increase dissipated in 7 weeks. NOLA prices slightly increased, but this response was

small in magnitude. In the UAN-GL model, the NOLA price did not respond to the shock and the 2% increase in the GL price disappears in about 4 weeks.

These impulse responses analysis follows the results of urea and DAP. The only price that are truly endogenous are the inland prices. This means that NOLA is the central market for UAN as well, and the inland regional markets follow the NOLA price. There is some evidence that corn affects the UAN price discovery process, but this was not seen in the impulse response analysis. So while these effects might be statically significant, they are not economically significant.

MAP

The interpretation of price dynamics of MAP is difficult because the lack of data and the fact that there was no cointegration found in the MAP-NGP and MAP-PNW. Appendix B has parameters of the VECM models of MAP-SGP and MAP-GL. The data that is available provides information on the MAP-SGP and the MAP-GL in the post-2010 periods.

Price Elasticities

Table 7.19 contains the long-term price elasticities MAP-SGP and MAP-GL. The spatial price elasticity is 0.96 for SGP-MAP and 0.88 for GL-MAP. These are similar price elasticities found in other nitrogen fertilizer models, and indicate there is substantial information transmission from NOLA to inland regions. The price elasticities between inland regional prices and the vertical markets are also similar to estimates in other model. They are very low, with negative signs on the price elasticities between corn and

inland regions. This goes against economic intuition, but there is no way to test if these estimates are different from zero. Overall, there is almost perfect price information transmission from New Orleans to the inland regional markets while controlling for shocks to the vertical markets. These vertical markets contribute almost no price information to the inland regional markets.

Speed of Adjustment

Table 7.20 shows the speed of adjustment parameters. In both the MAP-SGP and MAP-GL models, both the inland regional and NOLA prices adjust to deviations from equilibrium. In the MAP-SGP model, natural gas and corn also both adjust to deviations, which is the only model to have all four prices endogenous. There is no economic or industry explanation for this. This is not true in the MAP-GL model. The total adjustment in the MAP-SGP model is 0.61 and the total adjustment is 0.20 in the GL-Map model. MAP-SGP has the highest speed of adjustment in all of the models, and this is the greatest variance of adjustment between the models for one fertilizer. The speed of adjustment estimates are similar to other post-2010 results, but like UAN, a comparison to the pre-2007 period is not possible.

Granger Causality

Table 7.21 contains the Granger causality results. Granger causality tests show that there is bidirectional causality between SGP and NOLA. This bidirectional causality is not found in the MAP-GL model, where only NOLA granger caused GL. In MAP-SGP and MAP-GL, both NOLA and the inland regional price prices granger causes corn.

These same results were found in the post-2010 DAP models, which is not surprisingly because DAP and MAP are two closely related fertilizers. In MAP-SGP and MAP-GL, corn granger causes NOLA prices, but not GL prices. This is a strange result in the context that all other models, corn was found to granger causes both NOLA and the inland regional price in the post-2010 period.

There is no granger causality found between natural gas and MAP prices. This is similar to all other models and might provide evidence that natural gas has a lesser effect on nitrogen prices in the post-2010 model. In addition, inland regional prices never had a unidirectional causal relationship with NOLA, which means NOLA is the leading price in the MAP market as well.

Impulse Response Functions

Figure 7.21 to 7.24 show the impulse responses of MAP, with the actual magnitude of the impulse in both periods in table 7.22. Once again, there is no significant responses to shock in natural gas and corn. Impulses in these vertical prices also did not cause responses in either of the fertilizer prices. There are slightly different results for the MAP-GL and MAP-SGP models to shocks in NOLA. In the MAP-GL model, NOLA prices increase by 3% to a new equilibrium level in 2 to 3 weeks. The GL price responds by increasing 1.5% in 4 to 5 weeks. In the SGP-MAP model, the increase in NOLA price levels off at 3% in 5 to 6 weeks. SGP price increases by 2.5% in 6 to 7 weeks. These results indicate that MAP markets are relatively less efficient than urea and DAP markets. Shocks at NOLA are not fully transmitted to inland regions and the convergence to a new equilibrium in inland regions takes longer than the time to move

fertilizer from NOLA to these locations. A shock in the regional prices did not illicit significant responses from New Orleans price. The regional prices increased about 1% to a shock in their own prices, and this shock statistically disappear after 6 weeks in both MAP-SGP and MAP-GL.

This provides even more evidence that the inland regional price are truly endogenous to the other prices. Information is being transfer from NOLA to these inland regions, and not the other way around. NOLA is the central market and the inland regions adjust to always restore the long-term equilibrium relationships. While corn is found to significantly cause MAP prices, the magnitude of these casual relationships was small because MAP prices do not respond to impulse in the corn market.

Chapter Takeaway

- New Orleans is the central market for nitrogen fertilizer in the United States and shocks originating at NOLA are propagated to inland locations
- In terms of vertical price dynamics, corn had a greater influence on the fertilizer price discovery process in the post-2010 period. There is some evidence that natural gas had a greater influence in the pre-2007 period. Impulse responses analysis shows the magnitude of information transmission is low for both corn and natural gas.
- Nitrogen fertilizer markets seem to be more efficient in the post-2010 period.

Table 7.1: Autoregressive Order of Each Regional VECM

Model	Lag Length
Urea-NGP	4
Urea-SGP	5
Urea-GL	3
Urea-PNW	1
DAP-NGP	5
DAP-SGP	5
DAP-GL	5
UAN-NGP	4
UAN-SGP	4
UAN-GL	2
MAP-NGP	8
MAP-SGP	4
MAP-GL	3
MAP-PNW	4

Note: The autoregressive lag length for each model was chosen based on the minimum AICC of VARMA models that are estimated under alternative lag lengths and used in the cointegration tests and the estimation of the VECMs.

Table 7.2: Johansen Cointegration Test for Urea in the Pre-2007 Period

Model	Null	Eigenvalue	Trace	Pr > Trace
Urea-NGP	$r = 0$	0.1007	99.1737	<.0001
	$r = 1$	0.0376	33.4005	0.0767
	$r = 2$	0.0141	9.6208	0.6764
	$r = 3$	0.0014	0.8453	0.9688
Urea-SGP	$r = 0$	0.0899	92.0666	<.0001
	$r = 1$	0.0384	33.7265	0.0709
	$r = 2$	0.0134	9.4731	0.6908
	$r = 3$	0.0018	1.0978	0.9377
Urea-GL	$r = 0$	0.1095	106.7010	<.0001
	$r = 1$	0.0393	34.7012	0.0559
	$r = 2$	0.0143	9.7985	0.6590
	$r = 3$	0.0014	0.8456	0.9688

Note: The null hypothesis is $r = i$ against the alternative $r > i$. When the null hypothesis $r = i$ is not rejected, this is evidence that there are i cointegrating vectors between the prices.

Table 7.3: Johansen Cointegration Test for Urea in the Post-2010 Period

Model	Null	Eigenvalue	Trace	Pr > Trace
Urea-NGP	$r = 0$	0.1669	75.4461	0.0002
	$r = 1$	0.0527	21.4098	0.6345
	$r = 2$	0.0128	5.3901	0.9718
	$r = 3$	0.0053	1.5659	0.8611
Urea-SGP	$r = 0$	0.1245	59.0374	0.0168
	$r = 1$	0.0434	19.8260	0.7369
	$r = 2$	0.0150	6.7312	0.9132
	$r = 3$	0.0077	2.2767	0.7218
Urea-GL	$r = 0$	0.2026	91.3698	<.0001
	$r = 1$	0.0571	24.1185	0.4542
	$r = 2$	0.0142	6.6430	0.9183
	$r = 3$	0.0080	2.3888	0.6991
Urea-PNW	$r = 0$	0.1679	50.9722	0.0908
	$r = 1$	0.0641	21.0203	0.6604
	$r = 2$	0.0594	10.2294	0.6166
	$r = 3$	0.0016	0.2532	0.9996

Note: The null hypothesis is $r = i$ against the alternative $r > i$. When the null hypothesis $r = i$ is not rejected, this is evidence that there are i cointegrating vectors between the prices.

Table 7.4: Johansen Cointegration Test for DAP in the Pre-2007 Period

Model	Null	Eigenvalue	Trace	Pr > Trace
DAP-NGP	$r = 0$	0.0615	64.5199	0.0044
	$r = 1$	0.0277	25.2260	0.3854
	$r = 2$	0.0114	7.8224	0.8383
	$r = 3$	0.0012	0.7346	0.9796
DAP-SGP	$r = 0$	0.1220	105.4949	<.0001
	$r = 1$	0.0273	24.9482	0.4022
	$r = 2$	0.0109	7.8043	0.8397
	$r = 3$	0.0017	1.0262	0.9474
DAP-GL	$r = 0$	0.0613	62.7803	0.0066
	$r = 1$	0.0246	23.6417	0.4850
	$r = 2$	0.0124	8.2316	0.8046
	$r = 3$	0.0009	0.5384	0.9928

Note: The null hypothesis is $r = i$ against the alternative $r > i$. When the null hypothesis $r = i$ is not rejected, this is evidence that there are i cointegrating vectors between the prices.

Table 7.5: Johansen Cointegration Test for DAP in the Post-2010 Period

Model	Null	Eigenvalue	Trace	Pr > Trace
DAP-NGP	$r = 0$	0.1759	79.0463	0.0001
	$r = 1$	0.0480	21.9608	0.5975
	$r = 2$	0.0155	7.4438	0.8670
	$r = 3$	0.0096	2.8405	0.6108
DAP-SGP	$r = 0$	0.1283	62.7518	0.0066
	$r = 1$	0.0506	22.2476	0.5781
	$r = 2$	0.0140	6.9330	0.9012
	$r = 3$	0.0094	2.7768	0.6230
DAP-GL	$r = 0$	0.1497	69.8174	0.0007
	$r = 1$	0.0472	21.9905	0.5955
	$r = 2$	0.0157	7.7226	0.8461
	$r = 3$	0.0103	3.0490	0.5716

Note: The null hypothesis is $r = i$ against the alternative $r > i$. When the null hypothesis $r = i$ is not rejected, this is evidence that there are i cointegrating vectors between the prices.

Table 7.6: Johansen Cointegration Test for UAN in the Post-2010 Period

Model	Null	Eigenvalue	Trace	Pr > Trace
UAN-NGP	$r = 0$	0.1915	93.5123	<.0001
	$r = 1$	0.0671	30.5783	0.1443
	$r = 2$	0.0218	10.0330	0.6359
	$r = 3$	0.0117	3.4972	0.4925
UAN-SGP	$r = 0$	0.1501	74.2792	0.0002
	$r = 1$	0.0669	26.1218	0.3340
	$r = 2$	0.0142	5.6199	0.9647
	$r = 3$	0.0047	1.3871	0.8928
UAN-GL	$r = 0$	0.3198	150.0370	<.0001
	$r = 1$	0.0854	35.2033	0.0493
	$r = 2$	0.0162	8.6162	0.7710
	$r = 3$	0.0125	3.7345	0.4536

Note: The null hypothesis is $r = i$ against the alternative $r > i$. When the null hypothesis $r = i$ is not rejected, this is evidence that there are i cointegrating vectors between the prices.

Table 7.7: Johansen Cointegration Test for MAP in the Post-2010 Period

Model	Null	Eigenvalue	Trace	Pr > Trace
MAP-NGP	$r = 0$	0.0926	49.5252	0.1183
	$r = 1$	0.0456	21.1552	0.6514
	$r = 2$	0.0150	7.5318	0.8606
	$r = 3$	0.0106	3.1042	0.5614
MAP-SGP	$r = 0$	0.1228	59.7823	0.0139
	$r = 1$	0.0447	20.9914	0.6623
	$r = 2$	0.0141	7.4664	0.8654
	$r = 3$	0.0110	3.2678	0.5320
MAP-GL	$r = 0$	0.1520	68.0596	0.0014
	$r = 1$	0.0381	19.1019	0.7803
	$r = 2$	0.0153	7.5783	0.8571
	$r = 3$	0.0100	2.9950	0.5816
MAP-PNW	$r = 0$	0.1597	48.9514	0.1310
	$r = 1$	0.0668	20.2515	0.7102
	$r = 2$	0.0401	8.8359	0.7511
	$r = 3$	0.0125	2.0808	0.7614

Note: The null hypothesis is $r = i$ against the alternative $r > i$. When the null hypothesis $r = i$ is not rejected, this is evidence that there are i cointegrating vectors between the prices.

Table 7.8 : Estimated Price Elasticities for Urea

Model	Price	Pre-2007	Post-2010
Urea-NGP	New Orleans	0.78920	0.95662
	Northern Great Plains	1.00000	1.00000
	Natural Gas Futures	0.09728	-0.02913
	Corn Futures	0.05406	-0.03955
Urea-SGP	New Orleans	0.81515	1.02591
	Southern Great Plains	1.00000	1.00000
	Natural Gas Futures	0.04980	0.02489
	Corn Futures	-0.00663	-0.10419
Urea-GL	New Orleans	0.83680	0.86861
	Great Lakes	1.00000	1.00000
	Natural Gas Futures	0.08232	0.01435
	Corn Futures	0.06720	-0.01637
Urea-PNW	New Orleans	-	1.00224
	Pacific Northwest	-	1.00000
	Natural Gas Futures	-	0.03518
	Corn Futures	-	-0.02249

Note: The price elasticities are calculated by multiplying each β by (-1).

Table 7.9: Speed of Adjustment Parameters for Urea

	Price	Pre-2007	Post-2010
Urea-NGP	New Orleans	-0.01972	0.18691**
	Northern Great Plains	-0.13345***	-0.21984***
	Natural Gas Futures	0.03534	-0.03609
	Corn Futures	0.04819*	-0.08474
Urea-SGP	New Orleans	-0.02191	0.18372**
	Southern Great Plains	-0.18741***	-0.11911***
	Natural Gas Futures	-0.03814	-0.01010
	Corn Futures	0.02075	-0.13284**
Urea-GL	New Orleans	0.00693	0.08326
	Great Lakes	-0.10679***	-0.27047***
	Natural Gas Futures	-0.01568	0.05124
	Corn Futures	0.02226	-0.11776**
Urea-PNW	New Orleans	-	0.00480
	Pacific Northwest	-	-0.10205***
	Natural Gas Futures	-	-0.01990
	Corn Futures	-	-0.06256**

Note: Statistical Significance is determine with the Johansen Weak Exogeneity Test, where the null is $\alpha = 0$ and the alternative hypothesis is $\alpha \neq 0$. *, **, *** indicates significance at the 10%, 5%, and 1% levels, respectfully.

Table 7.10: Granger Causality Results for Urea in Pre-2007 Period

Model	Test	Chi-Square	Pr>ChiSq
Urea-NGP	NGP $\rightarrow$ NOLA	10.35**	0.0350
	NOLA $\rightarrow$ NGP	157.36***	<.0001
	NGP $\rightarrow$ Corn	7.85*	0.0973
	Corn $\rightarrow$ NGP	5.47	0.2426
	NOLA $\rightarrow$ Corn	5.25	0.2627
	Corn $\rightarrow$ NOLA	1.71	0.7887
	NGP $\rightarrow$ NG	1.27	0.8666
	NG $\rightarrow$ NGP	25.50***	<.0001
	NOLA $\rightarrow$ NG	5.49	0.2405
	NG $\rightarrow$ NOLA	19.37***	0.0007
Urea-SGP	SGP $\rightarrow$ NOLA	12.02**	0.0345
	NOLA $\rightarrow$ SGP	214.31***	<.0001
	SGP $\rightarrow$ Corn	13.92**	0.0161
	Corn $\rightarrow$ SGP	5.00	0.4153
	NOLA $\rightarrow$ Corn	5.37	0.3728
	Corn $\rightarrow$ NOLA	2.03	0.8456
	SGP $\rightarrow$ NG	1.59	0.9022
	NG $\rightarrow$ SGP	29.11***	<.0001
	NOLA $\rightarrow$ NG	4.94	0.4229
	NG $\rightarrow$ NOLA	15.04**	0.0102
Urea-GL	GL $\rightarrow$ NOLA	5.36	0.1475
	NOLA $\rightarrow$ GL	127.31***	<.0001
	GL $\rightarrow$ Corn	5.31	0.1506
	Corn $\rightarrow$ GL	1.61	0.6580
	NOLA $\rightarrow$ Corn	4.59	0.2042
	Corn $\rightarrow$ NOLA	0.77	0.8559
	GL $\rightarrow$ NG	1.42	0.7000
	NG $\rightarrow$ GL	24.56***	<.0001
	NOLA $\rightarrow$ NG	1.81	0.6123
	NG $\rightarrow$ NOLA	17.12***	0.0007

Note: The notation $X \rightarrow Y$ means X granger causes Y. The null hypothesis of the Granger Causality test is X does not granger cause Y. The alternative hypothesis is that X does granger causes Y. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectfully.

Table 7.11: Granger Causality Results for Urea in Post-2010 Period

Model	Test	Chi-Square	Pr>ChiSq
Urea-NGP	NGP $\rightarrow$ NOLA	6.84	0.1446
	NOLA $\rightarrow$ NGP	154.07***	<.0001
	NGP $\rightarrow$ Corn	4.54	0.3373
	Corn $\rightarrow$ NGP	9.25*	0.0552
	NOLA $\rightarrow$ Corn	5.91	0.2057
	Corn $\rightarrow$ NOLA	22.63***	0.0002
	NGP $\rightarrow$ NG	1.03	0.9048
	NG $\rightarrow$ NGP	4.75	0.3144
	NOLA $\rightarrow$ NG	0.74	0.9467
	NG $\rightarrow$ NOLA	2.73	0.6046
Urea-SGP	SGP $\rightarrow$ NOLA	11.83**	0.0372
	NOLA $\rightarrow$ SGP	109.86***	<.0001
	SGP $\rightarrow$ Corn	2.81	0.7295
	Corn $\rightarrow$ SGP	15.22***	0.0095
	NOLA $\rightarrow$ Corn	5.34	0.3762
	Corn $\rightarrow$ NOLA	22.76***	0.0004
	SGP $\rightarrow$ NG	1.01	0.9616
	NG $\rightarrow$ SGP	6.50	0.2602
	NOLA $\rightarrow$ NG	3.88	0.5674
	NG $\rightarrow$ NOLA	2.81	0.7300
Urea-GL	GL $\rightarrow$ NOLA	7.43*	0.0593
	NOLA $\rightarrow$ GL	160.54***	<.0001
	GL $\rightarrow$ Corn	3.38	0.3370
	Corn $\rightarrow$ GL	10.67**	0.0136
	NOLA $\rightarrow$ Corn	4.23	0.2374
	Corn $\rightarrow$ NOLA	19.38***	0.0002
	GL $\rightarrow$ NG	1.02	0.7956
	NG $\rightarrow$ GL	3.84	0.2795
	NOLA $\rightarrow$ NG	2.01	0.5709
	NG $\rightarrow$ NOLA	3.88	0.2748
Urea-PNW	GL $\rightarrow$ NOLA	2.34	0.1261
	NOLA $\rightarrow$ GL	35.78***	<.0001
	GL $\rightarrow$ Corn	0.80	0.3715
	Corn $\rightarrow$ GL	0.62	0.4303
	NOLA $\rightarrow$ Corn	6.26**	0.0124
	Corn $\rightarrow$ NOLA	0.01	0.9246
	GL $\rightarrow$ NG	3.25*	0.0713
	NG $\rightarrow$ GL	1.60	0.2061
	NOLA $\rightarrow$ NG	3.77*	0.0523
	NG $\rightarrow$ NOLA	1.27	0.2588

Note: The notation $X \rightarrow Y$ means X granger causes Y. The null hypothesis of the Granger Causality test is X does not granger cause Y. The alternative hypothesis is that X does granger causes Y. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectfully.

Figure 7.1: Response to Orthogonalized Impulse in NOLA's Price in Urea-NGP Model

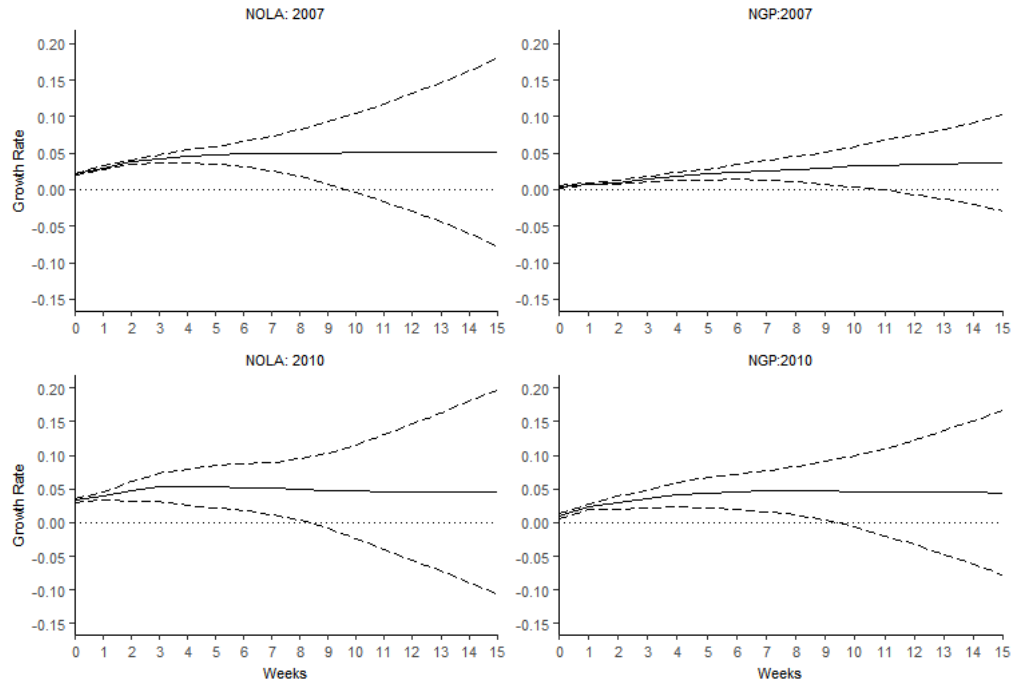


Figure 7.2: Response to Orthogonalized Impulse in NGP's Price in Urea-NGP Model

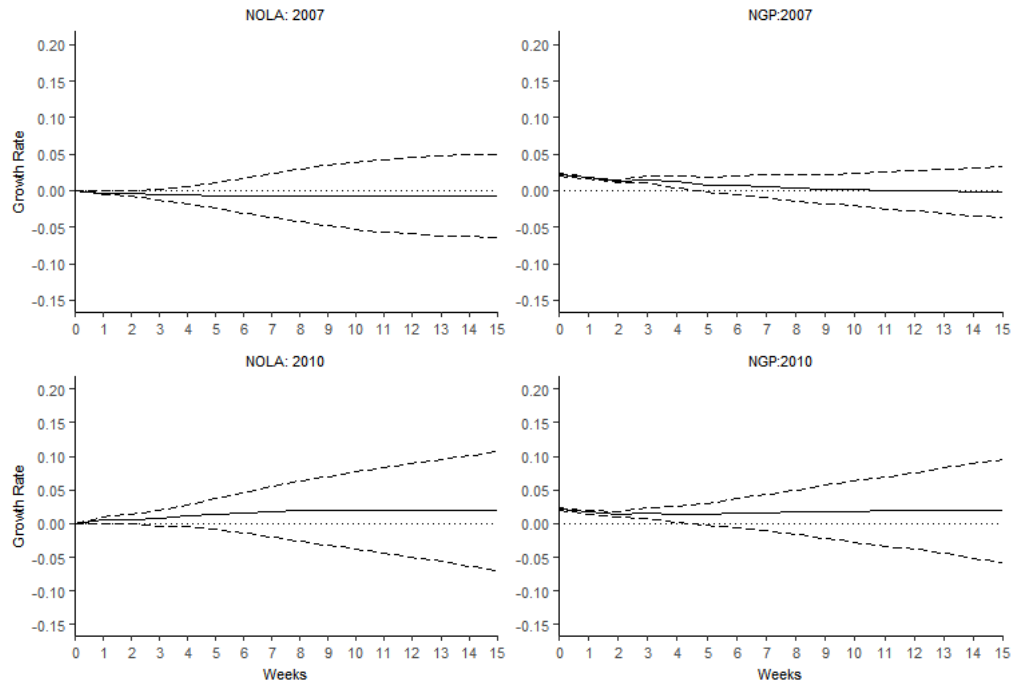


Figure 7.3: Response to Orthogonalized Impulse in NOLA's Price in Urea-SGP Model

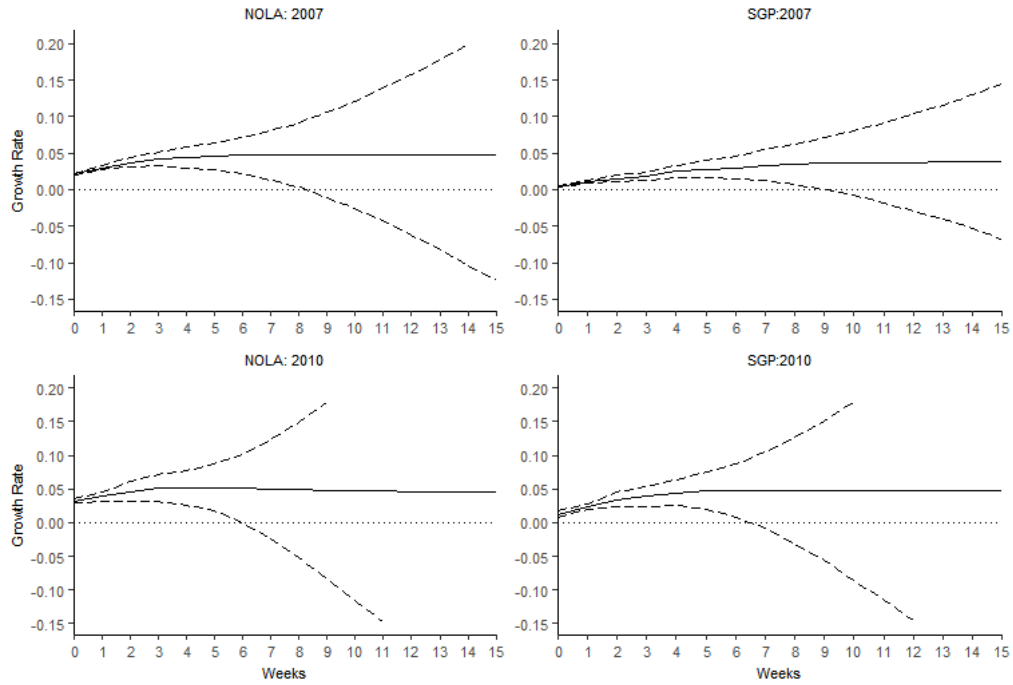


Figure 7.4: Response to Orthogonalized Impulse in SGP's Price in Urea-SGP Model

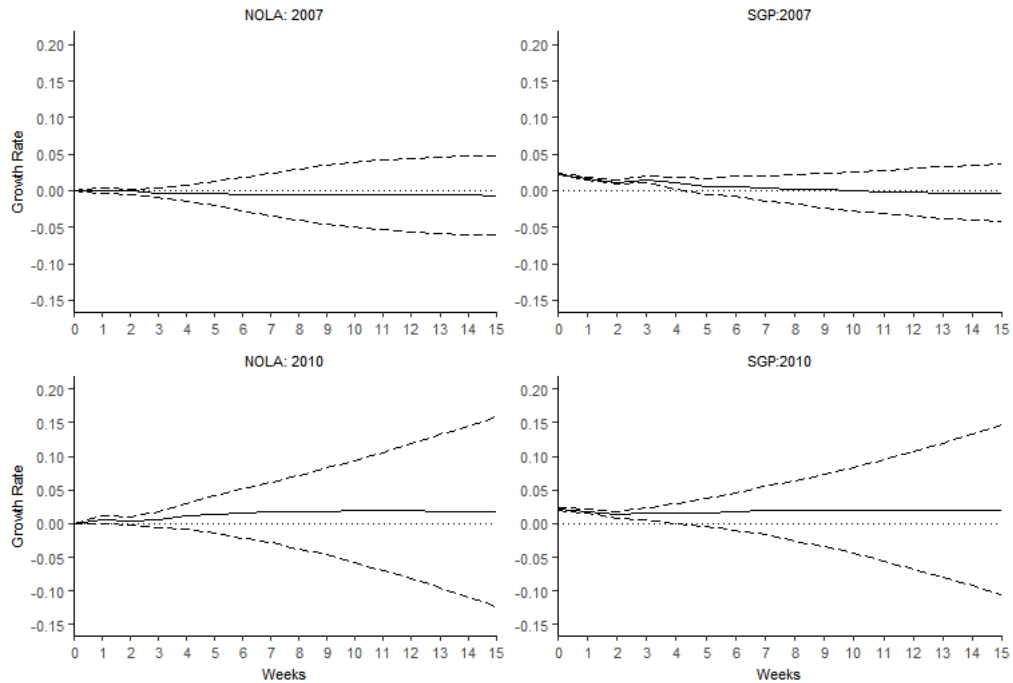


Figure 7.5: Response to Orthogonalized Impulse in NOLA's Price in Urea-GL Model

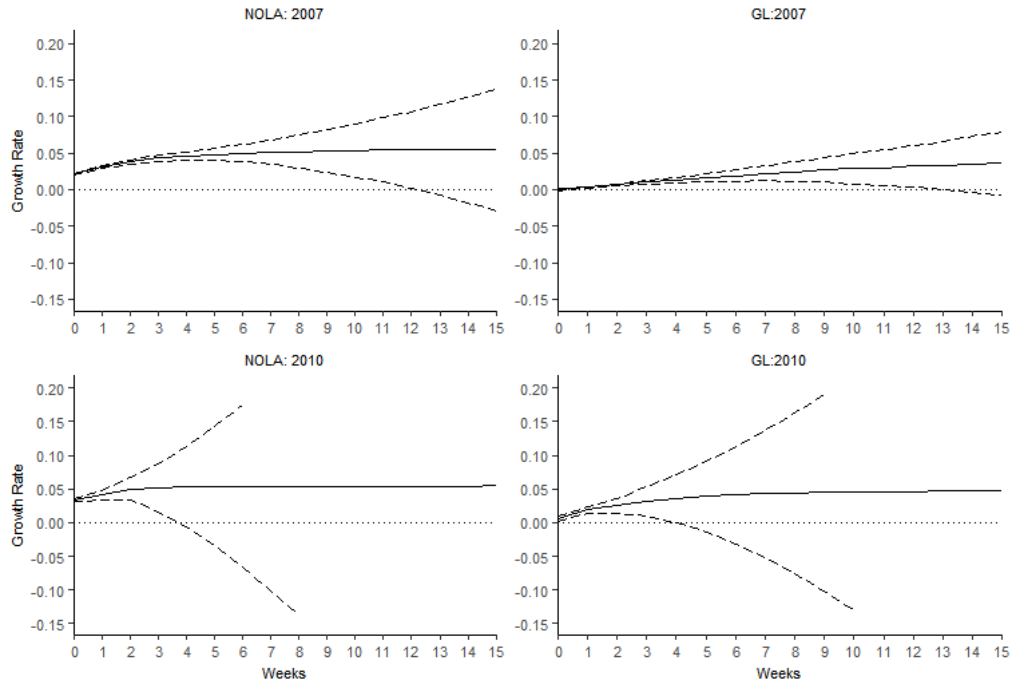


Figure 7.6: Response to Orthogonalized Impulse in GL's Price in Urea-GL Model

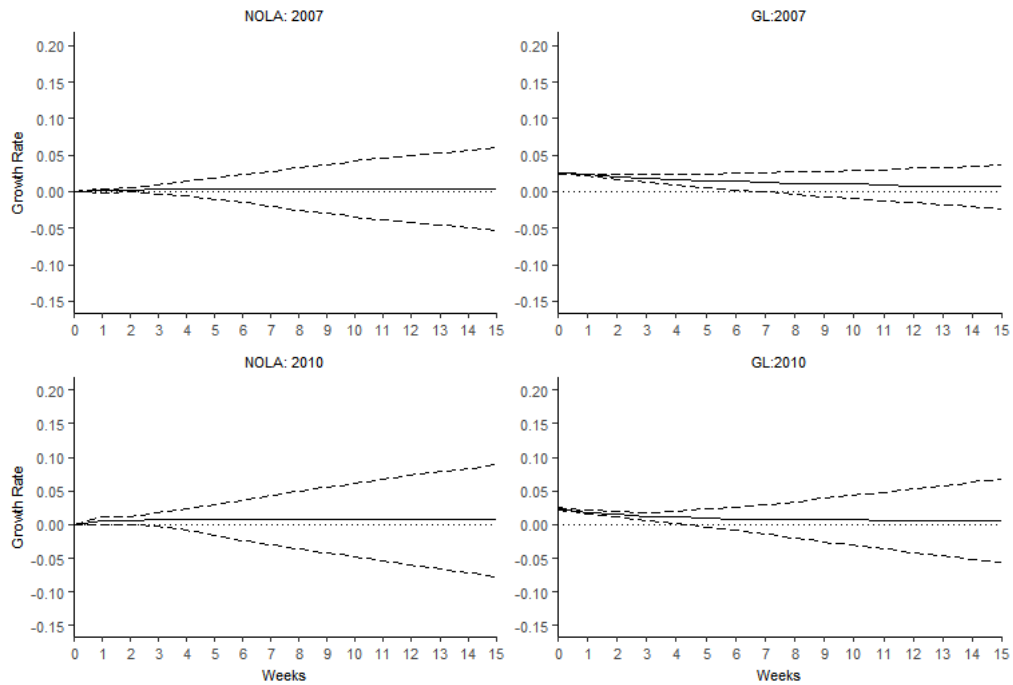


Figure 7.7: Response to Orthogonalized Impulse in NOLA's Price in Urea-PNW Model

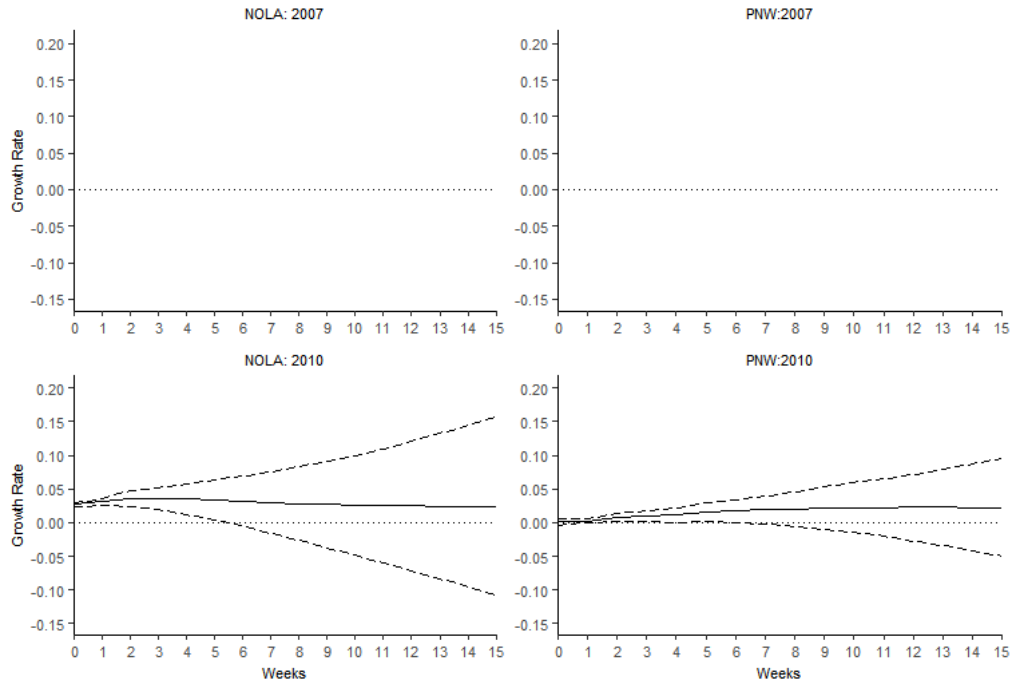


Figure 7.8: Response to Orthogonalized Impulse in PNW's Price in Urea-PNW Model

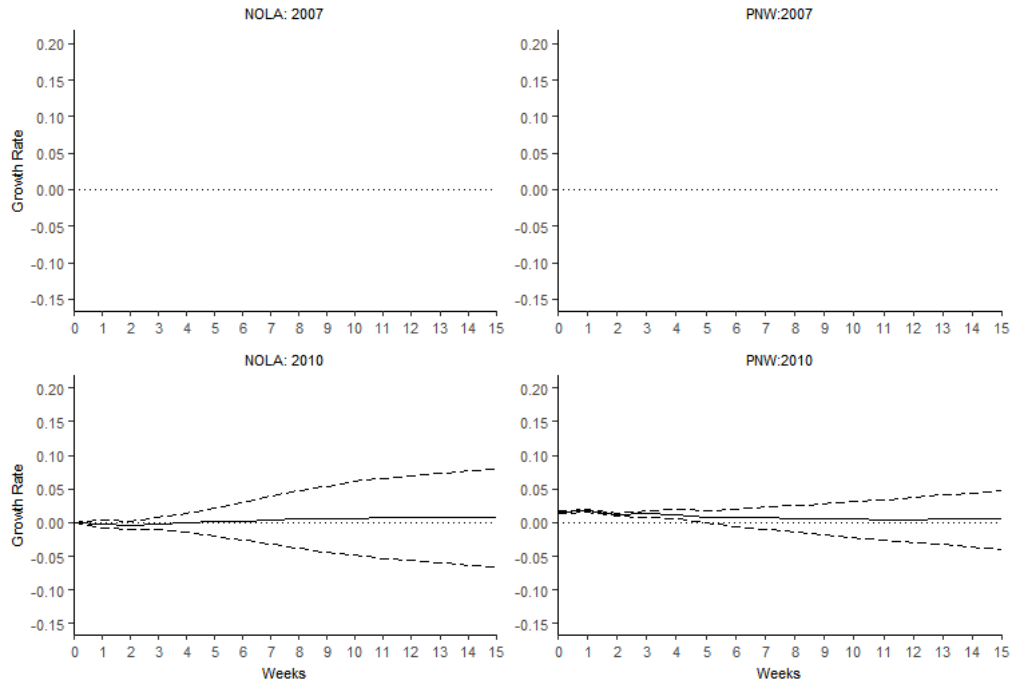


Table 7.12: Estimated Price Elasticities for DAP

Model	Price	Pre-2007	Post-2010
DAP-NGP	New Orleans	0.85485	0.87864
	Northern Great Plains	1.00000	1.00000
	Natural Gas Futures	0.04220	0.03438
	Corn Futures	0.03567	0.01646
DAP-SGP	New Orleans	0.91608	0.88195
	Southern Great Plains	1.00000	1.00000
	Natural Gas Futures	0.01991	0.01419
	Corn Futures	-0.02052	0.01415
DAP-GL	New Orleans	0.80975	0.96696
	Great Lakes	1.00000	1.00000
	Natural Gas Futures	0.06181	0.02638
	Corn Futures	0.06800	-0.02596

Note: The price elasticities are calculated by multiplying each β by (-1).

Table 7.13: Speed of Adjustment Parameters for DAP

	Price	Pre-2007	Post-2010
DAP-NGP	New Orleans	0.02502	0.13720**
	Northern Great Plains	-0.09210***	-0.22318***
	Natural Gas Futures	0.06074	0.09181
	Corn Futures	0.10063*	-0.07922
DAP-SGP	New Orleans	0.02962	-0.03337
	Southern Great Plains	-0.14079***	-0.25887***
	Natural Gas Futures	0.08647	0.12179
	Corn Futures	0.10005*	-0.01897
DAP-GL	New Orleans	0.01848	0.08002*
	Great Lakes	-0.07520***	-0.12899***
	Natural Gas Futures	0.09347	0.20212**
	Corn Futures	0.10421**	-0.05030

Note: Statistical Significance is determine with the Johansen Weak Exogeneity Test, where the null is $\alpha = 0$ and the alternative hypothesis is $\alpha \neq 0$. *, **, *** indicates significance at the 10%, 5%, and 1% levels, respectfully.

Table 7.14: Granger Causality Results for DAP in Pre-2007 Period

Model	Test	Chi-Square	Pr>ChiSq
DAP-NGP	NGP $\rightarrow$ NOLA	11.53**	0.0419
	NOLA $\rightarrow$ NGP	84.32***	<.0001
	NGP $\rightarrow$ Corn	10.86*	0.0542
	Corn $\rightarrow$ NGP	5.36	0.3732
	NOLA $\rightarrow$ Corn	18.42***	0.0025
	Corn $\rightarrow$ NOLA	4.23	0.5173
	NGP $\rightarrow$ NG	2.21	0.8187
	NG $\rightarrow$ NGP	8.19	0.1460
	NOLA $\rightarrow$ NG	6.56	0.2557
	NG $\rightarrow$ NOLA	7.92	0.1609
DAP-SGP	SGP $\rightarrow$ NOLA	5.88	0.3179
	NOLA $\rightarrow$ SGP	105.21***	<.0001
	SGP $\rightarrow$ Corn	14.65**	0.0119
	Corn $\rightarrow$ SGP	0.81	0.9762
	NOLA $\rightarrow$ Corn	18.42***	0.0025
	Corn $\rightarrow$ NOLA	4.23	0.5173
	SGP $\rightarrow$ NG	2.21	0.8187
	NG $\rightarrow$ SGP	8.19	0.1460
	NOLA $\rightarrow$ NG	3.52	0.6199
	NG $\rightarrow$ NOLA	8.41	0.1349
DAP-GL	GL $\rightarrow$ NOLA	5.39	0.3706
	NOLA $\rightarrow$ GL	68.82***	<.0001
	GL $\rightarrow$ Corn	9.45*	0.0925
	Corn $\rightarrow$ GL	9.82*	0.0806
	NOLA $\rightarrow$ Corn	18.42***	0.0025
	Corn $\rightarrow$ NOLA	4.23	0.5173
	GL $\rightarrow$ NG	2.21	0.8187
	NG $\rightarrow$ GL	8.19	0.1460
	NOLA $\rightarrow$ NG	22.25***	0.0005
	NG $\rightarrow$ NOLA	5.36	0.3741

Note: The notation $X \rightarrow Y$ means X granger causes Y. The null hypothesis of the Granger Causality test is X does not granger cause Y. The alternative hypothesis is that X does granger causes Y. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectfully.

Table 7.15: Granger Causality Results for DAP in Post-2010 Period

Model	Test	Chi-Square	Pr>ChiSq
DAP-NGP	NGP $\rightarrow$ NOLA	9.07*	0.1061
	NOLA $\rightarrow$ NGP	109.50***	<.0001
	NGP $\rightarrow$ Corn	13.58**	0.0185
	Corn $\rightarrow$ NGP	15.39***	0.0088
	NOLA $\rightarrow$ Corn	12.02**	0.0346
	Corn $\rightarrow$ NOLA	12.50**	0.0285
	NGP $\rightarrow$ NG	4.48	0.4821
	NG $\rightarrow$ NGP	2.30	0.8063
	NOLA $\rightarrow$ NG	2.50	0.7760
	NG $\rightarrow$ NOLA	5.01	0.4146
DAP-SGP	SGP $\rightarrow$ NOLA	4.57	0.4709
	NOLA $\rightarrow$ SGP	94.17***	<.0001
	SGP $\rightarrow$ Corn	13.47**	0.0193
	Corn $\rightarrow$ SGP	10.43*	0.0640
	NOLA $\rightarrow$ Corn	12.02**	0.0346
	Corn $\rightarrow$ NOLA	12.50**	0.0285
	SGP $\rightarrow$ NG	4.48	0.4821
	NG $\rightarrow$ SGP	2.30	0.8063
	NOLA $\rightarrow$ NG	4.91	0.4272
	NG $\rightarrow$ NOLA	5.69	0.3375
DAP-GL	GL $\rightarrow$ NOLA	73.79***	<.0001
	NOLA $\rightarrow$ GL	19.80***	0.0014
	GL $\rightarrow$ Corn	9.24*	0.0997
	Corn $\rightarrow$ GL	12.02**	0.0346
	NOLA $\rightarrow$ Corn	12.50**	0.0285
	Corn $\rightarrow$ NOLA	4.48	0.4821
	GL $\rightarrow$ NG	2.30	0.8063
	NG $\rightarrow$ GL	7.49	0.1865
	NOLA $\rightarrow$ NG	1.92	0.8596
	NG $\rightarrow$ NOLA	73.79***	<.0001

Note: The notation $X \rightarrow Y$ means X granger causes Y. The null hypothesis of the Granger Causality test is X does not granger cause Y. The alternative hypothesis is that X does granger causes Y. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectfully.

Figure 7.9: Response to Orthogonalized Impulse in NOLA's Price in DAP-NGP Model

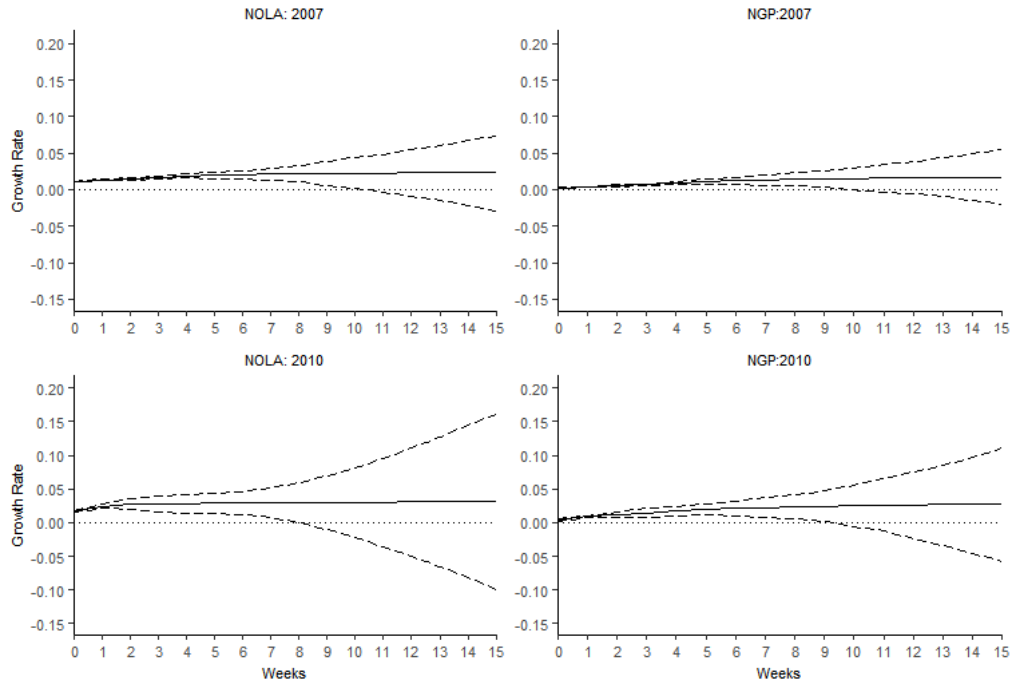


Figure 7.10: Response to Orthogonalized Impulse in NGP's Price in DAP-NGP Model

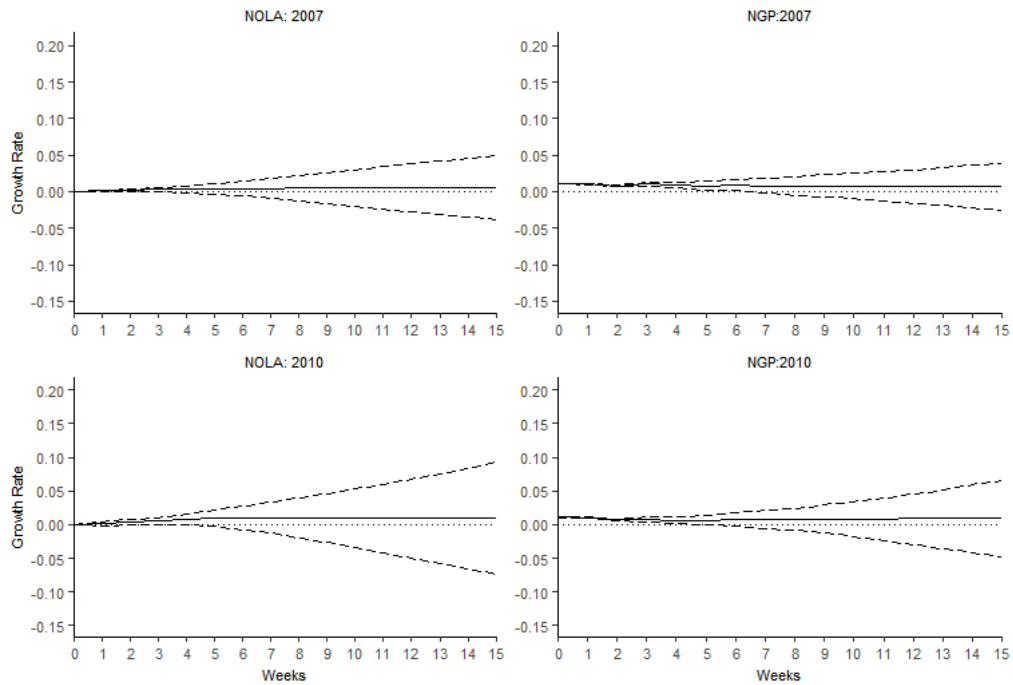


Figure 7.11: Response to Orthogonalized Impulse in NOLA's Price in DAP-SGP Model

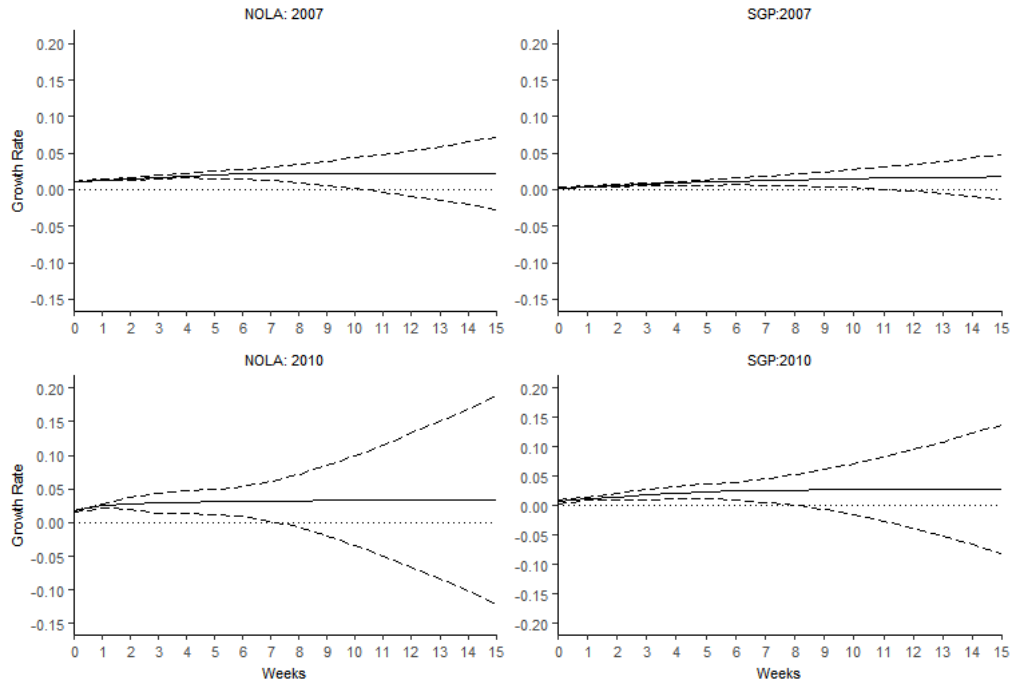


Figure 7.12: Response to Orthogonalized Impulse in SGP's Price in DAP-SGP Model

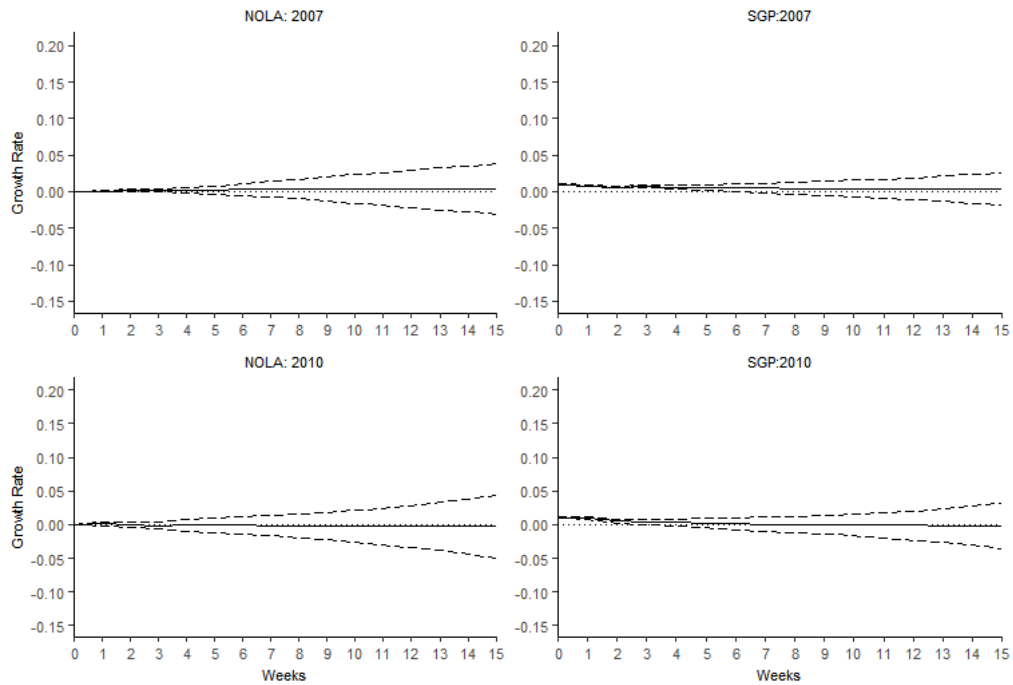


Figure 7.13: Response to Orthogonalized Impulse in NOLA's Price in DAP-GL Model

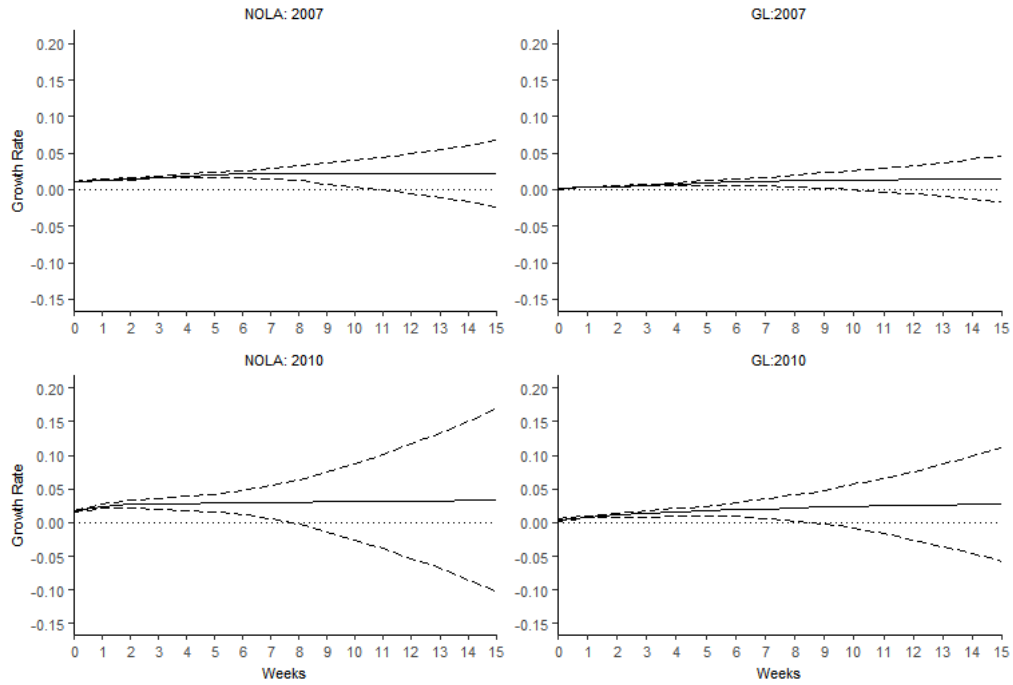


Figure 7.14: Response to Orthogonalized Impulse in GL's Price in DAP-GL Model

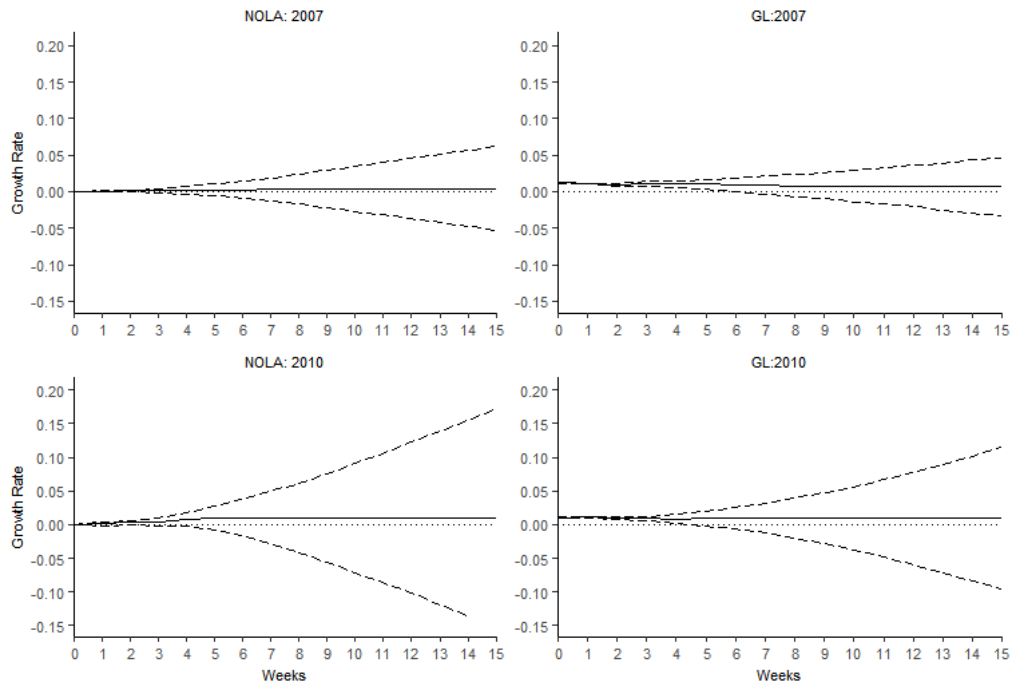


Table 7.16: Estimated Price Elasticities for UAN

Model	Price	Pre-2007	Post-2010
UAN-NGP	New Orleans	-	0.93573
	Northern Great Plains	-	1.00000
	Natural Gas Futures	-	-0.06939
	Corn Futures	-	-0.07771
UAN-SGP	New Orleans	-	1.01213
	Southern Great Plains	-	1.00000
	Natural Gas Futures	-	-0.07110
	Corn Futures	-	-0.05993
UAN-GL	New Orleans	-	0.85521
	Great Lakes	-	1.00000
	Natural Gas Futures	-	-0.08124
	Corn Futures	-	-0.00204

Note: The price elasticities are calculated by multiplying each β by (-1).

Table 7.17: Speed of Adjustment Parameters for UAN

	Price	Pre-2007	Post-2010
UAN-NGP	New Orleans	-	0.18671***
	Northern Great Plains	-	-0.19164***
	Natural Gas Futures	-	-0.10795
	Corn Futures	-	-0.06833
UAN-SGP	New Orleans	-	0.15978***
	Southern Great Plains	-	-0.09712***
	Natural Gas Futures	-	-0.01984
	Corn Futures	-	0.09351* *
UAN-GL	New Orleans	-	0.06006
	Great Lakes	-	-0.31939***
	Natural Gas Futures	-	0.03200
	Corn Futures	-	0.04272

Note: Statistical Significance is determine with the Johansen Weak Exogeneity Test, where the null is $\alpha = 0$ and the alternative hypothesis is $\alpha \neq 0$. *, **, *** indicates significance at the 10%, 5%, and 1% levels, respectfully.

Table 7.18: Granger Causality Results for UAN in Post-2010 Period

Model	Test	Chi-Square	Pr>ChiSq
UAN-NGP	NGP $\rightarrow$ NOLA	3.07	0.5456
	NOLA $\rightarrow$ NGP	94.26***	<.0001
	NGP $\rightarrow$ Corn	3.28	0.5125
	Corn $\rightarrow$ NGP	19.79***	0.0005
	NOLA $\rightarrow$ Corn	3.02	0.5552
	Corn $\rightarrow$ NOLA	25.98***	<.0001
	NGP $\rightarrow$ NG	3.15	0.5325
	NG $\rightarrow$ NGP	0.69	0.9523
	NOLA $\rightarrow$ NG	1.20	0.8780
	NG $\rightarrow$ NOLA	1.00	0.9092
UAN-SGP	SGP $\rightarrow$ NOLA	12.74**	0.0126
	NOLA $\rightarrow$ SGP	85.54***	<.0001
	SGP $\rightarrow$ Corn	0.42	0.9811
	Corn $\rightarrow$ SGP	25.81***	<.0001
	NOLA $\rightarrow$ Corn	3.02	0.5552
	Corn $\rightarrow$ NOLA	25.98***	<.0001
	SGP $\rightarrow$ NG	3.15	0.5325
	NG $\rightarrow$ SGP	0.69	0.9523
	NOLA $\rightarrow$ NG	4.54	0.3384
	NG $\rightarrow$ NOLA	0.32	0.9882
UAN-GL	GL $\rightarrow$ NOLA	1.05	0.5903
	NOLA $\rightarrow$ GL	126.01***	<.0001
	GL $\rightarrow$ Corn	0.33	0.8488
	Corn $\rightarrow$ GL	13.55***	0.0011
	NOLA $\rightarrow$ Corn	0.22	0.8945
	Corn $\rightarrow$ NOLA	17.37***	0.0002
	GL $\rightarrow$ NG	0.88	0.6451
	NG $\rightarrow$ GL	0.12	0.9422
	NOLA $\rightarrow$ NG	1.41	0.4952
	NG $\rightarrow$ NOLA	1.10	0.5765

Note: The notation $X \rightarrow Y$ means X granger causes Y. The null hypothesis of the Granger Causality test is X does not granger cause Y. The alternative hypothesis is that X does granger causes Y. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectfully.

Figure 7.15: Response to Orthogonalized Impulse in NOLA's Price in UAN-NGP Model

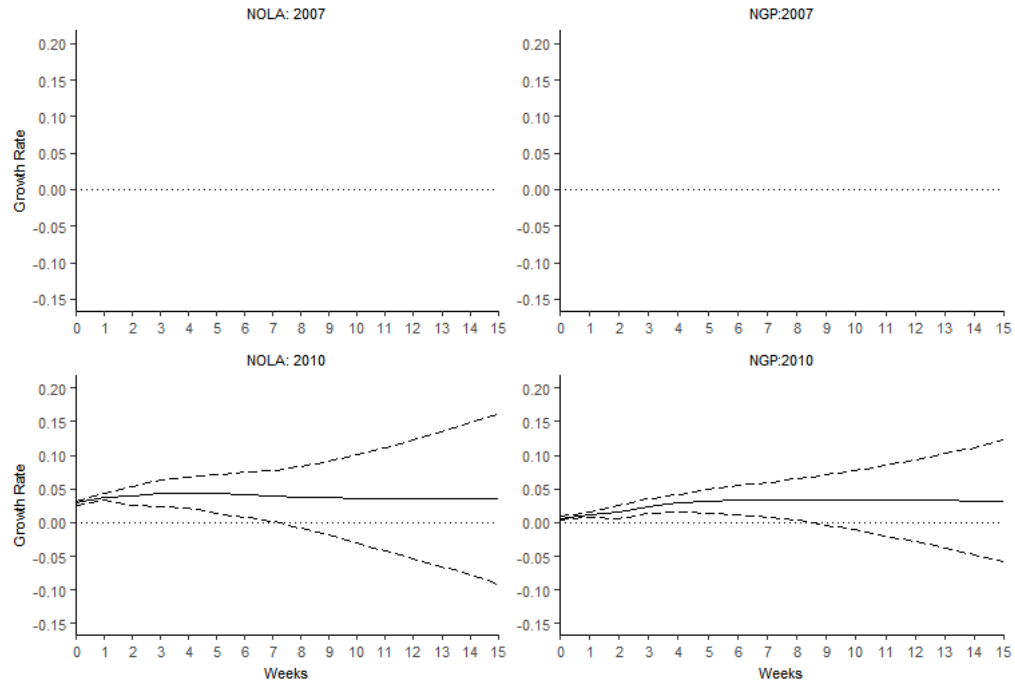


Figure 7.16: Response to Orthogonalized Impulse in NGP's Price in UAN-NGP Model

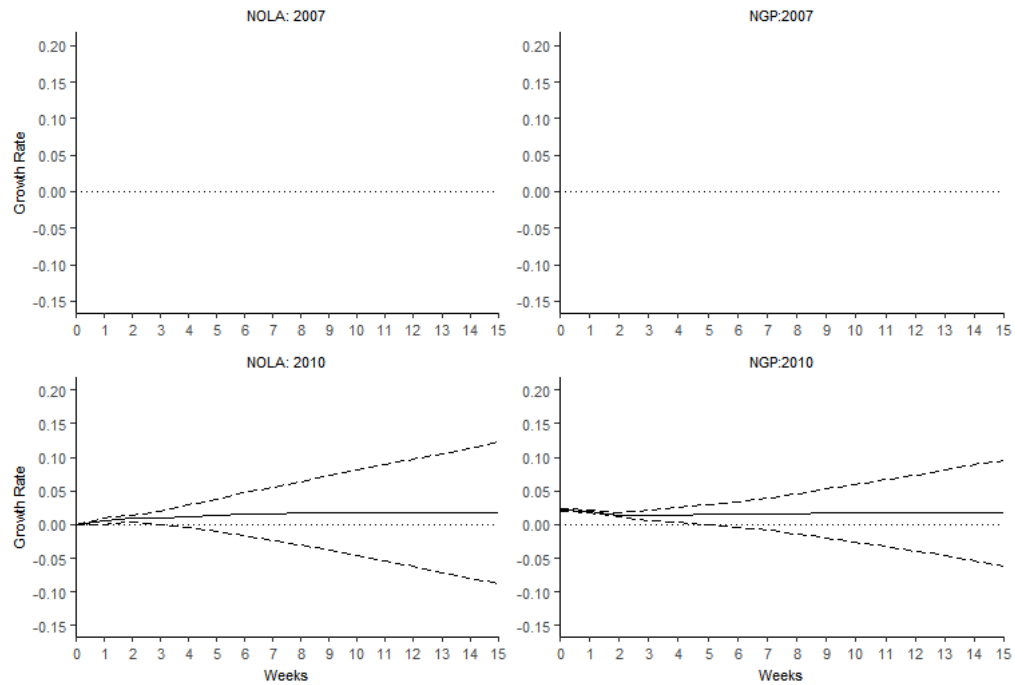


Figure 7.17: Response to Orthogonalized Impulse in NOLA's Price in UAN-SGP Model

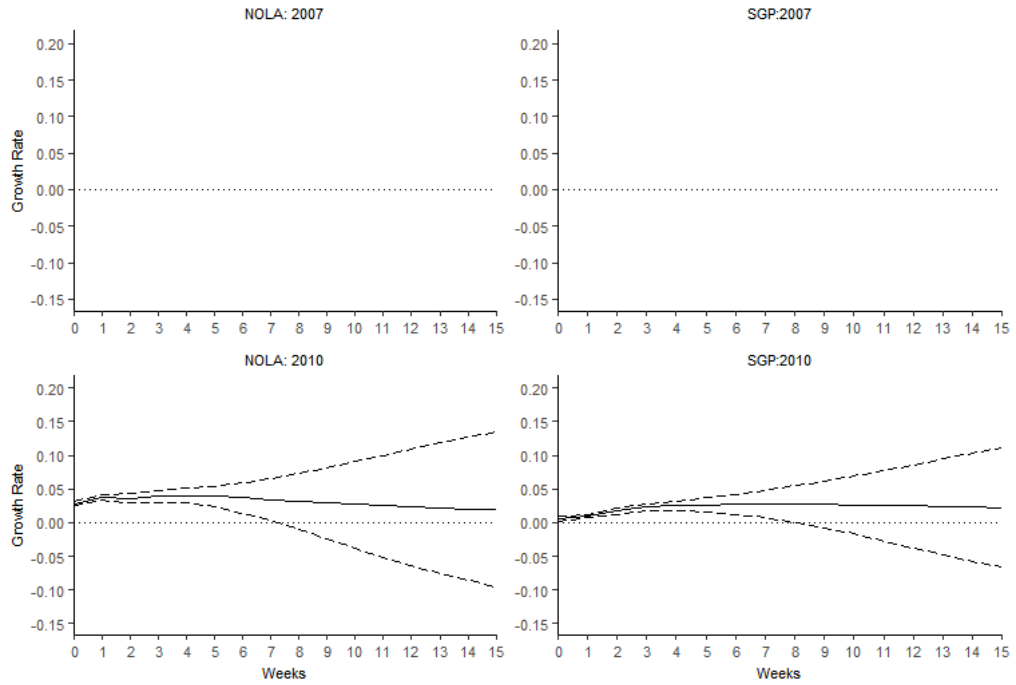


Figure 7.18: Response to Orthogonalized Impulse in SGP's Price in UAN-SGP Model

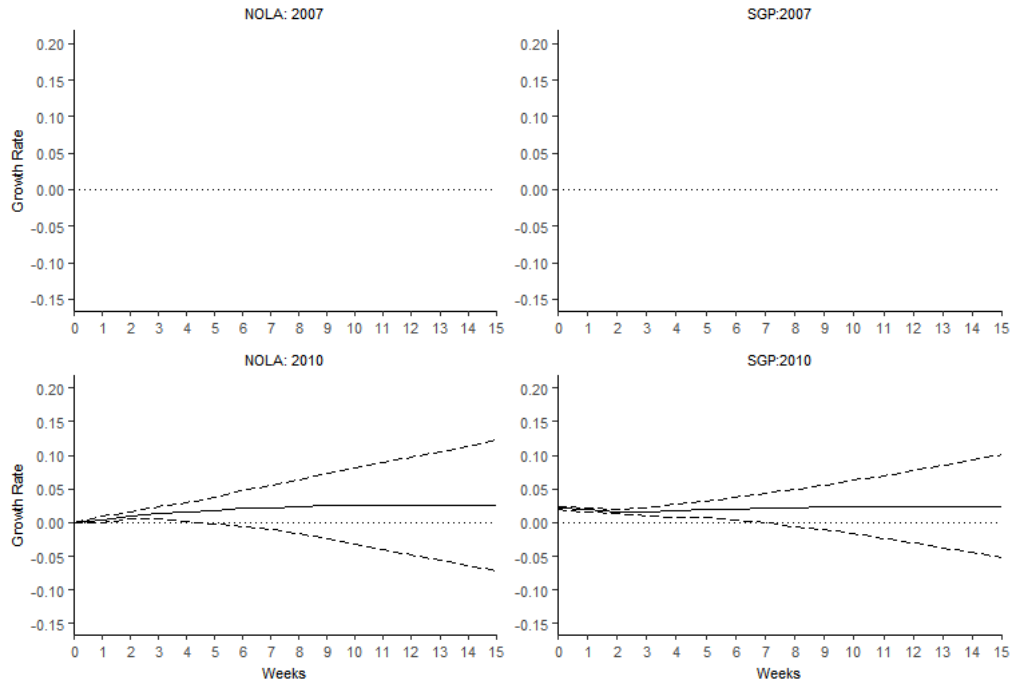


Figure 7.19: Response to Orthogonalized Impulse in NOLA's Price in UAN-GL Model

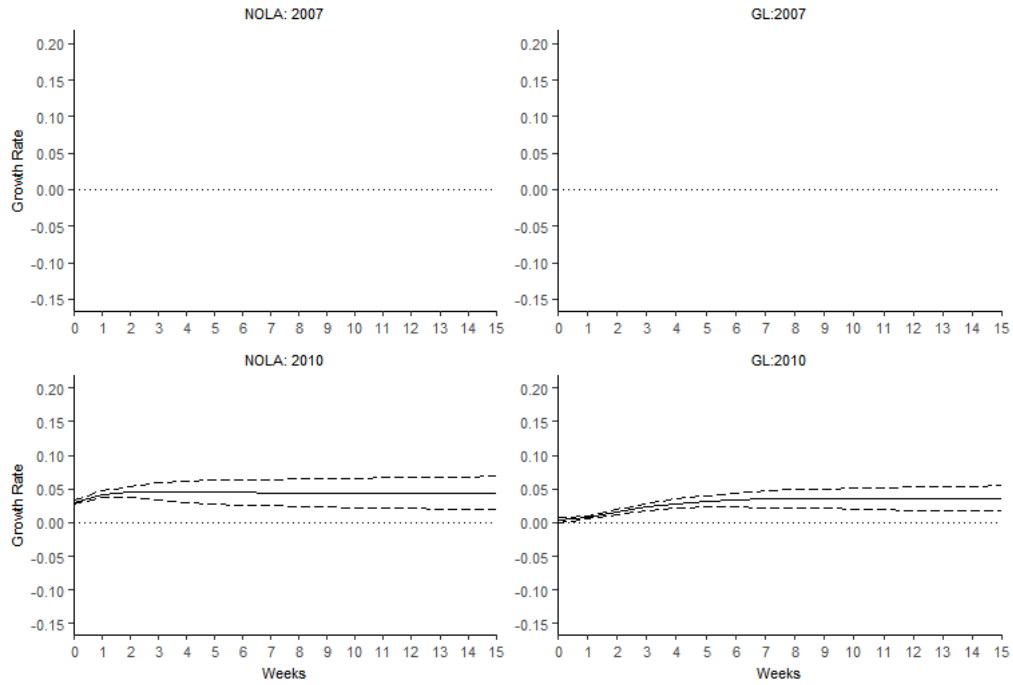


Figure 7.20: Response to Orthogonalized Impulse in GL's Price in UAN-GL Model

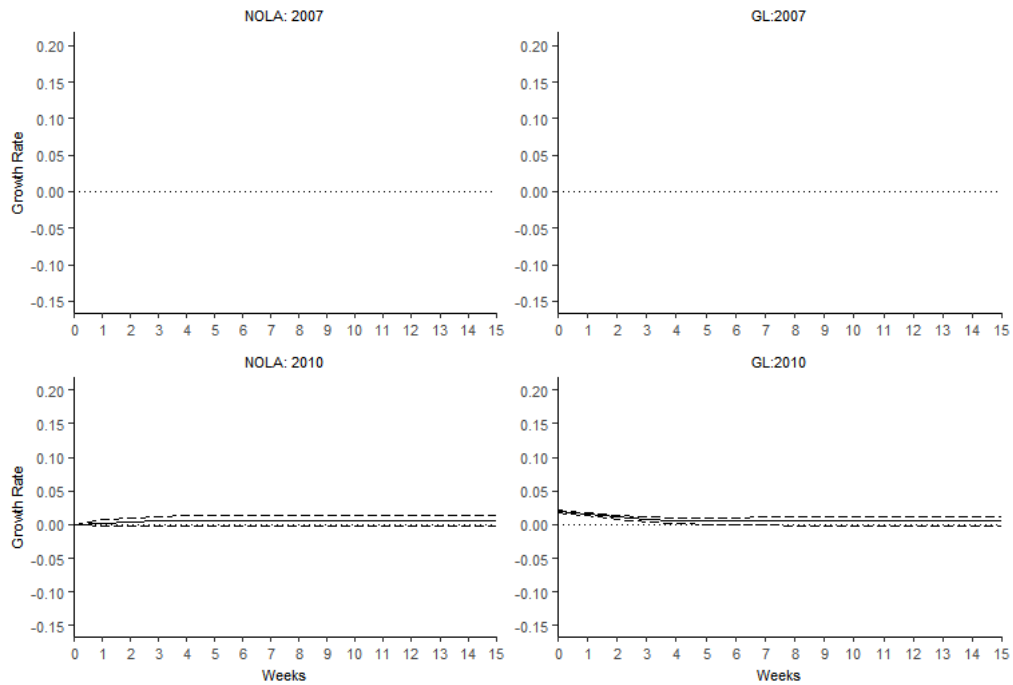


Table 7.19 : Estimated Price Elasticities for MAP

Model	Price	Pre-2007	Post-2010
MAP-SGP	New Orleans	-	0.96696
	Southern Great Plains	-	1.00000
	Natural Gas Futures	-	0.02638
	Corn Futures	-	-0.02596
MAP-GL	New Orleans	-	0.88820
	Great Lakes	-	1.00000
	Natural Gas Futures	-	0.01325
	Corn Futures	-	-0.01178

Note: The price elasticities are calculated by multiplying each β by (-1).

Table 7.20: Speed of Adjustment Parameters for MAP

	Price	Pre-2007	Post-2010
MAP-SGP	New Orleans	-	0.08574*
	Southern Great Plains	-	-0.12330***
	Natural Gas Futures	-	0.23485**
	Corn Futures	-	-0.16540*
MAP-GL	New Orleans	-	0.07496*
	Great Lakes	-	-0.12404***
	Natural Gas Futures	-	0.09326
	Corn Futures	-	-0.05915

Note: Statistical Significance is determine with the Johansen Weak Exogeneity Test, where the null is $\alpha = 0$ and the alternative hypothesis is $\alpha \neq 0$. *, **, *** indicates significance at the 10%, 5%, and 1% levels, respectfully.

Table 7.21: Granger Causality Results for MAP in Post-2010 Period

Model	Test	Chi-Square	Pr>ChiSq
MAP-SGP	SGP $\rightarrow$ NOLA	15.74***	0.0034
	NOLA $\rightarrow$ SGP	90.96***	<.0001
	SGP $\rightarrow$ Corn	9.20*	0.0563
	Corn $\rightarrow$ SGP	7.48	0.1125
	NOLA $\rightarrow$ Corn	9.57**	0.0482
	Corn $\rightarrow$ NOLA	7.63*	0.1060
	SGP $\rightarrow$ NG	5.90	0.2070
	NG $\rightarrow$ SGP	1.94	0.7474
	NOLA $\rightarrow$ NG	6.16	0.1872
	NG $\rightarrow$ NOLA	3.81	0.4330
MAP-GL	GL $\rightarrow$ NOLA	4.89	0.1802
	NOLA $\rightarrow$ GL	72.22***	<.0001
	GL $\rightarrow$ Corn	14.55***	0.0022
	Corn $\rightarrow$ GL	2.78	0.4263
	NOLA $\rightarrow$ Corn	8.70**	0.0336
	Corn $\rightarrow$ NOLA	7.30*	0.0628
	GL $\rightarrow$ NG	1.77	0.6225
	NG $\rightarrow$ GL	1.53	0.6763
	NOLA $\rightarrow$ NG	2.25	0.5228
	NG $\rightarrow$ NOLA	4.93	0.1772

Note: The notation $X \rightarrow Y$ means X granger causes Y. The null hypothesis of the Granger Causality test is X does not granger cause Y. The alternative hypothesis is that X does granger causes Y. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectfully.

Table 7.22: Magnitudes of Orthogonalized Impulses

Price	Region	Pre-2007	Post-2010
Urea	NOLA	0.328625	0.208776
	NGP	0.286759	0.191086
	SGP	0.282753	0.192752
	GL	0.293079	0.175208
	PNW	-	0.13154
DAP	NOLA	0.160863	0.135488
	NGP	0.146484	0.120578
	SGP	0.146119	0.122621
	GL	0.14592	0.118952
UAN	NOLA	-	0.188461
	NGP	-	0.153979
	SGP	-	0.156312
	GL	-	0.155368
MAP	NOLA	-	0.135828
	NGP	-	0.117896
	SGP	-	0.122781
	GL	-	0.113828
Natural Gas		0.548432	0.218488
Corn		0.176449	0.265776

Note: These magnitudes of the orthogonalized impulse are equivalent to one standard deviation of the respective price.

Figure 7.21: Response to Orthogonalized Impulse in NOLA's Price in MAP-SGP Model

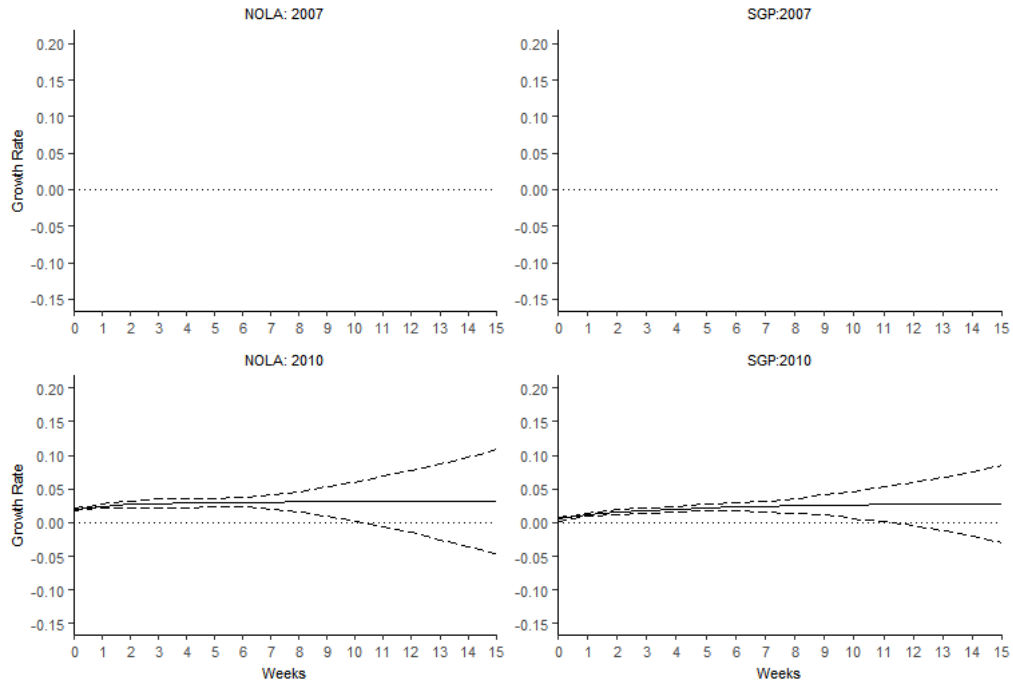


Figure 7.22: Response to Orthogonalized Impulse in SGP's Price in MAP-SGP Model

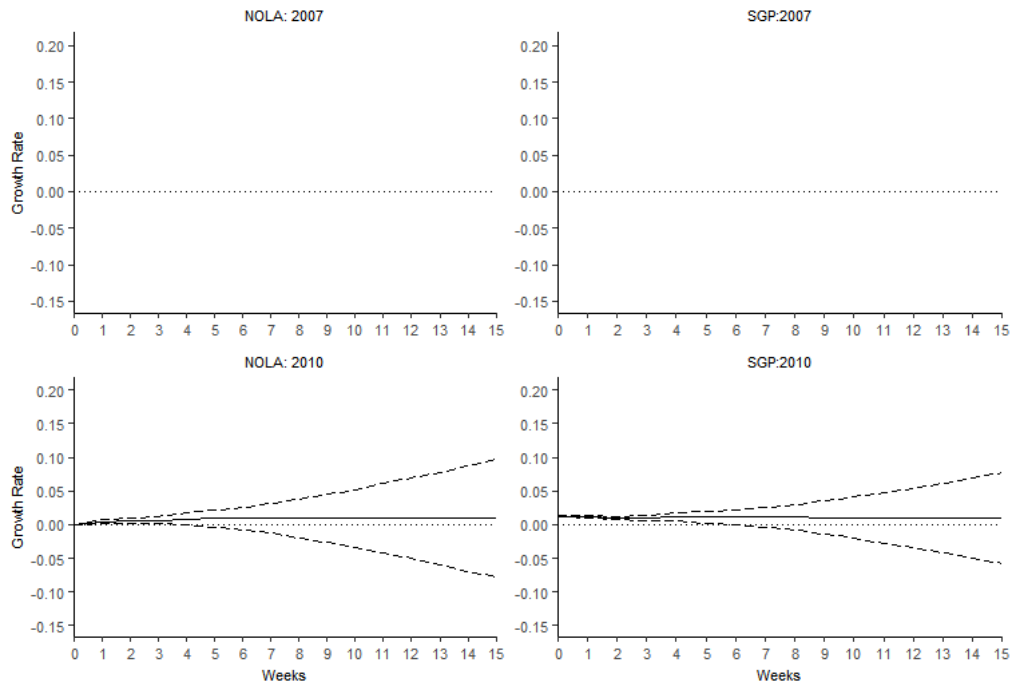


Figure 7.23: Response to Orthogonalized Impulse in NOLA's Price in MAP-GL Model

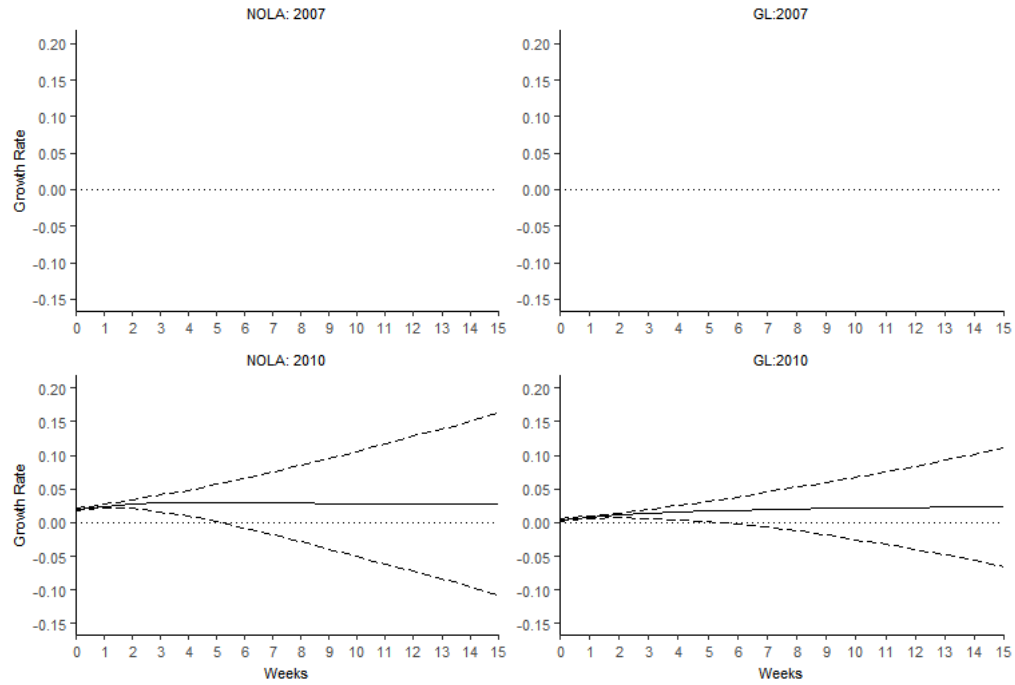
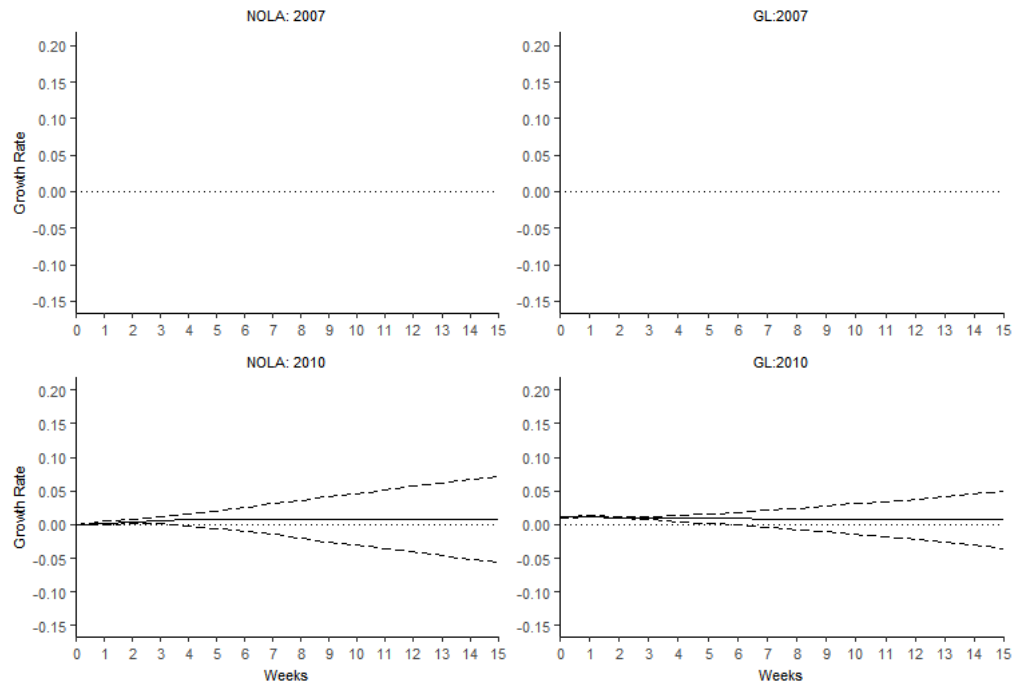


Figure 7.24: Response to Orthogonalized Impulse in GL's Price in MAP-GL Model



CONCLUSION

The objective of this study was to determine the price dynamics in the U.S. nitrogen fertilizer industry, measure information flow efficiency in spatially separated fertilizer markets, and understand to what extent structural changes due to policy and technology innovation in the late 2010s may have altered these price dynamics and information flow relationships. Information collected from industry interviews and econometric evidence indicated that New Orleans is the central market for nitrogen fertilizer in the United States and that shocks originating at NOLA are propagated to inland locations. Inland regions, where fertilizer is received from NOLA and then distributed to retail locations for sale to farm businesses, respond to these shocks and adjust to maintain a long-run relationship with the central NOLA market. Impulse response analysis is particularly useful in visualizing how market shocks in NOLA are associated with inland regional prices rising or falling to restore the long-run equilibrium between the two prices. However, shocks to fertilizer prices in inland regions do not illicit the same response in NOLA, but instead dissipate over time.

There is no clear pattern between spatial markets. One might expect that fertilizer prices in regions that are closer to NOLA, such as the Southern Great Plains, would react more quickly to shocks in the system. This is not the case. This may be because of formula-based pricing. A fertilizer wholesaler in Southeast Montana mentioned that Canadian producers look to New Orleans to price their fertilizer. If this is the case, and more northern regions source some of their fertilizer from Canada, then price shocks might not take longer to reach a region like the NGP.

There was a clear pattern between the two-subsamples. In the post-2010 period, there seems to be a more efficient flow of information in the nitrogen industry. For the most part, there was faster adjustments made to restore the equilibrium relationships after a shock in the post-2010 period. The reason for this is mostly likely related to introduction of renewable fuel standards in the United States, which changed the agricultural production markets so that more farms and farmland across the country produced corn, one of the largest consumers of nitrogen. This changed the underlying price discovery process of nitrogen fertilizer, where demand-side drivers had a greater influence in the post-2010 period. This change most likely resulted in a greater efficiency of price information transmission in nitrogen markets.

Granger causality results and weak exogeneity tests show that corn seems to have a greater effect on the price discovery of fertilizer in the post-2010 period. Although, according to the impulse response analysis, there is a low amount of information being transmitted from the corn market to the nitrogen market. Natural gas is exogenous in both periods, which is not surprising. Nitrogen fertilizer only makes up a small percentage of the demand for natural gas. There is some evidence that natural gas had a greater affect in the pre-2007 period on the price discovery process, especially for urea, but like corn, the actual magnitude of information transmission is low.

The main weakness of this study is that transactions costs are not accounted for, which could affect the inferences of the estimates used to measure the price dynamics between regional fertilizer markets. This is because accurately accounting for transaction costs is difficult and the data is not available. While Mississippi River levels were

included in the model, this variable does not control for the demand side drivers of the transportation market. Future studies might estimate threshold models, another econometric technique used to estimate transactions costs.

Any future work should also take into account that the entire price discovery process of this industry might change due increased production in inland regions. New fertilizer plants, that started producing in 2017, could disrupt the historic flow of information from New Orleans to inland regions. This study shows that New Orleans is the central market where price information is transmitted around the United States. Large nitrogen plants in inland regions could disrupt long-term relationships between New Orleans and inland regions. Inland regions that contain the plants might influence the price at New Orleans, and at some point may possibly become the central, leading market in the U.S. nitrogen fertilizer industry.

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APPENDICES

APPENDIX A

AUGMENTED DICKEY FULLER TEST RESULTS

Table A1: ADF Test Results for Level Urea Prices in the Pre-2007 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
NOLA	3	Zero Mean	0.22	0.7510	Non-stationary
		Single Mean	-1.66	0.4521	Non-stationary
		Trend	-2.27	0.4510	Non-stationary
NGP	4	Zero Mean	0.34	0.7835	Non-stationary
		Single Mean	-1.37	0.601	Non-stationary
		Trend	-2.12	0.5315	Non-stationary
SGP	4	Zero Mean	0.29	0.7704	Non-stationary
		Single Mean	-1.60	0.4828	Non-stationary
		Trend	-2.32	0.4213	Non-stationary
GL	2	Zero Mean	0.44	0.8091	Non-stationary
		Single Mean	-0.91	0.7866	Non-stationary
		Trend	-1.60	0.7916	Non-stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A2: ADF Test Results for Differenced Urea Prices in the Pre-2007 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
NOLA	2	Zero Mean	-9.18	<.0001	Stationary
		Single Mean	-9.18	<.0001	Stationary
		Trend	-9.27	<.0001	Stationary
NGP	3	Zero Mean	-9.18	<.0001	Stationary
		Single Mean	-9.18	<.0001	Stationary
		Trend	-9.27	<.0001	Stationary
SGP	3	Zero Mean	-8.61	<.0001	Stationary
		Single Mean	-8.61	<.0001	Stationary
		Trend	-8.69	<.0001	Stationary
GL	1	Zero Mean	-14.84	<.0001	Stationary
		Single Mean	-14.84	<.0001	Stationary
		Trend	-14.91	<.0001	Stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A3: ADF Test Results for Level Urea Prices in the Post-2010 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
NOLA	3	Zero Mean	-0.32	0.5709	Non-stationary
		Single Mean	-2.47	0.1231	Non-stationary
		Trend	-2.68	0.2465	Non-stationary
NGP	4	Zero Mean	-0.31	0.5744	Non-stationary
		Single Mean	-2.31	0.1698	Non-stationary
		Trend	-2.42	0.3684	Non-stationary
SGP	4	Zero Mean	-0.22	0.6085	Non-stationary
		Single Mean	-2.48	0.1216	Non-stationary
		Trend	-2.54	0.3100	Non-stationary
GL	3	Zero Mean	-0.27	0.5884	Non-stationary
		Single Mean	-2.12	0.2347	Non-stationary
		Trend	-2.27	0.4482	Non-stationary
PNW	4	Zero Mean	-0.99	0.2851	Non-stationary
		Single Mean	-1.87	0.3443	Non-stationary
		Trend	-2.74	0.2238	Non-stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A4: ADF Test Results for Differenced Urea Prices in the Post-2010 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
NOLA	2	Zero Mean	-6.99	<.0001	Stationary
		Single Mean	-6.98	<.0001	Stationary
		Trend	-7.02	<.0001	Stationary
NGP	3	Zero Mean	-6.09	<.0001	Stationary
		Single Mean	-6.09	<.0001	Stationary
		Trend	-6.14	<.0001	Stationary
SGP	1	Zero Mean	-9.10	<.0001	Stationary
		Single Mean	-9.09	<.0001	Stationary
		Trend	-9.13	<.0001	Stationary
GL	2	Zero Mean	-7.39	<.0001	Stationary
		Single Mean	-7.38	<.0001	Stationary
		Trend	-7.46	<.0001	Stationary
PNW	3	Zero Mean	-4.60	<.0001	Stationary
		Single Mean	-4.70	0.0002	Stationary
		Trend	-4.69	0.0011	Stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A5: ADF Test Results for Level DAP Prices in the Pre-2007 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
NOLA	4	Zero Mean	0.33	0.7813	Non-stationary
		Single Mean	-1.51	0.5310	Non-stationary
		Trend	-1.73	0.7397	Non-stationary
NGP	6	Zero Mean	0.38	0.7935	Non-stationary
		Single Mean	-1.18	0.6837	Non-stationary
		Trend	-1.63	0.7804	Non-stationary
SGP	4	Zero Mean	0.41	0.8000	Non-stationary
		Single Mean	-1.11	0.7132	Non-stationary
		Trend	-1.44	0.8476	Non-stationary
GL	12	Zero Mean	0.55	0.8343	Non-stationary
		Single Mean	-0.75	0.8314	Non-stationary
		Trend	-1.24	0.9007	Non-stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A6: ADF Test Results for Differenced DAP Prices in the Pre-2007 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
NOLA	6	Zero Mean	-7.47	<.0001	Stationary
		Single Mean	-7.47	<.0001	Stationary
		Trend	-7.56	<.0001	Stationary
NGP	3	Zero Mean	-9.36	<.0001	Stationary
		Single Mean	-9.39	<.0001	Stationary
		Trend	-9.40	<.0001	Stationary
SGP	3	Zero Mean	-9.54	<.0001	Stationary
		Single Mean	-9.54	<.0001	Stationary
		Trend	-9.59	<.0001	Stationary
GL	11	Zero Mean	-7.60	<.0001	Stationary
		Single Mean	-7.61	<.0001	Stationary
		Trend	-7.73	<.0001	Stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A7: ADF Test Results for Level DAP Prices in the Post-2010 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
NOLA	2	Zero Mean	-0.06	0.6639	Non-stationary
		Single Mean	-2.39	0.1449	Non-stationary
		Trend	-2.97	0.1418	Non-stationary
NGP	4	Zero Mean	-0.01	0.6784	Non-stationary
		Single Mean	-2.14	0.2277	Non-stationary
		Trend	-2.81	0.1960	Non-stationary
SGP	4	Zero Mean	-0.10	0.6496	Non-stationary
		Single Mean	-2.34	0.1589	Non-stationary
		Trend	-2.84	0.1840	Non-stationary
GL	2	Zero Mean	-0.01	0.6789	Non-stationary
		Single Mean	-2.28	0.1796	Non-stationary
		Trend	-2.95	0.1491	Non-stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A8: ADF Test Results for Differenced DAP Prices in the Post-2010 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
NOLA	1	Zero Mean	-9.73	<.0001	Stationary
		Single Mean	-9.70	<.0001	Stationary
		Trend	-9.68	<.0001	Stationary
NGP	3	Zero Mean	-7.10	<.0001	Stationary
		Single Mean	-7.08	<.0001	Stationary
		Trend	-7.11	<.0001	Stationary
SGP	3	Zero Mean	-6.37	<.0001	Stationary
		Single Mean	-6.35	<.0001	Stationary
		Trend	-6.36	<.0001	Stationary
GL	1	Zero Mean	-12.11	<.0001	Stationary
		Single Mean	-12.07	<.0001	Stationary
		Trend	-12.07	<.0001	Stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A9: ADF Test Results for Level UAN Prices in the Post-2010 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
NOLA	2	Zero Mean	-0.13	0.6399	Non-stationary
		Single Mean	-2.50	0.1163	Non-stationary
		Trend	-2.63	0.2686	Non-stationary
NGP	2	Zero Mean	0.08	0.7080	Non-stationary
		Single Mean	-2.29	0.1765	Non-stationary
		Trend	-2.08	0.5545	Non-stationary
SGP	1	Zero Mean	-0.05	0.6662	Non-stationary
		Single Mean	-1.75	0.4065	Non-stationary
		Trend	-1.99	0.6041	Non-stationary
GL	2	Zero Mean	0.04	0.6963	Non-stationary
		Single Mean	-2.31	0.1696	Non-stationary
		Trend	-2.34	0.413	Non-stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A10: ADF Test Results for Differenced UAN Prices in the Post-2010 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
NOLA	1	Zero Mean	-9.60	<.0001	Stationary
		Single Mean	-9.58	<.0001	Stationary
		Trend	-9.70	<.0001	Stationary
NGP	1	Zero Mean	-11.25	<.0001	Stationary
		Single Mean	-11.23	<.0001	Stationary
		Trend	-11.40	<.0001	Stationary
SGP	1	Zero Mean	-11.17	<.0001	Stationary
		Single Mean	-11.15	<.0001	Stationary
		Trend	-11.33	<.0001	Stationary
GL	1	Zero Mean	-9.80	<.0001	Stationary
		Single Mean	-9.79	<.0001	Stationary
		Trend	-9.93	<.0001	Stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A11: ADF Test Results for Levels MAP Prices in the Post-2010 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
NOLA	2	Zero Mean	-0.03	0.6732	Non-stationary
		Single Mean	-2.19	0.2114	Non-stationary
		Trend	-2.78	0.2073	Non-stationary
NGP	2	Zero Mean	0.05	0.6993	Non-stationary
		Single Mean	-1.81	0.3735	Non-stationary
		Trend	-2.41	0.3713	Non-stationary
SGP	4	Zero Mean	-0.05	0.6654	Non-stationary
		Single Mean	-2.26	0.1865	Non-stationary
		Trend	-2.81	0.1947	Non-stationary
GL	2	Zero Mean	0.15	0.7280	Non-stationary
		Single Mean	-1.76	0.3997	Non-stationary
		Trend	-2.45	0.3541	Non-stationary
	4	Zero Mean	-0.64	0.4381	Non-stationary
		Single Mean	-1.94	0.3116	Non-stationary
		Trend	-2.01	0.5896	Non-stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A12: ADF Test Results for Levels MAP Prices in the Post-2010 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
NOLA	1	Zero Mean	-9.88	<.0001	Stationary
		Single Mean	-9.85	<.0001	Stationary
		Trend	-9.84	<.0001	Stationary
NGP	1	Zero Mean	-10.05	<.0001	Stationary
		Single Mean	-10.03	<.0001	Stationary
		Trend	-10.11	<.0001	Stationary
SGP	3	Zero Mean	-5.90	<.0001	Stationary
		Single Mean	-5.88	<.0001	Stationary
		Trend	-5.92	<.0001	Stationary
GL	1	Zero Mean	-9.71	<.0001	Stationary
		Single Mean	-9.70	<.0001	Stationary
		Trend	-9.82	<.0001	Stationary
PNW	2	Zero Mean	-8.08	<.0001	Stationary
		Single Mean	-8.09	<.0001	Stationary
		Trend	-8.06	<.0001	Stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A13: ADF Test Results for Level Non-Fertilizer Data in the Pre-2007 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
Natural Gas	2	Zero Mean	-0.10	0.6501	Non-Stationary
		Single Mean	-2.07	0.2574	Non-Stationary
		Trend	-3.52	0.0382	Stationary
Corn	1	Zero Mean	0.55	0.8341	Non-Stationary
		Single Mean	-1.63	0.4659	Non-Stationary
		Trend	-1.39	0.8625	Non-Stationary
River	1	Zero Mean	-2.32	0.0199	Stationary
		Single Mean	-6.93	<.0001	Stationary
		Trend	-7.16	<.0001	Stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A14: ADF Test Results for Differenced Non-Fertilizer Data in the Pre-2007 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
Natural Gas	1	-16.70	<.0001	Stationary	-16.70
		-16.71	<.0001	Stationary	-16.71
		-16.71	<.0001	Stationary	-16.71
Corn	1	-16.79	<.0001	Stationary	-16.79
		-16.79	<.0001	Stationary	-16.79
		-16.81	<.0001	Stationary	-16.81

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A15: ADF Test Results for Level Non-Fertilizer Data in the Post-2010 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
Natural Gas	2	Zero Mean	-1.25	0.1955	Non-Stationary
		Single Mean	-2.23	0.1972	Non-Stationary
		Trend	-2.32	0.4203	Non-Stationary
Corn	2	Zero Mean	0.03	0.6935	Non-Stationary
		Single Mean	-1.49	0.5381	Non-Stationary
		Trend	-2.17	0.5025	Non-Stationary
River	1	Zero Mean	-1.57	0.1090	Non-Stationary
		Single Mean	-4.04	0.0015	Stationary
		Trend	-4.07	0.0078	Stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

Table A16: ADF Test Results for Differenced Non-Fertilizer Data in the Post-2010 Period

Region	Lags	Type	Tau	Pr < Tau	Interpretation
Natural Gas	1	-16.70	-11.59	<.0001	Non-Stationary
		-16.71	-11.63	<.0001	Non-Stationary
		-16.71	-11.61	<.0001	Non-Stationary
Corn	1	-16.79	-10.67	<.0001	Non-Stationary
		-16.79	-10.65	<.0001	Non-Stationary
		-16.81	-10.73	<.0001	Non-Stationary

Note: The null hypothesis for the ADF test is non-stationary against the alternative hypothesis of stationary.

APPENDIX B

VECM PARAMETER ESTIMATES

Table B1: Short-Run VECM Parameter Estimates for Urea-NGP in the Pre-2007 Period

Lagged Prices	ΔP_t^{NO}		ΔP_t^{NGP}		ΔP_t^{NG}		ΔP_t^{CN}	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NO}	0.46236***	0.04242	0.15733***	0.04452	0.08397	0.13488	0.12044*	0.06740
P_{t-1}^{NGP}	-0.11787***	0.03437	-0.03939	0.03607	-0.15695	0.10929	-0.05365	0.05461
P_{t-1}^{NG}	0.01126	0.01268	-0.00744	0.01331	0.15531***	0.04032	0.00470	0.02015
P_{t-1}^{CN}	0.00065	0.02516	-0.06224**	0.02640	0.05318	0.07999	-0.02598	0.03997
P_{t-2}^{NO}	0.14755***	0.04647	-0.09588**	0.04877	0.04040	0.14775	-0.00871	0.07383
P_{t-2}^{NGP}	0.01161	0.03518	-0.13671***	0.03692	0.03822	0.11187	-0.01644	0.05590
P_{t-2}^{NG}	0.05193***	0.01281	-0.00731	0.01345	-0.05118	0.04074	-0.00799	0.02036
P_{t-2}^{CN}	-0.01755	0.02536	-0.01766	0.02661	0.07999	0.08062	0.04596	0.04029
P_{t-3}^{NO}	-0.01146	0.04518	0.10151**	0.04742	-0.01488	0.14366	-0.04555	0.07178
P_{t-3}^{NGP}	0.00085	0.03422	0.19170***	0.03592	0.16932	0.10881	0.12259**	0.05437
P_{t-3}^{NG}	0.01216	0.01290	0.01859	0.01353	0.08985**	0.04101	-0.01528	0.02049
P_{t-3}^{CN}	-0.02952	0.02534	-0.04052	0.02659	0.00134	0.08056	0.00741	0.04026
Other								
Constant	0.01469	0.01158	0.09940	0.01216	-0.02632	0.03683	-0.00038	0.00016
River	0.00003	0.00010	0.00014	0.00010	-0.00040	0.00031	0.00474**	0.00308
Fall	0.00101	0.00194	0.00572***	0.00204	0.01268**	0.00617	0.00530	0.00398
Spring	-0.00230	0.00251	0.00924***	0.00263	0.00922	0.00797	0.00590	0.00356
Winter	0.00484**	0.00224	0.01011***	0.00235	-0.00183	0.00713	-0.00038*	0.00016

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B2: Short-Run VECM Parameter Estimates for Urea-NGP in the Post-2010 Period

	ΔP_t^{NO}		ΔP_t^{NGP}		ΔP_t^{NG}		ΔP_t^{CN}	
Lagged Prices	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NO}	0.33276***	0.07191	0.30107***	0.05213	-0.07543	0.09597	-0.08507	0.06935
P_{t-1}^{NGP}	0.01721	0.08122	-0.04082	0.05888	0.02548	0.10840	-0.02843	0.07833
P_{t-1}^{NG}	0.06923	0.04347	0.03108	0.03151	0.12537**	0.05801	-0.00711	0.04192
P_{t-1}^{CN}	0.17662***	0.06055	0.05797	0.04389	-0.08153	0.08081	0.21072***	0.05840
P_{t-2}^{NO}	0.29287***	0.07521	0.08377	0.05451	-0.07868	0.10037	-0.13616*	0.07252
P_{t-2}^{NGP}	-0.07763	0.07822	-0.08862	0.05670	-0.00581	0.10439	0.03823	0.07543
P_{t-2}^{NG}	0.01973	0.04410	0.03819	0.03197	-0.02915	0.05885	-0.00228	0.04253
P_{t-2}^{CN}	0.04736	0.06272	-0.01349	0.04546	-0.06686	0.08371	-0.02135	0.06049
P_{t-3}^{NO}	0.20749***	0.07292	-0.01464	0.05286	0.02451	0.09731	-0.03200	0.07032
P_{t-3}^{NGP}	-0.08681	0.06809	0.12423**	0.04936	-0.05243	0.09088	0.01443	0.06567
P_{t-3}^{NG}	-0.04731	0.04356	-0.02957	0.03157	-0.05216	0.05813	-0.02006	0.04200
P_{t-3}^{CN}	0.00625	0.06090	-0.00196	0.04415	0.11575	0.08128	0.11129*	0.05873
Other								
Constant	-0.13242	0.04073	0.15575	0.02952	0.02557	0.05435	0.06004	0.03928
River	0.00041***	0.00018	-0.00039***	0.00013	-0.00039	0.00025	-0.00014	0.00018
Fall	0.00242	0.00462	-0.00599*	0.00335	0.00753	0.00616	-0.00321	0.00445
Spring	-0.00462	0.00517	0.00328	0.00375	0.00873	0.00690	-0.00298	0.00499
Winter	-0.00017	0.00472	0.00190	0.00342	-0.00511	0.00630	0.00448	0.00455

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B3: Short-Run VECM Parameter Estimates for Urea-SGP in the Pre-2007 Period

Lagged Prices	ΔP_t^{NO}			ΔP_t^{SGP}			ΔP_t^{NG}			ΔP_t^{CN}		
	Parameter	S.E.		Parameter	S.E.		Parameter	S.E.		Parameter	S.E.	
P_{t-1}^{NO}	0.43766***	0.04410		0.21564***	0.04815		-0.00517	0.14073		0.13885**	0.07003	
P_{t-1}^{SGP}	0.01453	0.03606		-0.05525	0.03938		-0.01902	0.11509		-0.16313***	0.05727	
P_{t-1}^{NG}	0.01216	0.01269		-0.02771**	0.01386		0.15495***	0.04051		0.01010	0.02016	
P_{t-1}^{CN}	0.00656	0.02520		0.00011	0.02751		0.06871	0.08042		-0.01900	0.04002	
P_{t-2}^{NO}	0.12554***	0.04704		0.02655	0.05137		-0.06152	0.15014		-0.01131	0.07471	
P_{t-2}^{SGP}	-0.03940	0.03364		-0.12710***	0.03673		0.16236	0.10735		-0.00078	0.05342	
P_{t-2}^{NG}	0.05140***	0.01282		0.02105	0.01399		-0.06380	0.04090		-0.02175	0.02035	
P_{t-2}^{CN}	-0.01489	0.02520		-0.00884	0.02751		0.07913	0.08042		0.03745	0.04002	
P_{t-3}^{NO}	0.03784	0.04701		-0.08977*	0.05133		0.00712	0.15003		-0.01631	0.07466	
P_{t-3}^{SGP}	-0.07294**	0.03276		0.24301***	0.03577		-0.10772	0.10455		-0.09779*	0.05203	
P_{t-3}^{NG}	0.01065	0.01291		-0.01915	0.01409		0.09328**	0.04119		-0.01179	0.02050	
P_{t-3}^{CN}	-0.02470	0.02523		0.04504	0.02755		-0.01081	0.08052		0.00447	0.04007	
P_{t-4}^{NO}	-0.04338	0.04608		0.13149***	0.05032		-0.06824	0.14707		-0.00169	0.07318	
P_{t-4}^{SGP}	0.05821*	0.03358		-0.02645	0.03666		0.01505	0.10716		0.12076**	0.05333	
P_{t-4}^{NG}	0.02477*	0.01295		-0.01247	0.01413		-0.01115	0.04131		-0.02148	0.02056	
P_{t-4}^{CN}	0.01135	0.02523		0.06836**	0.02755		-0.02066	0.08051		0.00677	0.04007	
Other												
Constant	0.02269	0.02287		0.19408	0.02497		0.03950	0.07298		-0.02148	0.03632	
River	-0.00002	0.00009		-0.00020**	0.00009		-0.00034	0.00027		-0.00024*	0.00014	
Fall	0.00024	0.00194		0.00131	0.00212		0.01308**	0.00620		0.00541*	0.00309	
Spring	-0.00312	0.00249		0.00504*	0.00272		0.01177	0.00795		0.00661*	0.00396	
Winter	0.00384*	0.00220		0.00243	0.00240		-0.00102	0.00702		0.00717**	0.00349	

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B4: Short-Run VECM Parameter Estimates for Urea-SGP in the Post-2010 Period

Lagged Prices	ΔP_t^{NO}		ΔP_t^{SGP}		ΔP_t^{NG}		ΔP_t^{CN}	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NO}	0.29330***	0.07506	0.28229***	0.05676	-0.00112	0.10119	-0.13443*	0.07288
P_{t-1}^{SGP}	0.09090	0.08941	0.00190	0.06761	-0.11925	0.12054	0.12250	0.08682
P_{t-1}^{NG}	0.06045	0.04325	0.04592	0.03271	0.12608**	0.05831	0.00220***	0.04200
P_{t-1}^{CN}	0.17953***	0.05977	0.04394	0.04520	-0.07529	0.08058	0.21206	0.05804
P_{t-2}^{NO}	0.34586***	0.07791	0.28616***	0.05891	-0.06571	0.10503	-0.21044	0.07565
P_{t-2}^{SGP}	-0.24148***	0.08727	-0.24827***	0.06599	0.07852	0.11765	0.07627	0.08474
P_{t-2}^{NG}	0.00383	0.04358	-0.00907	0.03295	-0.02291	0.05875	-0.00338	0.04232
P_{t-2}^{CN}	0.05672	0.06196	0.04429	0.04685	-0.06640	0.08353	-0.03223	0.06016
P_{t-3}^{NO}	0.18833**	0.07979	0.06615	0.06033	-0.02708	0.10756	-0.09884	0.07747
P_{t-3}^{SGP}	-0.04767	0.08293	0.04746	0.06271	0.10830	0.11181	0.10209	0.08053
P_{t-3}^{NG}	-0.01687	0.04344	-0.00656	0.03285	-0.05244	0.05857	-0.02528	0.04219
P_{t-3}^{CN}	-0.03104	0.06187	0.01661	0.04678	0.14852*	0.08341	0.13526**	0.06008
P_{t-4}^{NO}	-0.00156	0.07521	0.06737	0.05687	-0.11492	0.10139	-0.12071*	0.07303
P_{t-4}^{SGP}	0.04250	0.07612	-0.01335	0.05756	0.12532	0.10262	0.08710	0.07392
P_{t-4}^{NG}	-0.06144	0.04299	-0.04526	0.03251	0.00602	0.05796	0.01969	0.04175
P_{t-4}^{CN}	0.07623	0.06085	0.12603***	0.04602	-0.09613	0.08204	-0.09181	0.05909
Other								
Constant	-0.12724	0.03950	0.08249	0.02987	0.00700	0.05325	0.09200	0.03836
River	0.00049**	0.00019	-0.00002	0.00015	-0.00036	0.00026	-0.00030	0.00019
Fall	-0.00038	0.00440	-0.00891***	0.00332	0.00861	0.00593	-0.00192	0.00427
Spring	-0.00088	0.00507	-0.00708*	0.00383	0.00809	0.00683	-0.00503	0.00492
Winter	0.00534	0.00496	-0.00555	0.00375	-0.00624	0.00668	0.00080	0.00481

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B5: Short-Run VECM Parameter Estimates for Urea-GL in the Pre-2007 Period

Lagged Prices	ΔP_t^{NO}		ΔP_t^{SGP}		ΔP_t^{NG}		ΔP_t^{CN}	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NO}	0.46446***	0.04075	0.07452	0.04768	0.05048	0.12919	0.08437	0.06447
P_{t-1}^{SGP}	0.03105	0.03231	0.02940	0.03781	-0.10422	0.10245	-0.06226	0.05113
P_{t-1}^{NG}	0.01372	0.01276	0.01218	0.01493	0.14604***	0.04045	0.00440	0.02019
P_{t-1}^{CN}	0.00556	0.02534	0.02675	0.02965	0.05155	0.08033	-0.02230	0.04009
P_{t-2}^{NO}	0.13498***	0.04272	0.02049	0.04999	-0.04071	0.13544	-0.05572	0.06759
P_{t-2}^{SGP}	0.05627*	0.03202	-0.00608	0.03747	0.07967	0.10152	0.03854	0.05066
P_{t-2}^{NG}	0.05500***	0.01278	0.01461	0.01496	-0.04457	0.04053	-0.01377	0.02023
P_{t-2}^{CN}	-0.00563	0.02537	-0.01950	0.02969	0.09064	0.08044	0.04655	0.04014
Other								
Constant	-0.00336	0.00514	0.05178	0.00601	0.00760	0.01629	-0.01079	0.00813
River	0.00000	0.00009	0.00020*	0.00011	-0.00024	0.00030	-0.00032**	0.00015
Fall	0.00020	0.00193	0.00256	0.00226	0.01405**	0.00613	0.00476	0.00306
Spring	-0.00462*	0.00245	0.00545*	0.00287	0.01067	0.00778	0.00688*	0.00388
Winter	0.00278	0.00218	0.00589**	0.00255	-0.00136	0.00692	0.00726**	0.00345

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B6: Short-Run VECM Parameter Estimates for Urea-GL in the Post-2010 Period

Lagged Prices	ΔP_t^{NO}		ΔP_t^{SGP}		ΔP_t^{NG}		ΔP_t^{CN}	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NO}	0.27657***	0.06949	0.20146***	0.04993	-0.03158	0.09164	-0.10324	0.06613
P_{t-1}^{SGP}	0.17561**	0.07653	0.02560	0.05498	0.00727	0.10091	-0.02760	0.07283
P_{t-1}^{NG}	0.08011*	0.04418	-0.02542	0.03174**	0.12157	0.05826	-0.00846	0.04204
P_{t-1}^{CN}	0.17627***	0.06109	0.00394	0.04389	-0.06103	0.08055	0.19728***	0.05813
P_{t-2}^{NO}	0.20318***	0.07050	-0.02370	0.05065	-0.05664	0.09297	-0.13344**	0.06709
P_{t-2}^{SGP}	-0.03747	0.06864	-0.00466	0.04932	0.14370	0.09052	-0.03392	0.06532
P_{t-2}^{NG}	0.02146	0.04451	0.01224	0.03198	-0.02685	0.05870	-0.02183	0.04236
P_{t-2}^{CN}	0.05509	0.06114	0.01507	0.04393	-0.02589	0.08063	-0.00306	0.05819
Other								
Constant	-0.08708	0.05286	0.28287	0.03798	-0.05358	0.06971	0.12316	0.05031
River	0.00017	0.00016	-0.00024**	0.00012	-0.00029	0.00021	-0.00009	0.00015
Fall	-0.00119	0.00450	-0.00459	0.00324	0.00918	0.00594	-0.00223	0.00429
Spring	-0.00382	0.00520	0.00699*	0.00374	0.00705	0.00686	-0.00211	0.00495
Winter	0.00196	0.00489	-0.00329	0.00352	-0.00498	0.00645	0.00192	0.00466

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B7: Short-Run VECM Parameter Estimates for Urea-PNW in the Post-2010 Period

ΔP_t^{NOLA}			ΔP_t^{SGP}		ΔP_t^{NG}		ΔP_t^{CN}	
Other	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
Constant	-0.00068	0.00424	0.00048	0.00018	-0.00023	0.00045	0.00884	0.00420
River	-0.00022	0.00029	0.00800***	0.00379	0.01518	0.00935	0.00002	0.00028
Fall	-0.00469	0.00593	0.00625**	0.00393	0.01225	0.00971	0.01049*	0.00589
Spring	-0.00679	0.00616	0.01585	0.00336	-0.00197	0.00829	0.00719	0.00611
Winter	0.01234**	0.00526	-0.00555***	0.00375	-0.00624	0.00668	0.00613	0.00522

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level. AICC chose 1 lag for this particular model, therefore lagged differenced prices are not available.

Table B8: Short-Run VECM Parameter Estimates for DAP-NGP in the Pre-2007 Period

Lagged Prices	ΔP_t^{NOLA}		ΔP_t^{NGP}		ΔP_t^{NG}		ΔP_t^{CN}	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NOLA}	0.27465***	0.04196	0.11778***	0.04441	0.07879	0.26790	-0.09529	0.13292
P_{t-1}^{NGP}	0.03636	0.03589	-0.00483	0.03799	-0.47050**	0.22916	-0.25838**	0.11370
P_{t-1}^{NG}	0.01138*	0.00633	0.00435	0.00670	0.15777***	0.04042	0.00432	0.02005
P_{t-1}^{CN}	0.00854	0.01261	0.00721	0.01334	0.04480	0.08050	-0.02850	0.03994
P_{t-2}^{NOLA}	0.06340	0.04315	0.09359**	0.04567	0.18217	0.27551	0.48879***	0.13670
P_{t-2}^{NGP}	0.05697*	0.03506	-0.07288**	0.03712	-0.15648	0.22390	-0.02972	0.11109
P_{t-2}^{NG}	0.01117*	0.00638	0.00299	0.00675	-0.04852	0.04074	-0.00798	0.02021
P_{t-2}^{CN}	-0.01551	0.01264	0.01304	0.01338	0.08159	0.08068	0.04497	0.04003
P_{t-3}^{NOLA}	0.17669	0.04349	-0.00850	0.04604	-0.01078	0.27770	-0.01273	0.13778
P_{t-3}^{NGP}	0.07746	0.03466	0.23731***	0.03668	0.22983	0.22129	-0.01267	0.10979
P_{t-3}^{NG}	0.00398	0.00638	0.00395	0.00675	0.08901	0.04074	-0.01017	0.02021
P_{t-3}^{CN}	0.01052	0.01258	-0.00029	0.01331	0.00312	0.08031	0.00557	0.03985
P_{t-4}^{NOLA}	0.02230***	0.04368	0.09240**	0.04624	0.33762	0.27892	0.30070**	0.13839
P_{t-4}^{NGP}	-0.04501**	0.03520	-0.07451**	0.03726	-0.02219	0.22478	0.13769	0.11153
P_{t-4}^{NG}	-0.00427	0.00635	0.00413	0.00672	0.00278	0.04056	-0.01799	0.02013
P_{t-4}^{CN}	-0.01258	0.01257	-0.02358*	0.01331	-0.02309	0.08029	0.01101	0.03984
Other								
Constant	-0.01600	0.01023	0.05890	0.01083	-0.03884	0.06534	-0.06435	0.03242
River	0.00008*	0.00004	-0.00008*	0.00004	-0.00031	0.00027	-0.06435	0.03242
Fall	-0.00024	0.00098	0.00038	0.00104	0.01403**	0.00628	-0.00017*	0.00013
Spring	-0.00360***	0.00125	0.00155	0.00133	0.01050	0.00801	0.00588	0.00312
Winter	-0.00002	0.00109	0.00134	0.00116	0.00067	0.00698	0.00481	0.00398

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B9: Short-Run VECM Parameter Estimates for DAP-NGP in the Post-2010 Period

	ΔP_t^{NOLA}		ΔP_t^{NGP}		ΔP_t^{NG}		ΔP_t^{CN}	
Lagged Prices	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NOLA}	0.51565***	0.06787	P_{t-1}^{NGP}	0.13001***	P_{t-1}^{NG}	0.17630	P_{t-1}^{CN}	0.12606
P_{t-1}^{NGP}	-0.02235	0.08249	P_{t-1}^{NG}	0.16822***	P_{t-1}^{CN}	0.21428		0.15321
P_{t-1}^{NG}	0.03923*	0.02252	P_{t-1}^{CN}	-0.00266	P_{t-2}^{NOLA}	0.05850		0.04183
P_{t-1}^{CN}	0.02681	0.03151	P_{t-2}^{NOLA}	0.00307	P_{t-2}^{NGP}	0.08184	0.20759***	0.05852
P_{t-2}^{NOLA}	0.09462	0.07144	P_{t-2}^{NGP}	-0.06130	P_{t-2}^{NG}	0.18557		0.13269
P_{t-2}^{NGP}	-0.00623	0.07908	P_{t-2}^{NG}	-0.16175***	P_{t-2}^{CN}	0.20543	0.37999**	0.14688
P_{t-2}^{NG}	-0.01491	0.02269	P_{t-3}^{NOLA}	0.01353	P_{t-3}^{NGP}	0.05894		0.04214
P_{t-2}^{CN}	0.08785**	0.03177	P_{t-3}^{NGP}	-0.02078	P_{t-3}^{NG}	0.08253	-0.01160	0.05901
P_{t-3}^{NOLA}	0.00396	0.06960	P_{t-3}^{NG}	0.02132	P_{t-3}^{CN}	-0.04975	-0.01504	0.12928
P_{t-3}^{NGP}	-0.00096	0.07799	P_{t-4}^{NOLA}	-0.02266	P_{t-4}^{NGP}	0.29023	-0.20036	0.14486
P_{t-3}^{NG}	0.00479	0.02255	P_{t-4}^{NGP}	0.04671	P_{t-4}^{NG}	0.18080	0.17467	0.04188
P_{t-3}^{CN}	0.01005	0.03232	P_{t-4}^{NG}	-0.03033**	P_{t-4}^{CN}	0.05857	-0.04944	0.06002
P_{t-4}^{NOLA}	0.06841	0.06804	P_{t-4}^{CN}	0.03737*		0.08395	0.10520*	0.12638
P_{t-4}^{NGP}	0.10560	0.06654		0.01739		0.17675	0.01037	0.12358
P_{t-4}^{NG}	0.00258	0.02230		0.04566		0.17284	0.00247	0.04142
P_{t-4}^{CN}	0.00909	0.03188		-0.07369*		0.05793	0.01464	0.05921
				0.02139		-0.10971	-0.13460**	
Other								
Constant	-0.09515	0.03676		0.15478		0.09549	0.05494	0.06828
River	0.00018**	0.00008		0.02467		0.00021	-0.00002	0.00015
Fall	-0.00539**	0.00230		-0.00002		0.00028	0.00090	0.00428
Spring	-0.00503**	0.00263		0.00187		0.00704	-0.00444	0.00488
Winter	-0.00310	0.00269		0.00155		0.00684	0.00698	0.00499
				0.00176		0.00682		
				-0.00194		0.00682		
				0.00180		0.00698		

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B10: Short-Run VECM Parameter Estimates for DAP-SGP in the Pre-2007 Period

Lagged Prices	ΔP_t^{NOLA}		ΔP_t^{SGP}		ΔP_t^{NG}		ΔP_t^{CN}	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NOLA}	0.28771***	0.04260	0.08966**	0.04078	0.01054	0.27159	-0.12450	0.13417
P_{t-1}^{SGP}	0.01071	0.04119	-0.02035	0.03943	-0.04087	0.26262	-0.10560	0.12974
P_{t-1}^{NG}	0.00953	0.00632	0.00568	0.00605	0.15453***	0.04027	0.00151	0.01989
P_{t-1}^{CN}	0.00671	0.01270	0.00439	0.01215	0.05003	0.08095	-0.03114	0.03999
P_{t-2}^{NOLA}	0.07612*	0.04423	0.01233	0.04234	0.03098	0.28204	0.47269***	0.13933
P_{t-2}^{SGP}	0.06137	0.03937	-0.14801***	0.03769	0.30697	0.25104	-0.08269	0.12402
P_{t-2}^{NG}	0.01090*	0.00637	0.01310**	0.00610	-0.05722	0.04061	-0.01470	0.02006
P_{t-2}^{CN}	-0.01790	0.01269	0.00206	0.01215	0.08080	0.08090	0.04345	0.03996
P_{t-3}^{NOLA}	0.20320***	0.04443	0.07468*	0.04253	-0.04057	0.28329	-0.04566	0.13995
P_{t-3}^{SGP}	0.01827	0.03916	0.18262***	0.03749	-0.05734	0.24968	0.13245	0.12334
P_{t-3}^{NG}	0.00408	0.00639	-0.00234	0.00612	0.08679	0.04077	-0.01348	0.02014
P_{t-3}^{CN}	0.01190	0.01261	-0.00559	0.01207	-0.01077	0.08039	0.00012	0.03971
P_{t-4}^{NOLA}	0.04317	0.04497	-0.07505*	0.04305	0.29666	0.28673	0.25605*	0.14165
P_{t-4}^{SGP}	-0.03509	0.03951	-0.05490	0.03782	0.14039	0.25192	0.28477**	0.12445
P_{t-4}^{NG}	-0.00569	0.00638	-0.00047	0.00611	-0.00478	0.04070	-0.02156	0.02011
P_{t-4}^{CN}	-0.01106	0.01263	-0.00481	0.01209	-0.02044	0.08053	0.01434	0.03978
Other								
Constant	-0.01922	0.01151	0.09137	0.01102	-0.05612	0.07340	-0.06493	0.03626
River	0.00009**	0.00005	-0.00024***	0.00004	-0.00016	0.00029	-0.00005	0.00014
Fall	0.00022	0.00102	-0.00115	0.00097	0.01387**	0.00647	0.00587	0.00320
Spring	-0.00292**	0.00124	0.00230**	0.00119	0.00889	0.00791	0.00456	0.00391
Winter	0.00030	0.00110	0.00011	0.00105	-0.00104	0.00701	0.00598*	0.00346

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B11: Short-Run VECM Parameter Estimates for DAP-SGP in the Post-2010 Period

Lagged Prices	ΔP_t^{NOLA}			ΔP_t^{SGP}			ΔP_t^{NG}			ΔP_t^{CN}		
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NOLA}	0.38288***	0.08003	0.11324**	0.05782	-0.01448	0.20536	-0.22266	0.14776				
P_{t-1}^{SGP}	0.10667	0.08973	0.11407*	0.06482	-0.27546	0.23025	0.13466	0.16566				
P_{t-1}^{NG}	0.03465	0.02278	0.01127	0.01645	0.14586**	0.05844	0.01442	0.04205				
P_{t-1}^{CN}	0.02840	0.03172	0.02479	0.02291	-0.09310	0.08138	0.20582***	0.05856				
P_{t-2}^{NOLA}	0.05434	0.07830	0.05686	0.05656	0.11008	0.20090	0.09569	0.14455				
P_{t-2}^{SGP}	-0.12840	0.08484	-0.20476***	0.06129	-0.15021	0.21769	0.37359**	0.15663				
P_{t-2}^{NG}	-0.01673	0.02283	0.02395	0.01649	-0.00864	0.05858	-0.00638	0.04215				
P_{t-2}^{CN}	0.08223**	0.03216	0.03364	0.02323	-0.05517	0.08252	-0.01550	0.05937				
P_{t-3}^{NOLA}	-0.05996	0.07488	0.02965	0.05409	0.28027	0.19212	-0.16251	0.13823				
P_{t-3}^{SGP}	-0.00022	0.08354	0.04858	0.06035	0.15272	0.21436	0.12844	0.15424				
P_{t-3}^{NG}	0.00357	0.02283	-0.01279	0.01649	-0.06489	0.05857	-0.05091	0.04214				
P_{t-3}^{CN}	-0.00108	0.03237	-0.02907	0.02338	0.16890**	0.08305	0.11239*	0.05976				
P_{t-4}^{NOLA}	0.04963	0.07496	0.04478	0.05415	0.01811	0.19233	-0.00361	0.13838				
P_{t-4}^{SGP}	-0.01790	0.07548	-0.00566	0.05453	0.07033	0.19367	0.05996	0.13935				
P_{t-4}^{NG}	0.00659	0.02253	0.00746	0.01628	-0.00805	0.05782	0.01314	0.04160				
P_{t-4}^{CN}	0.00735	0.03183	0.01709	0.02300	-0.11447	0.08168	-0.13381**	0.05877				
Other												
Constant	0.02296	0.04314	0.17810	0.03117	-0.08379	0.11070	0.01305	0.07965				
River	0.00015*	0.00009	0.00013**	0.00006	-0.00036	0.00022	0.00001	0.00016				
Fall	-0.00333	0.00255	0.00522***	0.00184	0.00596	0.00654	-0.00162	0.00470				
Spring	-0.00482*	0.00266	-0.00039	0.00192	0.00742	0.00682	-0.00497	0.00490				
Winter	0.00035	0.00268	0.00257	0.00194	-0.00792	0.00687	0.00539	0.00495				

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B12: Short-Run VECM Parameter Estimates for DAP-GL in the Pre-2007 Period

Lagged Prices	ΔP_t^{NOLA}		ΔP_t^{GL}		ΔP_t^{NG}		ΔP_t^{CN}	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NOLA}	0.28457***	0.04102	0.18012***	0.04544	-0.00739	0.25641	-0.11677	0.12861
P_{t-1}^{GL}	0.00391	0.03553	-0.01722	0.03935	-0.13094	0.22208	-0.21788*	0.11139
P_{t-1}^{NG}	0.00999	0.00642	-0.00113	0.00711	0.17000***	0.04011	0.00231	0.02012
P_{t-1}^{CN}	0.00671	0.01270	0.02703*	0.01407	0.06394	0.07940	-0.02869	0.03982
P_{t-2}^{NOLA}	0.07507*	0.04245	0.03242	0.04703	0.15216	0.26538	0.49030***	0.13310
P_{t-2}^{GL}	0.01406	0.03505	-0.02741	0.03882	0.20288	0.21910	-0.00707	0.10989
P_{t-2}^{NG}	0.01089*	0.00642	0.00526	0.00711	-0.04690	0.04015	-0.00870	0.02014
P_{t-2}^{CN}	-0.01921	0.01276	-0.00802	0.01414	0.09301	0.07978	0.04491	0.04001
P_{t-3}^{NOLA}	0.20110***	0.04282	0.03731	0.04743	-0.09877	0.26767	-0.03507	0.13425
P_{t-3}^{GL}	-0.00818	0.03478	0.16515***	0.03853	0.63809***	0.21745	0.03164	0.10907
P_{t-3}^{NG}	0.00573	0.00643	0.00168	0.00712	0.08482**	0.04018	-0.00910	0.02015
P_{t-3}^{CN}	0.01092	0.01269	0.00221	0.01406	-0.01947	0.07935	-0.00357	0.03980
P_{t-4}^{NOLA}	0.03147	0.04291	-0.00684	0.04754	0.28133	0.26826	0.30318**	0.13455
P_{t-4}^{GL}	0.00554	0.03446	0.01384	0.03817	-0.68787**	0.21540	0.15217	0.10803
P_{t-4}^{NG}	-0.00401	0.00642	-0.00452	0.00711	0.00681	0.04014	-0.01683	0.02013
P_{t-4}^{CN}	-0.01040	0.01271	-0.03960***	0.01408	-0.04486	0.07944	0.00778	0.03984
Other								
Constant	-0.01217	0.00838	-0.01217	0.00838	-0.06153	0.05236	-0.06860	0.02626
River	0.00003	0.00005	0.00003	0.00005	-0.00042	0.00030	-0.00037	0.00015
Fall	-0.00020	0.00097	-0.00020	0.00097	0.01232**	0.00605	0.00531*	0.00303
Spring	-0.00272**	0.00124	-0.00272**	0.00124	0.01013	0.00776	0.00649	0.00389
Winter	0.00026	0.00111	0.00026*	0.00111	-0.00060	0.00692	0.00649*	0.00347

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B13: Short-Run VECM Parameter Estimates for DAP-GL in the Post-2010 Period

Lagged Prices	ΔP_t^{NOLA}		ΔP_t^{GL}		ΔP_t^{NG}		ΔP_t^{CN}	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NOLA}	0.47808***	0.06378	0.14810***	0.04261	-0.16468	0.16433	-0.25496**	0.11746
P_{t-1}^{GL}	0.01562	0.08651	0.13718**	0.05780	0.40023*	0.22291	0.34814**	0.15933
P_{t-1}^{NG}	0.02639	0.02255	-0.00240	0.01507	0.12810**	0.05810	0.00147	0.04153
P_{t-1}^{CN}	0.01671	0.03139	0.02368	0.02097	-0.09761	0.08087	0.19060***	0.05781
P_{t-2}^{NOLA}	0.05253	0.06818	-0.01609	0.04555	0.03805	0.17568	0.11592	0.12557
P_{t-2}^{GL}	0.03705	0.08752	-0.03489	0.05847	-0.16010	0.22550	0.33458**	0.16118
P_{t-2}^{NG}	-0.01668	0.02252	-0.01094	0.01505	-0.01956	0.05803	-0.01601	0.04148
P_{t-2}^{CN}	0.08200***	0.03148	-0.00988	0.02103	-0.07773	0.08112	-0.03201	0.05798
P_{t-3}^{NOLA}	-0.00296	0.06674	-0.03230	0.04459	0.26237	0.17197	-0.24357**	0.12292
P_{t-3}^{GL}	-0.07045	0.08696	0.04417	0.05810	0.44519**	0.22407	0.43759***	0.16016
P_{t-3}^{NG}	-0.00197	0.02247	-0.00895	0.01501	-0.07794	0.05790	-0.04082	0.04138
P_{t-3}^{CN}	-0.00497	0.03184	0.01648	0.02127	0.17683**	0.08203	0.11928**	0.05863
P_{t-4}^{NOLA}	0.00605	0.06540	0.01790	0.04369	-0.02617	0.16852	0.03823	0.12046
P_{t-4}^{GL}	0.25046***	0.07310	0.00776	0.04884	0.07947	0.18835	-0.18961	0.13463
P_{t-4}^{NG}	-0.00480	0.02195	0.00203	0.01466	0.00306	0.05656	0.03364	0.04042
P_{t-4}^{CN}	0.01462	0.03126	0.02324	0.02088	-0.12743	0.08054	-0.15166***	0.05757
Other								
Constant	-0.05283	0.02487	0.08515	0.01662	-0.13344	0.06409	0.03320	0.04581
River	0.00014*	0.00008	-0.00002	0.00005	-0.00029	0.00021	0.00002	0.00015
Fall	-0.00528**	0.00231	0.00196	0.00154	0.00421	0.00595	-0.00335	0.00425
Spring	-0.00507**	0.00261	0.00078	0.00174	0.00634	0.00673	-0.00585	0.00481
Winter	-0.00157	0.00249	0.00167	0.00166	-0.00797	0.00641	0.00745	0.00458

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B14: Short-Run VECM Parameter Estimates for UAN-NGP in the Post-2010 Period

Lagged Prices	ΔP_t^{NOLA}		ΔP_t^{NGP}		ΔP_t^{NG}		ΔP_t^{CN}	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NOLA}	0.45247***	0.06254	0.01621	0.05087	-0.11057	0.09525	0.00513	0.06973
P_{t-1}^{NGP}	0.04376	0.06740	0.05277	0.05483	0.06028	0.10265	-0.06709	0.07515
P_{t-1}^{NG}	0.00395	0.03791	-0.01620	0.03084	0.11810**	0.05774	-0.00683	0.04227
P_{t-1}^{CN}	0.04714	0.05217	-0.01092	0.04244	-0.07042	0.07946	0.21673***	0.05817
P_{t-2}^{NOLA}	0.03416	0.06470	0.00941	0.05263	-0.21591**	0.09854	-0.13973**	0.07214
P_{t-2}^{NGP}	-0.02643	0.06477	-0.12867	0.05268	0.13518	0.09864	-0.01303	0.07222
P_{t-2}^{NG}	0.01730	0.03808	0.01733	0.03097	-0.02617	0.05800	-0.00312	0.04246
P_{t-2}^{CN}	0.09059*	0.05323	-0.02328**	0.04329	-0.05669	0.08106	-0.01246	0.05935
P_{t-3}^{NOLA}	0.25560***	0.06507	0.15362***	0.05293	-0.11288	0.09911	0.03638	0.07256
P_{t-3}^{NGP}	-0.05003	0.06441	0.02852	0.05239	0.03120	0.09810	0.05747	0.07182
P_{t-3}^{NG}	-0.04662	0.03756	0.00310	0.03055	-0.05851	0.05720	-0.02791	0.04188
P_{t-3}^{CN}	0.13914***	0.05228	0.02223	0.04253	0.10603	0.07963	0.07910	0.05830
Other								
Constant	-0.17630	0.04241	0.18096	0.03449	0.10194	0.06459	0.06452	0.04728
River	-0.00046***	0.00016	0.00032**	0.00013	-0.00014	0.00025	0.00014	0.00018
Fall	0.00557	0.00395	-0.00442	0.00321	0.00714	0.00601	-0.00237	0.00440
Spring	0.01115**	0.00508	-0.00579	0.00413	0.00334	0.00773	-0.00741	0.00566
Winter	0.00914**	0.00430	-0.00160	0.00350	-0.00819	0.00655	0.00189	0.00479

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B15: Short-Run VECM Parameter Estimates for UAN-SGP in the Post-2010 Period

Lagged Prices	ΔP_t^{NOLA}		ΔP_t^{SGP}		ΔP_t^{NG}		ΔP_t^{CN}	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NOLA}	0.41456***	0.05886	0.07057	0.04744	-0.08302	0.09047	0.08211	0.06618
P_{t-1}^{SGP}	0.02603	0.07092	-0.05568	0.05716	0.18803*	0.10901	-0.05380	0.07975
P_{t-1}^{NG}	-0.01022	0.03757	-0.00012	0.03028	0.13583**	0.05774	-0.00068	0.04224
P_{t-1}^{CN}	0.01332	0.05206	0.03084	0.04196	-0.05036	0.08001	0.20333***	0.05853
P_{t-2}^{NOLA}	-0.00010	0.06141	0.16066***	0.04949	-0.15171	0.09439	-0.04539	0.06905
P_{t-2}^{SGP}	0.12137*	0.06705	-0.05988	0.05404	-0.03080	0.10307	-0.01894	0.07540
P_{t-2}^{NG}	0.01625	0.03787	-0.01872	0.03052	-0.04196	0.05821	-0.00141	0.04258
P_{t-2}^{CN}	0.08236	0.05317	0.11493***	0.04286	-0.06005	0.08173	-0.02966	0.05979
P_{t-3}^{NOLA}	0.18872***	0.06178	0.14851***	0.04979	-0.09615	0.09495	0.13358**	0.06946
P_{t-3}^{SGP}	0.03738	0.06674	-0.08314*	0.05379	0.18494*	0.10258	-0.01625	0.07504
P_{t-3}^{NG}	-0.03773	0.03730	-0.00658	0.03006	-0.04432	0.05733	-0.03333	0.04194
P_{t-3}^{CN}	0.09358*	0.05260	-0.10761**	0.04239	0.12328	0.08085	0.07211	0.05914
Other								
Constant	-0.08443	0.01777	0.05132	0.01432	0.01048	0.02731	-0.04941	0.01998
River	-0.00058***	0.00018	0.00025*	0.00014	-0.00025	0.00027	-0.00031	0.00020
Fall	0.00060	0.00382	0.00161	0.00308	0.00859	0.00587	-0.00087	0.00429
Spring	0.00593	0.00467	-0.00082	0.00376	0.00702	0.00718	-0.00057	0.00525
Winter	0.00593	0.00413	0.00201	0.00333	-0.00631	0.00634	0.00576	0.00464

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B16: Short-Run VECM Parameter Estimates for UAN-GL in the Post-2010 Period

Lagged Prices	ΔP_t^{NOLA}		ΔP_t^{GL}		ΔP_t^{NG}		ΔP_t^{CN}	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NOLA}	0.41886***	0.06692	-0.10405**	0.04296	-0.05355	0.09751	0.04109	0.07141
P_{t-1}^{GL}	0.03313	0.07423	0.11867**	0.04765	0.10509	0.10816	0.04618	0.07921
P_{t-1}^{NG}	-0.02537	0.03953	-0.01882	0.02537	0.12390**	0.05759	-0.00445	0.04218
P_{t-1}^{CN}	0.04456	0.05303	0.06417*	0.03404	-0.07996	0.07727	0.22468***	0.05658
Other								
Constant	-0.03205	0.02395	0.17044	0.01538	-0.01708	0.03490	-0.02280	0.02556
River	-0.00029	0.00018	0.00052***	0.00012	-0.00038	0.00026	-0.00010	0.00019
Fall	0.00409	0.00411	-0.00064	0.00264	0.00867	0.00599	-0.00019	0.00439
Spring	0.00525	0.00503	-0.00328	0.00323	0.00881	0.00733	-0.00258	0.00536
Winter	0.00679	0.00441	-0.00196	0.00283	-0.00506	0.00643	0.00411	0.00471

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B17: Short-Run VECM Parameter Estimates for MAP-SGP in the Post-2010 Period

Lagged Prices	ΔP_t^{NOLA}		ΔP_t^{SGP}		ΔP_t^{NG}		ΔP_t^{CN}	
	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.
P_{t-1}^{NOLA}	0.25875***	0.06939	0.23221***	0.04635	-0.01313	0.15625	-0.22425**	0.11475
P_{t-1}^{SGP}	0.27325***	0.08705	0.12975**	0.05815	0.08728	0.19602	0.11280	0.14396
P_{t-1}^{NG}	0.02334	0.02539	0.02345	0.01696	0.14240**	0.05718	0.00758	0.04200
P_{t-1}^{CN}	0.00950	0.03518	0.04265*	0.02350	-0.08996	0.07923	0.19461***	0.05819
P_{t-2}^{NOLA}	0.06961	0.07029	0.08671	0.04696	0.10898	0.15829	-0.01381	0.11625
P_{t-2}^{SGP}	-0.08425	0.08419	-0.27858***	0.05624	-0.49447***	0.18960	0.33908**	0.13924
P_{t-2}^{NG}	0.00073	0.02559	0.01092	0.01710	-0.01313	0.05764	-0.00712	0.04233
P_{t-2}^{CN}	0.05174	0.03597	0.01001	0.02403	-0.07190	0.08099	-0.01795	0.05948
P_{t-3}^{NOLA}	0.00532	0.06537	0.02770	0.04367	0.40290***	0.14720	-0.23722**	0.10811
P_{t-3}^{SGP}	0.11458	0.07810	0.15900***	0.05217	0.27770	0.17588	0.12896	0.12917
P_{t-3}^{NG}	0.01275	0.02511	-0.01896	0.01677	-0.07852	0.05655	-0.02265	0.04153
P_{t-3}^{CN}	0.02763	0.03520	0.01956	0.02351	0.15862**	0.07926	0.06495	0.05821
Other								
Constant	-0.03524	0.01929	0.05068	0.01288	-0.09652	0.04343	0.06798	0.03190
River	0.00023**	0.00009	-0.00000	0.00006	-0.00024	0.00021	-0.00003	0.00015
Fall	-0.00849***	0.00266	0.00266	0.00178	0.00472	0.00599	-0.00071	0.00440
Spring	-0.00755**	0.00298	0.00042	0.00199	0.00563	0.00671	-0.00346	0.00493
Winter	-0.00206	0.00310	0.00097	0.00207	-0.01241*	0.00698	0.01024**	0.00513

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

Table B18: Short-Run VECM Parameter Estimates for MAP-GL in the Post-2010 Period

	ΔP_t^{NOLA}			ΔP_t^{GL}		ΔP_t^{NG}		ΔP_t^{CN}	
Lagged Prices	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	Parameter	S.E.	
P_{t-1}^{NOLA}	0.29149***	0.06341	0.10756***	0.03674	-0.12571	0.14391	-0.14921	0.10346	
P_{t-1}^{GL}	0.12422	0.09644	0.22050***	0.05589	0.37771*	0.21890	0.30179*	0.15737	
P_{t-1}^{NG}	0.02275	0.02569	0.02998**	0.01489	0.12232**	0.05832	-0.00382	0.04193	
P_{t-1}^{CN}	0.00671	0.03560	0.02502	0.02063	-0.05940	0.08079	0.18893***	0.05808	
P_{t-2}^{NOLA}	0.11796*	0.06204	0.00879	0.03595	-0.00003	0.14082	-0.02186	0.10124	
P_{t-2}^{GL}	0.04913	0.09288	-0.08519	0.05382	-0.06611	0.21080	0.34291**	0.15155	
P_{t-2}^{NG}	-0.00401	0.02568	-0.00788	0.01488	-0.05036	0.05828	-0.00998	0.04190	
P_{t-2}^{CN}	0.07555**	0.03505	0.00248	0.02031	-0.03829	0.07955	0.00125	0.05719	
Other									
Constant	-0.06394	0.03099	0.10598	0.01796	-0.08201	0.07034	0.04820	0.05057	
River	0.00019	0.00009	0.00001	0.00005	-0.00031	0.00021	0.00001	0.00015	
Fall	-0.00704	0.00263	0.00117	0.00152	0.00685	0.00597	-0.00269	0.00429	
Spring	-0.00785	0.00303	0.00088	0.00176	0.00611	0.00689	-0.00429	0.00495	
Winter	-0.00240	0.00295	0.00381**	0.00171	-0.00837	0.00671	0.00709	0.00482	

Note: This table contains the parameters estimates for the lagged differenced prices, seasons, and second lag of the Mississippi River levels. *, **, *** indicated statistical significance at the 10%, 5%, and 1% level.

APPENDIX C

JOHANSEN WEAK EXOGENEITY TESTS

Table C1: Johansen's Weak Exogeneity Test for Urea in the Pre-2007 Period

Model	Price	Chi-Square	Pr>ChiSq
Urea-NGP	New Orleans	1.35	0.2451
	Northern Great Plains	41.03***	<.0001
	Natural Gas Futures	0.22	0.6428
	Corn Futures	2.95*	0.0860
Urea-SGP	New Orleans	0.74	0.3912
	Southern Great Plains	34.33***	<.0001
	Natural Gas Futures	0.12	0.7256
	Corn Futures	0.32	0.5744
Urea-GL	New Orleans	0.33	0.5683
	Great Lakes	46.99***	<.0001
	Natural Gas Futures	0.29	0.5910
	Corn Futures	1.37	0.2410

Note: The Johansen weak exogeneity test the null hypothesis that $\alpha = 0$. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectfully.

Table C2: Johansen's Weak Exogeneity Test for Urea in the Post-2010 Period

Model	Price	Chi-Square	Pr>ChiSq
Urea-NGP	New Orleans	6.16**	0.0131
	Northern Great Plains	24.49***	<.0001
	Natural Gas Futures	0.11	0.7402
	Corn Futures	1.56	0.2115
Urea-SGP	New Orleans	3.99**	0.0457
	Southern Great Plains	8.02***	0.0046
	Natural Gas Futures	0.03	0.8726
	Corn Futures	4.03**	0.0448
Urea-GL	New Orleans	1.84	0.1746
	Great Lakes	44.06***	<.0001
	Natural Gas Futures	0.66	0.4160
	Corn Futures	5.38**	0.0204
Urea-PNW	New Orleans	0.20	0.6584
	Pacific Northwest	15.22***	<.0001
	Natural Gas Futures	0.29	0.5932
	Corn Futures	4.26**	0.0390

Note: The Johansen weak exogeneity test the null hypothesis that $\alpha = 0$. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectfully.

Table C3: Johansen's Weak Exogeneity Test for DAP in the Pre-2007 Period

Model	Price	Chi-Square	Pr>ChiSq
DAP-NGP	New Orleans	1.75	0.1853
	Northern Great Plains	23.44***	<.0001
	Natural Gas Futures	0.37	0.5423
	Corn Futures	3.05*	0.0809
DAP-SGP	New Orleans	2.21	0.1373
	Southern Great Plains	60.72***	<.0001
	Natural Gas Futures	1.08	0.2980
	Corn Futures	3.07*	0.0795
DAP-GL	New Orleans	1.92	0.1654
	Great Lakes	24.18***	<.0001
	Natural Gas Futures	0.72	0.3954
	Corn Futures	5.34**	0.0208

Note: The Johansen weak exogeneity test the null hypothesis that $\alpha = 0$. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectfully.

Table C4: Johansen's Weak Exogeneity Test for DAP in the Post-2010 Period

Model	Price	Chi-Square	Pr>ChiSq
DAP-NGP	New Orleans	5.62**	0.0178
	Northern Great Plains	29.57***	<.0001
	Natural Gas Futures	0.44	0.5070
	Corn Futures	0.52	0.4725
DAP-SGP	New Orleans	0.13	0.7160
	Southern Great Plains	20.65***	<.0001
	Natural Gas Futures	0.42	0.5148
	Corn Futures	0.09	0.7626
DAP-GL	New Orleans	3.75**	0.0527
	Great Lakes	18.68***	<.0001
	Natural Gas Futures	3.83**	0.0503
	Corn Futures	0.50	0.4791

Note: The Johansen weak exogeneity test the null hypothesis that $\alpha = 0$. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectfully.

Table C5: Johansen's Weak Exogeneity Test for UAN in the Post-2010 Period

Model	Price	Chi-Square	Pr>ChiSq
UAN-NGP	New Orleans	11.92***	0.0006
	Northern Great Plains	18.97***	<.0001
	Natural Gas Futures	2.53	0.1119
	Corn Futures	1.86	0.1725
UAN-SGP	New Orleans	15.52***	<.0001
	Southern Great Plains	6.12**	0.0134
	Natural Gas Futures	0.42	0.5183
	Corn Futures	4.03**	0.0447
UAN-GL	New Orleans	1.52	0.2170
	Great Lakes	79.54***	<.0001
	Natural Gas Futures	0.14	0.7057
	Corn Futures	0.51	0.4758

Note: The Johansen weak exogeneity test the null hypothesis that $\alpha = 0$. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectfully.

Table C6: Johansen's Weak Exogeneity Test for MAP in the Post-2010 Period

Model	Price	Chi-Square	Pr>ChiSq
MAP-SGP	New Orleans	2.68*	0.1014
	Southern Great Plains	10.26***	0.0014
	Natural Gas Futures	4.51**	0.0337
	Corn Futures	3.74*	0.0531
MAP-GL	New Orleans	3.74*	0.0533
	Great Lakes	26.59***	<.0001
	Natural Gas Futures	1.18	0.2767
	Corn Futures	0.86	0.3536

Note: The Johansen weak exogeneity test the null hypothesis that $\alpha = 0$. *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectfully.

APPENDIX D

SMALL SAMPLE PERFORMANCE OF UREA-NGP IN THE POST-2010 PERIOD

Table D1: Johansen Cointegration Test for Urea-NGP in Subsamples of the Post-2010 Period

Model	Observations	Null	Eigenvalue	Trace	Pr > Trace
Full Sample	300	$r = 0$	0.1669	75.4461	0.0002
		$r = 1$	0.0527	21.4098	0.6345
		$r = 2$	0.0128	5.3901	0.9718
		$r = 3$	0.0053	1.5659	0.8611
01/2011 to 10/2015	247	$r = 0$	0.1982	71.4717	0.0004
		$r = 1$	0.0585	17.7863	0.8502
		$r = 2$	0.0093	3.1394	0.9991
		$r = 3$	0.0036	0.8759	0.9655
01/2012 to 10/2015	195	$r = 0$	0.2034	64.5872	0.0044
		$r = 1$	0.0745	21.1434	0.6522
		$r = 2$	0.0199	6.3545	0.9336
		$r = 3$	0.0131	2.5109	0.6747
01/2013 to 10/2015	143	$r = 0$	0.2558	62.8826	0.0064
		$r = 1$	0.1076	21.8146	0.6074
		$r = 2$	0.0345	5.9904	0.9506
		$r = 3$	0.0080	1.1103	0.9360
01/2014 to 10/2015	91	$r = 0$	0.3437	57.8098	0.0222
		$r = 1$	0.1919	21.1752	0.6501
		$r = 2$	0.0285	2.6361	0.9995
		$r = 3$	0.0014	0.1237	1.0000

Note: The null hypothesis is $r = i$ against the alternative $r > i$. When the null hypothesis $r = i$ is not rejected, this is evidence that there are i cointegrating vectors between the prices.

Table D2: Estimated Price Elasticities for Urea-NGP in Subsamples of the Post-2010 Period

Model	Observations	Price	Elasticity
Full Sample	300	New Orleans	0.95662
		Northern Great Plains	1.00000
		Natural Gas Futures	-0.02913
		Corn Futures	-0.03955
01/2011 to 10/2015	247	New Orleans	0.96096
		Southern Great Plains	1.00000
		Natural Gas Futures	-0.01978
		Corn Futures	-0.05323
01/2012 to 10/2015	195	New Orleans	0.95936
		Great Lakes	1.00000
		Natural Gas Futures	-0.02705
		Corn Futures	-0.05840
01/2013 to 10/2015	143	New Orleans	1.01982
		Pacific Northwest	1.00000
		Natural Gas Futures	-0.04649
		Corn Futures	-0.14737
01/2014 to 10/2015	91	New Orleans	0.76050
		Pacific Northwest	1.00000
		Natural Gas Futures	0.06478
		Corn Futures	-0.13405

Note: The price elasticities are calculated by multiplying each β by (-1).

Table D3: Speed of Adjustment Parameters for Urea-NGP in Subsamples of the Post-2010 Period

Model	Observations	Price	Post-2010
Full Sample	300	New Orleans	0.18691**
		Northern Great Plains	-0.21984***
		Natural Gas Futures	-0.03609
		Corn Futures	-0.08474
01/2011 to 10/2015	247	New Orleans	0.18562**
		Southern Great Plains	-0.24426***
		Natural Gas Futures	-0.03451
		Corn Futures	-0.11720*
01/2012 to 10/2015	195	New Orleans	0.15850*
		Great Lakes	-0.25449***
		Natural Gas Futures	-0.05021
		Corn Futures	-0.11224
01/2013 to 10/2015	143	New Orleans	0.12520*
		Pacific Northwest	-0.26180***
		Natural Gas Futures	-0.07883
		Corn Futures	-0.24004***
01/2014 to 10/2015	91	New Orleans	0.13477
		Pacific Northwest	-0.43735***
		Natural Gas Futures	0.18581
		Corn Futures	-0.34152***

Note: Statistical Significance is determine with the Johansen Weak Exogeneity Test, where the null is $\alpha = 0$ and the alternative hypothesis is $\alpha \neq 0$. *, **, *** indicates significance at the 10%, 5%, and 1% levels, respectfully.