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Natural Gas Price Shocks and the U.S. Fertilizer Market: Are All Price Shocks Alike?

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Abstract

This paper examines how shocks in the natural gas and corn markets influence nitrogen fertilizer prices and how these relationships change after the 2005 and 2007 changes in biofuel policies. Using a block-recursive structural VAR framework, we decompose changes in fertilizer prices into structural shocks driven by supply, demand, and precautionary demand. The results show that fertilizer prices are influenced mainly by demand-side shocks, while supply shocks have only small effects on prices. After the structural break, corn demand shocks become more influential, indicating tighter linkages between corn and fertilizer markets. These findings imply that biofuel policies increased nitrogen fertilizer price volatility by strengthening the linkages between energy and agriculture, with fertilizer price movements driven primarily by demand-side shock

Key words: demand shocks, nitrogen fertilizer market, structural break, structural vector autoregressive model, supply shocks, urea

JEL CLASSIFICATION: Q13, Q41, C32

Introduction

How do shocks in natural gas and corn markets influence nitrogen fertilizer prices, and how did these relationships changed after structural breaks? Interest in these questions has been spurred by the recent surge in nitrogen fertilizer prices and the desire to understand the drivers of high prices. Since natural gas and corn represent the primary input and output markets for nitrogen fertilizer, their prices are widely used to explain movements in fertilizer prices, and numerous studies have examined price interrelationships (Galbraith, 2010; Beckman & Riche, 2015; Etienne et al., 2016; Crespi et al., 2022). However, there is still no consensus on the factors driving fertilizer price changes. On one hand, several studies argue that fluctuations in nitrogen fertilizer prices are primarily driven by shocks in the natural gas market rather than demand-side pressure (Huang, 2007; Dong, Beckman, and Arita, 2025). On the other hand, some recent studies find strong connections between nitrogen fertilizer and corn markets, highlighting a demand-side relationship (Beckman & Riche, 2015; Bekkerman et al., 2021; Bushnell & Humber, 2017; Etienne et al., 2016). To address this gap, the primary objective of this study is to more precisely determine when the U.S. nitrogen fertilizer market has responded more to supply and when more to demand shocks.

Fertilizers are essential to food production and a crucial factor in agricultural productivity, comprising nearly 20% of cash expenses for farming in the United States. Among fertilizers, nitrogen fertilizer accounts for the largest share of fertilizer use at 56% (IFA, 2024; Aftab and Hakeem, 2022), and globally, its use increased fourfold between 1960 and 2021 (FAO, 2024). Nitrogen fertilizer prices have been volatile over the past two decades, showing a persistent upward trend with sharp spikes in 2008 and again in 2022. In 2008, fertilizer prices surged to historic highs, with nitrogen fertilizer increasing by 32%, which was accompanied by dramatic increases in crop prices—corn by 100%, wheat by 83%, and soybeans by 112%. Unlike some other agricultural inputs—such as labor or machinery—that can be substituted or whose purchase can be delayed, nitrogen fertilizer carries over little from one year to the next, making its purchase difficult to postpone. Consequently, sharp increases in fertilizer prices haveraised concerns that fertilizer application may decline globally, potentially leading to greater food insecurity (Vos et al., 2025). Understanding fertilizer markets is therefore critical to better prepare for the next nitrogen fertilizer price spike.

While China uses coal to produce urea (Hu et al. 2025), the rest of the world mostly uses natural gas, which accounts for 70%–90% of nitrogen fertilizer variable production costs (Bicer et al., 2016). Accordingly, natural gas prices are expected to be a key driver of nitrogen fertilizer prices. Likewise, corn is the most widely planted crop in the United States, covering 94.1 million acres in 2023. It is the largest user of nitrogen fertilizer, with fertilizer accounting for 33–44% of operating costs in corn production (Ribaudo, Livingston, & Williamson, 2012). Therefore, natural gas and corn markets serve as the primary determinants of nitrogen fertilizer price fluctuations in this study.

Despite many studies on these markets, limitations of existing studies continue to constrain our understanding of these price dynamics. In this paper, we revisit this question using the approach introduced by Kilian (2009). One limitation of existing literature on the relationship between fertilizer and natural gas prices is that natural gas prices are often assumed to be exogenous. However, changes in the corn market can also influence natural gas prices (Yang, 2022), making it necessary to account for this reverse causality. This means that cause and effect are not well defined in previous literature. To address this issue, some studies have used reduced-form vector autoregression (VAR) and vector error correction (VEC) models to examine the interrelationships among these markets (Beckman & Riche, 2015; Crespi et al., 2022; Etienne et al., 2016; Galbraith, 2010). However, these models do not explicitly account for contemporaneous correlations among endogenous variables (Baum, 2013)[3]. Another limitation of the previous literature is that the impact of higher natural gas prices on the fertilizer market can be evaluated without identifying the causes of increases in natural gas prices. In particular, many studies focus only on either demand-side shocks or supply-side shocks, which may exaggerate the impact of a single side (Wang & McPhail, 2014). However, to the extent that demand and supply shocks in the natural gas market have different effects on corn and nitrogen fertilizer markets, as documented in Kilian and Park (2009), regressions of fertilizer prices on natural gas price changes will be biased toward finding insignificant relationships. Although demand and supply shocks are distinguished, both are identified using price variables (Dong, Beckman, and Arita. 2025). As a result, the distinction between shocks is based on price movement rather than actual changes in production or economic activity

In addition to these limitations, considering structural changes is crucial to understand how the connections between these markets have changed. Since the mid-2000s, many studies examining the linkages among these markets considered the implementation of U.S. biofuel policies as structural breaks in fertilizer markets. The Renewable Fuel Standard (RFS), created in 2005, required gasoline and diesel in the United States to contain increasing amounts of biofuels. Because most U.S. biofuel is made from corn, biofuel expansion sharply raised corn demand. Following the RFS, corn-for-fuel use tripled, corn acreage increased by 15%, and average farm-level corn prices nearly doubled (Bekkerman, Gumbley, and Brester, 2021). Biofuel policies changed producers' cropping decisions, suggesting that corn prices became a more influential driver of fertilizer demand through changes in cropland allocation (Bekkerman et al., 2021). In

[3] Baum (2013) points out that a limitation of the impulse response function (IRF) derived from a VAR model is that it estimates the effect of a one-time unit shock over time under the assumption that all other factors remain constant. Yet, because shocks in a reduced-form VAR are contemporaneously correlated, this assumption does not hold.

addition, the expansion of U.S. ethanol production also increased the linkage between corn and natural gas markets, as ethanol production relies heavily on natural gas as an energy source. Therefore, this paper hypothesizes that structural breaks associated with U.S. biofuel policies reshaped the transmission of corn and natural gas market shocks to the nitrogen fertilizer market.

To address these limitations, this paper employs the structural vector autoregression (SVAR) framework developed for energy markets by Kilian (2009) and Kilian and Park (2009). Following this framework, we use a block-recursive SVAR that accounts for endogenous relationships, allowing each variable to depend on its own lags as well as the lags of other variables. However, rather than the SVAR models typically estimated in agricultural economics that use only prices, the Kilian approach genuinely seeks to decompose shocks into supply and demand shocks. In this study, we disentangle demand and supply shocks in the U.S. natural gas market. The paper distinguishes three structural shocks: natural gas supply shocks, corn demand shocks, and natural-gas–market-specific demand shocks capturing precautionary demand related to concerns about future supply. In addition, we divide our sample into two periods based on a structural break and demonstrate that the RFS policy created a structural break that reshaped the transmission of structural shocks to the nitrogen fertilizer market.

The results show that shocks in the precautionary demand for natural gas were a strong driver of fertilizer price fluctuations both before and after the structural change, while natural gas supply shocks remained weak. Before the structural break, U.S. nitrogen fertilizer prices responded mainly to demand shocks originating in the natural gas market, while corn demand shocks had only limited and short-lived effects. Following the structural break associated with the biofuel policies, however, the transmission of shocks to fertilizer prices changed markedly. Corn demand shocks became both stronger and more persistent, reflecting tighter linkages between corn and fertilizer use under the Renewable Fuel Standard. Variance decomposition analysis confirms these patterns. In the pre-2006 period, natural-gas-specific demand shocks accounted for the largest share of fertilizer price movements. After 2006, corn demand shocks explain a larger portion of fertilizer price movements than before, while natural gas supply shocks remain modest. These findings suggest that U.S. nitrogen fertilizer prices have become increasingly linked to corn in the post-biofuel policy period.

Data

This study is based on a monthly dataset spanning January 1990 to December 2024. Table 1 shows the summary statistics for U.S. urea, corn, and natural gas markets. All price variables were deflated using the Consumer Price Index (CPI). Urea is chosen as the representative nitrogen fertilizer because it accounts for a large share of nitrogen use in U.S. crop production and is widely traded in international markets. The natural gas price series is the U.S. spot price for natural gas, measured in U.S. dollars per million British thermal units (USD/MMBtu), obtained from the World Bank Commodity Markets ("Pink Sheet") database.

U.S. corn price data were obtained from the USDA Economic Research Service (ERS) Feed Grains Yearbook Tables using the Central Illinois No. 2 Yellow Corn price. Corn is the dominant nitrogen-using crop in the United States and therefore serves as a natural proxy for fertilizer demand conditions in the agricultural sector. As a measure of supply conditions in the natural gas market, we use marketed U.S. natural gas production, measured in million cubic feet (MMcf), obtained from the U.S. Energy Information Administration (EIA). Following Kilian

(2009), natural gas production is measured in monthly growth rates (the first difference of the log production series), while prices are used in levels.

Table 1. Summary statistics for U.S. urea, corn, and natural gas markets, 1992–2024

Variable	Mean	Std. Dev.	Min	Max
U.S. Gulf NOLA urea price ($/mt)	214.23	105.42	84.09	662.82
U.S. corn price ($/bu)	3.54	1.60	1.49	8.15
U.S. natural gas price ($/mcf)	3.80	2.13	13.52	1.21
U.S. natural gas production($/MMcf)	2,106,426	614,234	1,400,941	3,593,870

Econometric models

We estimate a structural vector autoregression (SVAR) model with four variables. The vector of endogenous variables is $Z_t = (\Delta ngpro, Corn_t, NGprice_t, urea_t)$ where $\Delta ngpro$ denotes U.S. natural gas production growth; $Corn_t$ is the U.S. corn price; $NGprice_t$ is U.S. natural gas price; $urea_t$ is U.S. urea price; t indicates time; and Δ denotes percentage change. Following Kilian (2009), the production variable is expressed in percentage changes, while price variables—including natural gas, corn, and fertilizer prices—are expressed in levels. A recurring question in applied research is whether to express energy prices in levels or in growth rates, which depends on whether the price series exhibits a long-term trend. However, differencing price variables can remove the long cycles that are characteristic of commodity markets, thereby downplaying the importance of flow demand shocks (Kilian & Zhou, 2020, Hoover, Johansen, & Juselius, 2008). Wang and Tomek (2007) also argued against the idea that commodity prices have unit roots. For these reasons, using price variables in levels provides a more meaningful structural interpretation of the dynamic interactions among energy, agricultural, and fertilizer markets.

The SVAR model is represented as

$$\boldsymbol{A_0 Z_t} = \boldsymbol{\alpha} + \sum_{i=1}^{\rho} \boldsymbol{A_i Z_{t-i}} + \boldsymbol{\varepsilon_t}$$

where $\boldsymbol{Z_t}$ is a k vector of endogenous variables, $\boldsymbol{\alpha}$ is an $n \times 1$ vector of constants, $\boldsymbol{A_0}$ and $\boldsymbol{A_i}$ are coefficient matrixes to be estimated, and ρ denotes the lag order of the model. Models with shorter lags may fail to capture cyclical dynamics, understating the effect of flow demand shocks. Therefore, conventional lag selection criteria such as the AIC or SIC are therefore not recommended (Kilian & Zhou, 2020)[4]. The reduced form of the VAR is specified as

$$\boldsymbol{Z_t} = \boldsymbol{A_0^{-1}\alpha} + \sum_{i=1}^{\rho} \boldsymbol{A_0^{-1} A_i Z_{t-i}} + \boldsymbol{e_t}$$

where $\boldsymbol{e_t}$ is the vector of residuals in the reduced form and can be represented as

$$\boldsymbol{e_t} = \boldsymbol{A_0^{-1}\varepsilon_t}$$

The reduced form errors ($\boldsymbol{e_t}$) can be expressed into the following components:

$$\begin{pmatrix} \varepsilon_t^{\Delta ngpro} \\ \varepsilon_t^{Corn} \\ \varepsilon_t^{NGprice} \\ \varepsilon_t^{Urea} \end{pmatrix} = \begin{pmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix} \begin{pmatrix} e_{1t}^{Natural\ gas\ supply\ shock} \\ e_{2t}^{corn-specific\ demand\ shock} \\ e_{3t}^{Natural\ gas\ sepcific\ demand\ shock} \\ e_{4t}^{residual\ shock\ to\ fertilizer\ market} \end{pmatrix}$$

Impulse response is used to show the effects of demand and supply shocks on commodity prices. The reduced-form VAR can be expressed in the following Vector Moving Average (VMA) form (Sims, 1980):

[4] We set the lag order to $\rho = 12$ to capture the long and variable transmission of natural gas and oil price shocks (Hamilton & Herrera, 2004; Boeck & Zörner, 2024).

$$\boldsymbol{x_t} = \boldsymbol{\varphi}(\boldsymbol{\beta})\boldsymbol{e_t}$$

Substituting $\boldsymbol{e_t} = \boldsymbol{A_0^{-1}}\boldsymbol{\varepsilon_t}$ into this equation:

$$\boldsymbol{x_t} = \boldsymbol{\varphi}(\boldsymbol{\beta})\boldsymbol{A_0^{-1}}\boldsymbol{\varepsilon_t} = \boldsymbol{\theta}(\boldsymbol{L})\boldsymbol{\varepsilon_t}$$

where $\boldsymbol{\theta}(\boldsymbol{L}) = \sum_i^{\infty} \boldsymbol{\theta_i}\boldsymbol{L^i}$ and each $\boldsymbol{\theta_i}$ is a 4×4 matrix of parameters from the structural model. The above equation implies that the response of $\boldsymbol{x_{t+i}}$ to $\boldsymbol{\varepsilon_t}$ is $\boldsymbol{\theta_i}$. Accordingly, the sequence $\{\boldsymbol{\theta_i}\}$ for $i = 0,1,2,\ldots$, indicates the dynamic response of the variable to each of the four shocks.

Identification of natural gas and corn shocks and US fertilizer market

Our model adopts a block-recursive identification framework to describe the contemporaneous relationship between the reduced-form disturbances and structural disturbances, following Kilian and Park (2009). The first block represents the U.S. natural gas and corn markets, while the second block corresponds to the fertilizer market. In the first block, we identify three structural shocks that explain fluctuations in the real price of natural gas: (1) natural gas supply shocks, measured by growth in natural gas production; (2) corn demand shocks, captured by changes in corn price which transmit to the natural gas market through fertilizer production and use; (3) natural gas-specific demand side shock that cannot be explained by natural gas supply shocks or shocks to corn demand.

This model assumes a vertical short-run supply curve for natural gas and a downward-sloping demand curve. Given high adjustment costs in natural gas production, natural gas supply is assumed not to respond contemporaneously to innovations in natural gas demand within the same month. Under this identifying assumption, unexpected movements in natural gas production can be interpreted as supply shocks. In contrast, demand-side innovations cannot be absorbed through quantities in the short run and therefore affect market equilibrium through immediate price adjustments. Accordingly, short-run movements in the real price of natural gas following these shocks are interpreted as demand-driven.

In the fertilizer market block, there is only one equation: (4) residual shock to fertilizer market that is not measured by the first three components. The structure of identification implies that U.S. natural gas production, corn demand, and the real price of natural gas are predetermined with respect to the U.S. nitrogen fertilizer market. This means that while the nitrogen fertilizer market can respond immediately to shocks in natural gas supply and demand, the residual fertilizer-market shock affects corn and natural gas markets with at least a one-month lag.

Natural gas supply shock

Natural gas supply shocks occur when the actual supply available to the market differs from what was expected, due to disruptions in production, transportation, or capacity constraints.[5] To identify this shock, the supply of natural gas is assumed to be highly inelastic in the short run, characterized by a vertical supply curve. This assumption is consistent with EIA (2024) indicating a two-month lag between rig activity and new gas production. These lags, caused by drilling schedules, well completion, and infrastructure limitations, make short-term production

[5] Kilian (2009) defines supply shocks as unexpected innovations to the physical availability of the commodity.

adjustments difficult. In the short run, natural gas production cannot be increased immediately in response to unexpected demand changes.

Corn demand shock

Kilian (2009) defines the aggregate demand shock as an unanticipated change in global economic activity that simultaneously affects the demand for all industrial commodities. In contrast, this study focuses on the U.S. nitrogen fertilizer market, which represents a sectoral rather than global system. Accordingly, we reinterpret the aggregate demand shock in a sector-specific context and define it as the corn demand shock (ε_{2t}). ε_{2t} is driven by the agricultural sector, capturing unexpected changes in corn demand (including storage demand). This identification is supported by the empirical importance of corn in U.S. agriculture. Corn is the dominant crop in U.S. agriculture and the largest consumer of nitrogen fertilizer, accounting for more than half of total nitrogen use and a greater acreage than any other major crop. The restriction for ε_{2t} is motivated as follows. Since agricultural production and consumption adjust slowly due to biological and seasonal cycles—planting, growth, and harvest, short-term input price shocks cannot immediately affect cropping decisions. This implies that corn demand does not respond to a shock to the demand for natural gas or fertilizer market within the same month.

Natural gas market-specific demand shock

The third structural shock (ε_{3t}) primarily captures innovations in the real price of natural gas that cannot be explained by natural gas supply shocks or corn demand shocks and is therefore interpreted as a natural gas–specific demand shock. This structural shock will reflect fluctuations in precautionary demand—the residual not explained by supply or aggregate demand disturbances (Kilian, 2009). This shock arises when market participants anticipate future supply shortfalls and respond by expanding current purchases and inventory holdings, thereby increasing prices. In this paper, the terms natural gas–market specific demand shock and precautionary demand shock are used interchangeably.

Although this shock may also reflect other types of market-specific demand shocks, there are reasons to interpret this shock as exogenous shifts in precautionary demand. First, the timing and magnitude of ε_{3t} correspond to major exogenous events that increased global uncertainty about natural gas prices (see Figure 2). For example, Hurricanes Katrina and Rita (August–September 2005) increased uncertainty about future natural gas supply in the Gulf of Mexico, leading market participants to raise precautionary demand and contributing to a sharp increase in natural gas prices. Similarly, during the post-COVID recovery (2020–2021), reduced uncertainty lowered precautionary demand, resulting in lower natural gas prices. Second, the large immediate impact of natural gas–market specific shocks documented in the results section is difficult to explain without expectation-driven shocks (Killian, 2009). Third, recent studies show that it is strongly correlated with the precautionary component in the real price of natural gas based on futures markets. For example, Mensi et al. (2024) found that dependence between futures and spot prices of natural gas intensified during periods of severe economic and political events as well as throughout the COVID-19 pandemic. This forward-looking behavior supports interpreting ε_{3t} as a precautionary demand shock reflecting expectation-driven responses to future shortages.

Residual shock to fertilizer market

Whereas ε_{1t}, ε_{2t}, and ε_{3t} may be interpreted as structural innovations associated with natural gas supply, corn demand, and gas-market–specific precautionary demand, respectively, ε_{4t} is not a truly structural shock. Instead, ε_{4t} represents a residual shock encompassing fertilizer-market shocks that cannot be explained by the existing structural factors. Consistent with the block-recursive framework, the fertilizer market can respond contemporaneously to shocks in the natural gas and agricultural sectors, whereas ε_{4t} is assumed to influence those upstream markets with at least a one-month lag. This residual disturbance represents an idiosyncratic or sector-specific shock, arising from factors such as trade frictions, policy interventions, or unexpected events like weather disruptions and changes in preferences (Kilian and Park, 2009; Dong, Beckman, and Arita (2025).

Structural break

The Renewable Fuel Standard (RFS) was introduced to reduce U.S. dependence on imported oil, enhance energy security, lower greenhouse gas emissions, and stimulate rural economies by expanding the use of domestically produced renewable fuels. The first RFS was enacted under the Energy Policy Act of 2005, which required gasoline blenders to use 7.5 billion gallons of renewable fuel by 2012. The RFS was subsequently expanded under the Energy Independence and Security Act of 2007 (RFS2), which increased the mandate to 36 billion gallons by 2022 and established separate categories of renewable fuel, with corn-based ethanol designated as conventional renewable fuel (Bracmort, 2025). Because corn-based ethanol is the dominant biofuel produced in the United States, the RFS substantially increased corn demand, which led to sharp increases in corn prices during 2006–2008. Correspondingly, planted corn acreage increased by 50 percent or more in many counties across the Northern and Southern Great Plains, while increases of 10–25 percent were observed across the Corn Belt between the pre-2007 and post-2010 periods (Bekkerman et al., 2021).

The expansion of corn-based ethanol production led to an increase in natural gas demand and prices through both processing energy use and fertilizer production. Although empirical evidence suggests that a structural transition in these markets occurred during the 2000s, there is no consensus on when this structural break occurred. Beckman and Riche (2015) provide evidence of a structural break between natural gas and ammonia prices in mid-2008. Galbraith (2010) found differences in commodity and fertilizer price relationships between the 2002–2005 and 2006–2009 periods. Etienne, Trujillo-Barrera, and Wiggins (2016) point out that the relationship between corn and ammonia prices changed after 2006. These studies suggest that important changes in the U.S. fertilizer industry occurred between 2005 and 2007, but they do not identify a conclusive breakpoint. Following this timeline, this study selects 2006—the midpoint between the 2005 and 2007 biofuel policies—as the structural break associated with biofuel policy implementation.

Results and Discussion

The reduced-form VAR model is estimated using ordinary least squares. The VAR estimates are used to construct the structural VAR representation with confidence intervals obtained from a recursive-design wild bootstrap with 2,000 replications (Silvia Goncalves and Kilian 2004).

Effects of Natural Gas Demand and Supply Shocks on the Real Prices of Nitrogen Fertilizer

Before assessing the effect of structural shocks on the U.S. nitrogen fertilizer market, it is important to examine how these shocks—natural gas supply shocks, corn demand shocks, precautionary demand shock—transmit through natural gas prices. Understanding the price linkages between these shocks and the natural gas market is a crucial first step, since the fertilizer market depends heavily on natural gas prices as a key input cost. Figure 1 illustrates the dynamic responses of the real price of natural gas to the three structural shocks identified in the VAR model. The central finding in Figure 33 is that the three structural shocks have distinct effects on real natural gas prices.

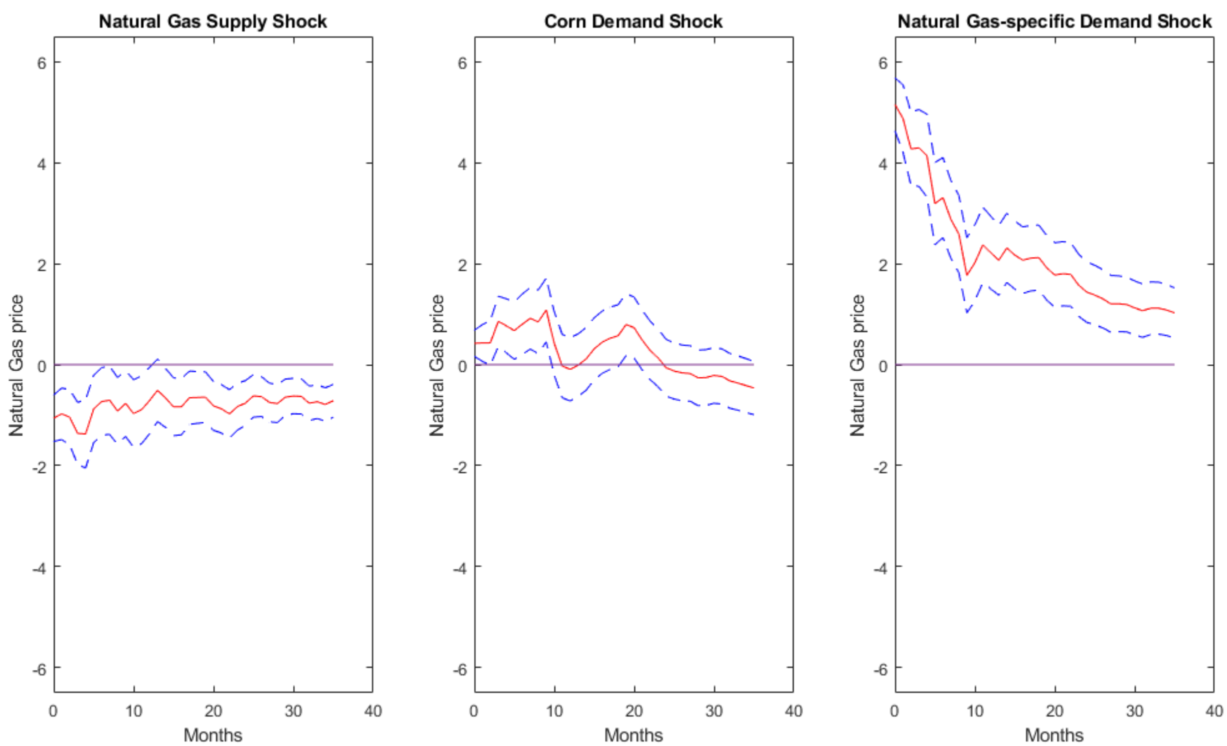

Figure 1. Responses of the real natural gas price to structural shocks, with one-standard-error bands indicated by dashed and dotted lines.

For instance, an unexpected increase in natural gas production causes a persistent negative response to the natural gas price. The effect decays only gradually over the horizon, indicating more persistent price effects than those typically observed in oil markets (Kilian and Park, 2009). This persistence is consistent with features of natural gas markets: (1) Transportation rigidities: Unlike crude oil, natural gas is primarily transported through fixed pipeline networks and liquefied natural gas (LNG) terminals, both of which are costly and time-consuming to expand. As a result, supply adjustments and rerouting are difficult in the short run, and terminal capacities remain limited. (Zörner & Petz, 2022). (2) High market concentration: Natural gas markets are dominated by a few major producers (e.g., Russia, Qatar, and the United States), which limits supply adjustment, making price shocks more persistent. An unanticipated corn demand disruption leads to an immediate, but temporary, increase in natural gas prices. This transitory response occurs because corn accounts for only a small share of total industrial gas consumption, and the broader gas system can absorb the shock rapidly. In contrast, a natural gas-specific demand shock has an immediate and persistent increase in natural gas prices. Our results suggest that short-run volatility in natural gas prices is primarily driven by demand—especially precautionary demand, as emphasized by Kilian and Park (2009)—while supply shocks lead to more persistent yet relatively weak negative effects.

Historical Decomposition of Fertilizer Prices

Although impulse response functions show the timing and size of the effects of demand or supply shocks in the natural gas market, natural gas price fluctuations in the real world are rarely driven by a single, one-time shock. Their cumulative impact is demonstrated with a historical decomposition, which traces changes in the real price of natural gas to each type of shock (Killian and Park, 2009). Figure 2 shows the cumulative contributions of natural gas supply shocks, corn demand shocks, and natural gas–specific demand shocks to the real price of fertilizer based on the historical decomposition. The results in Figure 2 show that natural gas supply shocks have made only limited contributions to fertilizer price fluctuations, while natural gas price shocks are primarily driven by corn demand shocks and natural gas-specific demand shocks. This finding is consistent with the oil market literature, where oil supply shocks play only a limited role and demand shocks dominate the historical evolution of prices (Kilian 2009; Kilian and Park 2009). For example, the increase in the real price of natural gas in 2000 and 2001 was mainly driven by an increase in precautionary demand during the California energy crisis, when surging electricity demand and depleted gas inventories led to precautionary buying in natural gas markets. Similarly, the spike in natural gas prices in 2005–2006 corresponds to Hurricanes Katrina and Rita, which disrupted LNG terminals and refining facilities in the Gulf of Mexico, thereby increasing precautionary demand shocks. Another surge in natural gas prices occurred during the 2013–14 winter. Persistent cold weather and record inventory drawdowns pushed the Henry Hub spot price up 16% from 2013, reflecting supply concerns and expectations of another cold winter (U.S. Energy Information Administration, 2015). More recently, when uncertainty declined— such as during the post-COVID recovery (2020–2021) — the cumulative effect of natural gas market-specific demand turned negative, as inventories fell and market expectations returned to normal. The decomposition further indicates that natural gas price volatility reflects the combined influence of agricultural demand pressures and market-specific shocks.

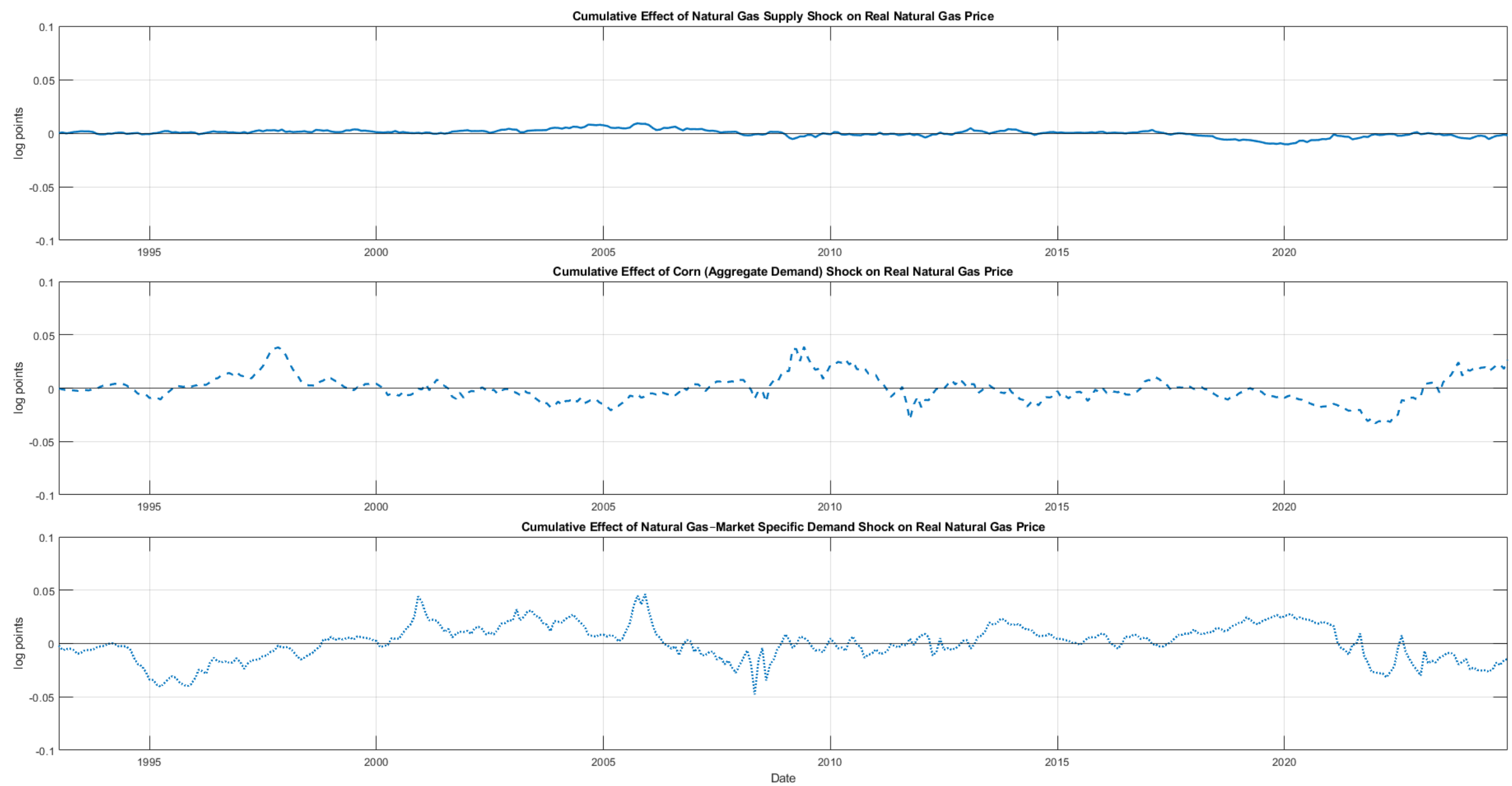

Figure 2. Historical Decomposition of Real Price of Natural Gas

Figure 3 plots the impulse response functions for the full sample period and for two periods identified through structural breaks: full sample period (1990-2024, green line), period 1 (1990–2005, blue line) and period 2 (2006–2024, red line). This comparison illustrates how the transmission of three structural shocks (e_{1t}, e_{2t} and e_{3t}) to fertilizer prices has changed over time. For the full sample period (1990~2024), an unanticipated increase in natural gas production leads to a slight rise in fertilizer prices after six to seven months. This result is not consistent with standard economic theory, since higher natural gas production would lower natural gas prices and reduce fertilizer production costs. In contrast, both corn demand and natural-gas-specific demand shocks generate statistically significant and persistent increases in fertilizer prices. This finding illustrates that fertilizer prices respond to both higher crop prices that boost fertilizer demand, and precautionary demand shocks in the natural gas market that increase production costs. During the earlier period (1990–2005), unanticipated increased natural gas production has a significant negative impact for a horizon up to 3 months and then gradually dissipates. On the other hand, disruptions in corn demand cause a nonsignificant impact on fertilizer prices (partially significant, but with a transitory impact) indicating limited pass-through to fertilizer prices. This pattern suggests that the corn demand–price channel was not quantitatively important in this period. An increase in the precautionary demand for natural gas would cause a sustained increase in U.S. fertlizer prices.

In period 2 (2006–2024), the results show that the impacts of demand-side shocks are much stronger and more persistent than in the earlier period. An increase in natural gas production has a significant negative effect on U.S. nitrogen fertilizer prices for up to four months. The effect of an unanticipated corn demand expansion on fertilizer prices has a stronger and more persistent influence: fertilizer prices increase sharply upon impact, followed by a temporary dip around months 6–7, and subsequently rebound to remain elevated. This dip-rebound pattern is consistent with seasonal nitrogen applications in U.S. corn production. Nitrogen fertilizer is applied several times throughout the year: during the fall, early spring, and after planting (Wade & Claassen, 2016). The initial increase in fertilizer prices is caused by increased nitrogen applications in fall and spring, while the second rebound corresponds to the after-planting application. The overall stronger effect reflects a tighter linkage between corn and fertilizer markets following the introduction of the Renewable Fuel Standard (RFS) in 2005 and 2007.

Natural gas market-specific demand shocks also play a dominant role in the post–biofuel policy period. An unexpected increase in precautionary demand has an immediate, large and persistent positive effect on fertilizer prices that is highly statistically significant. The spike observed in the first few months can be explained by precautionary demand shocks driven by increased unceratinty about future shortfalls in natural gas supply. In 2022, about 99% of total U.S. natural gas imports came from Canada, transported almost entirely through fixed cross-border pipelines (EIA, 2023). This infrastructure limits the flexibility of supply adjustments and thereby increases price volatility: when expectations of future shortages increase, market participants attempt to secure gas supplies in advance, placing immediate upward pressure on prices. Overall, these results show that supply shocks remain minor and transitory, whereas demand-side disturbances have become increasingly persistent drivers of fertilizer prices in the post-2006 period.

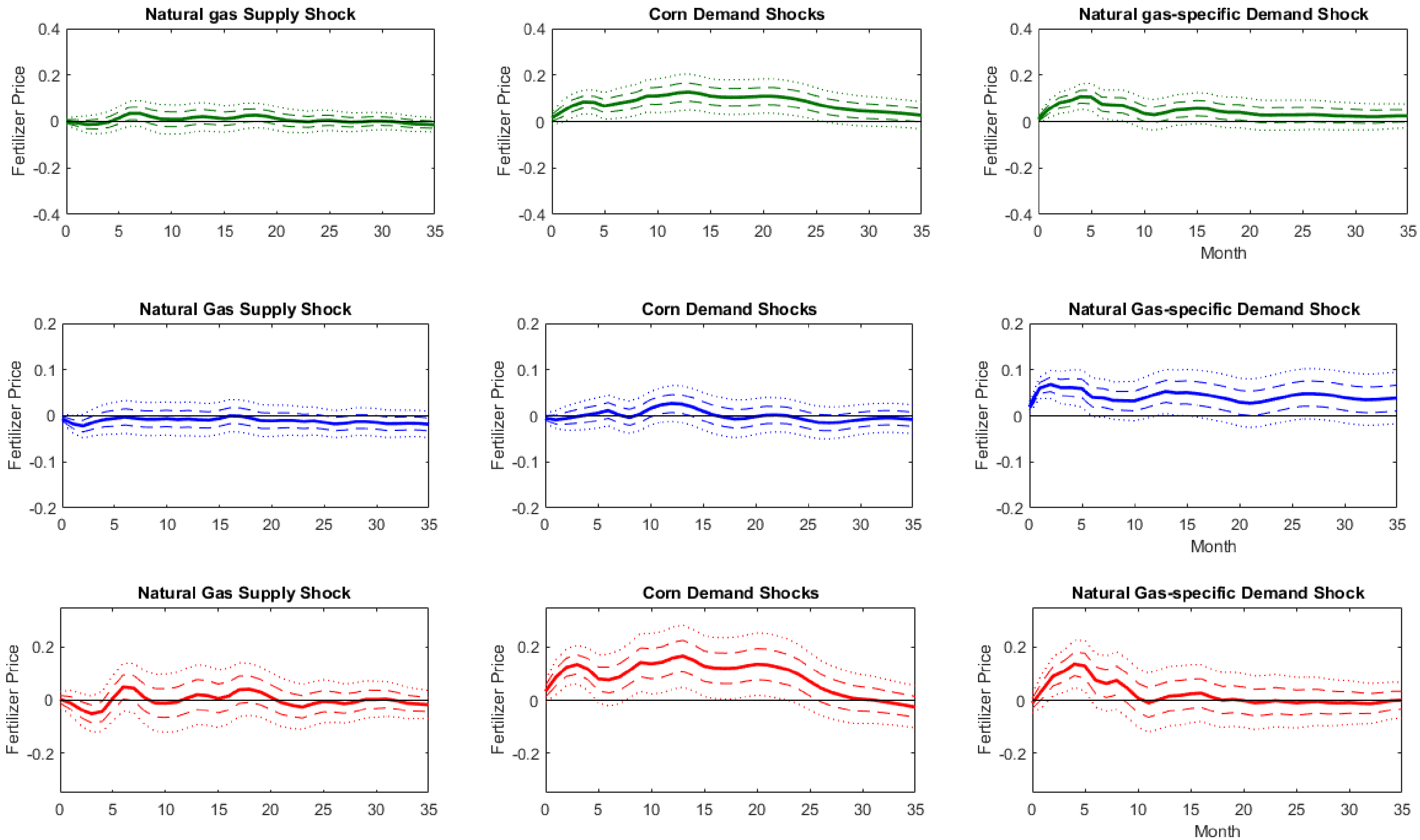

Figure 3. Fertilizer price responses to natural gas and corn shocks

Note: The y-axis shows responses in units of the fertilizer price (scaled as indicated). Green: Full sample (1990–2024); Blue: pre-2006 (1990–2005); Red: post-2006 (2006–2024)

Tables 2, 3 and 4 show variance decompositions that quantify the extent to which fluctuations in U.S. nitrogen fertilizer prices can be attributed to the three identified structural shocks (e_{1t}, e_{2t} and e_{3t}) before and after the structural break as well as the full sample period. In the pre-2006 sample (1990–2005), the explanatory power of these shocks is relatively minor in the short run: only about 1.8% of the variation in fertilizer prices is explained by shocks from the natural gas market. As the horizon lengthens, the explanatory power gradually increases; in the long run, about 30% of the variability in fertilizer prices is explained by the three shocks, with natural gas–specific demand shocks accounting for the largest share (16.5%). By contrast, in the post-2006 period (2006–2024), corn demand shocks become much more important. In the long run, they explain nearly 20% of the variance, a sixfold increase compared with the earlier period. Natural gas supply shocks, however, remain small across both subsamples. These results indicate that, following the implementation of the 2005 and 2007 biofuel policy, U.S. fertilizer prices became more closely linked to the corn market than to the natural gas market.

Table 2. Percentage contribution of demand and supply shocks in the natural gas market to the overall variability of U.S. real fertilizer prices (1990-2005)

Horizon	NG Supply Shock	Corn Demand Shock	NG-specific Demand Shock	Other Shocks
1	0.07	0.55	1.26	98.13
2	0.32	0.16	11.81	87.72
3	1.01	0.19	15.95	82.84
12	7.62	1.22	18.22	72.94
24	7.86	1.98	13.51	76.67
36	7.60	2.59	12.51	77.30
∞	8.82	3.84	16.47	70.87

Table 3. Percentage contribution of demand and supply shocks in the natural gas market to the overall variability of U.S. real fertilizer prices (2006-2024)

Horizon	NG Supply Shock	Corn Demand Shock	NG-specific Demand Shock	Other Shocks
1	0.08	1.13	0.04	98.81
2	0.13	3.25	0.91	95.72
3	1.05	5.97	4.90	88.07
12	1.57	9.85	10.93	77.65
24	1.74	20.70	10.36	67.19
36	2.96	20.02	10.58	66.45
∞	3.96	19.86	12.14	64.03

Table 4. Percentage contribution of demand and supply shocks in the natural gas market to the overall variability of U.S. real fertilizer prices (1990-2024)

Horizon	NG Supply Shock	Corn Demand Shock	NG-specific Demand Shock	Other Shocks
1	0.001	0.25	0.25	99.50
2	0.03	0.75	2.97	96.26
3	0.11	1.51	6.76	91.49
12	1.16	9.43	12.04	77.37
24	1.25	17.03	11.40	70.32
36	1.37	17.21	11.73	69.69
∞	2.28	18.79	12.25	66.68

Summary and Conclusions

This paper examines how shocks in the U.S. natural gas and corn markets influence nitrogen fertilizer prices and how structural breaks reshaped these relationships over time. We use a block-recursive SVAR to disentangle the shocks into natural-gas supply shocks, corn-specific demand shocks, and natural-gas-market–specific (precautionary) demand shocks, while accounting for the structural changes associated with the mid-2000s biofuel policies. The results have four implications. First, impulse responses show that corn demand shocks and natural-gas-specific demand shocks led to statistically significant and persistent increases in fertilizer prices in the full sample, whereas natural-gas supply shocks were comparatively weak and temporary. Second, after accounting for the structural break, the impact of supply shocks became statistically significant and more consistent with economic theory. Third, the strength and persistence of these demand-driven effects intensified in the post-2006 period, reflecting the seasonal timing of nitrogen application sand the strengthened corn–fertilizer linkage after the RFS expansion. Fourth, variance decompositions support these dynamics: while the precautionary demand shock accounts for the largest share before 2006, corn demand shocks became more dominant after 2006, explaining nearly one-fifth of the long-run variance. In contrast, natural gas supply shocks remained quantitatively small in both subsamples.

These results imply that the post-2006 fertilizer market was driven primarily by demand-side forces linked to agricultural sector and precautionary behavior in energy markets, rather than by supply disruptions in natural gas. The structural interpretation is economically intuitive. Biofuel policies increased the derived demand for corn and, through both fertilizer and natural gas use in ethanol production, strengthened the link between agricultural and energy markets. Limited short-run inventory adjustment and restricted natural gas transport capacity cause demand shocks to have larger effects on prices, making fertilizer prices more vulnerable to precautionary demand shocks than to short-term supply disruptions. Since fertilizer prices are driven primarily by demand shocks from corn and natural gas markets rather than supply disruptions, forecasts may need to place greater emphasis on changes in agricultural demand and expectations in energy markets. With respect to biofuel policy, the finding that fertilizer prices became more tightly linked to the corn market after 2006 suggests that fuel standards transmitted significant input-cost volatility into crop production. Overall, the post-2006 U.S. fertilizer market has stronger and more persistent sensitivity to demand-driven shocks from corn and natural gas than to supply shocks in natural gas.

REFERENCES

Aftab, T., and K.R. Hakeem. 2022. *Sustainable Plant Nutrition: Molecular Interventions and Advancement for Crop Improvement.* Cambridge, MA: Academic Press.

Alquist, R., and L. Kilian. 2010. "What Do We Learn from the Price of Crude Oil Futures?" *Journal of Applied Econometrics* 25(4): 539–573.

Baumeister, C., and G. Peersman. 2013. "Time-Varying Effects of Oil Supply Shocks on the U.S. Economy." *American Economic Journal: Macroeconomics* 5(4): 1–28.

Beckman, J., and S. Riche. 2015. "Changes to the Natural Gas, Corn, and Fertilizer Price Relationships from the Biofuels Era." *Journal of Agricultural and Applied Economics* 47(4): 494–509.

Bekkerman, A., T. Gumbley, and G.W. Brester. 2021. "The Impacts of Biofuel Policies on Spatial and Vertical Price Relationships in the U.S. Fertilizer Industry." *Applied Economic Perspectives and Policy* 43(3): 802–822.

Boeck, M., and T.O. Zörner. 2025. "Natural Gas Prices, Inflation Expectations, and the Pass-Through to Euro Area Inflation." *Energy Economics* 141: 108061.

Bracmort, K. 2025. *The Renewable Fuel Standard (RFS): An Overview* (CRS Report R43325). Congressional Research Service.

Bushnell, J., and J. Humber. 2017. "Rethinking Trade Exposure: The Incidence of Environmental Charges in the Nitrogenous Fertilizer Industry." *Journal of the Association of Environmental and Resource Economists* 4(3): 857–894.

Crespi, J.M., C. Hart, C.C. Pudenz, L.L. Schulz, O. Wongpiyabovorn, and W. Zhang. 2022. *An Examination of Recent Fertilizer Price Changes.* Staff Report 22-SR 117, Center for Agricultural and Rural Development, Iowa State University.

Dong, F., J. Beckman, and S. Arita. 2025. "Unraveling Demand and Supply Shocks in the U.S. Nitrogen Market." *Applied Economic Perspectives and Policy.* In Press.

Dornbusch, R. 1976. "Expectations and Exchange Rate Dynamics." *Journal of Political Economy* 84(6): 1161–1176.

Energy Information Administration (EIA). 2010a. *Annual Energy Review 2009.* Washington, DC: U.S. Department of Energy.

Etienne, X.L., A. Trujillo-Barrera, and S. Wiggins. 2016. "Price and Volatility Transmissions Between Natural Gas, Fertilizer, and Corn Markets." *Agricultural Finance Review* 76(1): 151–171.

Gonçalves, S., and L. Kilian. 2004. "Bootstrapping Autoregressions with Conditional Heteroskedasticity of Unknown Form." Journal of Econometrics 123 (1): 89–120.

Hamilton, J.D., and A.M. Herrera. 2004. "Comment: Oil Shocks and Aggregate Macroeconomic Behavior: The Role of Monetary Policy." *Journal of Money, Credit and Banking* 36(2): 265–286.

Hoover, K.D., S. Johansen, and K. Juselius. 2008. "Allowing the Data to Speak Freely: The Macroeconometrics of the Cointegrated Vector Autoregression." *American Economic Review* 98(2): 251–255.

Huang, W. 2007. "Impact of Rising Natural Gas Prices on U.S. Ammonia Supply." U.S. Department of Agriculture, Economic Research Service.

Hu, Z., Yan, L., Yuan, J., and Etienne, X. (2025). Deconstructing fertilizer price spikes: Evidence from Chinese urea fertilizer market. *Food Policy*, *133*, 102829.

International Fertilizer Association (IFA). 2024. "Fertilizer Consumption – Historical Trends by Country and Region in the World." https://www.ifastat.org/databases/graph/1_1.

Jones, K., and F.K. Nti. 2022. "Impacts and Repercussions of Price Increases on the Global Fertilizer Market." *International Agricultural Trade Report*, USDA Foreign Agricultural Service.

Kilian, L. 2008. "Exogenous Oil Supply Shocks: How Big Are They and How Much Do They Matter for the U.S. Economy?" *Review of Economics and Statistics* 90(2): 216–240.

Kilian, L. 2009. "Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market." *American Economic Review* 99(3): 1053–1069.

Kilian, L., and D.P. Murphy. 2014. "The Role of Inventories and Speculative Trading in the Global Market for Crude Oil." *American Economic Review* 104(3): 379–383.

Kilian, L., and C. Park. 2009. "The Impact of Oil Price Shocks on the U.S. Stock Market." *International Economic Review* 50(4): 1267–1287.

Kilian, L., and X. Zhou. 2020. "The Econometrics of Oil Market VAR Models." Federal Reserve Bank of Dallas Working Paper No. 2006.

Koirala, N.P., L. Nyiwul, Z. Hu, R. Al-Hmoud, and D.P. Koirala. 2025. "Geopolitical Risks and Energy Market Dynamics." *Energy Economics* 150: 108814.

Monaco, H., N. Paulson, and G. Schnitkey. 2025. "Trends in Fertilizer Use and Efficiency in the U.S." *farmdoc daily* 15(98).

Mensi, W., M. Brahim, S. Hammoudeh, A.K. Tiwari, and S.H. Kang. 2024. “Time-Varying Causality and Correlations Between Spot and Futures Prices of Natural Gas, Crude Oil, Heating Oil, and Gasoline.” *Resources Policy* 93: 105077.

Oliver, M.E., C.F. Mason, and D.C. Finnoff. 2014. “Pipeline Congestion and Basis Differentials.” *Journal of Regulatory Economics* 46(3): 261–291.

Sims, C.A. 1980. “Macroeconomics and Reality.” *Econometrica* 48(1): 1–48.

Stewart, W., and T. Roberts. 2012. “Food Security and the Role of Fertilizer in Supporting It.” *Procedia Engineering* 46: 76–82.

United States Department of Agriculture (USDA). 2019. “Fertilizer Use and Price.” USDA Economic Research Service. https://www.ers.usda.gov/data-products/fertilizer-use-and-price.

United States Department of Agriculture, National Agricultural Statistics Service (USDA NASS). 2024. “Corn Planted Acreage Down 3% from 2023, Soybean Acreage Up 3% from Last Year.” https://www.nass.usda.gov/Newsroom/2024/06-28-2024.php.

United States Geological Survey (USGS). 2000. “Nitrogen Statistics and Information: Mineral Yearbook.” https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/mineral-pubs/mcs/mcs2000.pdf.

U.S. Energy Information Administration (EIA). 2015. “Natural Gas Prices Drop Following Strong Production Growth.” *Today in Energy.* https://www.eia.gov/todayinenergy/detail.php?id=19751

U.S. Energy Information Administration (EIA). 2024. *Drilling Productivity Report: Methodology and Sources.* Washington, DC: U.S. Department of Energy.

Wade, T., and R. Claassen. 2016. “Major Crop Producers Apply Most Nitrogen Fertilizer in the Spring and After Planting.” USDA Economic Research Service.

Wang, D., & Tomek, W. G. (2007). Commodity prices and unit root tests. *American Journal of Agricultural Economics*, *89*(4), 873-889.

Wang, S.L., and L. McPhail. 2014. “Impacts of Energy Shocks on U.S. Agricultural Productivity Growth and Commodity Prices—A Structural VAR Analysis.” *Energy Economics* 46: 435–444.

Wongpiyabovorn, O., and C. Hart. 2024. “Examining the Factors of Fertilizer Pricing.” *Journal of the Agricultural and Applied Economics Association* 3: 572–583.

World Bank. 2025. *Commodity Prices (“Pink Sheet”).* World Bank, Washington, DC. Available online at https://www.worldbank.org/en/research/commodity-markets

Yang, Z., X. Du, L. Lu, and H. Tejeda. 2022. "Price and Volatility Transmissions Among Natural Gas, Fertilizer, and Corn Markets: A Revisit." *Journal of Risk and Financial Management* 15(2): 1–14.

Zörner, T., and N. Petz. 2022. "Macroeconomic Implications and Differences of Oil and Gas Price Shocks." SUERF Policy Brief No. 335.