Regional Dynamic Price Relationships of Distillers Dried Grains in U.S. Feed Markets

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I dedicate this work to Meg and our much-anticipated son, Weston. I also dedicate this to my brothers and sisters in Law Enforcement pursuing higher education: in order to refine our communities we must first refine ourselves.

ABSTRACT

Distillers dried grains with solubles (DDGS) is now a mainstream substitute in U.S. animal feed rations. DDGS is rich in fat and protein content and serves as a competitive feed source in livestock markets. The objective of this study is to identify dynamic price relationships among DDGS, corn, soybean meal, and livestock outputs in context of specific livestock sectors and their geographic location. Four locations associated with a predominant livestock sector are selected for analysis by measuring density and relative proportion of a livestock sector's grain consumption at the county level. A vector error correction model is applied to post-mandate weekly price data in California, Iowa, Kansas and Georgia to estimate dynamic price relationships among DDGS, corn, soybean meal, and livestock sector outputs. Results from Granger causality tests and forecast error variance decomposition show DDGS exhibits varied relationships with the commodities among the four markets. Inconsistent causal structures in the two Midwest locations reveals differences in DDGS utilization among Iowa hog and Kansas cattle markets. Price relationships appear less developed in California dairy industries while no evidence of these interactions is discovered in Georgia poultry markets.

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CHAPTER I: INTRODUCTION

Background

U.S. ethanol production surged in the 2000's after the Renewable Fuels Standard (RFS) was introduced in the Energy Act of 2005 and subsequently revised to a higher target level in the Energy Independence and Security Act of 2007 (EPA 2007). The RFS mandated a corn-ethanol production increase from 8 billion gallons in 2008 to 15 billion gallons per year from 2015 through 2022. Increased ethanol production resulted in a corresponding increase in the production of ethanol coproducts (Mathews and McConnell 2009). Distillers dried grains with solubles (DDGS), is the main value-added commodity of the corn-ethanol industry and accounts for the majority of ethanol coproducts produced in the U.S. (Hoffman and Baker 2010). DDGS supply is directly proportionate to ethanol production volume as one bushel of corn converts to roughly 2.8 gallons of ethanol and 17.5 pounds of DDGS (Dooley and Martens 2008). The U.S. Department of Agriculture (USDA) data reports DDGS production increased from about 9.2 million metric tons in 2005-2006 to 36.1 million metric tons in 2014-2015 (USDA 2015). DDGS has long been used as a feed ingredient in livestock rations in limited quantities (Wright, Mitchell, and Hudson 2012). DDGS have emerged as a mainstream feed ration ingredient in the U.S. and plays a key role in both livestock and ethanol industry profits.

The ethanol refinement process removes the starch content from the corn while the remaining content of proteins, fat, and other minerals is subsequently dried to form DDGS (Hoffman and Baker 2010). The coproduct also retains other components of corn such as fiber and key minerals (Berger and Good 2008). Due to its concentrated nutritional value relative to traditional feed grains, DDGS has been a flexible component in a number of livestock sector feed rations to meet energy and protein requirements (Dooley 2008). The protein content in DDGS

allows livestock producers to substitute DDGS for soybean meal (SBM) in feed rations, and its fat content reduces the need for a carbohydrate grain such as corn. For example, DDGS may provide 110-130% energy value relative to corn in finishing-cattle applications (Berger and Good 2008). The per-pound nutritional value of DDGS is greater than an equivalent combination of traditional feed grains: on average, one metric ton of DDGS is estimated to substitute around 1.22 metric tons of combined corn and SBM feeds in the aggregate U.S. livestock market (Hoffman and Baker 2011). In addition to protein and energy content, concentrated levels of amino acids and nutrients present in DDGS potentially lower the need for mineral supplement in feed rations (Mathews and McConnell 2009). Clearly, DDGS's high nutrient value has made it an attractive input for livestock producers.

Rising feed costs challenge profit margins in livestock operations. Babcock (2010) observed a $2/bushel increase in corn and $90/ton increase in SBM prices from April 2010 to November 2012. The author estimated costs of feeding hogs, cattle on feed, dairy cattle, laying hens, and broiler chickens increased by 27%, 24%, 21%, 12%, and 8%, respectively. Animal producers rapidly adopted DDGS to offset feed costs in years immediately following ethanol mandates and potential DDGS demand was quickly saturated among midwestern livestock markets (Dooley 2008). The National Agricultural Statistics Service (NASS) surveyed roughly 9,400 Midwestern livestock operations regarding ethanol coproduct use as of 2006 (USDA 2007). Results show a sizable percentage of livestock operations already utilized DDGS in feed rations within a year following the 2005 Energy Act; 22% of dairy cattle, 14% of cattle on feed, 13% of beef cattle, and 37% swine operations reported DDGS use in 2006. Additionally, a substantial percentage of operations reported that they considered coproduct use. A 2008 survey of Nebraska cattle producers reported roughly 59% of respondents included coproducts in feed

rations (Waterbury et al. 2009). Hoffman and Baker (2011) average several estimates of DDGS consumption by livestock sector and conclude beef industries consume approximately 65.4% of domestic DDGS, dairy industries consume 14.6%, swine consume 8.2%, and poultry industries consume 11.8%. Additionally, the maximum recommended amount of DDGS an animal type is able consume, as a percent of dry matter intake, may vary from one livestock sector to another. Reports of maximum inclusion rates are 30% for beef cows, dairy cows and market hogs. However, max inclusion rates for cattle on feed and poultry industries are 40% and 15%, respectively (Hoffman and Baker 2011).

In addition to cost-saving incentives among livestock producers, DDGS is also a value-added product to ethanol refineries. Dhuyvetter, Kastens, and Boland (2005) predicted ethanol production mandates would attract many new market entrants and coproducts would become increasingly important to financial success as competition in the fuel ethanol industry increased. USDA reports additional revenues generated by DDGS are crucial to sustain ethanol plant profitability, especially during phases of low fuel prices (Matthews and McConnell 2009). Roughly 30% of corn's value is retained through DDGS sales and the coproduct typically accounts for 10-20% of ethanol plant revenue (Arora, Wu, and Wang 2010; Moss, Schmitz, and Schmitz 2014).

Problem Identification

DDGS quickly emerged as a valuable commodity essential for profitability among both producers and end-users. However, its rapid evolution as a mainstream feed ingredient outpaced efforts to measure basic market information. DDGS price reports and related economic figures are particularly limited compared to traditional feed commodities. Although a substantial number of ethanol plants actively participate in the DDGS market, coproduct pricing is only publicly

reported for a handful of markets (Schroeder 2009). Stroade et al. (2010) explained the coproduct market appears thinly traded since transactions between DDGS buyers and sellers are often private and unreported. The authors noted ethanol plants frequently price DDGS using formula methods, which also limit negotiated cash transactions.

Numerous studies investigate optimal DDGS inclusion rates for various livestock sectors from animal performance in feeding trials. The U.S. Grains Council published a thorough literature review on this topic and compiled general estimates of DDGS feeding practices (USGC 2012). However, no general consensus exists among DDGS inclusion rate studies and a number of studies produce conflicting results (Anderson, Anderson, and Sawyer 2008; Wright, Mitchell, and Hudson 2012). Jones et al. (2007) noted many DDGS feed performance studies are potentially biased due to a narrow scope that often references a single or few feed trials. Additionally, Klasing (2012) reported the majority of this research focuses on identifying an upper threshold for DDGS inclusion rates where animal growth, efficiency, and carcass quality exhibit diminishing marginal returns. The author argues actual inclusion rates are determined according to a least-cost feed ration formula and depend upon production factors specific to an individual firm.

The geographic distribution and population density of various livestock sectors are key factors influencing DDGS utilization, and the coproduct's application varies substantially according to dietary requirements specific to each animal type (Hoffman and Baker 2011). For example, DDGS potentially replaces a larger maximum percentage of dry matter in feed rations for ruminating livestock (e.g. dairy and beef) compared to monogastric species (e.g. swine and poultry) due to their capacity to digest fiber (Berger and Good 2008). U.S. livestock production is unevenly distributed across the country and varies in both spatial location and animal

population density (Klasing 2012). Dhuyvetter, Kastens, and Boland (2005) map the distribution of livestock inventories and report major animal sectors are clustered and situated in certain U.S. regions. The authors also note the likelihood of livestock producers adopting DDGS increases for operations in close proximity to ethanol production, and these operations may consume higher levels of DDGS than those further from coproduct sources.

Perhaps the most prominent source of regional variation in DDGS utilization is spatial dependence in the coproduct's price relative to competing feed ration inputs. Feed prices in a given location reflect local supply and demand conditions and other region-specific factors unique to a market (Klasing 2012). Faced with these prices, livestock producers formulate least-cost rations to reflect the most cost-effective combination of inputs while meeting minimum nutritional requirements. DDGS price and nutritional content determine its feeding value within least-cost ration formulas (Beckman, Keeney, and Tyner 2011), and the volume of DDGS utilized in animal diets is contingent upon its value in relation to competing feed inputs (Baker and Babcock 2008). Additionally, DDGS serves as a dual-purpose feed ingredient and may displace both corn and SBM simultaneously in livestock feed rations. Therefore, price fluctuations in corn, SBM, DDGS, or any combination of the three affect relative DDGS price and impact its application in feed rations (Moss, Schmitz, and Schmitz 2014).

Livestock operations frequently adjust feed rations according to fluctuations in feed prices to maintain least-cost formulas, and DDGS may displace an ingredient if the coproduct's value is higher than the alternative feed (Klasing 2012). Market prices of frequently substituted feeds become correlated over time as a manifestation of an underlying economic equilibrium relationship (Anderson, Anderson, and Sawyer 2008). These dynamic price relationships among feedstuffs illustrate underlying behaviors of market participants in a given area. The literature

contains examples of DDGS price dynamics research conducted at the national level or studies limited to individual markets. However, no studies compare dynamic relationships among local spot prices across multiple markets. The spatial dimension of the research problem and the need to understand how DDGS is utilized differently among separate regions has yet to be addressed. Furthermore, no studies attempt to connect dynamic price relationships between DDGS, competing feed inputs, and livestock outputs to individual livestock sectors' least-cost feed rationing practices.

Research Objective

Acknowledging the gap in DDGS price study literature regarding a regional comparison of DDGS price relationships, the primary research objective is identifying and comparing dynamic price relationships between DDGS, corn, soybean meal, and livestock commodities across regional U.S. livestock markets. The study evaluates a hypothesis that DDGS substitution into feed rations varies regionally based on geographic distributions of major DDGS-consuming livestock sectors.

CHAPTER II: LITERATURE REVIEW

The literature review is organized into three sections. First, feed ration cost-minimization studies are reviewed and summarized for conceptual framework in this study. Second, recent DDGS price analyses using time-series econometric procedures are outlined to explore relevant analytical methods, explore gaps in the research topic, and compare outcomes of similar studies. Third, studies employing spatial analysis procedures in similar topics are discussed to explore several of the methods used in this study and to demonstrate the advantages of analyzing the spatial context of a research problem.

DDGS in Least Cost Feed Rations

Solutions to the least cost feed ration problem for DDGS are explored in the literature to investigate how DDGS replaces other feeds in animal diets. Jones et al. (2007) analyze DDGS as a corn substitute specifically for beef feedlot rations under a cost-minimization framework. The study models the relative price of other feed ingredients in effort to find an economically optimal DDGS inclusion rate given varying grain prices and transportation costs. Results suggest, holding the price of other feeds constant at 2007 prices, an optimal DDGS inclusion rate is 22% of fed cattle dry matter intake. The model allows DDGS transportation costs to vary, and optimal DDGS inclusion rates to decrease by 3% for every additional 50 mile increase in transportation distance. A sensitivity analysis is conducted to explore hypothetical change under a high DDGS-to-corn price ratio. Optimal DDGS inclusion rates range from 10%-35% given historical relative prices of DDGS and corn.

Baker and Babcock (2008) estimate the shadow price of energy, protein and other nutrients for DDGS and other common feed in a typical feed ration using a cost-minimizing linear programming model. Using weekly DDGS, SBM, and corn prices from northern Iowa, the

authors calculate a maximum price each livestock sector would be willing to pay for DDGS based on its nutritional offering. With a corn bushel price of $4.65 and SBM ton price of $337, results show beef cattle, dairy cattle, hogs, and poultry should be willing to pay an average of $293.07, $318.16, 236.14, and $220.43 per ton of DDGS, respectively. The article factors transportation costs into the model and notes livestock operations near DDGS suppliers will benefit by acquiring DDGS far below the calculated willingness-to-pay figure.

Arora, Wu, and Wang (2010) estimate DDGS feed displacement ratios in beef, dairy, swine, and poultry rations. Displacement ratios are based on animal-specific inclusion rate and computed at two levels of DDGS market penetration. Potential DDGS use is measured in grain consuming animal units (GCAU) developed by USDA's Economic Research Service. The study reports DDGS are able to replace a proportion of 1.20, 0.44, 0.58, and 0.55 of corn for beef, dairy, swine, and poultry, respectively. The ratios for SBM are 0.55, 0.42, and 0.48 for dairy, swine, and poultry, respectively. Beef displacement ratios for SBM are not measured.

Identifying a research gap in sector-level substitution practices, Beckman, Keeney, and Tyner (2011) evaluate DDGS demand responsiveness in feed ration decisions. A hybrid model consisting of econometric methods and feed ration simulations is constructed to measure adjustments in feed rationing as feed prices increase. Using the relative price of competing inputs and their nutrient profiles, optimal rations are determined using a cost minimization procedure. The authors find, despite popular use of DDGS as a protein replacement, the feed is more responsive to price fluctuation in energy feed substitutes.

A feed-ration model developed by Moss, Schmitz, and Schmitz (2014) compares the benefit-cost ratio of inputs in livestock and poultry diets. The cost-minimization model allows a derived demand curve to be developed for a variety of feedstuffs and effects of increased ethanol

production are analyzed under this framework. The model reports lower DDGS price and increased usage following ethanol-induced rises in corn price. In addition, the authors determine ethanol producer profitability partially depends on the relative price of corn, SBM, and DDGS.

DDGS Dynamic Price Relationships

A number of studies in the literature approach DDGS market analysis by measuring the strength of price relationships among feed grains in the U.S. feed marketplace. Specifically, the degree to which DDGS price co-moves with prices of other feed inputs is observed. These co-movements are determined econometrically by a measure of market cointegration, or the general tendency for market prices to exhibit long-run relationships with each other (Johansen 1988). Cointegration studies initiate from the economic notion of equilibrium price relationships between a commodity and its competing substitutes. Manifest price deviations follow supply and demand shocks, and prices may exhibit interactive behavior as the economy returns to equilibrium (Engle and Granger 1987). Testing for cointegration in livestock feed markets allows identification of long-run economic relationships among DDGS and other feedstuffs.

Anderson, Anderson, and Sawyer (2008) explore a relationship between Texas corn price and Illinois DDGS price from years 1982-2007, testing for cointegration between the two markets. The authors identify a structural change in the data series and split the analysis into two periods: one period spanning 1982-1988 and the other 1989-2007. Results from their vector error correction model (VECM) show price relationships, though initially weak in the first period, strengthen in the second period. The study provides evidence of a developing relationship between corn and DDGS during the early stages of the ethanol surge.

Van Winkle and Schroeder (2008) test for DDGS spatial market cointegration in 11 locations to determine the nature of DDGS price discovery. The authors also include corn and

SBM futures in a pairwise testing procedure and evaluate dynamic price relationships among DDGS prices and the two substitute feeds at each location. Using weekly price data from 2001-2006, they determine weak cointegration among DDGS markets and conclude cross hedging with corn and SBM futures is not feasible. The authors note DDGS markets are spatially segmented and markets and operate independently. Schroeder (2009) reexamines the topic with an expanded dataset from 2001-2008 and includes an additional location. The results are comparable to Van Winkle and Schroeder (2008): the author concludes cross-hedge opportunities remain risky and DDGS markets are both inefficient and information-starved. These studies assess DDGS dynamic price relationships with corn and SBM on a large scale. However, the research focuses on DDGS interactions with corn and SBM futures prices in order to evaluate cross-hedge opportunities. The lack of long-run relationships between DDGS prices, corn futures, and SBM futures highlights the need to evaluate DDGS price with local spot prices.

Murguia and Lawrence (2010) evaluate DDGS cross-hedge opportunities using DDGS market price with corn and SBM futures prices in Iowa from October 2006 to March 2009. The authors include a wide array of models to evaluate the best method of determining optimal cross-hedge weights. Two VECMs are fit to estimate dynamic price relationships among DDGS and the other variables: one model includes a constant term and the other is specified with both constant and trend terms in the equation. Each of the models reports a cointegrating relationship between DDGS and corn futures, while the model including a trend term shows DDGS is cointegrated with both corn and SBM futures price. The VECM is one of the more effective methods of determining optimal hedging strategies and reduces DDGS price risk by 71% for a 13-week out-of-sample hedge. This study also focuses on DDGS interactions with futures' prices rather than spot prices. Although the analysis is limited to a single location, the authors find

concrete evidence of dynamic price relationships with both of the coproduct's major substitute feeds in a period shortly after U.S. energy policy was instated.

Etienne and Hoffman (2015) explore spatial DDGS price relationships among 10 DDGS market locations using a pairwise cointegration analysis. Using weekly prices from November 2007 to May 2015, the authors discover DDGS markets are well integrated in recent years. The authors also examine dynamic price relationships between DDGS, corn, and SBM futures from January 2000 to May 2015 and find evidence of a long-run price relationship between SBM and DDGS. The authors then divide the dataset into sub periods from January 2000 to December 2006 and January 2007 to May 2015. They find DDGS prices have significant relationships with both corn and SBM prices in the later sub period and determine DDGS price relationships have strengthened following the ethanol surge. This study provides evidence the U.S. DDGS market has continued to evolve into the current decade.

Silvestri (2015) explores price relationships between DDGS, corn, and SBM spot prices in Iowa. The study tests for cointegration using weekly prices data ranging from April 2007 to December 2014. The author finds a long-run equilibrium relationship is present after introducing a seasonal dummy variable. Corn is discovered to be weakly exogenous in the model and both corn and SBM prices have a substantial effect on DDGS market price in Iowa.

Spatial Analysis of DDGS Markets

Dhuyvetter, Kastens, and Boland (2005) evaluate geographical characteristics of the developing ethanol and coproduct markets. The study maps potential DDGS demand on a county level basis and measures potential feed-consumption density. Geographical distributions of grain prices, grain production, livestock populations, and livestock operation size are represented on a county-level basis to provide insight on DDGS demand and how it might affect the location of

future ethanol expansion. The authors conclude future refineries must consider both corn input supplies and market demand for coproducts when selecting new plant locations. The simple spatial analysis techniques allowed the authors to map geographic distributions of livestock populations, grain production, and commodity prices at a fine resolution.

Dooley and Martens (2008) disaggregate DDGS supply and demand by U.S. Census regions to show spatial characteristics in DDGS markets. Livestock inventories are disaggregated to U.S. Census regions to estimate potential DDGS production and consumption. The analysis focuses on DDGS-surplus and -deficit regions to identify future needs for transportation infrastructure. In 2010, the authors estimate midwestern states will possess the highest amounts of DDGS surplus while California, Texas, Oklahoma, and North Carolina are expected to have the largest deficits. The authors incorporated spatial analysis into the study to enhance presentations of each Census region's DDGS production and consumption. Dooley and Marten's study is an example of disaggregating national DDGS consumption to a smaller areal unit.

An article by Lambert et al. (2008) evaluates county-level determinants of ethanol plant locations following the surge in ethanol production. The authors use spatial analysis to visualize the distribution of ethanol refineries and employ a Local Moran's I clustering method to support their probit regression model. The spatial methods allowed a null hypothesis to be formulated and tested in conjunction with the econometric model. The authors report counties with high probabilities of attracting potential ethanol plant investments are tightly clustered in midwestern states.

Clarke (2013) creates a spatial network model for optimal DDGS transportation. The study disaggregates DDGS consumption and production by USDA crop reporting districts, states, and grouped-state regions. DDGS demand is calculated in each of these areas using

livestock populations and the author calculates a proxy figure for each sector's DDGS consumption based on corn inclusion rates. Linear programming transshipment and transportation models are formulated to optimize hypothetical DDGS distribution throughout the US. The author finds local availability of corn inputs and economies of scale in production are important factors in ethanol refinery success.

CHAPTER III: CONCEPTUAL FRAMEWORK

Least-Cost Feed Ration Problem

Cost-minimizing livestock producers use linear programming methods to formulate least-cost feed rations: optimal quantities of feed inputs are chosen to minimize overall feed ration expense while satisfying minimum dietary requirements (Moss, Schmitz, and Schmitz 2014). A feed's substitution into a ration is determined by its cost versus the nutritional content received by the consumer (Dahlke and Lawrence 2008). As market prices fluctuate, the relative values of feed inputs shift and livestock producers substitute higher-value feeds to maintain a least-cost ration (Jones et al. 2007). A firm's feed ration cost for a specific time period can be expressed as:

(1) $$Total\ Cost = C = p_{\text{corn}}x_{\text{corn}} + p_{\text{sbm}}x_{\text{sbm}} + p_{\text{ddgs}}x_{\text{ddgs}}$$

where total cost is a function of quantity of feed x_{i} and its respective market price, p_{i}, for corn, soybean meal, and distillers dried grains with solubles. Therefore, the objective function of the cost minimization problem is to:

(2) Minimize: $$C = p_{\text{corn}}x_{\text{corn}} + p_{\text{sbm}}x_{\text{sbm}} + p_{\text{ddgs}}x_{\text{ddgs}}$$

Subject to: $$f^1\left(x_{\text{corn}}, x_{\text{sbm}}, x_{\text{ddgs}}\right) \geq r_1$$

$$f^2\left(x_{\text{corn}}, x_{\text{sbm}}, x_{\text{ddgs}}\right) \geq r_2$$

and $$x_{\text{corn}}, x_{\text{sbm}}, x_{\text{ddgs}} \geq 0$$

where f^1 and f^2 represent energy and protein requirements denoted by $r_1$and r_2, respectively. The Lagrangian equation is expressed:

(3) $$\mathcal{L} = p_{\text{corn}}x_{\text{corn}} + p_{\text{sbm}}x_{\text{sbm}} + p_{\text{ddgs}}x_{\text{ddgs}} + \lambda_1\left[r_1 - f^1\left(x_{\text{corn}}, x_{\text{sbm}}, x_{\text{ddgs}}\right)\right] + \lambda_2\left[r_2 - f^2\left(x_{\text{corn}}, x_{\text{sbm}}, x_{\text{ddgs}}\right)\right]$$

The first-order conditions (FOCs) for the minimal-cost solution are:

(4) $$\frac{\partial \mathcal{L}}{\partial x_{\text{corn}}} = p_{\text{corn}} - \lambda_1 \frac{\partial f^1}{\partial x_{\text{corn}}} - \lambda_2 \frac{\partial f^2}{\partial x_{\text{corn}}} = 0$$

$$\frac{\partial \mathcal{L}}{\partial x_{\text{sbm}}} = p_{\text{sbm}} - \lambda_1 \frac{\partial f^1}{\partial x_{\text{sbm}}} - \lambda_2 \frac{\partial f^2}{\partial x_{\text{sbm}}} = 0$$

$$\frac{\partial \mathcal{L}}{\partial x_{\text{ddgs}}} = p_{\text{ddgs}} - \lambda_1 \frac{\partial f^1}{\partial x_{\text{ddgs}}} - \lambda_2 \frac{\partial f^2}{\partial x_{\text{ddgs}}} = 0$$

$$\frac{\partial \mathcal{L}}{\partial \lambda_1} = r_1 - f^1\left(x_{\text{corn}}, x_{\text{sbm}}, x_{\text{ddgs}}\right) = 0$$

$$\frac{\partial \mathcal{L}}{\partial \lambda_2} = r_2 - f^2\left(x_{\text{corn}}, x_{\text{sbm}}, x_{\text{ddgs}}\right) = 0$$

The FOCs may be solved in a stepwise manner by setting either λ_1 or $\lambda_2 = 0$. For example, setting $\lambda_2 = 0$ implies the FOC of corn, SBM, and DDGS as:

(5) $$p_{\text{corn}} = \lambda_1 \frac{\partial f^1}{\partial x_{\text{corn}}}$$

$$p_{\text{sbm}} = \lambda_1 \frac{\partial f^1}{\partial x_{\text{sbm}}}$$

$$p_{\text{ddgs}} = \lambda_1 \frac{\partial f^1}{\partial x_{\text{ddgs}}}$$

Isolating λ_1 yields:

(6) $$\frac{p_{\text{corn}}}{\partial f^1 / \partial x_{\text{corn}}} = \frac{p_{\text{sbm}}}{\partial f^1 / \partial x_{\text{sbm}}} = \frac{p_{\text{ddgs}}}{\partial f^1 / \partial x_{\text{ddgs}}} = \lambda_1$$

This equality describes the cost of gaining an additional unit of protein or energy by including an additional unit of feed in the ration. At the cost-minimizing input quantities, the marginal cost of each feed is equal across inputs. In other words, λ_1 measures the additional costs associated with expanding the ration's protein or energy constraint to a certain degree (Nicholson and Snyder 2008). Firms following a cost-minimizing ration will adjust quantities of each feed used in the ration to maintain a minimal-cost formula and a common marginal cost among chosen inputs.

Different livestock sectors formulate feed rations to obtain the most cost-effective solutions given feed prices in their area (Klasing 2012). These industries also have unique sets of nutritional constraints based on specific dietary needs of each animal type. The manner in which DDGS is substituted into a feed ration will vary according to the amount of protein and energy required in an individual sector's diet. Given the geographical variation livestock population types and relative feed prices, DDGS will be substituted into feed rations in different combinations from one market to the next to achieve a minimal-cost ration. These differences in DDGS substitutability translate into distinctive equilibrium relationships between DDGS and competing feedstuffs and form the underpinnings of the dynamic price relationships to be investigated in the study.

CHAPTER IV: METHODS AND DATA

Spatial Analysis

The analysis aims to identify dynamic price relationships and attribute these findings to individual livestock sectors within the U.S. However, major livestock industry territories inevitably overlap each other and identifying areas characterized by a single sector may be difficult. Additionally, dynamic price relationships may not be present in markets with low amounts of feedstuff demand. Therefore, the study begins with a spatial analysis procedure is developed to identify major regional livestock markets. The process ensures dynamic price relationships between DDGS and competing feedstuffs are studied in relevant markets where the coproduct is commonly used. Additionally, the spatial analysis procedure defines market locations characterized by a single livestock sector. This allows model results to be analyzed in context of an individual livestock sector and its feed rationing practices. Three criteria are developed for the market selection procedure.

The first criterion ensures market locations represent a major DDGS-consuming livestock sector. Hoffman and Baker (2010) list a total of 10 livestock sectors organized into 4 primary livestock categories in their estimation of potential DDGS consumption:

1. Beef cattle: beef cows, cattle on feed, and other cattle,
2. Dairy cattle: dairy cows,
3. Swine: breeding swine, market swine, and
4. Poultry: broilers, layers, pullets, and turkeys

A single livestock sector is designated to represent each of the 4 categories. The sector with the highest potential DDGS market share is selected to represent its respective category based on estimates from Hoffman and Baker (2010). Cattle on feed, dairy cows, market swine, and

broilers are selected for the analysis. Similar to methods used in Dhuyvetter, Kastens, and Boland (2005), county-level livestock populations for each sector are queried from the 2012 Census of Agriculture.

If a market exhibits limited potential feedstuff demand (i.e. an area with low livestock population levels), dynamic price relationships between competing feeds may be weak or non-existent. Therefore, the purpose of the second criterion is to identify locations distinguished by a high level of potential feedstuff demand. This is accomplished by multiplying each livestock sector's county population by its grain consuming animal unit (GCAU). Similar to the calculations in Clarke (2013), this figure is a proxy measure of potential consumption of DDGS and other feeds. A standardized figure developed by the USDA from 1969-1971, GCAUs are indexed values of an animal's total annual grain consumption relative to a dairy cow in the 1969-1971 time period (Capehart, Allen, and Bond 2013). Analogous, this non-assumptive measure is used as an effort to avoid a potential misspecification associated with a fixed DDGS feed ration inclusion rate. The multi-sector GCAU dataset is created with values for each county in the contiguous U.S., and is then joined to an ArcMap shapefile of U.S. county boundaries.

County GCAU values for individual sectors are weighted by county area in square miles. This transformation provides a measure of each livestock sector's population density for each county. Livestock sector GCAU density is represented by D_{ij} or the amount of GCAU per square mile (Area) in a given county:

$$D_{ij} = \frac{GCAU_{ij}}{Area_i} \qquad \text{...for sector } j \text{ in county } i \tag{7}$$

where j represents each livestock sector in the analysis and i represents each U.S. county in the lower 48 states. *The* shapefile is then assessed for clustered areas of grain demand. Analogous to the methods found in Lambert et al. (2008), the Anselin Local Moran's I technique is employed

here to identify statistically significant clusters of counties with high GCAU density values. The Local Moran's I statistic is a measure of spatial association and is defined by Anselin (1995) as:

$$(8) \qquad I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j\neq 1}^{n} w_{ij}(x_j - \bar{X})$$

where x_i is the attribute value for county *i*, $\bar{X}$ is the mean of that attribute among proximal neighbors, w_{ij} is matrix of weighted spatial relationships between counties *i* and *j*. Also,

$$(9) \qquad S_i^2 = \frac{\sum_{j=1, j\neq 1}^{n} (x_j - \bar{X})^2}{n-1} - \bar{X}^2$$

where *n* equals the total number of contiguous U.S. counties. The spatial weights matrix, w_{ij}, is created using Inverse Distance Weighting (IDW). IDW is a common tool used to create spatial weight matrices and it explicitly assumes objects closer to one another are more related than objects far apart. Thus, spatial association in Equation 8 decreases as a function of distance. The *I* statistic represents a deviational measure of a county's D_{ij} relative to its local mean. This identifies counties where a sector's feed demand density is significantly higher than that of its neighboring counties. Each county is evaluated according to its own *I* value and that of surrounding counties. Counties with a statistically high or low Moran's I value are classified into one of the following cluster categories: high values near other high values (HH), high values near low values (HL), low values near high values (LH), or low values near low values (LL).

Figures 1-4, in the Appendix, report each livestock sector's results from the Local Moran's I analysis where HH clusters are shown in black. Figure 1 shows counties with dense dairy cattle GCAUs are tightly clustered in Wisconsin, California, and throughout the Northeast. Figure 2 displays cattle GCAU clusters are situated throughout the Midwest especially within Nebraska, Kansas, and parts of Iowa. Figure 3 reveals a large hog GCAU cluster in Iowa and parts of southern Minnesota. Figure 4 shows broiler GCAU clusters formed several pockets

throughout the Southeast with the largest areas lying in parts of Georgia and Arkansas. Counties identified as high-high (HH) clusters are extracted from the original shapefile. Subsequently, each county within a HH cluster is evaluated according to an individual livestock sector's contributing proportion to that county's total GCAU values.

Cluster analysis output reveals several livestock sectors display clusters in close proximity to others. If more than one sector is prevalent in a certain market, time series model results cannot be attributed to a single livestock sector. Thus, a final criterion in the spatial analysis procedure identifies areas within HH clusters where a single livestock sector commands a large portion of county total GCAUs. The proportion of each sector's GCAU is relative to county total GCAUs for all 10 livestock sectors initially mentioned. Each sector's GCAU density is represented as a proportion, or P_{ij}, of county total GCAU density (summed D_{ij}) for ten DDGS-consuming livestock sectors such that

$$(10) \qquad P_{ij} = \frac{D_{ij}}{\sum_{i=1}^{10} D_{ij}}$$

Using the extracted county clusters identified by the Moran's I test, P_{ij} values are evaluated within ArcMap and the process is iterated for each of the sectors. Results from this stage are reported in Figures 5-8 and the maps are used to finalize market locations for the time series analysis. GCAU proportions are presented with a monochromatic color scheme where darker (lighter) shades correspond to a higher (lower) GCAU proportions for a given livestock sector.

Figure 5 reveals suitable dairy market locations in California and New York. Figure 6 illustrates cattle GCAU proportions are highest in Nebraska and western Kansas. Figure 7 shows a majority of clustered Iowa counties had high proportions of hog GCAUs with the exception of a few counties. Figure 8 reports broiler GCAU proportions appear the highest in northern Georgia, Delaware, and Maryland.

The final step involved matching candidate locations with time series data available in the same approximate location. California is chosen as the dairy market location since its cluster is large and the GCAU proportion is high. Wisconsin and New York are viable options: however, parts of the Wisconsin dairy cluster overlapped with the hog clusters in nearby states and a complete dataset for New York including all the variables is unavailable. Kansas is chosen as the cattle location. Nebraska's results are slightly more favorable but data availability issues prevented its inclusion. Iowa is chosen for the hog location considering the size of the GCAU cluster. Even so, data is not available for the North Carolina market. Lastly, Georgia is the only location with a complete and usable data series for broiler markets. In summary; California, Kansas, Iowa, and Georgia are chosen to represent dairy, cattle, hog, and broiler sectors, respectively.

Multivariate Time Series Analysis

Cointegration analysis is used to evaluate dynamic price relationships for DDGS, corn, SBM and livestock sector output price at each identified location. The initial step in a cointegration test procedure is to evaluate whether a data series is stationary (Harris 1995). An Augmented Dickey-Fuller (ADF) test is used to test for unit root presence to ensure proper model specification. The ADF tests the null hypothesis of a unit root, which indicates a series is nonstationary. A data series may also include deterministic regressors that describe temporal price movements. Therefore, the analysis followed the procedure described by Enders (1995) to test for stationarity with price at level, level with intercept term, level with both terms, and also first-differenced values. The basic test equation is expressed as:

$$(11) \quad \Delta y_t = \gamma y_{t-1} + \sum_{i=2}^{p} \beta_i \Delta y_{t-i+1} + \epsilon_t$$

where y is the variable of interest, γ is the coefficient evaluated for the unit root process, p is the lag order, β is a coefficient on a time trend, and ϵ is an error term. Additionally, the test may be modified to include an intercept term a_0, a linear time trend $a_2 t$, or both terms as discussed above. The test is evaluated with a null hypothesis of $H_O: \gamma = 0$ against the alternative $H_A: \gamma > 0$ (Enders 1995).

Additional unit root testing is employed to avoid potential misdiagnosis in the event of a structural break. Zivot and Andrews (2002) introduced a unit root test where a possible break point is endogenously determined by a data series. The test is similar to the ADF equation except that an additional break point term is allowed in the model. The null hypothesis of a unit root with a one-time structural break is evaluated versus an alternative of stationary at levels with an identical break. The break point is endogenously determined by solving for a date that minimizes the one tailed t-statistic in favor of the null hypothesis. Therefore, the equation is solved to isolate the most likely point for a potential structural break. This test is applied to price series determined nonstationary by the initial ADF test.

Results from the unit root testing determine the appropriate model type used for the time series analysis. The standard VAR framework for multivariate models is expressed as:

(12) $$Y_t = \sum_{K=1}^{K} A_i Y_{t-1} + E_t$$

where Y_t is an *n* by 1 vector of feed price variables, A_i is a *n* by *n* matrix of parameters to be estimated, and E_t is a *n* by 1 vector of corresponding error terms (Enders 1995). This representation is appropriate for analyzing several stationary price series. However, empirical price series are often nonstationary and proper analysis requires a modified equation.

If one or more series at a location are discovered to be nonstationary, a vector error correction model (VECM) is necessary to permit contemporaneous variation in the error terms

(Johansen 1988). The model, as described by Engel and Granger (1987) and Johansen (1988), is expressed as:

$$\Delta Y_t = \sum_{i=1}^{K-1} A_i \Delta Y_{t-1} + \prod Y_{t-1} + E_t \quad (13)$$

where ΔY_t is a n by 1 vector of the first difference of feed price variables, $K-1$ is the lag of the first-differenced price series and A_i (n by n) are the parameters to be estimated. The lagged variable (Y_{t-1}) is the error correction term and its parameter $\prod$ represents the speed of adjustment, and E_t is the corresponding vector of random error terms.

A minimal information criteria (IC) approach is employed to jointly specify appropriate lag lengths and cointegrating ranks of the VECM at each location. The IC is conducted by modeling multiple VECM iterations for each combination of lag length and cointegrating rank, and the final model is selected according to the lowest Akaike Information Criteria (AIC) value. This procedure avoids potential misspecification issues of the traditional Johansen trace test for cointegration introduced by Johansen (1988), which requires an arbitrary pre-specification of lag lengths in the model (Phillips 1996; Aznar and Salvador 2002).

The dynamic price relationships between feedstuffs and livestock commodities are identified through Granger causality tests at each location. This test, developed by Granger (1988), evaluates whether one variable's lagged values improve the predictive performance of another variable's equation within the VECM (Enders 1995). Thus, Granger causality implies the existence of an economic relationship between two or more price variables in a model. Coefficients of the lagged variables are tested for significance to determine the presence and directional nature of dynamic price relationships. Therefore, if a lagged variable is significant in one of the LHS vector equations, it is said to "Granger cause" the representative dependent variable. As models may be specified with multiple lag lengths, Granger causality in the *n*th-lag

case is determined by a Wald or Block Exogeneity test. This evaluates if a variable's *n* lags are jointly significant in another's LHS equation. Granger causality tests for and identifies significant dynamic price relationships among variables in a model. However, further testing is needed to estimate the magnitude and velocity characteristics of these relationships.

Further analysis into price relationships is presented with forecast error variance decomposition (FEVD), which is a moving average presentation of the output from the VECM model. FEVD describes a variable's contemporaneous effect, in percent, on variations or uncertainty of another variable's forecasted value over a set period of time. In this instance, the procedure essentially determined how strongly the fluctuations in one price are linked to the price of other evaluated commodities. Traditional FEVD analysis requires a Cholesky decomposition which specifies the order of contemporaneous effects from one variable to another a decomposition order can be chosen based on a priori knowledge and comparing results from alternative orders. However, the FEVD outcomes are often highly sensitive to the variable ordering and incorrect specification may translate to misleading results (Enders 1995). Therefore, a *generalized* FEVD (GFEVD), based on the work of Pesaran and Shin (1997), is employed to obtain an order-invariant measure of forecast error variance in the models. Lanne and Nyberg (2016) introduce a modified version of the Persaran and Shin representation that allows contributions in the GFEVD to be interpreted as a percent of the total contribution to a variable's forecast error variance. The GFEVD equation introduced by Lanne and Nyberg (2016) is expressed as:

$$(14) \quad \lambda_{ij,w_{t-1}}(h) = \frac{\sum_{l=0}^{h} GI(l,\delta_{jt},w_{t-1})_i^{\,2}}{\sum_{j=1}^{K}\sum_{l=0}^{h} GI(l,\delta_{jt},w_{t-1})_i^{\,2}}, \quad i,j = 1,\dots,K.$$

where *GI* is the generalized impulse response function described in Pesaran and Shin (1997) in the forecast horizon period *l*, the price shock δ_{jt}, given the historical value w_{t-1}conditioned by previous shocks. Therefore, our λ value (between 0 and 1) is the forecast error variance contribution from a price shock of *j* on variable *i* given the historical conditioned value w_{t-1} at time horizon *h*. The value of λ is equal to the accumulated effect of the *j*th shock as a proportion of the accumulated effect of all shocks in period *h* (Lanne and Nyberg 2016). As such, our GFEVD output is interpreted as the percent contribution of *j*'s price shock on the forecast error variance in variable *i.*

Data

The data series for California, Kansas, and Iowa are drawn from USDA's Agricultural Marketing Service (AMS) Livestock and Grain Market News Portal and the Georgia series is gathered from *Feedstuffs* magazine (USDA 2014; Feedstuffs 2014). To facilitate the time series analysis, weekly average price figures from January 2007 to December 2014 included: DDGS, corn grain, high-protein SBM, live market hogs, fed cattle, broiler chickens, and nonfat dry milk (NFDM). The data is transformed to represent each feed's price per hundred pounds. For-weekly livestock output prices; hogs are live, negotiated, weighted-average market purchases; cattle are live, free-on-board, weighted-average steers; NFDM is per-ten pound price; and broilers are frozen, whole-chicken, loading dock prices. Table 1 in the Appendix reports descriptive statistics for each price series. Additionally, Figures 9-12 provide a graphical display of the price data from the 2007-2014 period for each location.

The county-level animal inventories for ten different livestock and poultry groups reported in the 2012 Census of Agriculture are used in the spatial analysis. The ten sectors include beef cows and heifers that calved, fed cattle, dairy cows and heifers that calved, other

cattle (including steers, bulls, calves, and heifers not yet calved), market hogs, breeding hogs, broiler chickens, layer chickens, pullet chickens, and turkeys.

CHAPTER V: RESULTS AND DISCUSSION

Unit Root, Cointegration Tests, and Model Specifications

Table 2 in the Appendix reports the ADF test p-values of the four price variables at each location. The unit root procedure tests for stationarity of each price series at level and first difference with no deterministic term, an intercept term, and both intercept and trend terms. Iowa hog price is the only series stationary at level with an intercept at a 5% statistical level. Iowa hog price and Iowa, Kansas, and Georgia SBM prices are reported stationary with an intercept and trend term at the 5% level. All other price series are nonstationary at level for each of the term specifications. However, unit roots are not observed in those prices at first-difference, suggesting those prices are integrated at one or I(1). Given the nonstationary nature of the data, further investigative testing is conducted to avoid issues with spurious regression if a structural break is present in the data.

Tables 3a−3d in the Appendix show results from the Zivot-Andrews unit root test for each market. Here, each price series is again tested for a unit root while allowing for the possible presence of one unknown structural break in the data. The data series are evaluated for unit roots and potential structural break with an intercept term, trend term, and both terms. If a Zivot-Andrews statistic fell outside (or is more negative than) the critical value, the null hypothesis may be rejected. Each California series is nonstationary at level and the Zivot-Andrews test is comprehensive. According to Appendix Table 3a, no evidence is found to support a structural break. Nonstationary prices in Kansas included cattle, DDGS, and corn. As highlighted earlier, SBM is discovered stationary at level and no further testing is necessary. No evidence from the results in Appendix Table 3b suggested a structural break. Iowa DDGS and Corn prices are nonstationary while hog and SBM prices are stationary at level and did not require further

testing. Appendix Table 3c reports the Zivot-Andrews test results and no evidence of a structural break is found. Georgia broiler, DDGS, and corn prices are nonstationary level while SBM is stationary. Again, the Zivot-Andrews test results in Appendix Table 3d report no evidence of a structural break in the data. All Zivot-Andrews test statistics fell within the critical range of statistical values, suggesting the ADF unit roots tests are robust after a potential endogenous break point is considered.

Concluding the presence of unit roots in the price data, a VECM is fit at each location using the AIC selection method. The procedure is iterated with a maximum five lag lengths and up to three potential cointegrating ranks. Appendix Table 4a reports the AIC values for model selection in California. The optimal model included one lag length, rank of one, and an intercept term in the cointegration equation. The model selection AIC values for Kansas are reported in Appendix Table 4b. Here, the optimal model included a lag length of five, rank of one, and an intercept in the cointegration equation. Appendix Table 4c reports the AIC values for Iowa's model selection. An optimal model is found with a lag length of one, rank of one, and an intercept in the cointegration equation. Finally, Appendix Table 4d reports model selection AIC values for Georgia. The optimal model specification included two lag lengths, rank of one, a linear trend in the data, and both intercept and trend terms in the cointegration equation.

Error Correction Term and Long-run Causality

Results from the cointegration equation of each market illustrate which variables exhibited long-run price relationships with DDGS. DDGS was specified as the dependent variable and coefficients are normalized to reflect a DDGS price response given a one-unit change in another variable. Appendix Table 5 reports the cointegration equations for each location.

In California, SBM price impacted DDGS price in the long run with a coefficient of -1.27 and is significant at the 5% statistical level. In the Iowa market, all three variables had a significant impact on DDGS in the long run at a 5% statistical level. Iowa coefficients are estimated at -0.71, -0.48, and 0.06 for corn, SBM, and hog prices, respectively. In Kansas, corn and SBM had a significant relationship with DDGS in the long run at the 5% statistical level with coefficients of -0.71 and -0.27, respectively. Georgia's model reveals corn and SBM prices exhibit significant long-run relationships with DDGS price at a 5% statistical level. Georgia's coefficients are estimated at -0.74 and -0.63 for corn and SBM, respectively. The trend term specified in Georgia model is 0.017.

In summary, analysis of each model's ECT revealed which variables significantly impacted DDGS in the long run. Corn price is a significant factor in determining DDGS price in each location except California, and SBM is significant in each of the four markets. Corn price speed-of-adjustment coefficients are nearly identical in Iowa, Kansas, and Georgia. However, speed-of-adjustment figures for SBM varied greatly among the four locations. Additionally, Iowa's model is the only instance of long-run significance in output prices. The speed-of-adjustment coefficient for hog price is much smaller relative to the feed grain prices.

Granger Causality and Short-Run Dynamics

In addition to determining each model's long-run causal structures among the locations, the lagged VECM coefficients are analyzed for significance in each variable's vector equation. It is also essential to note dynamic price relationships in the short run form the underpinnings from which long-run relationships evolve. Granger causality tests evaluate whether a variable's lagged values are significant determinants of other variables in subsequent time periods. Each variable is presumably affected by lagged values of its own price in the short run and essentially Granger

causes itself. However, analysis of short-run dynamic price relationships focuses on significant lagged coefficients impacting the price of other variables in the model. In instances of multiple lag lengths (i.e. Kansas and Georgia), the VECM coefficients must be jointly evaluated for statistical significance.

Table 6a in the Appendix reports short-run VECM coefficients in California. Lagged values of DDGS, corn, and SBM are significant predictors in the DDGS vector equation at 5%, 5%, and 10% statistical levels, respectively. In addition to DDGS price, lagged SBM price is also a significant determinant of corn price and its own price at the 5% level. Also, historical NFDM price is a significant in its own equation at the 5% statistical level.

In Iowa, Appendix Table 6b illustrates each variable's lagged values are significant predictors in their respective equations at the 5% level. Lagged prices of Corn, SBM, and hog all have bearing on DDGS price in the vector equation and are significant at 5%, 5%, and 10% statistical levels. Lastly, previous values of corn and hog prices are significant determinants of SBM price at the 5% level.

VECM short-run coefficients for Kansas are presented in Appendix Table 6c. Each variable's historical prices are significant in their respective equations during various lag lengths at the 5% statistical level. DDGS price at one lag length had a significant impact on corn and SBM prices at the 5% and 10% level, respectively. DDGS price had a significant response to each of the other prices at various lag lengths: corn prices at one and three lags are significant at the 5% statistical level, SBM prices at four and five lags are significant at the 10% level, and cattle price at two lags is significant at the 5% level. SBM price also reacted to lagged prices of all three corresponding variables: DDGS at one lag is significant at the 10% level; corn prices at one, three, and five lags are all significant at the 5% level; and cattle price at a single lag is

significant at the 10% level. DDGS price at one lag and SBM price at three lags are significant determinants of corn price at the 5% statistical level. Lastly, cattle price is only significantly affected by SBM price at 5 lags at the 5% level.

Table 6d in the Appendix reports the Georgia market short-run coefficients. Again, lagged values of each variable are significant factors own-price vector equations. However, lagged prices are only significant predictors of other prices in two instances. Corn at two lags is significant in the DDGS equation at the 10% statistical level. Additionally, SBM at a single lag length significantly impacted corn price at the 10% level.

These lagged coefficients define the Granger-causal structure and identify short-run dynamic price relationships within each market. For models with specified with a single lag length (i.e. California and Iowa), coefficients are directly interpreted as Granger causalities. However, coefficients in models specified with multiple lag lengths must be tested for joint significance to validate Granger relationships. A Wald test is employed to jointly evaluate these lagged coefficients in the Kansas and Georgia equations.

Wald test results for the Kansas model are reported in Appendix Table 6e. Initially, Table 6c reported numerous significant lagged coefficients in the VECM: however, the Wald test identified only three significant Granger relationships. Lagged coefficients of corn prices Granger caused the price of both DDGS and SBM at a 5% statistical level. Additionally, lagged SBM prices drove cattle prices at a 10% level. Two lagged coefficients are significant in Georgia's VECM output from Appendix Table 6d. However, Wald test results reported in Table 6f reveal no significant Granger causality for the Georgia model at a 5% or 10% statistical level.

Granger causality results for each location are summarized in Appendix Table 7. A total of three dynamic price relationships are found significant in California. SBM price Granger-

caused corn price at a 5% statistical level while corn and SBM prices caused DDGS price at 5% and 10% levels, respectively. A total of five relationships are significant in Iowa: corn, SBM, and hog prices all Granger caused DDGS at 5%, 5%, and 10% levels; and both corn and hog prices drove SBM price at the 5% level. Although Kansas exhibited numerous significant lagged coefficients, only three relationships are jointly significant: DDGS and SBM prices are both Granger caused by corn price at the 5% level while SBM price drove cattle price at the 10% statistical level. Strictly speaking, no Granger relationships are identified in Georgia at the 5% or 10% levels. However, corn price's causality with DDGS price reported a p-value of 0.1067 and the analysis considers this reasonable evidence of a Granger relationship.

In summary, analysis of short-run dynamic relationships revealed DDGS market characteristics unique to each location. Granger relationships for the coproduct are most prevalent in the Iowa market where DDGS is responsive to all three other prices in short-run periods. Both corn and SBM prices affect California's DDGS price. Finally, DDGS exhibited only one dynamic relationship in Kansas and Georgia markets where corn prices drove DDGS prices in these locations.

Generalized Forecast Error Variance Decomposition (GFEVD)

Graphical GFEVD representations illustrate the rate of change and shape of contributions to a variable's forecast error variance along a 16-week time path. Observing these time paths offers additional insight into the nature of dynamic price relationships identified in each model. Given short- and long-run price relationships identified in the previous sections, this portion of the analysis reveals a price's contemporaneous reactions to other variables in terms of its forecast error variance.

Figures 13a-13d display the GFEVD time paths for the California model. The variations in forecasted price of corn and NFDM are primarily affected by their own shocks during the forecast horizon of 16 weeks. This suggests those two prices are relatively exogenous in the dairy market. DDGS and SBM exhibit stronger changes in their forecast error variance, yet their time paths are shaped much differently. Forecast error variance in corn is mostly explained by its own shocks throughout the 16-week period. Corn's self-contribution falls below the 90% mark around the 4th week and gradually increased as time progressed. Forecast error variance for DDGS shows corn and SBM contributions quickly increase until the 2nd week and then gradually plateau. Corn's proportion continues to increase throughout the 16-week period while SBM's effect decays after week 6. Forecast error variance in SBM price is increasingly attributed to the other variables and accumulates gradually throughout the forecast window. DDGS is the primary contributor to change in SBM forecast error variance while corn has a smaller effect. NFDM exhibits very little change to forecast error variance during the forecast period. Its decline is slow and appears linear.

GFEVD time paths for Iowa are displayed in Figures 14a-14d. Corn and SBM exhibits similar shaped time paths: their sizable initial contributions to each other's forecast error variance gradually decay while contributions from DDGS and hog price shocks increase. The DDGS time path shows a rapid increase in forecast error variance attributed to corn, and to a lesser extent, SBM. Corn and SBM contributions plateau near the 6th week where DDGS forecast error variance remains stable throughout the remaining periods. Hog forecast error variance is stable until the 6th week where it begins a slight but steady decline attributed mainly to SBM.

Figures 15a-15d report GFEVD time paths for Kansas market variables. Corn exhibits only minor changes to its forecast error variance, however its initial self-contribution is below

80%. Interestingly, contributing price shocks from DDGS and SBM appear inverted: SBM's contribution is initially high and tapers quickly while the DDGS contribution rises steadily following the 3rd week. Similar to the other Midwest location, Kansas DDGS forecast error variance shows a rapid increase attributed to corn price. However, the effect is persistent and does not plateau within the forecast window period as it does in Iowa. SBM forecast error variance displays a low initial self-contribution similar to corn. Its time path decreases in a linear fashion and is almost entirely attributed to corn price shocks. Finally, cattle forecast error variance exhibits minimal changes throughout the forecast periods and effects appear negligible until the 6th week.

Figures 16a-16d present GFEVD time paths for the Georgia market. Here, corn indicates a low initial self-contribution to its forecast error variance, well below 80%, and a gradual decrease thereafter is primarily attributed to DDGS. DDGS forecast error variance also exhibits a low initial self-contribution, yet effects of corn price shocks reveal relatively minor changes to the time path and plateau at the 4th week. SBM forecast error variance demonstrates an increase to self-contribution as corn's initial effect decreases over time. Contributions from SBM and DDGS appear inverted similar to the instance in Kansas corn GFEVD where DDGS price shocks are the primary contributor to SBM forecast error variance in the end period. Broiler forecast error variance is analogous to output examples at the other locations. However, effects of SBM price shocks are not apparent until the forecast's halfway mark.

Appendix Table 8 reports end-of-forecast contribution figures for the variables at each of the four locations. In California, corn's forecast error variance is attributed to DDGS at 5.25%, SBM at 2.52%, and NFDM at 0.71% during the 16th week. Forecast error variance for NFDM is mainly attributed to SBM price shocks at 4.66%, while corn and DDGS contribute negligible

effects with 0.23% and 1.33%, respectively. Conversely, DDGS forecast error variance at week 16 is primarily attributed to the perturbations in corn price, 15.51%, while shocks in SBM accounted for 5.60% of the changes in DDGS forecast error variance over the same time. Similarly, SBM forecast error variance is explained by contributions from shocks in corn price at 6.08% and DDGS price at 10.64%.

Iowa GFEVD results show hog forecast error variance is attributed to price shocks in corn, SBM, and DDGS at 2.50%, 0.81%, and 5.19% levels at the 16th week, respectively. Corn forecast error variance is attributed to price shocks of DDGS, SBM, and hog at 7.76%, 3.35%, and 6.42% in the final period, respectively. Changes to SBM forecast error variance are slightly larger with corn, DDGS, and Hog price shocks contributing 8.08%, 13.04%, and 4.32% in the final week, respectively. Price shocks from corn and SBM contribute to 26.34% and 8.24% of DDGS forecast error variance at the 16th week.

Results from Kansas GFEVD analysis reveal marginal changes to cattle forecast error variance: DDGS contributes 1.56% while corn and SBM contributed 0.26% and 1.07% at the 16th week horizon, respectively. DDGS and SBM shocks impact corn forecast error variance with 16.10% and 6.71% contributions in the final period, respectively. Changes to SBM price variability are more substantial where corn, DDGS and cattle price shocks contribute 28.23%, 4.92%, and 3.77% at week 16, respectively. Finally, DDGS exhibites the most notable shifts in forecast error variance in the analysis. The increase is primarily attributed to corn at 42.51% while SBM contributes to a relatively smaller portion at 9.10% at the 16th week.

Price shocks in Georgia show corn contributes 5.78% and DDGS contributes 16.12%, to SBM forecast error variance at the 16-week horizon. More notable effects are present in corn where price shocks in DDGS explain 32.85% of corn's price variability in the final period.

Additionally, SBM and price shocks exhibit minor contributions of 2.70%. Corn is the main contributor to DDGS forecast error variance at 26.48% while SBM contributes to a lesser extent at 4.41%. Finally, minor changes in broiler forecast error variance is mainly attributed to SBM at 4.07% as corn and DDGS each contribute less than half a percent.

Results from the GFEVD analysis reveal similarities and differences of dynamic price relationships among locations. Specifically, the magnitude and temporal features of price shocks affecting variables' forecast error variance are of interest. It is useful to compare results by location since these attributes represent DDGS price market behavior in each location's representative livestock sector. To facilitate this comparison, DDGS forecast error variance time paths of corn, SBM, and DDGS self-contributions are individually juxtaposed in graphs.

Figure 17 compares each location's cumulative loss in DDGS's contributions to its own forecast error variance over the 16-week period (axis scaled at 100). The graph contrasts the extent to which deviations in DDGS price are attributed to general market shocks in the three corresponding price variables. Clearly, the Kansas time path drops quicker and to a greater degree than other locations and does not plateau. DDGS contributions to its own forecast error variance swiftly decrease in early periods in California and Iowa. However, the California time path settles at a highest self-contribution level of the four markets. Georgia's time path shows a relatively slow decline and displays the least amount of changes to DDGS forecast error variance contributions.

Figure 18 contrasts corn's contribution to DDGS forecast error variance for each area (axis scaled at 100). Contributions in California, Iowa and Kansas markets increase rapidly during initial periods: conversely, changes are far more gradual in Georgia location. Corn's contribution to DDGS forecast error variance in California exhibits the smallest magnitude of the

four markets. Here, corn's contribution increases sharply until the second period and steadies thereafter. Corn price shocks in Kansas exhibit the largest magnitude effect on DDGS forecast error variance by a wide margin. Additionally, this effect does not plateau within the forecast periods and increases persistently into the 16th week horizon. In Iowa, corn's contribution to DDGS forecast error variance is the second largest in magnitude. Its initial rise is similar to the instance in Kansas and is characterized by a sharp increase in preliminary periods. However, the time path begins to plateau at the 4th week where it remains stagnant for the remaining forecast periods. The time path for Georgia corn price is distinct from the other markets: its initial contribution to DDGS forecast error variance is considerably higher relative to other locations and increases only slightly throughout the forecast period.

Figure 19 compares SBM contributions to DDGS forecast error variance at each market location (axis scaled at 50). Overall, the magnitudes and progressive changes of these time paths are minor relative to those of corn and the vertical axis is scaled to 50 to increase detail. In California, SBM exhibits the highest initial contribution to DDGS forecast error variance. Interestingly, California SBM price shows a significant decline in its contribution after the 4th period. SBM time paths in Iowa and Kansas markets appear similar both in terms of magnitude and shape. Georgia's SBM contribution to DDGS forecast error variance is the smallest in magnitude of the four locations and the time path exhibits little movement across the horizons.

Figure 20 reports contributions to DDGS forecast error variance for each market's output price (axis scaled at 10). The time paths exhibit negligible contributions to DDGS forecast error variance and there is minimal divergence from initial output contributions throughout the forecast period. A vertical axis scale of 10 is necessary to differentiate the time paths. The only

discernable difference in these time paths is associated with Iowa hog price where a minor increase is evident following the 8th week.

Overall, corn exhibits the largest contributions to DDGS forecast error variance among the four locations. These effects show varying degrees of magnitude and are markedly larger in the Kansas market. SBM's contributions to DDGS forecast error variance are much less pronounced relative to corn and have a tighter convergence through the end of the forecast. Though SBM contributions display similar magnitudes among the four markets, SBM's contribution in California reveals a noteworthy decline across the forecast intervals. Contributions from output prices are negligible relative to corn and SBM examples. Aside from the marginal Iowa hog price contribution, no significant output price contributions are perceived.

In summary, GFEVD outputs further expand the analysis of DDGS dynamic price relationships among the four markets. The ECT equations define long-run price co-movements and Granger causality tests identify which variables impact DDGS in the short run. Additionally, the GFEVD analysis measures the relative extent of these model dynamics and defines the magnitude of DDGS price relationships in each market.

CHAPTER VI: CONCLUSION

The U.S. DDGS market experienced significant growth in recent years and it continually expands along with the fuel ethanol industry. As DDGS evolves into a mainstream feed, this research examines dynamic price relationships between DDGS, corn, SBM, and livestock output prices to determine the extent of growth among major U.S. livestock production regions. The study evaluates a hypothesis of geographic variation in DDGS dynamic price relationships with major competing feedstuffs. By identifying market locations where a single livestock sector dominates feedstuff demand, DDGS market growth can also be analyzed in context of individual livestock sector feed rationing practices.

Results suggest California DDGS is primarily used as a protein feed and replaces SBM in dairy feed rations. With the smallest impact to DDGS forecast error variance by corn, DDGS is not likely a common substitute for corn in dairy rations in this region, or perhaps corn is not a primary feed for many of these operations. California is home wide variety of high-fiber carbohydrate feeds and DDGS may compete with feedstuffs other than corn in dairy rations.

The Iowa market exhibited strong dynamic relationships between DDGS and feedstuffs as well as livestock outputs. Due to significant statistical evidence of dynamic price relationships, DDGS likely fills a role as both a protein and energy source for Iowa's hog producers. The Iowa hog industry benefits from minimal transportation and logistical costs due to local DDGS supply and this may increase DDGS value relative to other market locations. Hog market price shows a significant relationship with DDGS in both short- and long-run periods. This is the only instance of an output–DDGS relationship in the study and it suggests a highly efficient Iowa DDGS market.

Model results in Kansas support a strong dynamic price link between DDGS and corn and suggest cattle producers in Kansas primarily use DDGS as an energy feed in animal rations. Corn has a substantial impact on DDGS forecast error variance, and transmits a large amount of information to DDGS price in contemporaneous time. The high carbohydrate and fat levels common to cattle feedlot diets may explain the strong dynamic relationship as energy-type feeds such as corn and DDGS are used heavily.

Dynamic price relationships in the Georgia market appear weak in relation to other market locations. The model reveals only corn and DDGS share a long- and short-run link. Furthermore, these relationships are supported by weaker statistical evidence. Given the results from the VECM, DDGS is unlikely a popular or widely used feed relative to the other locations. Georgia is not in close proximity to DDGS production regions and high transportation and logistical costs may prohibit DDGS from being cost-effective in broiler feed rations.

Overall, statistical evidence presented in the study points toward a DDGS market with unique geographical properties and diverse market characteristics across major U.S. livestock production regions. The discoveries support previous research and knowledge regarding DDGS integration into the U.S. feed complex following the fuel ethanol surge. DDGS prices continue to develop dynamic relationships with other staple feedstuffs and structure of these relationships varies across major U.S. livestock regions. The study concludes DDGS utilization among various markets is largely dependent upon both unique production factors specific to individual livestock sectors and local market conditions affecting DDGS value in least-cost feed ration formulas.

Implications, Future Research, and Limitations

Statistical evidence and conclusions presented in this study provide several implications to DDGS market participants. First, observing local price interactions among DDGS and its

substitute feedstuffs may potentially enhance price-risk management techniques. Cross-hedge strategies tailored to specific markets may improve financial security for both producers and consumers. Additionally, commodities outside the realm of corn and SBM may prove useful as evidenced by the discovery of Iowa's hog-DDGS price interaction. Second, ethanol production mandates continue to increase and refineries must expand marketing to new regions. Careful research into factors affecting a region's livestock feed demand may enhance DDGS marketing efforts and profitability. Variables such as sector-specific dietary requirements, relative substitute feed prices, and even end-user prices after transportation costs could significantly impact DDGS demand in new markets. Lastly, as U.S. ethanol policy continues to evolve, policy makers must consider DDGS utilization across regions and livestock sectors. Ethanol policy has a substantial influence on overall economic welfare, and understanding how policy changes might impact sectors and regions differently is crucial to holistic welfare analysis.

The primary limitations in this study are the availability and spatial precision of time-series price data. While the spatial analysis provided a very high resolution for identifying potential analysis locations, the precision of the price variables is often limited to state or multi-state regions. Finer resolution in spatial price data would have allowed a far more precise spatial context to be developed. Reiterating data issues discussed in the literature, DDGS price series are only available for a handful of market locations and several series are incomplete. The number of potential analysis locations is limited by usable DDGS price data. Another limitation is the length of time-series price data. Given the timeline of U.S. ethanol policy, data observations prior to the 2005 and 2007 Energy Acts are unusable in context of the research problem. Although the dataset met the requirements for the time-series methods, a longer time-series dataset would inherently possess more information and provide a richer analysis.

Several future research opportunities are apparent following the spatial analysis techniques allowing the identification of markets defined by an individual sector. First, this research could be expanded to include more locations and additional livestock sectors to further illustrate the U.S. DDGS market. Additionally, a study could compare dynamic price relationships among two or more markets characterized by the same livestock sector (i.e. California versus Wisconsin dairy markets). This may shed light on factors not specific to a certain livestock sector that affect DDGS utilization. Finally, an in-depth look at individual markets could provide detailed information valuable to market participants in a defined area. Such an approach permits inclusion of additional feed prices relevant to a specific market rather than a set of uniform variables necessary for the market comparison in this study.

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APPENDIX

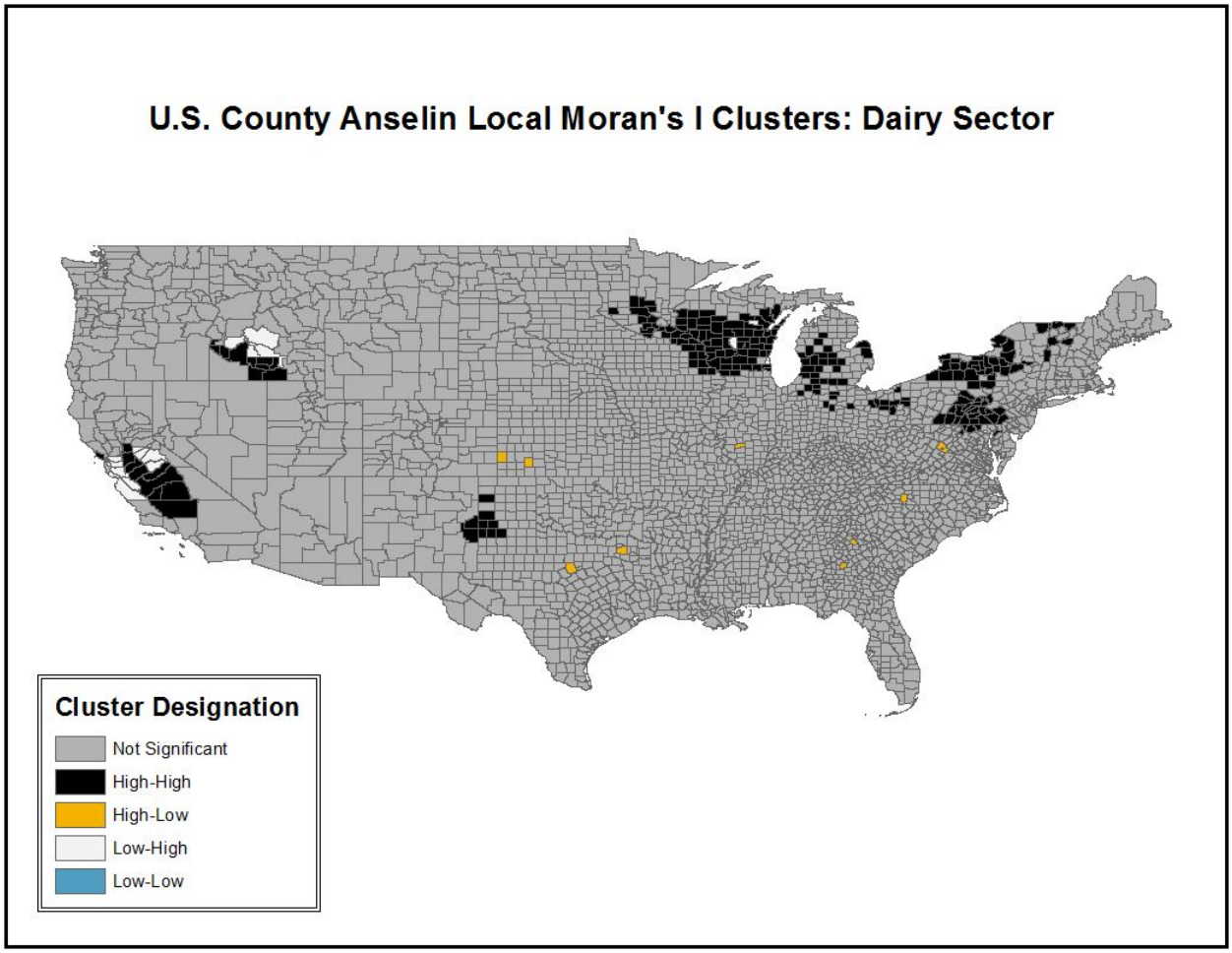


Figure 1: Anselin Local Moran's I County Clusters for Dairy Cattle Grain Consuming Animal Units in the United States.

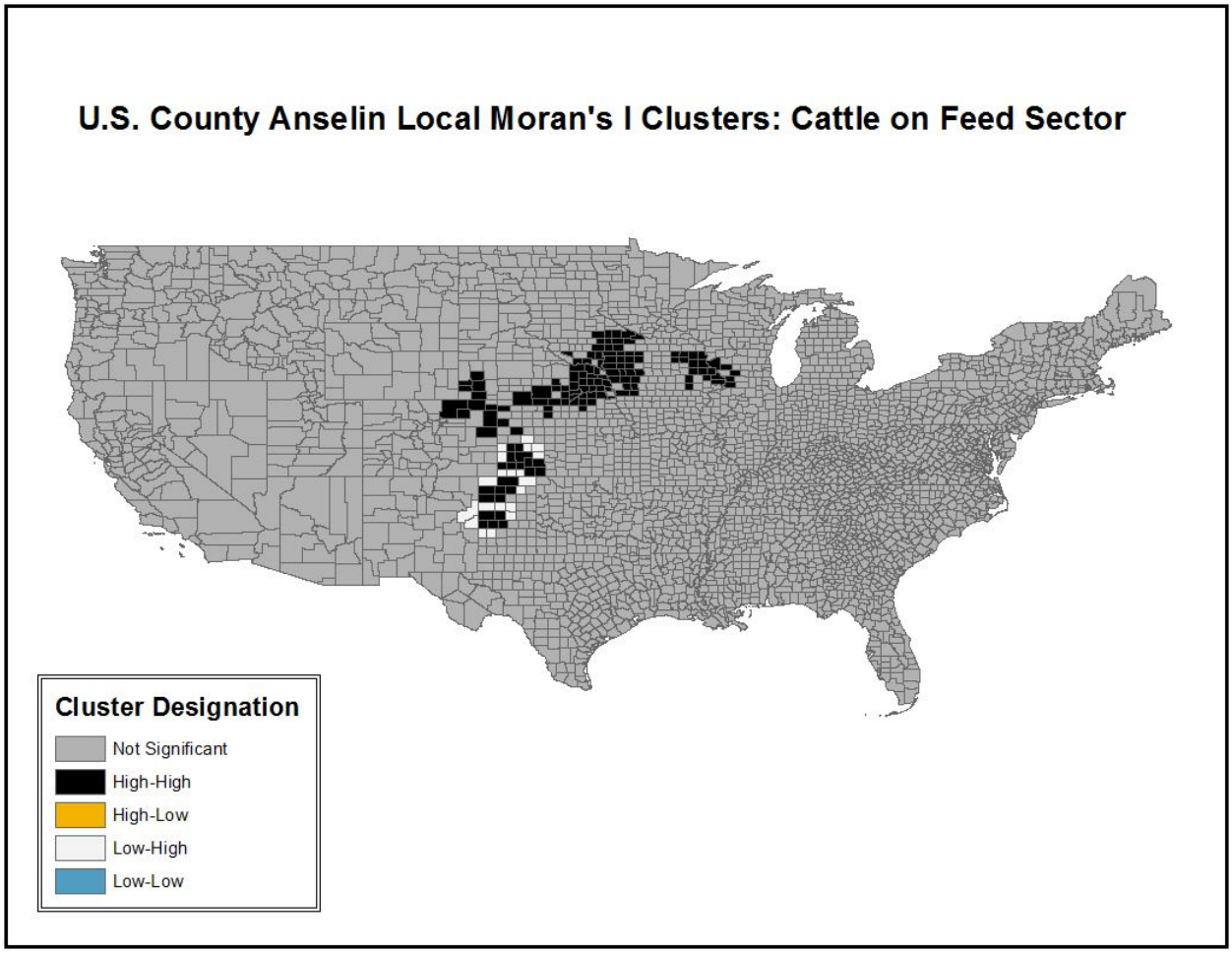


Figure 2: Anselin Local Moran's I County Clusters for Cattle on Feed Grain Consuming Animal Units in the United States.

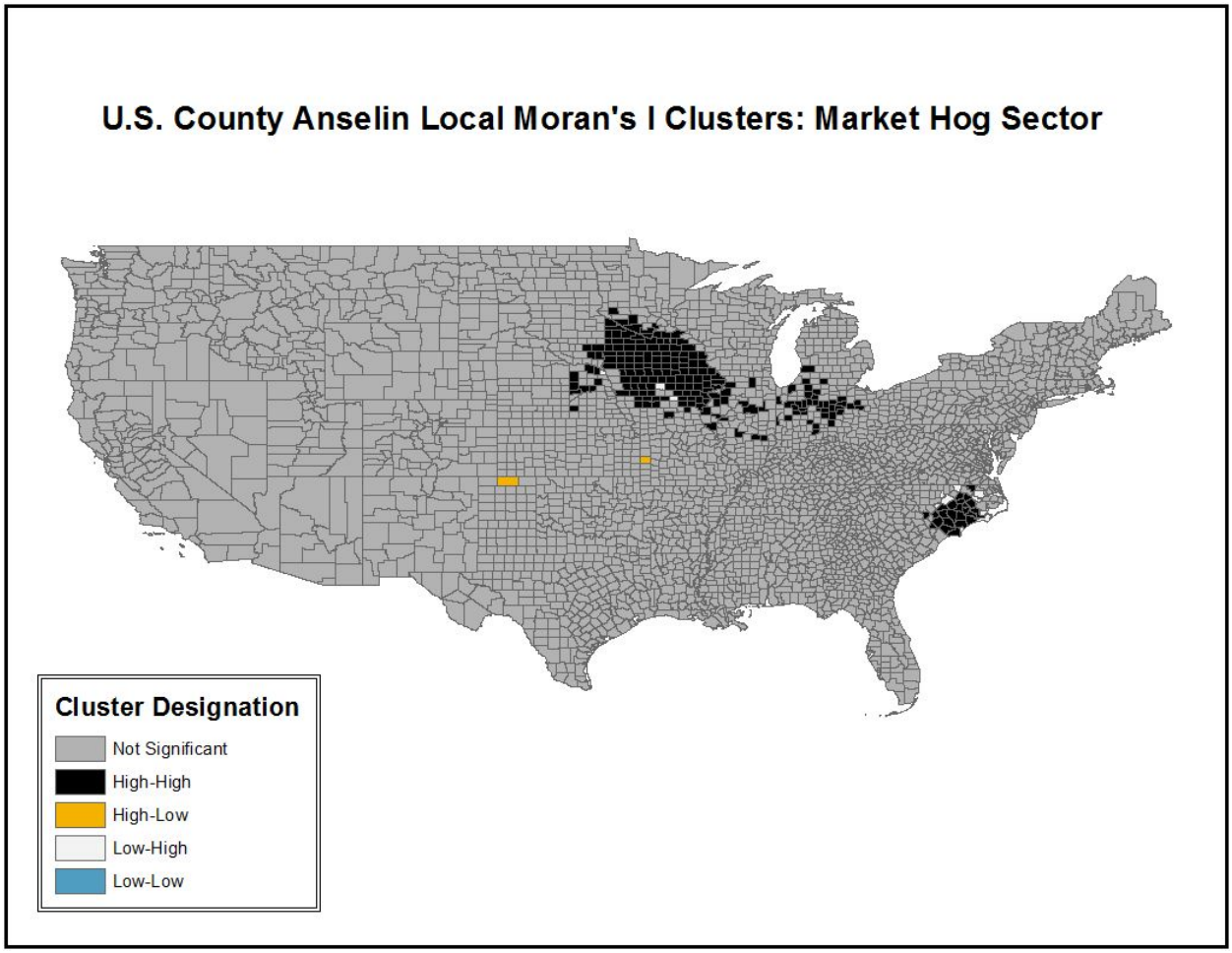


Figure 3: Anselin Local Moran's I County Clusters for Market Hog Grain Consuming Animal Units in the United States.

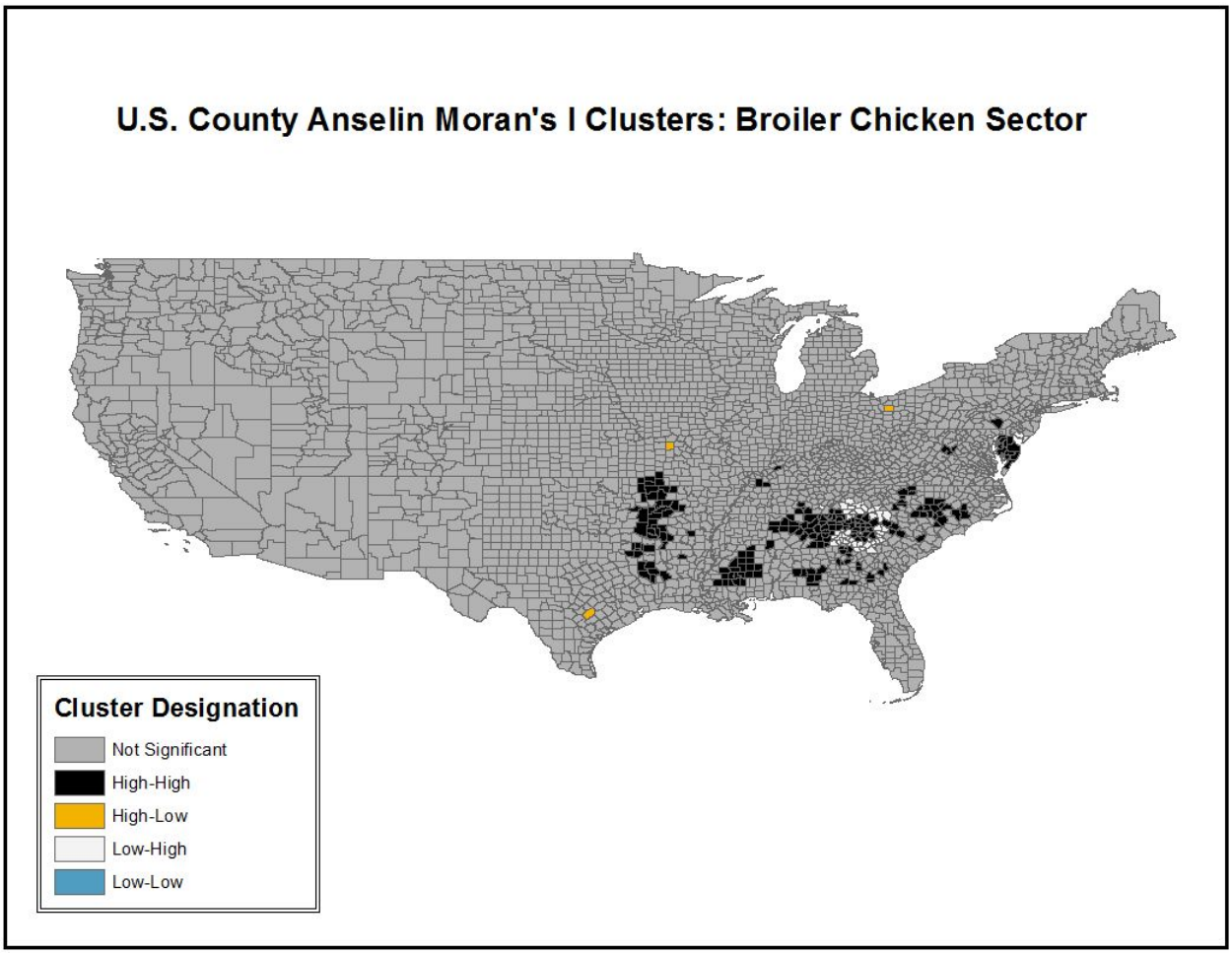


Figure 4: Anselin Local Moran's I County Clusters for Broiler Chicken Grain Consuming Animal Units in the United States.

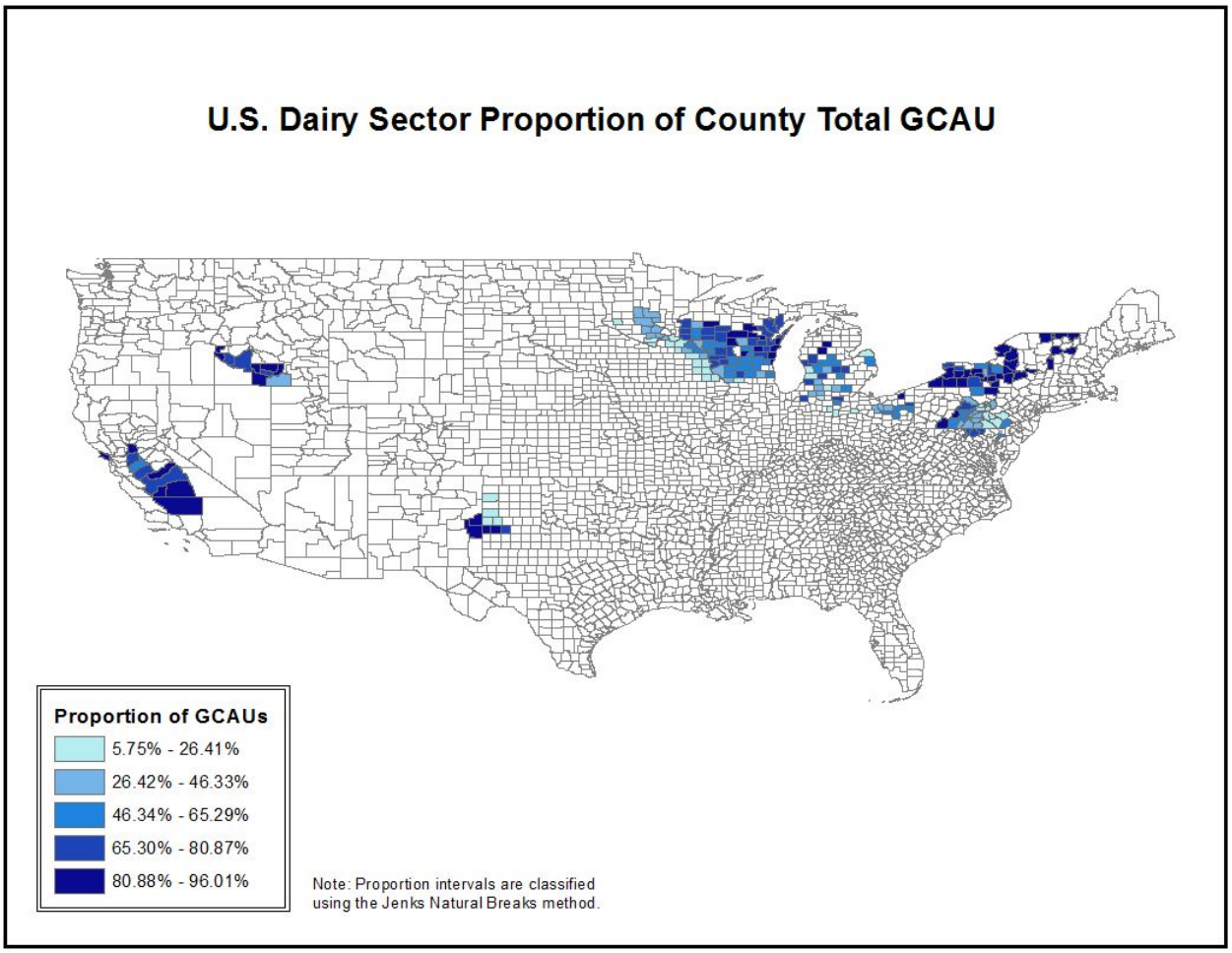


Figure 5: Proportion of County Total Dairy Cattle Grain Consuming Animal Units (GCAUs) within U.S. Dairy Cattle Sector Clusters.

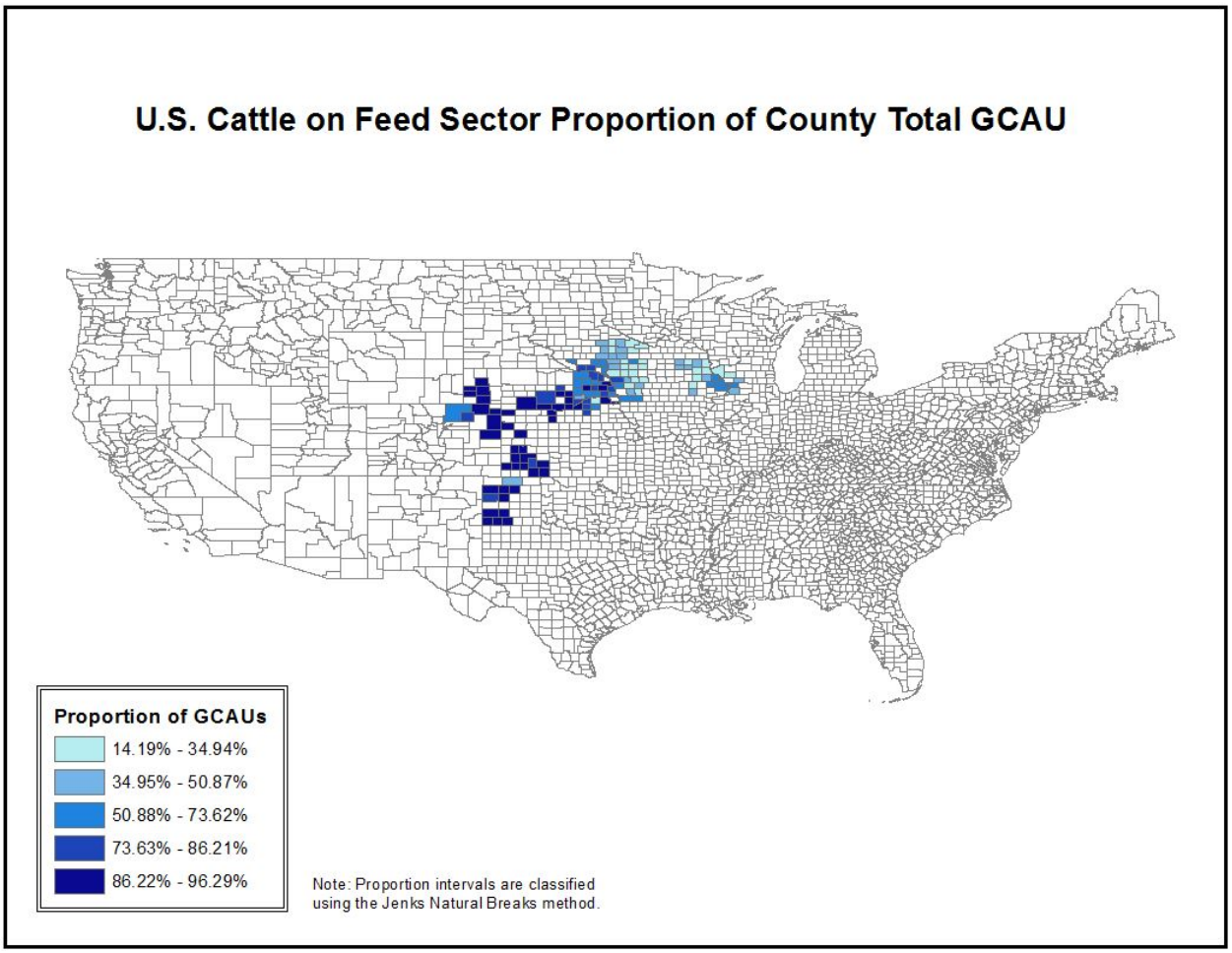


Figure 6: Proportion of County Total Cattle on Feed Grain Consuming Animal Units (GCAUs) within U.S. Cattle on Feed Sector Clusters.

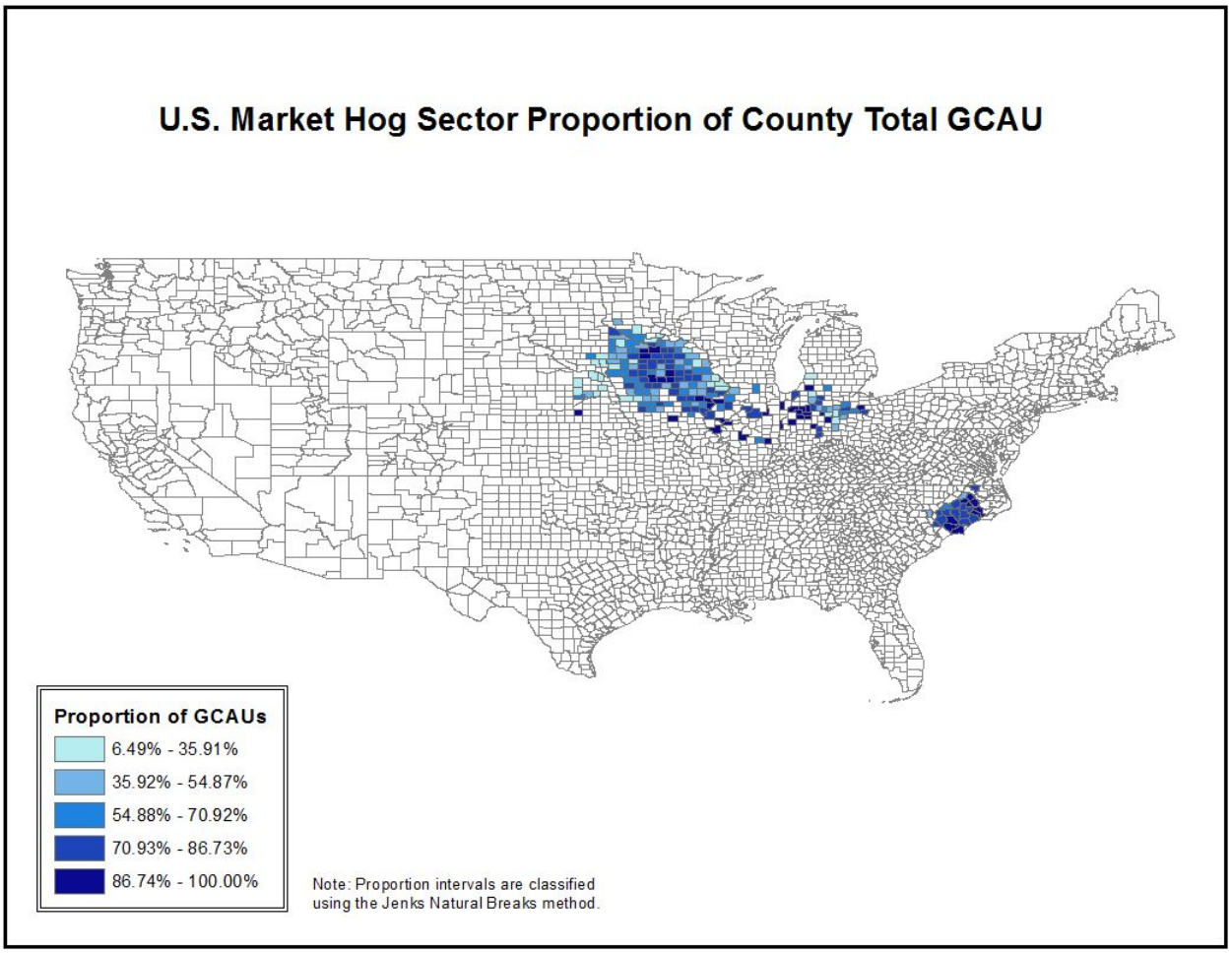


Figure 7: Proportion of County Total Market Hog Grain Consuming Animal Units (GCAUs) within U.S. Market Hog Sector Clusters.

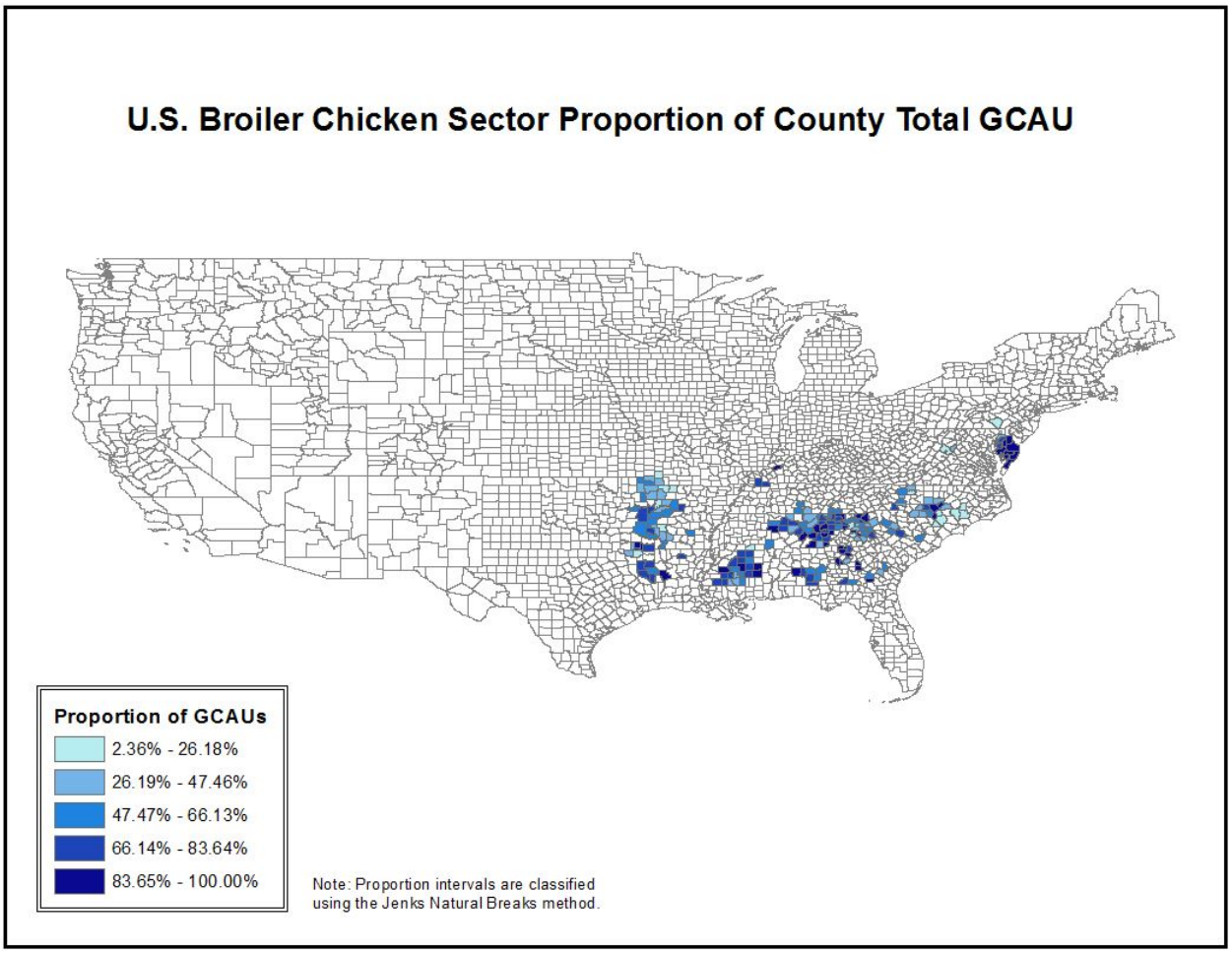


Figure 8: Proportion of County Total Broiler Chicken Grain Consuming Animal Units (GCAUs) within U.S. Broiler Chicken Sector Clusters.

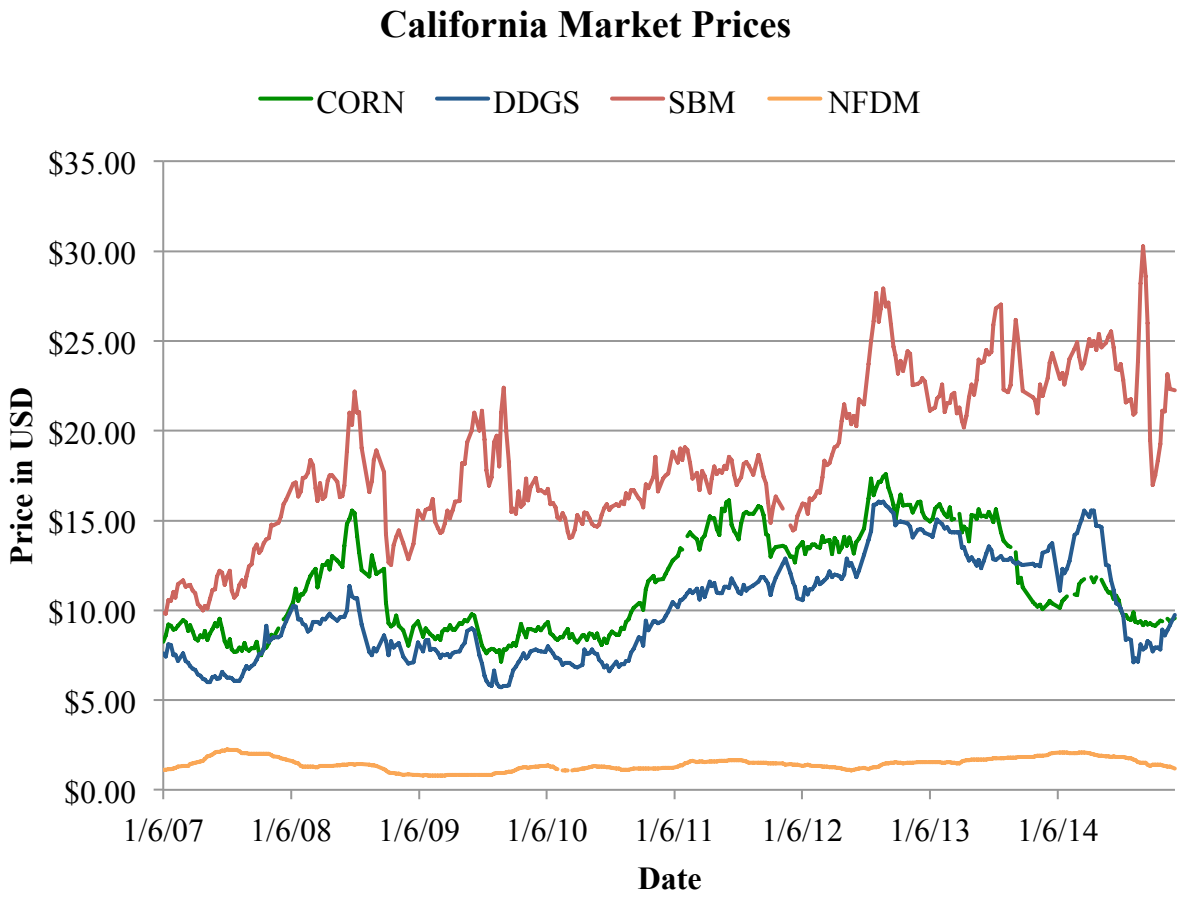


Figure 9: California Market Spot Prices (U.S. Dollars) for Corn, Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Nonfat Dry Milk (NFDM) from January 2007 through December 2014.

Source: USDA 2014, Feedstuffs 2014

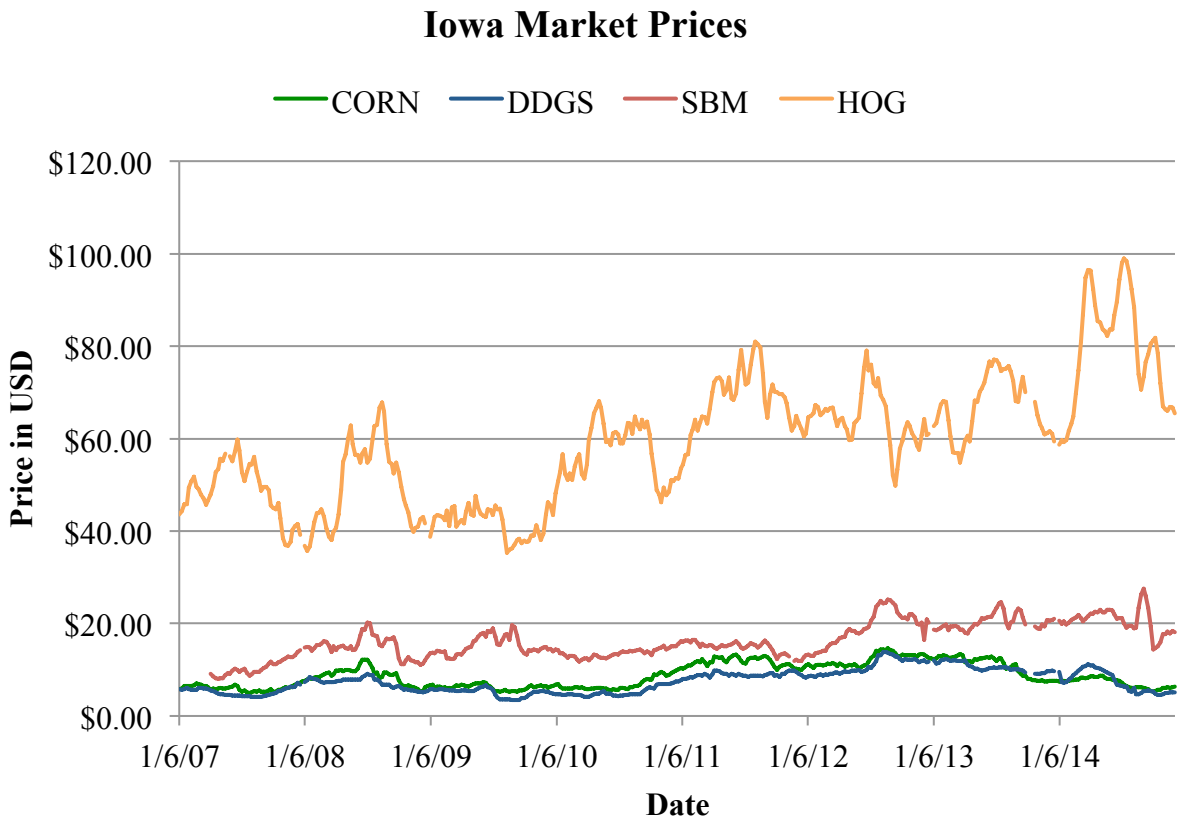


Figure 10: Iowa Market Spot Prices (U.S. Dollars) for Corn, Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Market Hogs from January 2007 through December 2014.

Source: USDA 2014, Feedstuffs 2014

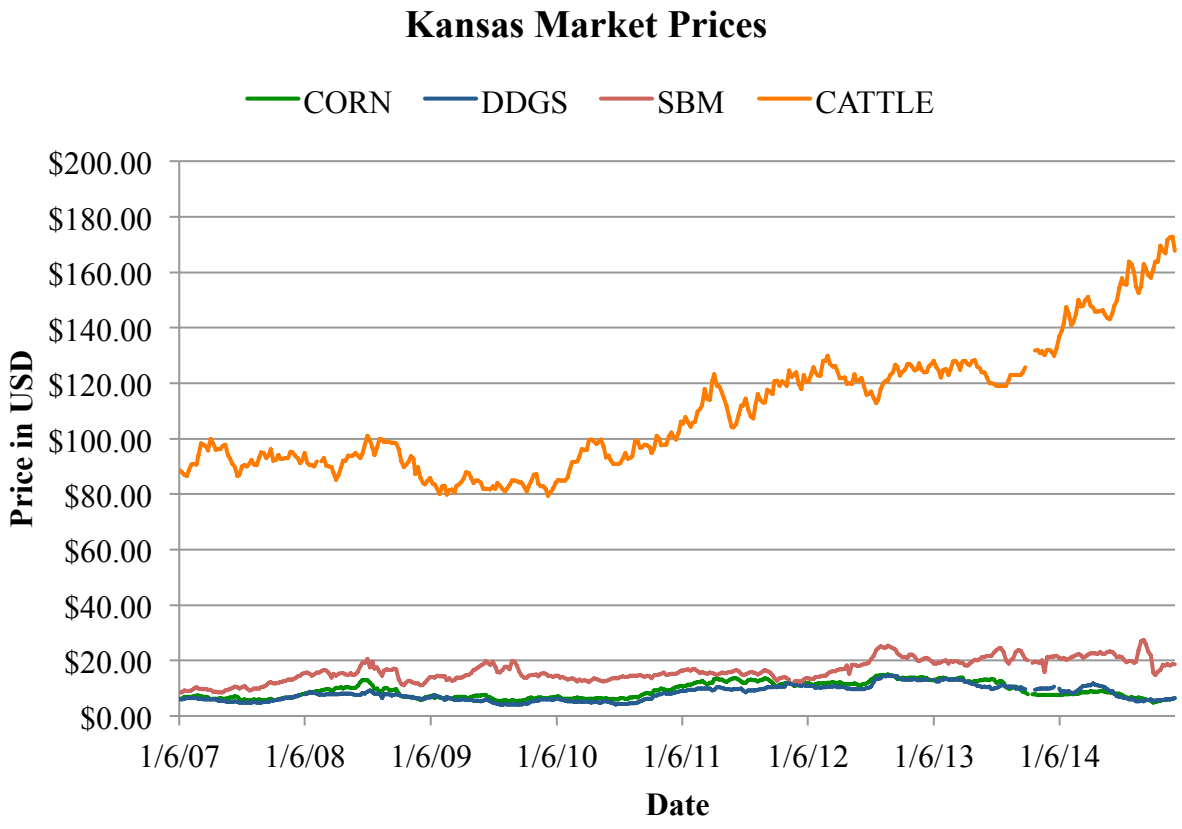


Figure 11: Kansas Market Spot Prices (U.S. Dollars) for Corn, Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Cattle on Feed from January 2007 through December 2014.

Source: USDA 2014, Feedstuffs 2014

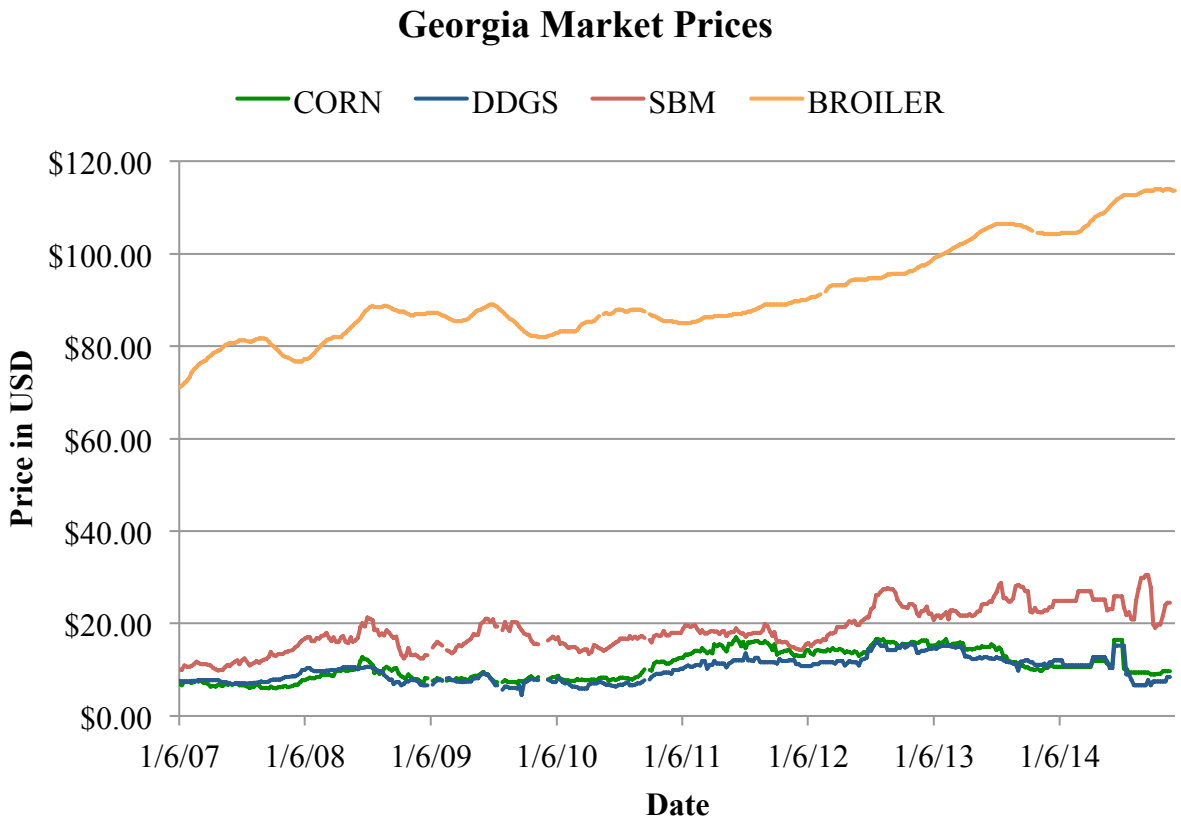


Figure 12: Georgia Market Spot Prices (U.S. Dollars) for Corn, Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Broiler Chickens from January 2007 through December 2014.

Source: USDA 2014, Feedstuffs 2014

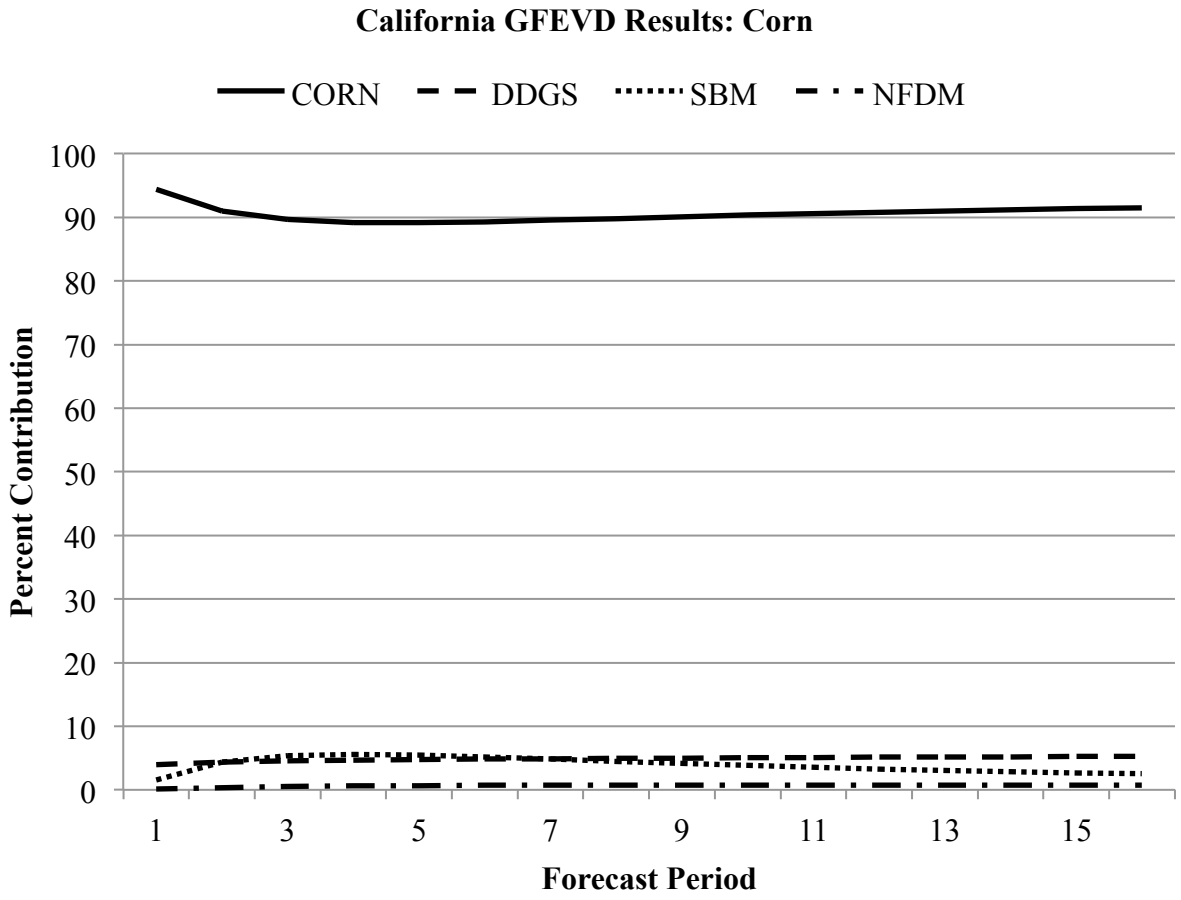


Figure 13a: Corn Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Nonfat Dry Milk (NFDM) Prices in California over 16 Week Forecast Period.

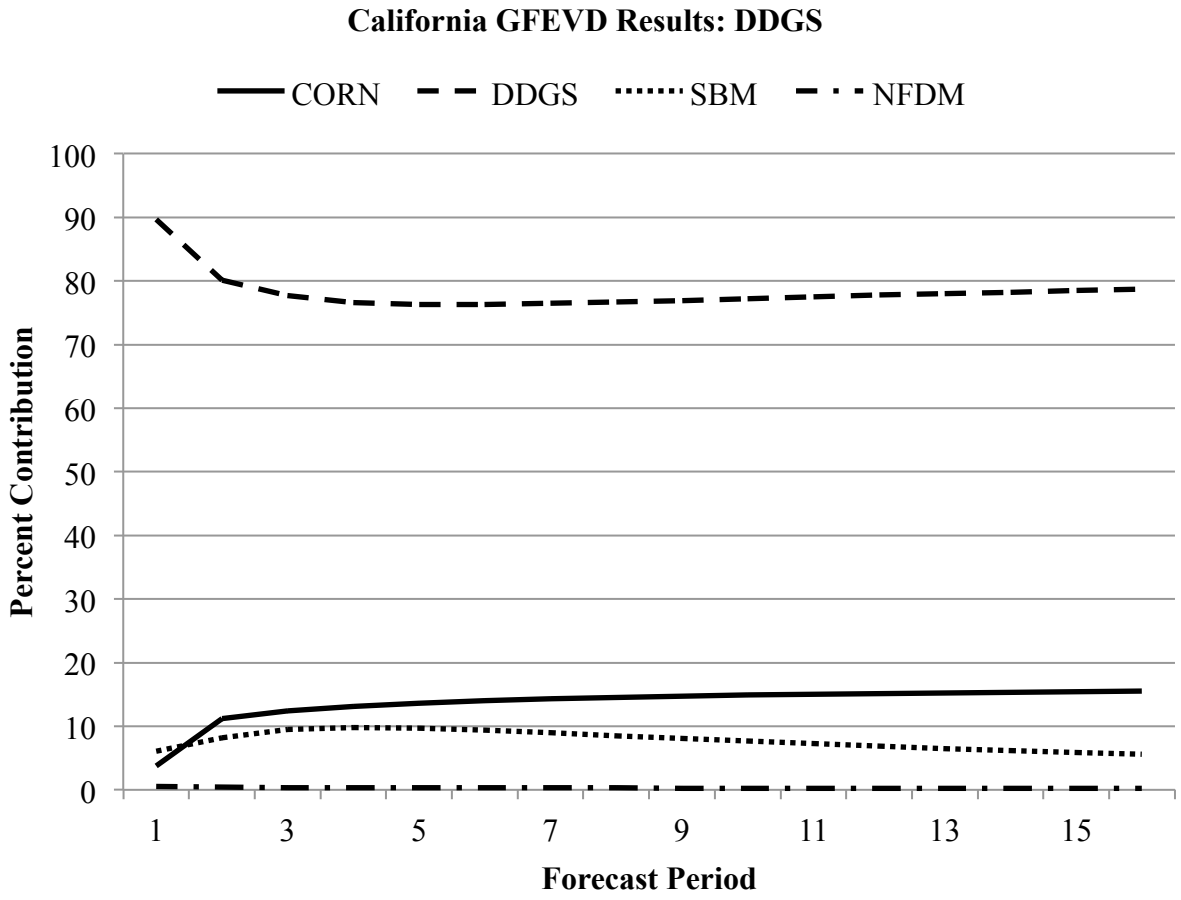


Figure 13b: Distillers Dried Grains with Solubles (DDGS) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Corn, Soybean Meal (SBM), and Nonfat Dry Milk (NFDM) Prices in California over 16 Week Forecast Period.

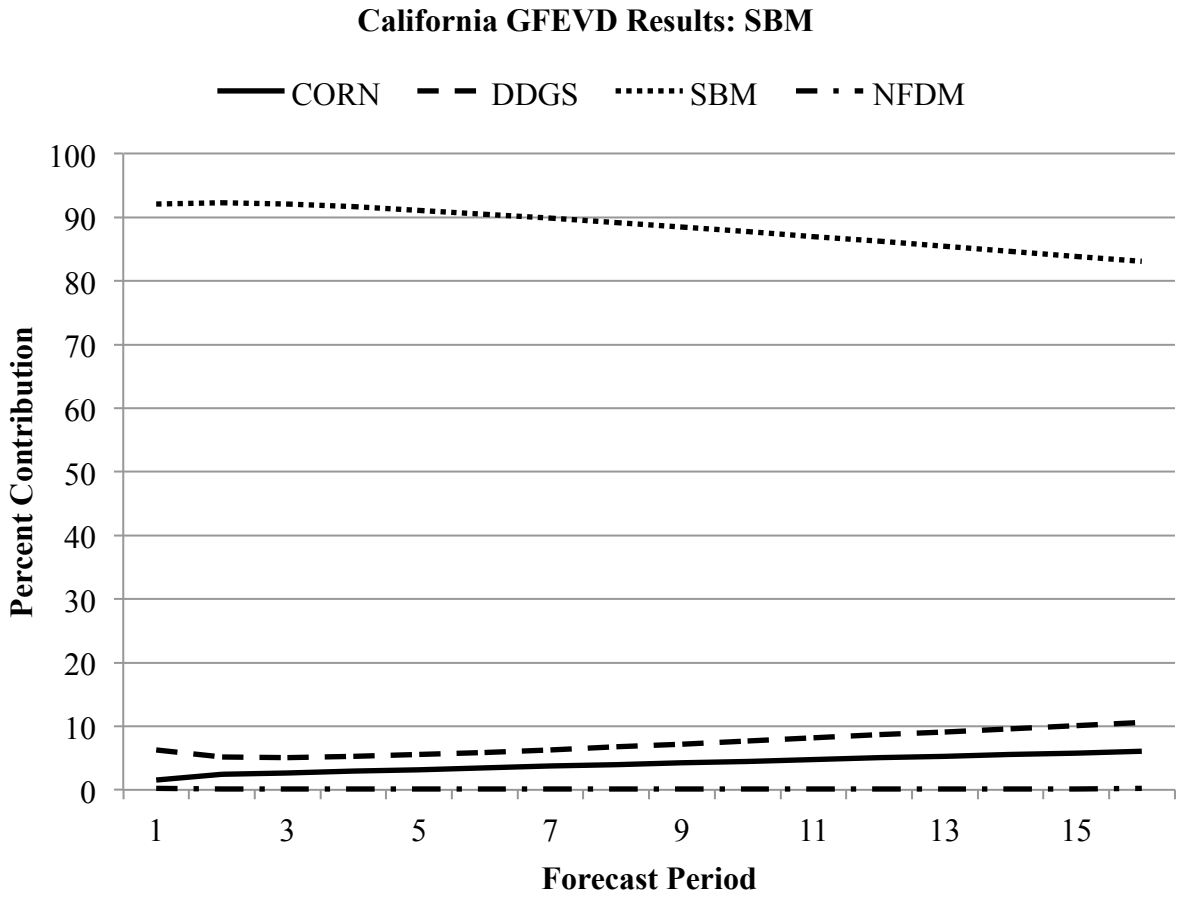


Figure 13c: Soybean Meal (SBM) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Corn, Distillers Dried Grains with Solubles (DDGS) and Nonfat Dry Milk (NFDM) Prices in California over 16 Week Forecast Period.

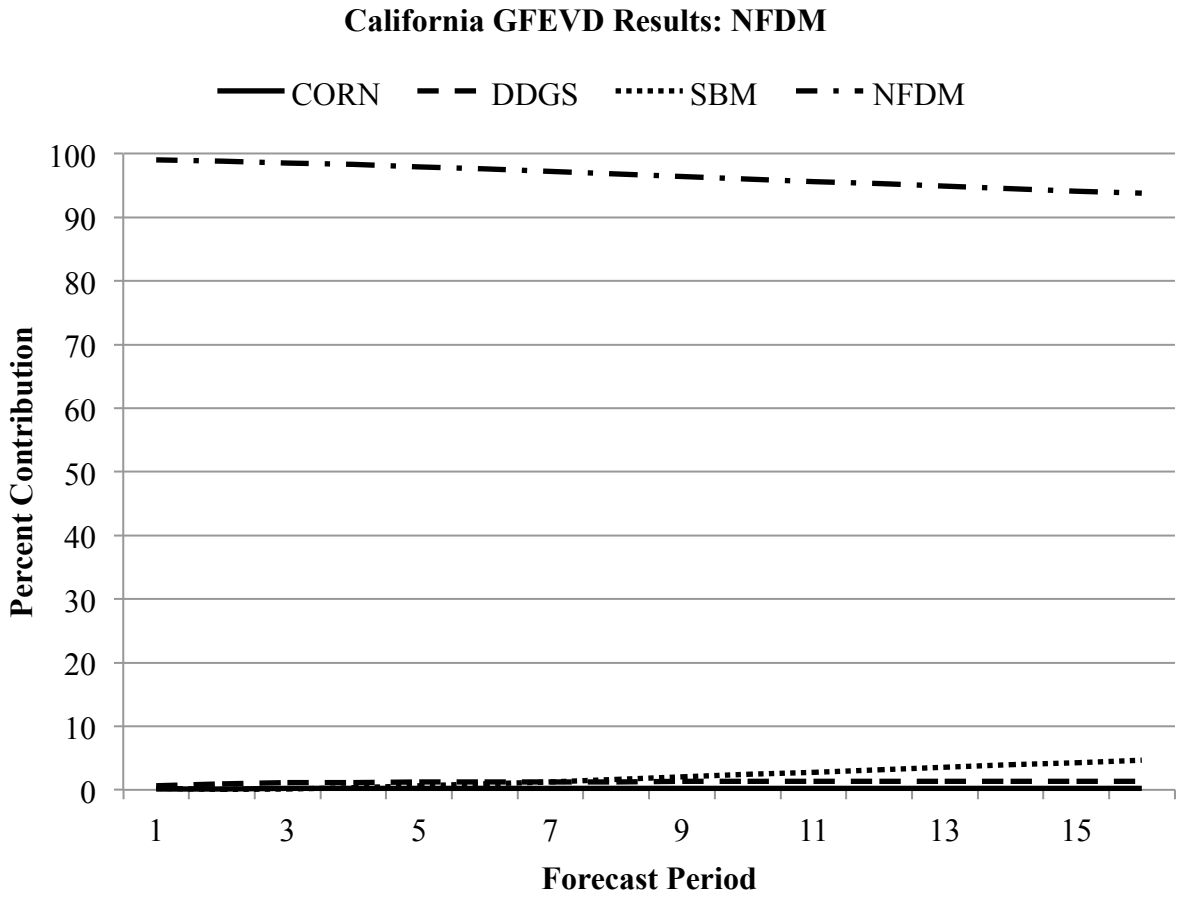


Figure 13d: Nonfat Dry Milk (NFDM) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Corn, Distillers Dried Grains with Solubles (DDGS), and Soybean Meal (SBM) Prices in California over 16 Week Forecast Period.

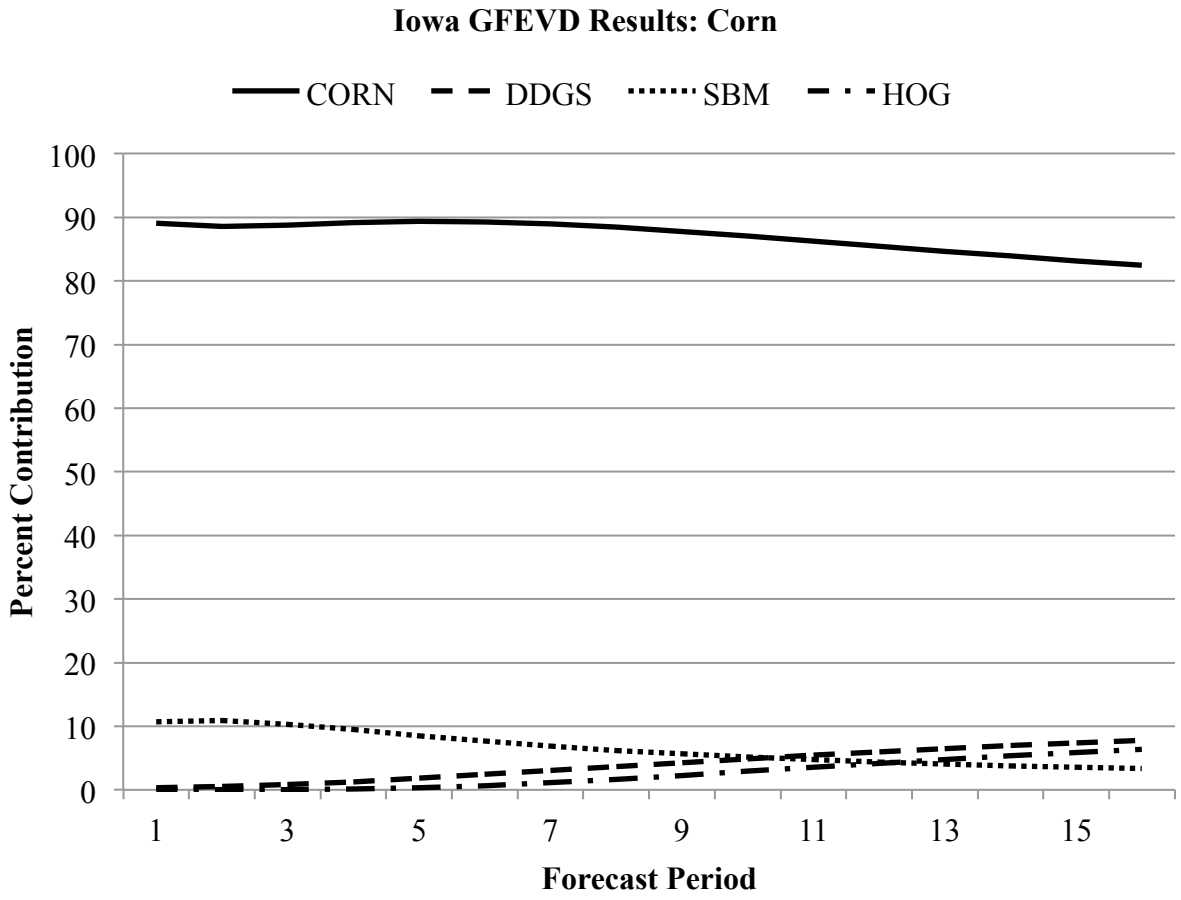


Figure 14a: Corn Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Market Hog Prices in Iowa over 16 Week Forecast Period.

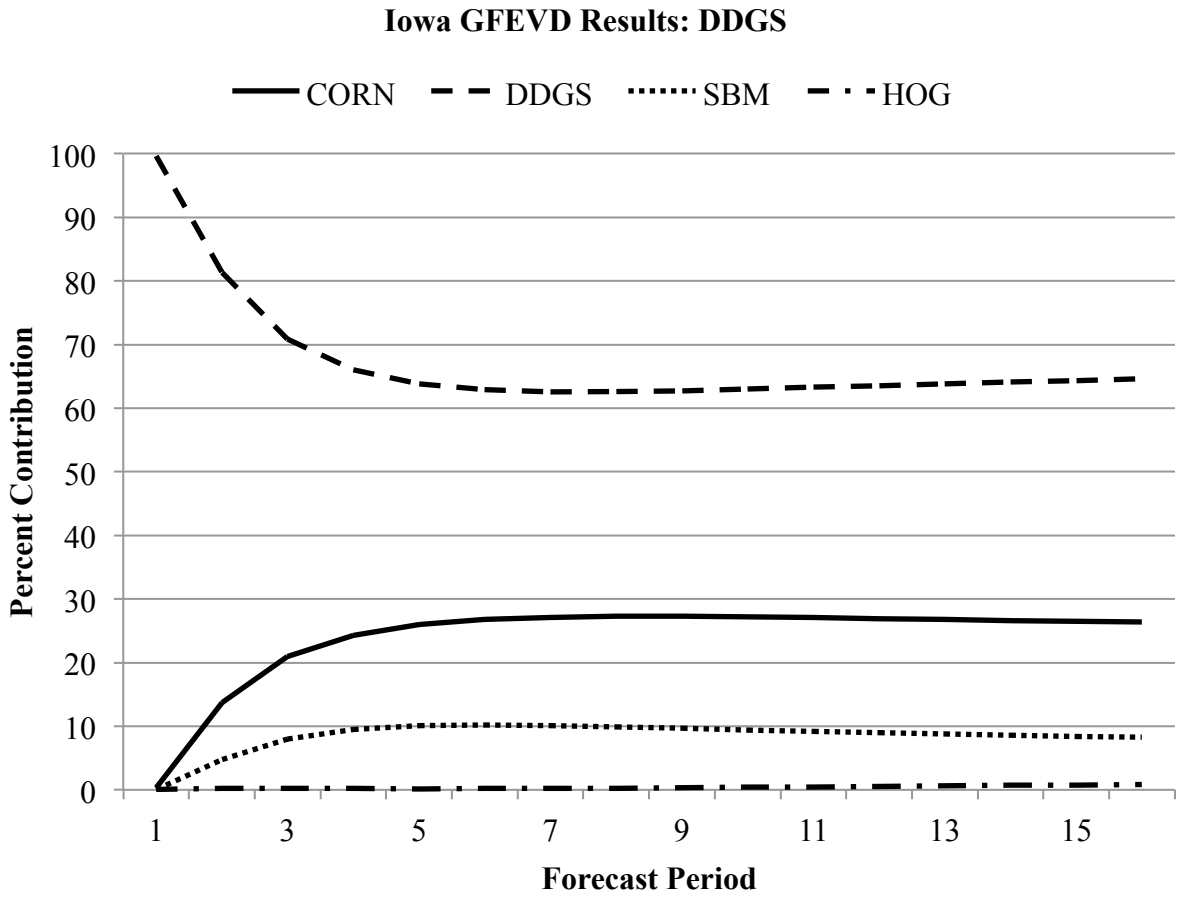


Figure 14b: Distillers Dried Grains with Solubles (DDGS) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Corn, Soybean Meal (SBM), and Market Hog Prices in Iowa over 16 Week Forecast Period.

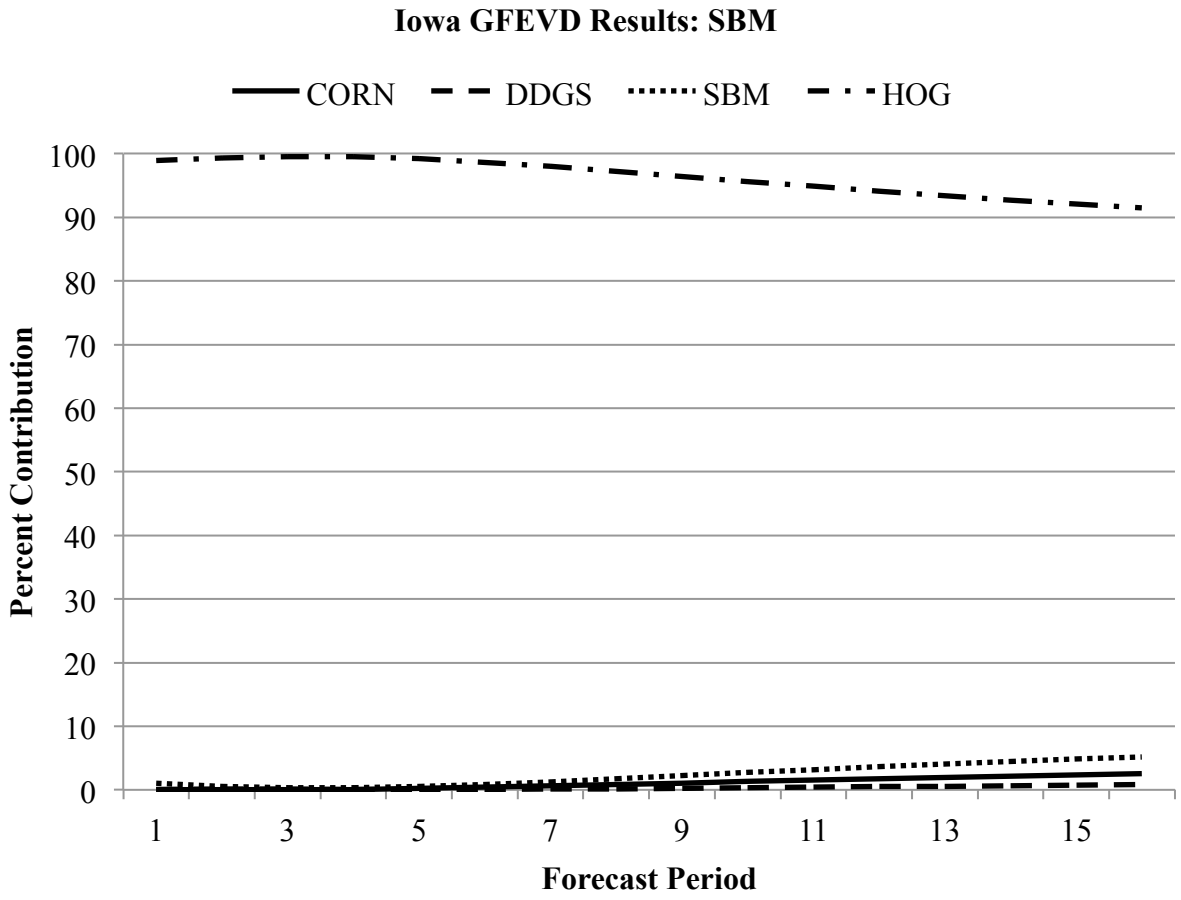


Figure 14c: Soybean Meal (SBM) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Corn, Distillers Dried Grains with Solubles (DDGS) and Market Hog Prices in Iowa over 16 Week Forecast Period.

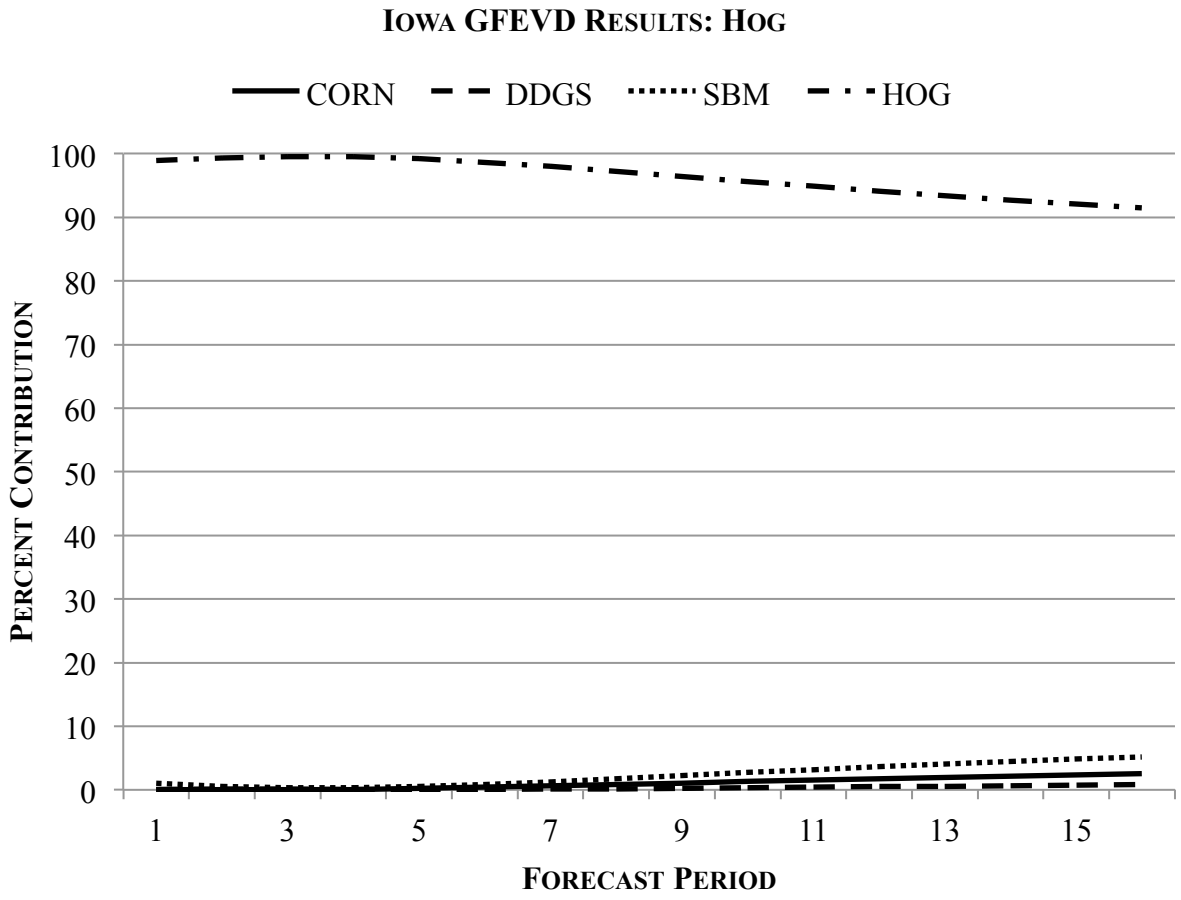


Figure 14d: Market Hog Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Corn, Distillers Dried Grains with Solubles (DDGS), and Soybean Meal (SBM) Prices in Iowa over 16 Week Forecast Period.

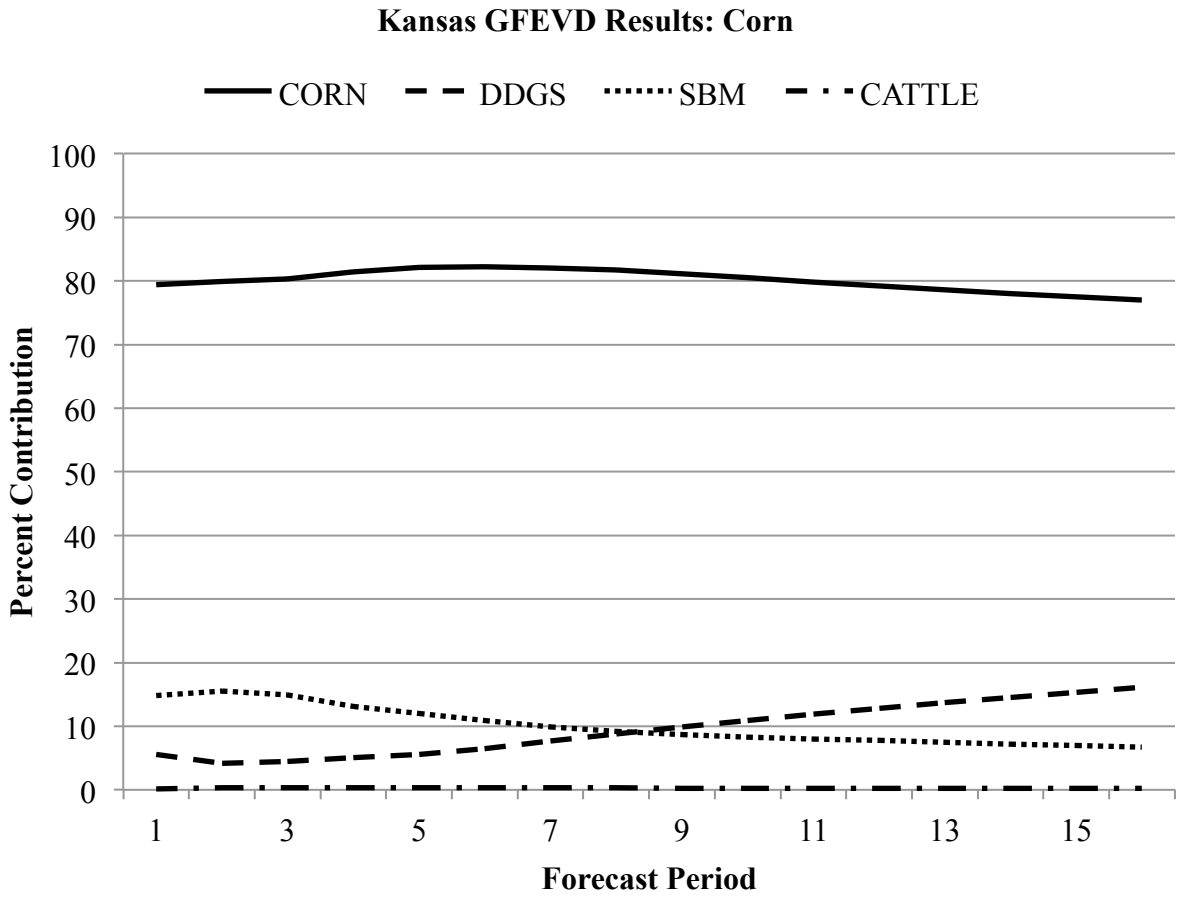


Figure 15a: Corn Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Cattle on Feed Prices in Kansas over 16 Week Forecast Period.

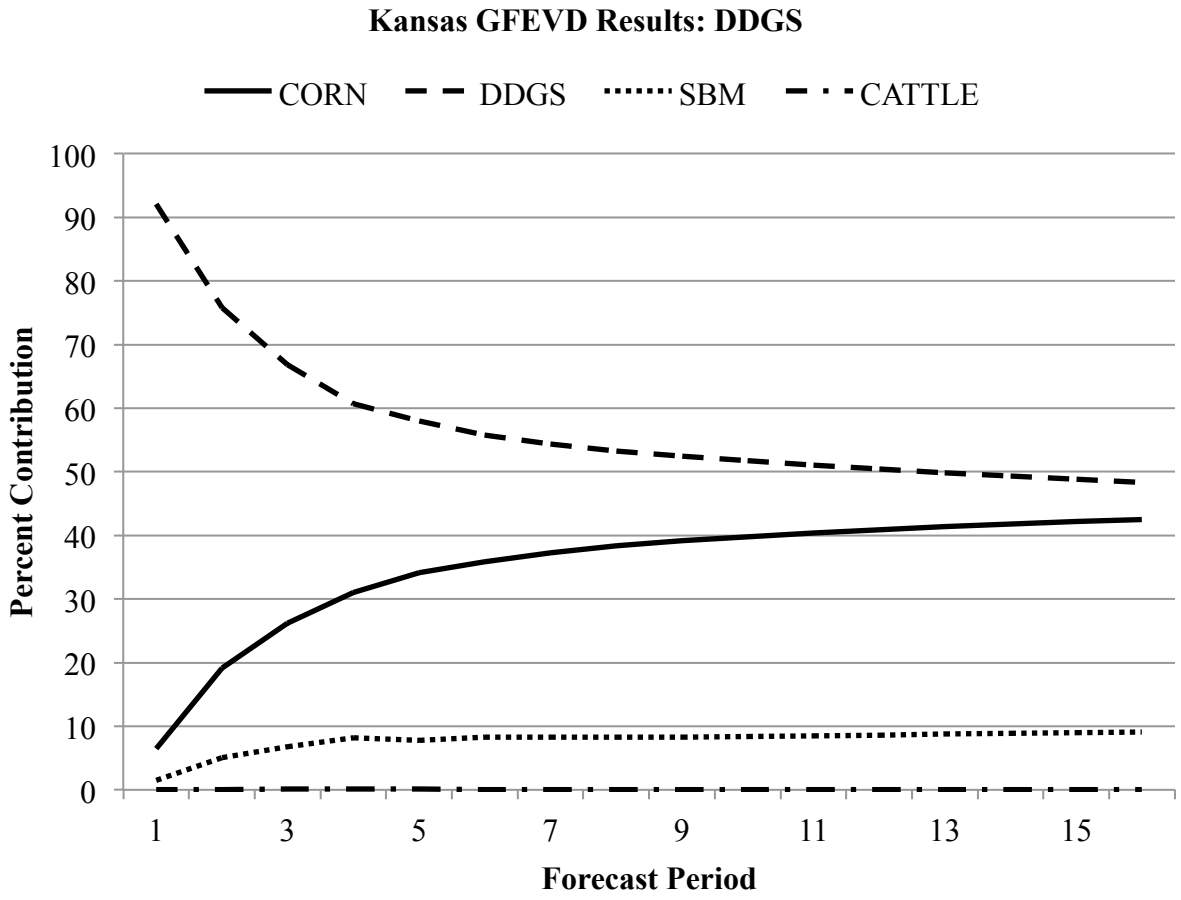


Figure 15b: Distillers Dried Grains with Solubles (DDGS) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Corn, Soybean Meal (SBM), and Cattle on Feed Prices in Kansas over 16 Week Forecast Period.

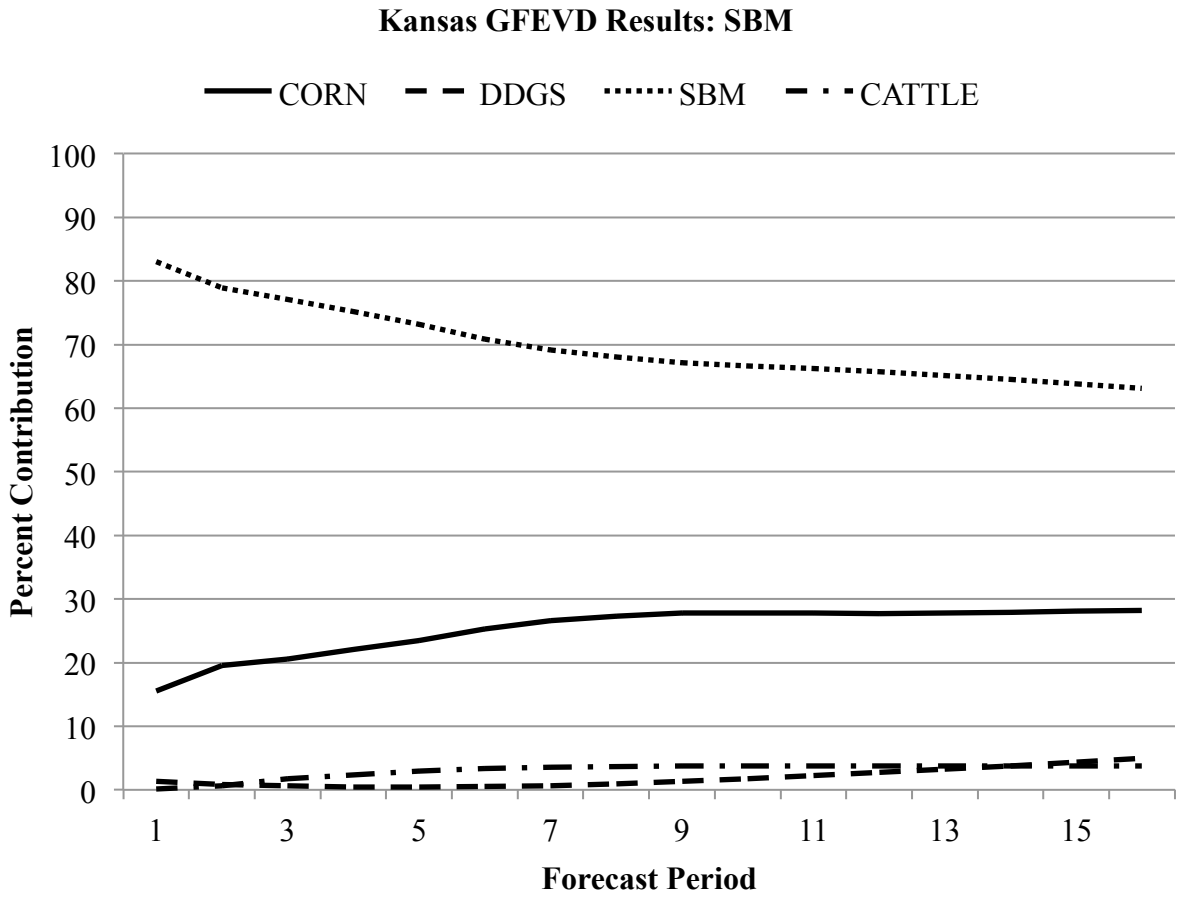


Figure 15c: Soybean Meal (SBM) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Corn, Distillers Dried Grains with Solubles (DDGS) and Cattle on Feed Prices in Kansas over 16 Week Forecast Period.

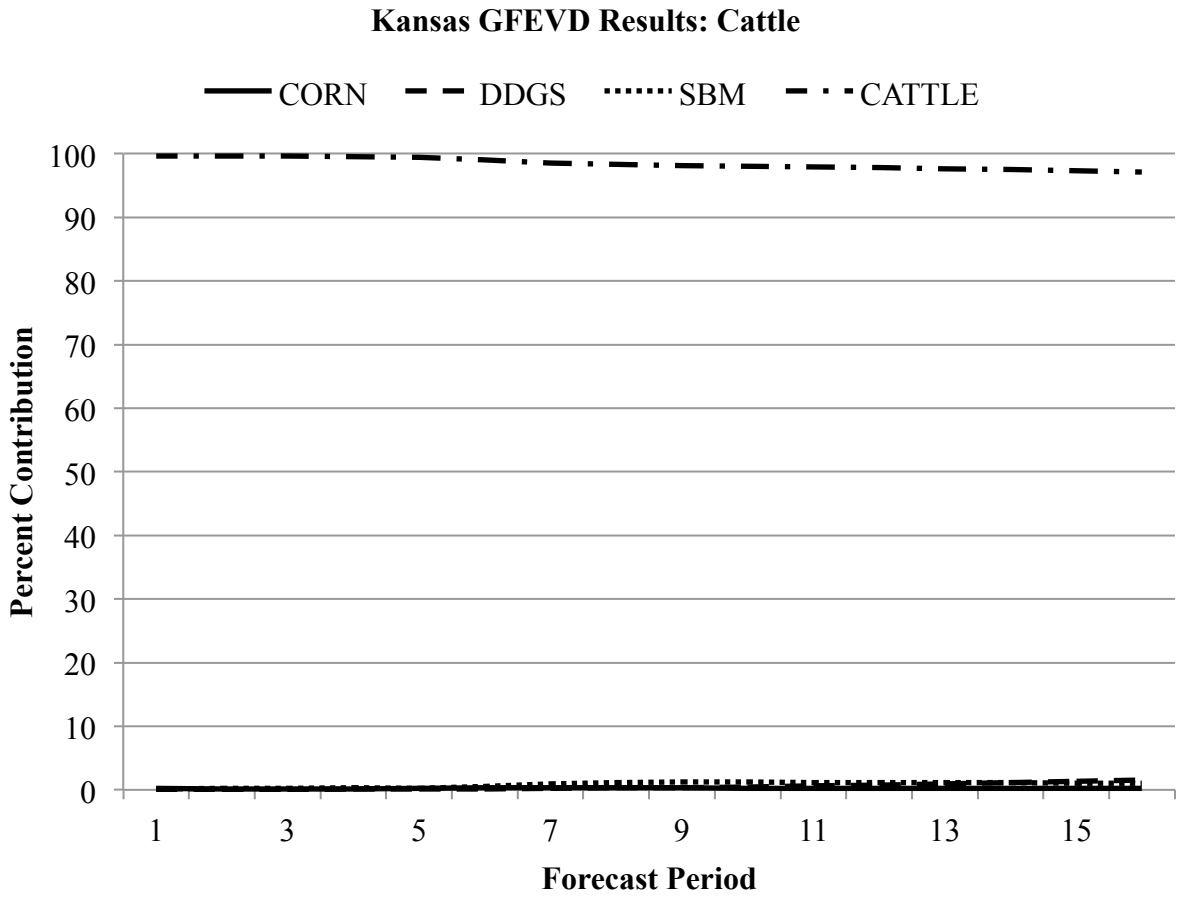


Figure 15d: Cattle on Feed Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Corn, Distillers Dried Grains with Solubles (DDGS), and Soybean Meal (SBM) Prices in Kansas over 16 Week Forecast Period.

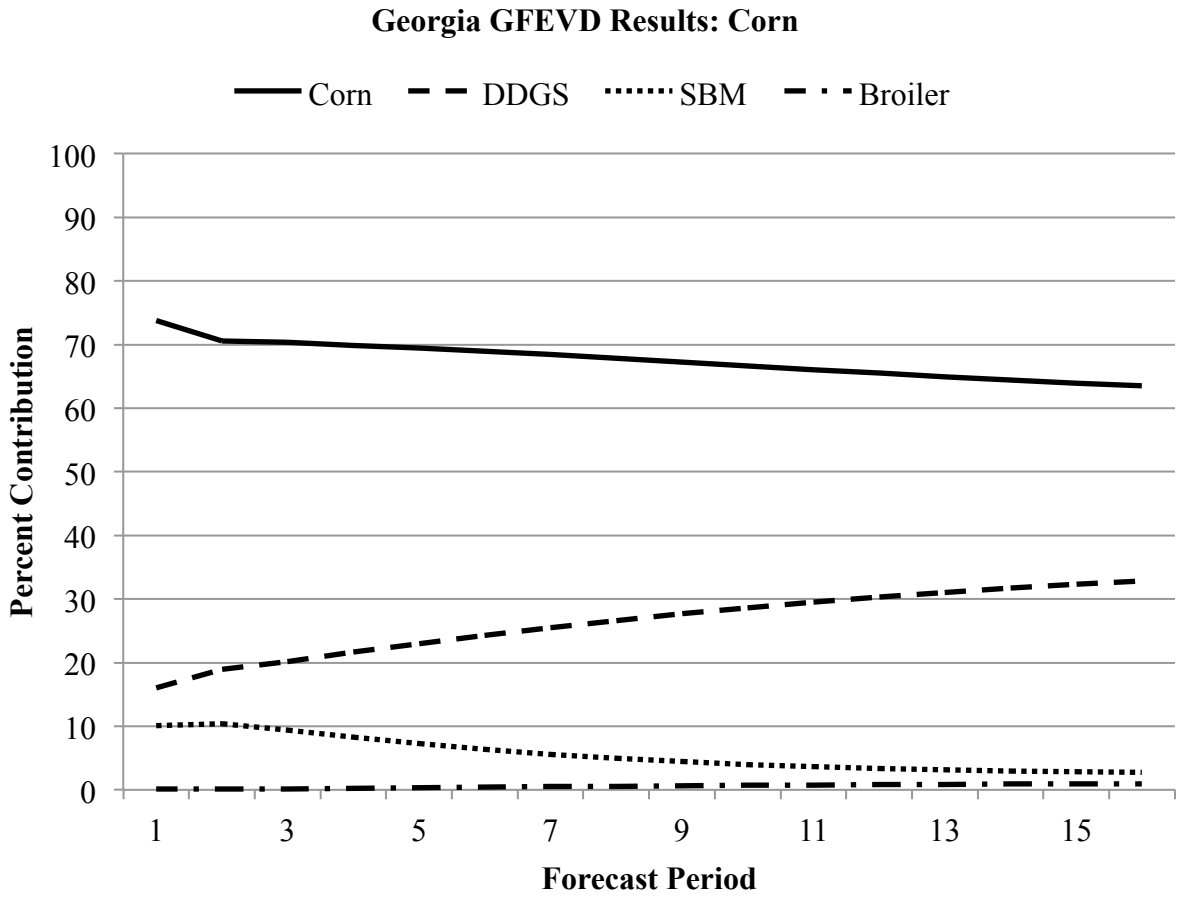


Figure 16a: Corn Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Broiler Chicken Prices in Georgia over 16 Week Forecast Period.

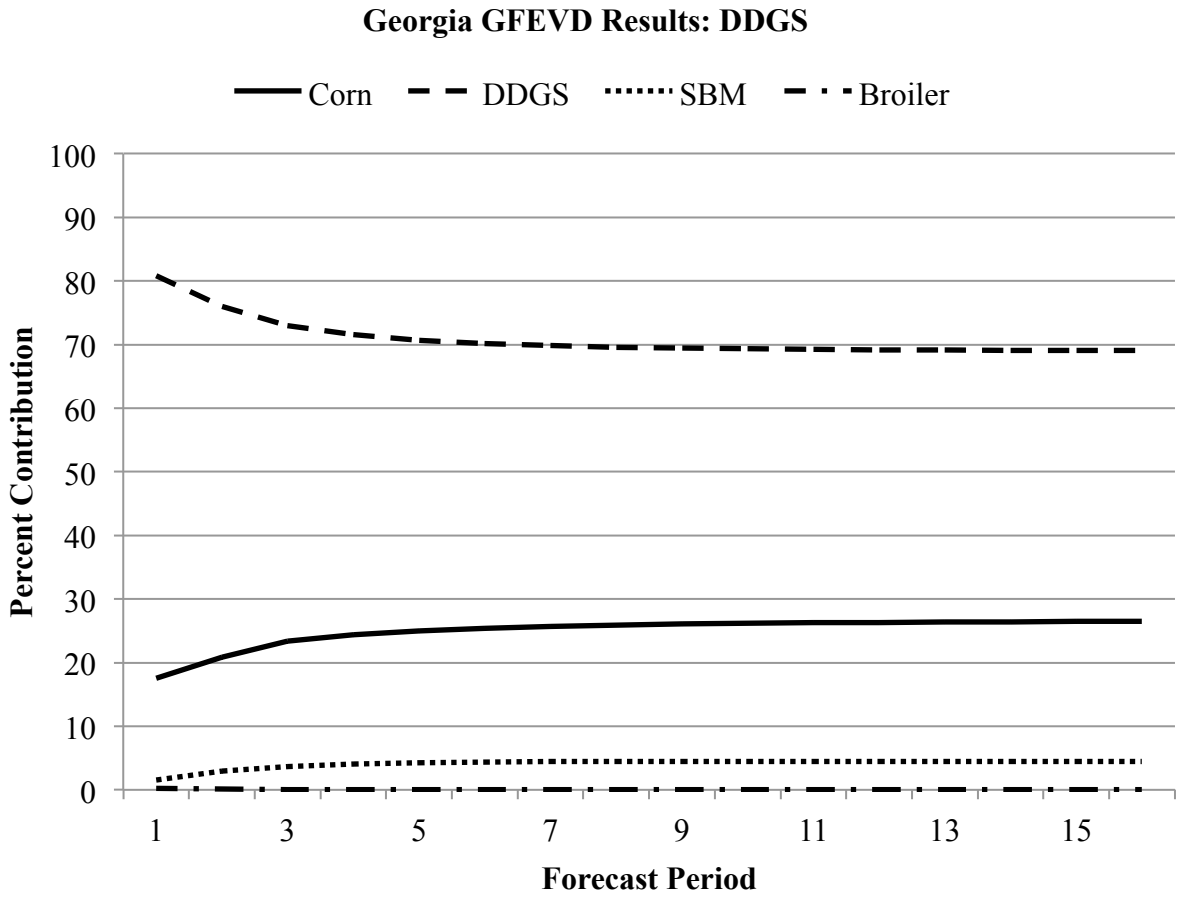


Figure 16b: Distillers Dried Grains with Solubles (DDGS) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Corn, Soybean Meal (SBM), and Broiler Chicken Prices in Georgia over 16 Week Forecast Period.

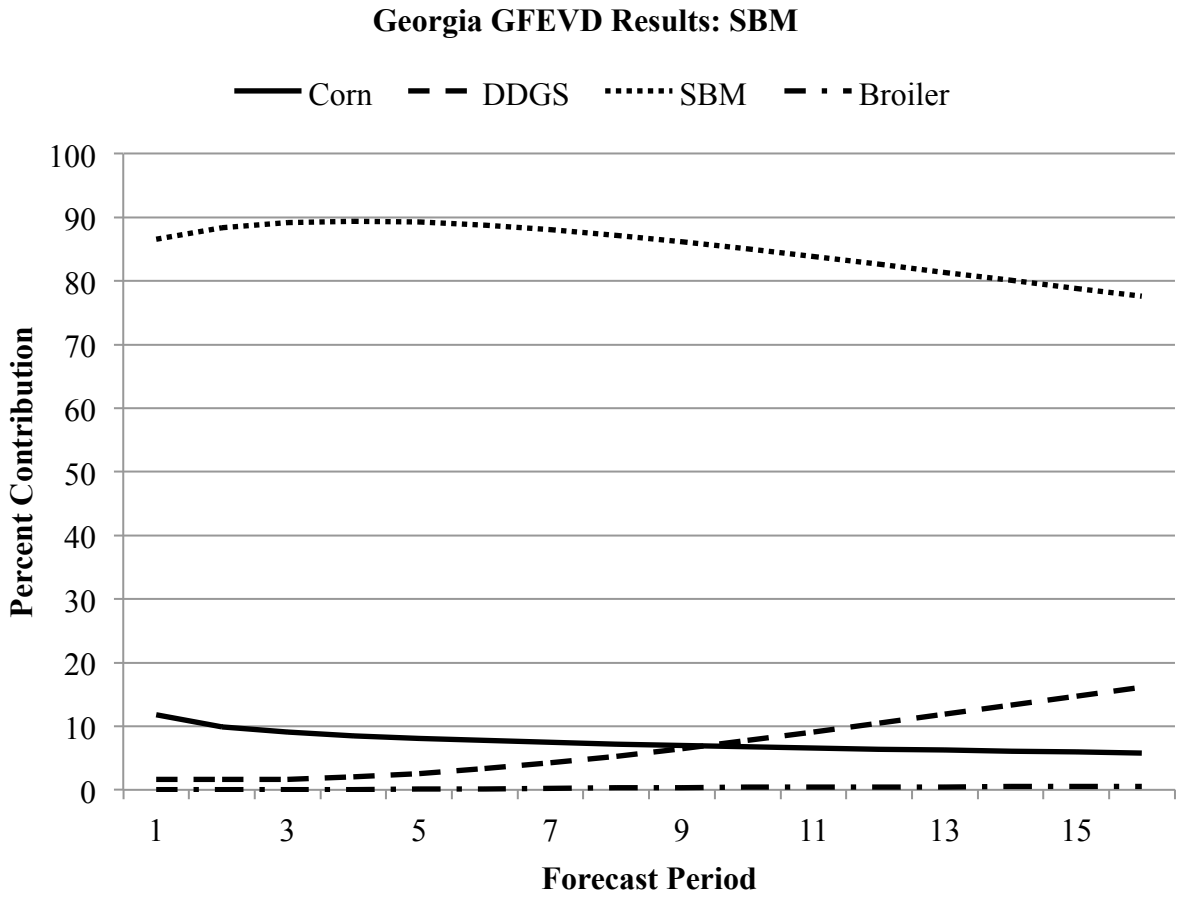


Figure 16c: Soybean Meal (SBM) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Corn, Distillers Dried Grains with Solubles (DDGS), and Broiler Chicken Prices in Georgia over 16 Week Forecast Period.

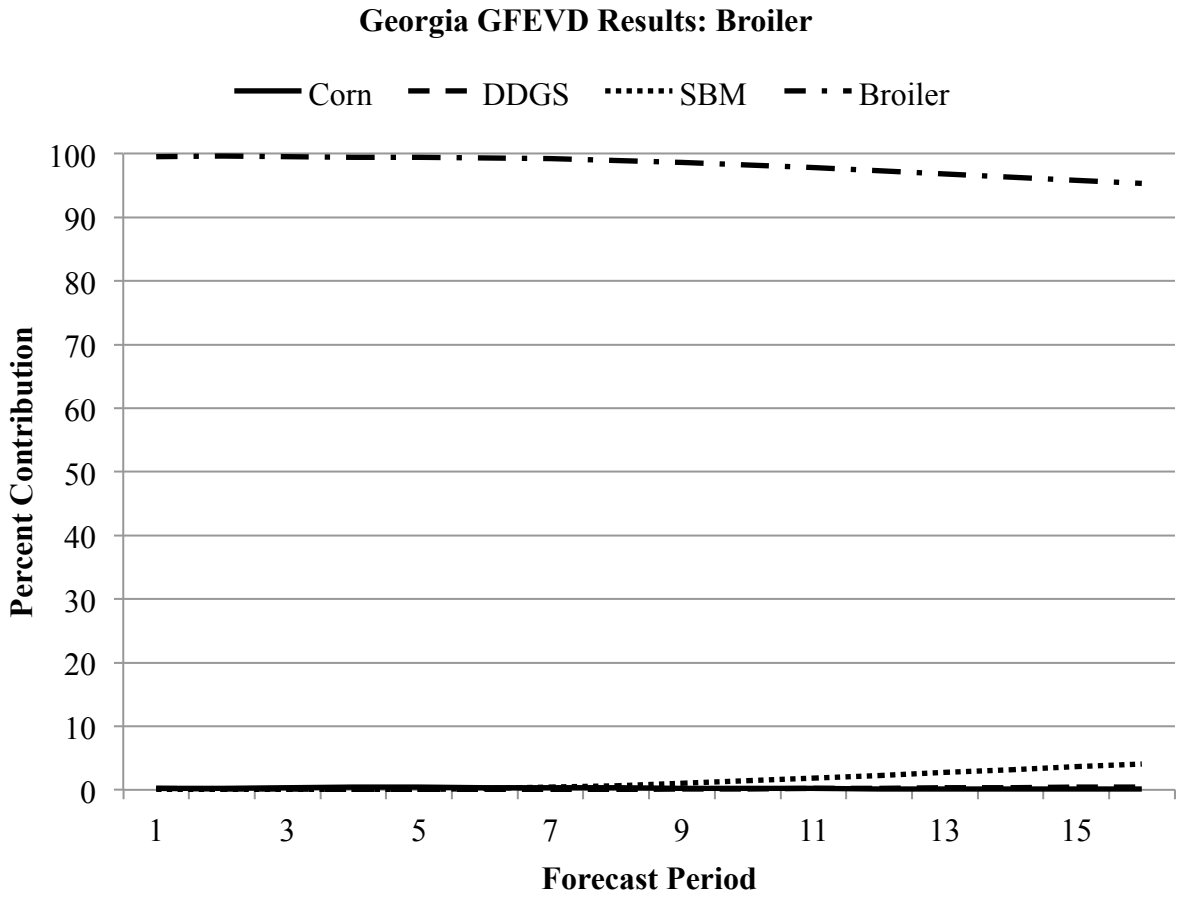


Figure 16d: Broiler Chicken Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contribution Time Paths for Corn, Distillers Dried Grains with Solubles (DDGS), and Soybean Meal (SBM) Prices in Georgia over 16 Week Forecast Period.

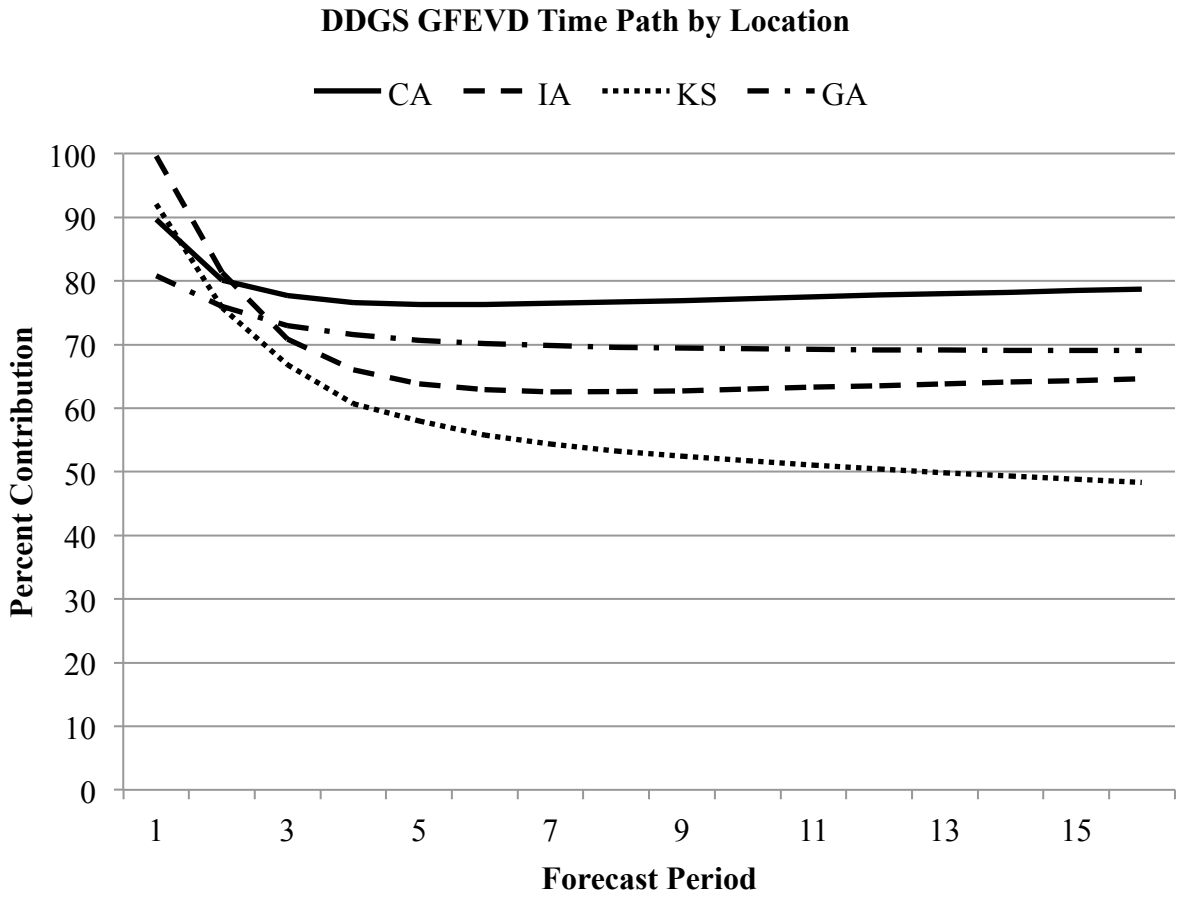


Figure 17: Comparison of Cumulative Changes in Distillers Dried Grains with Solubles (DDGS) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Self-Contributions in California, Iowa, Kansas, and Georgia Livestock Markets over 16 Week Forecast Period (Axis Scaled at 100 Percent).

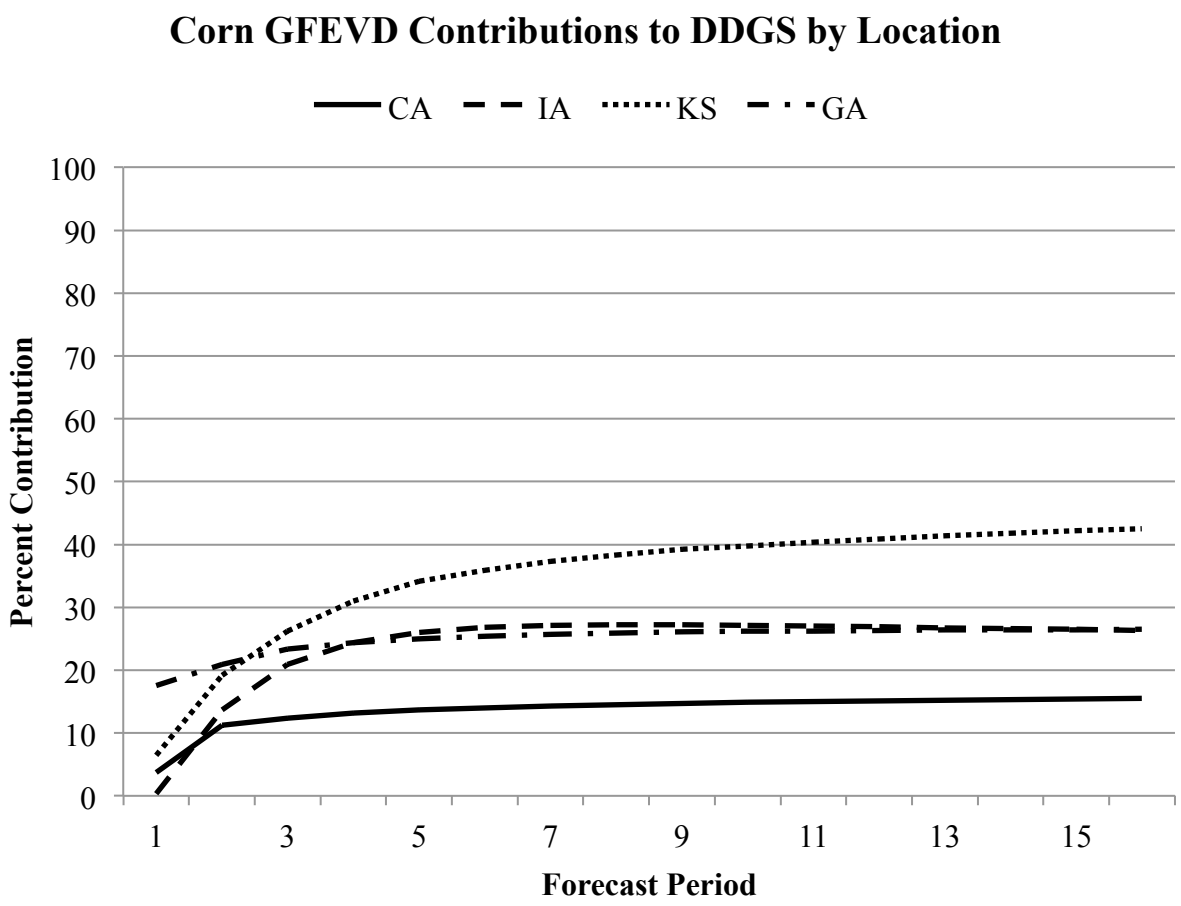


Figure 18: Comparison of Cumulative Changes in Distillers Dried Grains with Solubles (DDGS) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contributions Attributed to Corn Price in California, Iowa, Kansas, and Georgia Livestock Markets over 16 Week Forecast Period (Axis Scaled at 100 Percent).

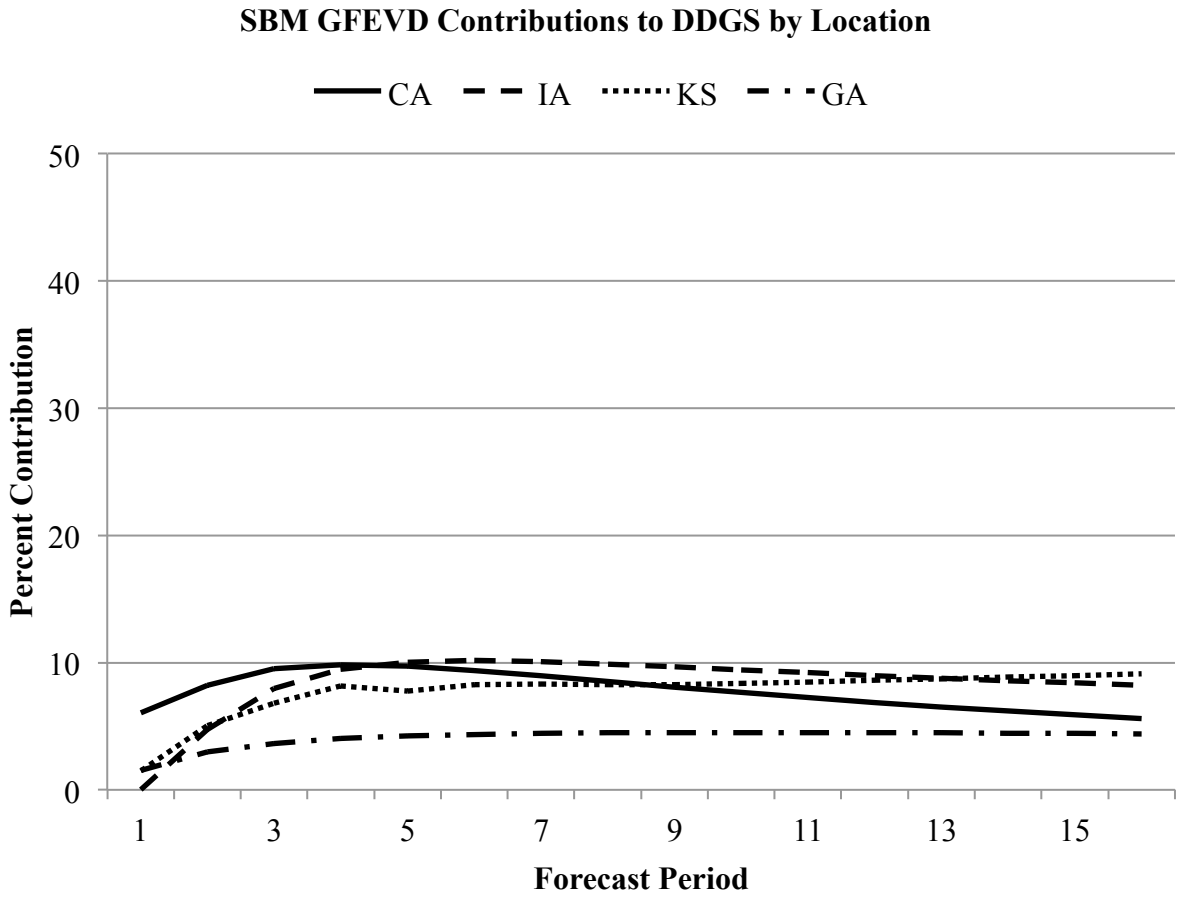


Figure 19: Comparison of Cumulative Changes in Distillers Dried Grains with Solubles (DDGS) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contributions Attributed to Soybean Meal (SBM) Price in California, Iowa, Kansas, and Georgia Livestock Markets over 16 Week Forecast Period (Axis Scaled at 50 Percent).

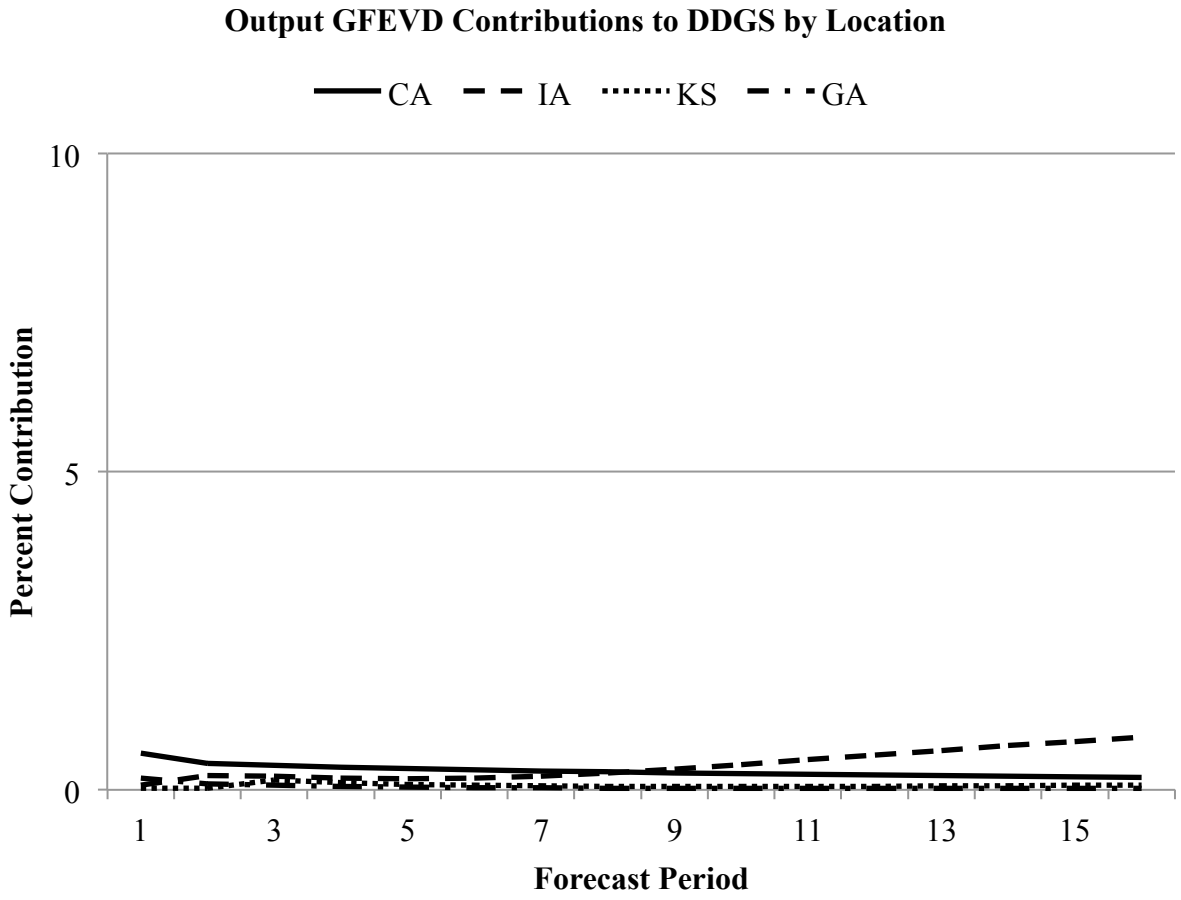


Figure 20: Comparison of Cumulative Changes in Distillers Dried Grains with Solubles (DDGS) Price Generalized Forecast Error Variance Decomposition (GFEVD) Percent Contributions Attributed to Livestock Output Prices in California, Iowa, Kansas, and Georgia Livestock Markets over 16 Week Forecast Period (Axis Scaled at 10 Percent).

Table 1: Descriptive Statistics for Feedstuff and Livestock Output Prices for California, Iowa, Kansas and Georgia from January 2007 to December 2014 in U.S. Dollars.

Location	Variable	Max.	Min.	Avg.	Var.	Std. Dev.
California	Corn	17.60	7.13	11.41	7.93	2.82
	DDGS	16.06	5.72	9.97	7.92	2.81
	SBM	30.28	9.81	18.30	18.19	4.26
	NFDM	2.25	0.80	1.44	0.12	0.35
Iowa	Corn	14.72	4.95	8.72	7.35	2.71
	DDGS	13.87	3.45	7.51	6.42	2.53
	SBM	27.50	8.04	16.24	15.03	3.88
	Hog	99.02	35.26	59.35	186.80	13.67
Kansas	Corn	14.95	4.82	9.10	7.91	2.81
	DDGS	14.63	3.95	8.14	7.25	2.69
	SBM	27.50	8.48	16.37	15.85	3.98
	Cattle	172.94	79.36	109.63	501.11	22.39
Georgia	Corn	17.09	5.98	10.90	10.45	3.23
	DDGS	15.97	4.54	9.96	6.99	2.64
	SBM	30.39	9.84	18.69	21.77	4.67
	Broiler	114.00	71.00	91.22	105.68	10.28

Table 2: Augmented Dickey-Fuller Unit Root Test P-Values for Corn, Soybean Meal (SBM), Distillers Dried Grains with Solubles (DDGS), and Livestock Outputs for California, Iowa, Kansas, and Georgia Livestock Markets.

Market & Commodity	Data at Level			Data at First Difference		
	No term	Intercept	Int. & Trend	No term	Intercept	Int. & Trend
CA Corn	0.583	0.7007	0.9532	<0.0001*	<0.0001*	<0.0001*
CA SBM	0.6872	0.3825	0.1648	<0.0001*	<0.0001*	<0.0001*
CA DDGS	0.5955	0.3194	0.6012	<0.0001*	<0.0001*	<0.0001*
CA Output	0.5464	0.1592	0.375	<0.0001*	<0.0001*	<0.0001*
IA Corn	0.5222	0.5393	0.9181	<0.0001*	<0.0001*	<0.0001*
IA SBM	0.71	0.1092	0.0414*	<0.0001*	<0.0001*	<0.0001*
IA DDGS	0.4102	0.3694	0.5541	<0.0001*	<0.0001*	<0.0001*
IA Output	0.5409	0.0337*	0.0034*	<0.0001*	<0.0001*	<0.0001*
KS Corn	0.5359	0.5707	0.9272	<0.0001*	<0.0001*	<0.0001*
KS SBM	0.6879	0.0953	0.0223*	<0.0001*	<0.0001*	<0.0001*
KS DDGS	0.4985	0.3218	0.5084	<0.0001*	<0.0001*	<0.0001*
KS Output	0.9923	0.9929	0.9249	<0.0001*	<0.0001*	<0.0001*
GA Corn	0.7986	0.5997	0.7381	<0.0001*	<0.0001*	<0.0001*
GA SBM	0.7196	0.1386	0.0027*	<0.0001*	<0.0001*	<0.0001*
GA DDGS	0.4753	0.2285	0.4508	<0.0001*	<0.0001*	<0.0001*
GA Output	0.9852	0.9214	0.6323	<0.0001*	<0.0001*	<0.0001*

Note: * = Significance at a 5% statistical level.

Table 3a: Zivot-Andrews (Z.A.) Unit Root Test Statistics, Critical Values, and Break Point Dates for Corn, Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM) and Nonfat Dry Milk (NFDM) Prices for California from January 2007 to December 2014.

Variable	Type	Z.A. Stat.	Crit. Value	Date
NFDM	Intercept	-3.539	-4.93	4/5/2008
	Trend & Int.	-3.741	-4.42	11/8/2008
	Both	-3.85	-5.08	8/8/2009
DDGS	Intercept	-3.103	-4.93	9/4/2010
	Trend & Int.	-2.663	-4.42	5/19/2012
	Both	-3.285	-5.08	10/15/2011
Corn	Intercept	-1.427	-2.874	7/3/2010
	Trend & Int.	-1.531	-4.42	10/13/2012
	Both	-1.949	-5.08	10/6/2012
SBM	Intercept	-3.278	-4.93	3/31/2012
	Trend & Int.	-3.02	-4.42	11/24/2012
	Both	-3.662	-5.08	7/26/2008

Table 3b: Zivot-Andrews (Z.A.) Unit Root Test Statistics, Critical Values, and Break Point Dates for Corn, Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM) and Cattle on Feed Prices for Kansas from January 2007 to December 2014.

Variable	Type	Z.A. Stat.	Crit. Value	Date
Cattle	Intercept	-2.937	-4.93	10/4/2008
	Trend	-2.762	-4.42	5/16/2009
	Both	-3.23	-5.08	10/4/2008
DDGS	Intercept	-3.574	-4.93	8/28/2010
	Trend	-3.21	-4.42	12/22/2012
	Both	-3.961	-5.08	6/23/2012
Corn	Intercept	-3.002	-4.93	7/27/2013
	Trend	-2.518	-4.42	8/18/2012
	Both	-3.257	-5.08	9/4/2010
SBM	Intercept	-4.732	-4.93	5/12/2012
	Trend	-3.81	-4.42	9/4/2010
	Both	-4.885	-5.08	5/12/2012

Table 3c: Zivot-Andrews (Z.A.) Unit Root Test Statistics, Critical Values, and Break Point Dates for Corn, Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM) and Market Hog Prices for Iowa from January 2007 to December 2014.

Variable	Type	Z.A. Stat.	Crit. Value	Date
Hog	Intercept	-4.153	-4.93	8/23/2008
	Trend	-3.845	-4.42	12/27/2008
	Both	-4.398	-5.08	1/2/2010
DDGS	Intercept	-3.354	-4.93	9/11/2010
	Trend	-3.315	-4.42	7/6/2013
	Both	-4.087	-5.08	6/16/2012
Corn	Intercept	-3.066	-4.93	7/27/2013
	Trend	-2.573	-4.42	8/11/2012
	Both	-3.265	-5.08	9/4/2010
SBM	Intercept	-4.615	-4.93	3/31/2012
	Trend	-3.663	-4.42	5/29/2010
	Both	-4.649	-5.08	3/31/2012

Table 3d: Zivot-Andrews (Z.A.) Unit Root Test Statistics, Critical Values, and Break Point Dates for Corn, Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM) and Broiler Chicken Prices for Georgia from January 2007 to December 2014.

Variable	Type	Z.A. Stat.	Crit. Value	Date
Broiler	Intercept	-4.409	-4.93	7/4/2009
	Trend	-4	-4.42	9/17/2001
	Both	-4.463	-5.08	7/4/2009
DDGS	Intercept	-2.977	-4.93	12/11/2010
	Trend	-2.317	-4.42	7/7/2012
	Both	-3.013	-5.08	8/21/2010
Corn	Intercept	-3.215	-4.93	6/29/2013
	Trend	-2.364	-4.42	4/16/2011
	Both	-3.235	-5.08	8/21/2010
SBM	Intercept	-5.441	-4.93	6/9/2012
	Trend	-4.729	-4.42	10/1/2011
	Both	-5.432	-5.08	6/9/2012

Table 4a: Akaike Information Criterion (AIC) Model Selection and Specification by Lag Length and Model Rank with Data Trend and Intercept or Trend Terms in Cointegrating Equation (CE) for California.

	Data Trend:	None	None	Linear	Linear
	CE Intercept:	None	Intercept	Intercept	Intercept
	CE Trend:	None	None	None	Trend
Lags	Model Rank				
1	1	9.830	9.826*	9.849	9.827
	2	9.872	9.853	9.867	9.853
	3	9.931	9.912	9.920	9.896
2	1	9.904	9.892	9.919	9.897
	2	9.954	9.934	9.952	9.928
	3	10.019	9.995	10.004	9.987
3	1	9.879	9.880	9.910	9.892
	2	9.936	9.939	9.959	9.931
	3	9.999	10.006	10.017	9.999
4	1	9.957	9.961	9.994	9.987
	2	10.005	10.020	10.043	10.027
	3	10.081	10.087	10.099	10.094
5	1	10.150	10.129	10.162	10.172
	2	10.197	10.181	10.203	10.205
	3	10.282	10.250	10.262	10.272

Note: * = Minimal AIC value.

Table 4b: Akaike Information Criterion (AIC) Model Selection and Specification by Lag Length and Model Rank with Data Trend, with Intercept and or Trend Terms in Cointegrating Equation (CE) for Kansas.

	Data Trend:	None	None	Linear	Linear
	CE Intercept:	None	Intercept	Intercept	Intercept
	CE Trend:	None	None	None	Trend
Lags	Model Rank				
1	1	8.272	8.266	8.275	8.268
	2	8.298	8.297	8.303	8.295
	3	8.334	8.338	8.340	8.332
2	1	8.243	8.238	8.242	8.230
	2	8.269	8.269	8.268	8.257
	3	8.298	8.302	8.305	8.298
3	1	8.267	8.262	8.265	8.26
	2	8.293	8.293	8.293	8.289
	3	8.323	8.328	8.33	8.331
4	1	8.174	8.167	8.166	8.166
	2	8.196	8.194	8.191	8.189
	3	8.223	8.226	8.230	8.231
5	1	8.064	8.059*	8.061	8.064
	2	8.082	8.082	8.079	8.084
	3	8.111	8.117	8.118	8.124

Note: * = Minimal AIC value.

Table 4c: Akaike Information Criterion (AIC) Model Selection and Specification by Lag Length and Model Rank with Data Trend, with Intercept and or Trend Terms in Cointegrating Equation (CE) for Iowa.

	Data Trend:	None	None	Linear	Linear
	CE Intercept:	None	Intercept	Intercept	Intercept
	CE Trend:	None	None	None	Trend
Lags	Model Rank				
1	1	7.802	7.797*	7.812	7.817
	2	7.829	7.817	7.827	7.813
	3	7.86	7.852	7.857	7.841
2	1	7.86	7.853	7.869	7.872
	2	7.883	7.874	7.884	7.866
	3	7.917	7.909	7.914	7.892
3	1	7.92	7.911	7.927	7.931
	2	7.935	7.926	7.937	7.924
	3	7.971	7.96	7.965	7.945
4	1	7.944	7.938	7.955	7.96
	2	7.954	7.954	7.965	7.95
	3	7.992	7.984	7.989	7.967
5	1	8.023	8.021	8.038	8.033
	2	8.038	8.041	8.053	8.031
	3	8.076	8.066	8.072	8.051

Note: * = Minimal AIC value.

Table 4d: Akaike Information Criterion (AIC) Model Selection and Specification by Lag Length and Model Rank with Data Trend, with Intercept and or Trend Terms in Cointegrating Equation (CE) for Georgia.

	Data Trend:	None	None	Linear	Linear
	CE Intercept:	None	Intercept	Intercept	Intercept
	CE Trend:	None	None	None	Trend
Lags	Model Rank				
1	1	4.968	4.941	4.944	4.946
	2	4.980	4.952	4.952	4.958
	3	5.008	4.985	4.986	4.975
2	1	4.839	4.817	4.819	4.816*
	2	4.859	4.836	4.835	4.824
	3	4.887	4.870	4.870	4.851
3	1	4.925	4.900	4.902	4.902
	2	4.944	4.914	4.911	4.899
	3	4.974	4.949	4.949	4.927
4	1	4.952	4.922	4.925	4.924
	2	4.977	4.941	4.939	4.928
	3	5.008	4.977	4.976	4.956
5	1	4.998	4.988	4.993	4.997
	2	5.027	5.012	5.011	5.011
	3	5.064	5.048	5.049	5.040

Note: * = Minimal AIC value.

Table 5: California, Iowa, Kansas, and Georgia Long-Run Error Correction Term Equations for Corn, Soybean Meal (SBM), and Livestock Outputs Normalized for Distillers Dried Grains with Solubles (DDGS) with Constant and Trend Term(s).

Location	DDGS		Corn	SBM	Output	Constant	Trend
California	1	=	0.2399	-1.2704*	-0.0240	14.1029	-
Iowa	1	=	-0.7104*	-0.4790*	0.0626*	2.8586	-
Kansas	1	=	-0.7073*	-0.2728*	-0.0058	3.3079	-
Georgia	1	=	-0.7375*	-0.6276*	0.0400	2.6018	0.0174*

Note: * = Significance at a 5% level.

Table 6a: California Market Vector Error Correction Model Coefficients and T-Statistics (Below Coefficients) for Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Nonfat Dry Milk (NFDM).

Lagged Variable	DDGS	Corn	SBM	NFDM
DDGS	-0.1649	-0.0176	-0.235	0.3992
	-2.6027*	-0.2321	-1.466	0.7704
Corn	0.2364	-0.0756	0.1532	0.0963
	4.7208*	-1.2612	1.2092	0.2350
SBM	0.0451	0.0803	0.3049	-0.1966
	1.8466**	2.7473*	4.9340*	-0.9837
NFDM	-0.0028	0.0064	0	0.4698
	-0.4170	0.7971	-0.0018	8.5830*

Note: * = Significance at a 5% level, ** = Significance at a 10% level.

Table 6b: Iowa Market Vector Error Correction Model Coefficients and T-Statistics (Below Coefficients) for Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Market Hog.

Lagged Variable	DDGS	Corn	SBM	Hog
DDGS	0.1586	0.0035	-0.0753	0.4409
	3.9170*	0.0579	-0.5602	1.1882
Corn	0.3152	0.2117	0.2970	-0.5191
	8.5253*	3.8495*	2.4195*	-1.5318
SBM	0.0563	0.0294	0.2155	0.1125
	3.4315*	1.2067	3.9587*	0.7486
Hog	0.0088	-0.0026	-0.0587	0.4487
	1.7041**	-0.3434	-3.4196	9.4671*

Note: * = Significance at a 5% level, ** = Significance at a 10% level.

Table 6c: Kansas Market Vector Error Correction Model Coefficients and T-Statistics (Below Coefficients) for Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Cattle on Feed.

Lagged Variable	Lags	DDGS	Corn	SBM	Cattle
DDGS	1	-0.0674	-0.1390	-0.3000	0.1774
		-1.2379	-2.0168*	-1.9501**	0.4738
DDGS	2	0.0375	0.0637	-0.1741	0.0579
		0.6954	0.9336	-1.1421	0.1562
DDGS	3	0.1392	0.0129	-0.2192	-0.3255
		2.6178*	0.1921	-1.4595	-0.8904
DDGS	4	0.1897	-0.0176	0.1774	0.3931
		3.5965*	-0.2634	1.1899	1.0836
DDGS	5	0.0183	0.0630	-0.0206	-0.3522
		0.3663	0.9950	-0.1457	-1.0242
Corn	1	0.2929	0.2749	0.4266	0.1948
		6.0959*	4.5211*	3.1421*	0.5897
Corn	2	0.0615	-0.0350	0.0430	0.1225
		1.2265	-0.5520	0.3035	0.3553
Corn	3	0.0998	0.1025	0.3304	-0.1356
		2.0009*	1.6242	2.3447*	-0.3954
Corn	4	0.0271	-0.1392	0.1514	0.4330
		0.5369	-2.1794*	1.0614	1.2476
Corn	5	-0.0452	0.0619	0.3243	0.3002
		-0.8890	0.9612	2.2566*	0.8582
SBM	1	0.0104	0.0179	0.0693	-0.1596
		0.5316	0.7190	1.2499	-1.1825
SBM	2	-0.0087	-0.0137	0.0568	-0.0487
		-0.4659	-0.5766	1.0726	-0.3779
SBM	3	0.0079	-0.0564	-0.1172	-0.0297
		0.4259	-2.3908*	-2.2234*	-0.2316
SBM	4	-0.0348	0.0214	-0.1347	-0.0139
		-1.7441**	0.8473	-2.3911*	-0.1013
SBM	5	0.0355	-0.0317	-0.1806	-0.4223
		1.6892**	-1.1926	-3.0439*	-2.9246*
Cattle	1	0.0017	-0.0077	-0.0373	0.1881
		0.2204	-0.7780	-1.6773**	3.4792*
Cattle	2	0.0188	0.0087	-0.0351	-0.2635
		2.3882*	0.8745	-1.5798	-4.8737*
Cattle	3	-0.0068	-0.0025	0.0018	0.0160
		-0.8410	-0.2480	0.0811	0.2904
Cattle	4	-0.0038	-0.0052	-0.0159	0.0396
		-0.4907	-0.5253	-0.7197	0.7384
Cattle	5	-0.0020	-0.0043	-0.0048	0.0730
		-0.2568	-0.4401	-0.2191	1.3822

Note: * = Significance at a 5% level, ** = Significance at a 10% level.

Table 6d: Georgia Market Vector Error Correction Model Coefficients and T-Statistics (Below Coefficients) for Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), Broiler Chickens, and Trend Term.

Lagged Variable	Lags	DDGS	Corn	SBM	Broiler
DDGS	1	-0.1438	0.0690	-0.0666	-0.0082
		-2.6443*	1.2916	-0.7189	-0.5053
DDGS	2	0.0274	-0.0209	-0.1079	-0.0128
		0.5344	-0.4146	-1.2330	-0.8358
Corn	1	0.1003	-0.1234	-0.0795	0.0106
		1.5597	-1.9539**	-0.7257	0.5559
Corn	2	0.1084	0.0550	0.0590	0.0241
		1.7979**	0.9281	0.5739	1.3423
SBM	1	0.0308	0.0573	0.2224	0.0016
		0.9134	1.7316**	3.8753*	0.1631
SBM	2	-0.0135	-0.0202	0.0671	0.0106
		-0.3872	-0.5910	1.1301	1.0241
Broiler	1	0.0921	-0.1096	-0.0865	0.7151
		0.5225	-0.6324	-0.2877	13.6196*
Broiler	2	-0.0765	0.2127	0.2439	0.0848
		-0.4392	1.2430	0.8217	1.6350
C	N/A	0.0103	0.0070	0.0025	0.0224
		0.3232	0.2237	0.0463	2.3517

Note: * = Significance at a 5% level, ** = Significance at a 10% level.

Table 6e: Kansas Market Granger Causality/Wald Test P-Values for Distillers Dried Grains with Solubles (DDGS), Corn, Soybean Meal (SBM), and Cattle on Feed.

Cause	**Effect**			
	DDGS	Corn	SBM	Cattle
DDGS	-	0.3036	0.1280	0.7229
Corn	0.0000*	-	0.0023*	0.7229
SBM	0.2466	0.1073	-	0.0965**
Cattle	0.1468	0.8331	0.2344	-

Note: * = Significance at a 5% level, ** = Significance at a 10% level.

Table 6f: Georgia Market Granger Causality/Wald Test P-Values for Distillers Dried Grains with Solubles (DDGS), Corn, Soybean Meal (SBM), and Broiler Chicken.

Cause	Effect			
	DDGS	Corn	SBM	Broiler
DDGS	-	0.3357	0.4210	0.6681
Corn	0.1067*	-	0.5580	0.3981
SBM	0.6300	0.2041	-	0.5717
Broiler	0.8714	0.3966	0.6047	-

Note: *P-value for the corn-DDGS relationship is near a 10% level.

Table 7: California, Iowa, Kansas, and Georgia Markets Granger Causality Results Summary for Corn, Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Livestock Outputs.

Cause	Effect			
	Corn	DDGS	SBM	Output
Corn	-	CA*, IA*, KS*, GA**	IA*, KS*	x
DDGS	x	-	x	x
SBM	CA*	CA**, IA*	-	KS**
Output	x	IA**	IA*	-

Note: * = Significance at a 5% level, ** = Significance at a 10% level.

Table 8: California, Iowa, Kansas, and Georgia Market Sixteen-Week Generalized Forecast Variance Decomposition (GFEVD) for Corn, Distillers Dried Grains with Solubles (DDGS), Soybean Meal (SBM), and Livestock Output Prices.

Location	Variable	Corn	DDGS	SBM	Output
California	Corn	91.52	5.25	2.52	0.71
	DDGS	15.51	78.70	5.60	0.20
	SBM	6.08	10.64	83.09	0.20
	Output	0.23	1.33	4.66	93.78
Iowa	Corn	82.48	7.76	3.35	6.42
	DDGS	26.34	64.59	8.24	0.83
	SBM	8.08	13.04	74.56	4.32
	Output	2.50	0.81	5.19	91.49
Kansas	Corn	76.99	16.10	6.71	0.21
	DDGS	42.51	48.31	9.10	0.07
	SBM	28.23	4.92	63.08	3.77
	Output	0.26	1.56	1.07	97.11
Georgia	Corn	63.51	32.85	2.70	0.93
	DDGS	26.48	69.08	4.41	0.02
	SBM	5.78	16.12	77.60	0.50
	Output	0.10	0.48	4.07	95.34

Note: GFEVD row contributions sum to 100.

VITA

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