

TRANSACTION COSTS AND MARKET THINNESS
IN CROP BYPRODUCT MARKETS

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Chapter One – Introduction

Crop byproducts are created when raw agricultural commodity crops are processed in into human food products, biofuels, and other intermediate or final goods. Some examples of processing would be creating sweeteners or ethanol from corn, milling wheat or rice to make flour, and crushing soybeans for soybean oil. From those processes, byproducts such as corn gluten feed, wheat middlings, rice bran, and soybean hulls are produced simultaneously. Thus, these processing procedures take the raw crop, and create a new desired product, as well as byproducts that are not necessarily valued the same. However, these byproducts are not completely without value. For instance, they can be used as an additive in livestock feed, which can act as a nutrient replacement for another ingredient, at a possibly lower price (Staples 2007).

To clarify, byproducts are different from crop residues. When referencing a crop residue, this can sometimes mean the same thing as a processed byproduct (Aregheore and Chimwano 1992). Typically, however, residues refer to the leftover plant remains on a field after harvesting a crop (Owen and Aboud 1988). And so while residues may be mentioned briefly, they will be ignored for the most part.

Considering a processor may not have direct use for particular byproducts, and that gathering them to marketing them may prove costly, a facility's byproducts may never end up being used or even sold to another party. However, in reality these byproducts are indeed sold and bought by some processors and livestock producers, with some having strong market presences in the animal feed industry. (Staples 2007; Patience 2013).

Determining the true extent of byproduct sales and ultimate usage is problematic, though. Many byproducts are traded in smaller markets, meaning that they are not quoted, and instead are priced based on negotiations with brokers over the phone. Due to their lack of size, crop

byproduct markets are more illiquid and have poorer information compared to traditional, larger cash crops. Figures and data about these byproducts can be largely unavailable, difficult to find, or have self-stated concerns with accuracy, even with the growth of more popular ones such as DDGS (Hoffman and Baker 2011). However, since they serve as feed components, they still can be priced to an extent in relation to established substitutes like corn and soybean meal (Ferris 2006). But being in such a small market, byproduct supply and demand levels are weakened enough to result in market price distortions (Thompson and Sonka 1997). Even with poor confidence levels (in terms of accurate price discovery, or rather “arriving at a supply and demand based true market price”), thin markets still play a role in the animal feed economy and continue to survive despite their problems. And thus, if market participants face greater levels of uncertainty as a result, they have to address the problem in some way.

I expect that these thin byproduct markets will not operate like the corn and soybean market given the aforementioned price distortions. After all, the size and unique characteristics of the markets should have their own issues that lead to price variances. These pricing issues can be potentially observed through market player characteristics such as changes in production, pricing, sales, contracting, regulation, transportation, handling, and others over time (Anderson, Hudson, and Harri 2007).

As different byproducts grow, maintain, decline, disappear, or change in any way over the years, the causes and effects of those changes should provide insight into their associated transaction costs. These costs, incurred by buyers and sellers in the market, have traditionally been described as the costs in discovering, negotiating, and contracting prices before a sale, in addition to acquiring information, monitoring actions, and enforcing agreed upon terms after a sale (Coase 1937). Underlying these concepts are other influences such as active and passive

deception, frequency of purchases, quality, delivery window, necessity of a particular good, and more, showing the many ways in which additional costs can affect a market participant outside of the pure price of a good, slowing down a transaction or distorting its price (Williamson 1979).

With this in mind, the proposed research question is this: “How do firms deal with transaction costs in crop byproduct markets?” While this question addresses and includes problematic price discovery, underlying this question will also be research objectives of addressing other, related questions, namely:

- What spot purchasing, contracting, and vertical integration choices do firms make in response to the crop byproducts market, and why?
- How do different transaction costs impact this market?
- What factors influence prices in byproduct markets, and how do they compare to each other?

In regards to firm decisions (that involve problematic price forecasting and transaction costs), there are different possible solutions such as: 1) The firms do not care about the issues and just deal with them on the spot market. 2) The price uncertainty is significant enough that firms contract prices and quantities. 3) The contracts are insufficient, and so the firm vertically integrates. The three choices are in line with the logic of Klein, Crawford, and Alchian (1978). The main goal is to see how smaller markets behave, how well issues can be dealt with, and how firms adapt to these markets based on the degree of volume and price uncertainty.

This research is important because it will help to expand knowledge on thin markets and their behavior effects of size on price distortion, and in turn how that distortion affects market participant governance and contracting choices. Livestock feed costs are a significant portion of those types of operations, ranging from 40 to 70 percent of total livestock production costs (Lalman 1996; Patience 2013). The livestock market is important to monitor, because overall it

continues to be a large part of human food diets globally, and byproducts as a major input of this industry will have to overcome transaction costs that hinder efficient livestock production. The value gained from thin market behavior findings would be captured by livestock producers, those in the crop processing industries, other related industries such as feed producers, and even raw commodity crop producers to an extent.

The established literature on crop byproducts has focused more heavily with nutritional content, and less on the market implications, general pricing, and economics of actually using them. It is true that several nutritional papers would speak of general “cost savings” in regards to using byproducts over the traditional feed options of corn and soybean meal, but those nutritional papers provide no additional quantitative analysis (Neil and Williams 2010; Weber 2012). While some authors have used simple models to look at costs of certain byproducts and to forecast their prices, these papers have been sporadic through the 1970s into the 2000s (e.g., Brorsen, Grant, and Chavas 1985; Ferris 2006). In terms of the current decade, only dried distillers grains with solubles (DDGS) have received any real attention, with the most recent price forecasting and modeling done by Hoffman and Baker (2011).

Some literature exists that looks at the theoretical concept of thin markets in a nebulous, simulated, and general sense, and others that look at real life, specific markets such as hogs (e.g. Saleth, Braden, and Eheart 1991; Nelson and Turner 1995) (e.g. Cason and Friedman 1996; Franken and Parcell 2012). By addressing some of the informational issues in these markets, this study’s framework could help more accurately determine the influences on byproduct prices. The theory behind thin market exchange is a major motivation for this research, and seeing if new empirical evidence from this thesis aligns with thin market theory. One can then take the implications of the findings and attempt to apply it to other markets in the future.

Rostek and Weretka (2008) described the basic issues behind thin markets, stating that they are low in number of trades (in terms of both offered and completed trades), and thereby high in price volatility. The two authors stated this as creating geographic difficulties, inconsistent trade arrangements, imbalances with information and market power, and more. As a result, this leads to weak buyer-supplier relationships and high transaction costs. Crop byproducts are the leftover portions after crop processing (with specific and partial utilization), have no futures markets, serve only as a generally smaller portion of feed diets (Grasser, Fadel, Garnett, and Depeters 1995), have limited literature on their markets, and are shown to be more price volatile than traditional commodity crops through the dataset of this thesis, which begin to justify thin market classification for crop byproduct market. Following that assumption means these thin crop byproduct markets face the issues described by Rostek and Weretka, most notably that the market has high transaction costs.

Following the logic from Coase (1937) again, as various transaction costs rise within a market (such as gathering information on a product and seller, negotiating the terms of a purchase agreement, or demanding compensation for a defective product), the assumption is the high transaction costs of the byproduct market would increase a producer's desire to either contract or to vertically integrate. However, since crop byproducts are used as livestock feed (Chenost and Sansoucy 1989), and farms have been increasingly larger and more specialized over time, the costs for a farm to vertically integrate and produce its own crops and byproducts are recognized to be substantial. While vertical integration remains an option, especially for the large operations, it is hypothesized that contracting or trading directly through the market are more likely choices for a smaller buyer especially.

Haddock and McChesney (1991) theorize that bargaining is the primary method of thin market trading, and that there are opposing incentives to both reveal and conceal information, and to secure rents through opportunistic behavior, respectively. This leads to the question on how contracting and vertical integration can affect transaction costs in crop byproduct markets.

Although price variability may create concerns about risk, previous literature points to protein, energy, and other nutritional aspects as the most important factors in using crop byproducts (Chenost and Sansoucy 1989; Bista, Hubbs, Richert, Tyner, and Preckel 2008; Ferris 2006; Urbanchuk 2003). Given the usage, availability, and variety of corn and soybean meal in livestock feed, the analysis will assume that switching to alternatives is not costly. Thus, a general hypothesis from these statements is that byproduct market buyers will either use the thin crop byproduct market without contracting, especially if they are small. Alternatively my assumption is that an operation will contract the byproduct, or switch to a substitute feed when price becomes too volatile, supply becomes too low, or when the buyer has a larger operation.

The main research question is that “how do firms deal with transaction costs in crop byproduct markets?” Following that were two objective questions of “what spot purchasing, contracting, and vertical integration choices do firms make in response to the crop byproducts market, and why?” along with “how do different transaction costs impact this market?” Given limitations in available data, I turn to the interview responses from livestock producers, feed mill grain buyers, and ethanol plant merchandisers across these byproduct markets to gain insight on these three issues, covered in Chapter Three. These interviews are made up of 40 separate questions spanning seven different focus areas, which ultimately address many market metrics related to the studied crop byproduct markets. Also included in this interview are questions on

how the market participants have taken actions in dealing with the different types of transaction costs.

The remaining objective question is “what factors influence prices in byproduct markets, and how do markets compare to each other?” Chapter Four will use Chebyshev’s inequality to use historical price data and volatility measures to estimate the transaction quantities needed in order to achieve given levels of price accuracy. Using this part of the model will help measure the degree of market thinness as measured by both the degree of output and the patterns of outputs across time.

Chapter Five consists of regression models for the five crop byproducts of corn gluten feed, dried distillers grains (DDGs), soybean hulls, wheat midds, and rice bran. These models use the explanatory independent variables of corn price, soybean meal price, and the prices of other byproduct substitutes to estimate the factors influencing of byproduct prices. While I believe it would be optimal to address the nutrition measurements, seasonality, quality, location, and region to look at historical substitute, temporal, local traits, and transportation measurements in this model, the data is quite limited, which creates associated limitations.

My main hypothesis is that as the negative thin market traits of crop byproducts are magnified (low volume, high volatility, high transaction costs), then buyers will move towards contracting first if possible, and then vertical integration or out of the market to substitute products instead as needed. Following that hypothesis is that as these negative thin market traits are reduced, then buyers will move more easily towards contracting or basic market exchange instead. As a result, I anticipate a small number of players and product information issues, combined with the inherent volatility of agriculture, will impact the market the most, covered by the byproduct market interviewees. Through the work involving Chebyshev’s inequality, I

predict that it will show lower production volume markets will experience a greater level of volatility that points back to being thinner markets. Through regression modeling, I predict that it will show byproduct prices as influenced by substitute product prices, most strongly connected to corn and SBM still, but also to other byproducts to an extent.

Chapter Two – Literature Review

Introduction and Transaction Costs

General economic knowledge has viewed commodity markets (such as corn and soybean) as close to being and representing the concept of perfect competition. Perfect competition is said to have a homogeneous product, perfect information, zero transaction costs, no barriers to entry, and many buyers and sellers. This does not perfectly fit commodity markets in the end. This literature review will address those characteristics and go into how crop byproduct markets are different from these traditional commodity markets, by featuring heterogeneous products, imperfect information, high transactions costs, and fewer buyers and sellers. These aspects of byproduct markets lead to the market failures (inefficiencies) that differentiate them from the perfect market concept. In this chapter, I will demonstrate what the basics of transaction costs are, show what specific types of transaction costs are faced in a thin market, and then connect thin market transaction costs to crop byproduct markets. I will discuss these characteristics of crop byproduct markets to help expand knowledge on thin market size effects on price distortion and other market failures. I will then examine how these effects are actually manifest in my empirical studies.

Crop byproducts are what remain after a crop is processed and the resulting portions with the greatest economic value are subsequently gathered and sold. Since these crop byproducts are the leftovers of processing methods, they can be thrown away and disposed of or alternatively collected and sold primarily as livestock feed additive. This is a method of taking what can be essentially waste and capturing potential value to a processing operation. In terms of why a producer would be interested in purchasing byproducts, the idea is that they are likely cheaper than traditional feed like corn and wheat. However, these cost savings can be offset by lower

resulting energy and nutrition content of byproducts. So in essence, crop byproducts are an alternative option in feed components that further complicate livestock management and costs for a producer (Belyea, Steevens, Restrepo, and Clubb 1989).

Before I discuss crop byproduct markets, I will explain the root cause of their problems, which are transaction costs. These costs contribute directly to the aspects of the markets and lead to market failures, which will be discussed in further detail below. To begin, I will provide an overview on a few important papers that shaped the concept of transaction costs. Doing so will help lead into the discussion of thin market and crop byproduct market characteristics.

In “The Nature of the Firm,” author Ronald Coase presents the issue of price discovery as whether or not to use the spot market, contract, or vertically integrate in order to most efficiently produce a good (Coase 1937). Coase also goes over the “costs of transacting” as discovering prices, negotiating terms, and contracting if needed. Underlying these are the costs of obtaining information, bargaining, monitoring, and enforcing agreements, which applies precisely to the concept of transaction costs. While the specific term of “transaction costs” does not show up within Coase’s paper, the information it presents is still very relevant and directly related to the later papers that address the topic more explicitly.

Williamson (1979) establishes a strong, basic understanding of transaction costs. He identifies uncertainty, recurrence frequency (repeat purchases), and idiosyncrasy (asset specificity) as the main factors affecting transaction costs. Further discussion by Williamson says that more asset specialization leads to a greater risk of opportunistic behavior, which is a main factor in transaction costs. So the author states that when there is a continuous trade relationship, then the incentive to contract rises to avoid these increasing transaction costs, as well as the incentive to vertically integrate if those costs are sufficiently higher.

Klein, Crawford, and Alchian (1978) presents the concept of trading parties taking advantage of one another, asserting how contracts are incomplete and costly to enforce, but are one way (aside from the even costlier process of vertical integration) to combat opportunistic behavior and to avoid the extraction of gains and benefits from the other party. The authors suggest that long-term contracts are optimal, but reiterate that opportunistic behavior will still occur due to the costs of detection. However, the authors state that buyer and seller actions of working against one another will lead to a final result that is worse off for both parties, compared to faithfully working together. While they say that tools such as reputation help deter opportunistic behavior, their conclusion is that buyer and seller relationships are complex and thus difficult to optimally reconcile for both parties.

These three primary papers establish the basic theoretical elements that tie into real costs borne by firms at varying degrees. As these fundamental concepts are now established, the next section of the chapter will introduce the market type that crop byproducts primarily fall into. These types of markets will observe a lot of issues in terms of these transaction costs mentioned above, and they are called “thin markets.” Thin markets, with smaller trade counts and participant volumes, are supposed to be particularly susceptible to these transaction cost issues.

Thin Markets

Much of the literature is able to define thin markets in a simple manner. However, definitions have not been able to agree on the specifics completely. Rostek and Weretka (2008) defined the characteristics of thin markets as low volume, high price volatility, and large differences in asked and offered prices. The authors proceed to state that modeling thin markets

is difficult due to inefficiencies and distortions in market prices and competition, and define the main issues of thin markets as having information and market power imbalances, in addition to weak business relationships as higher transaction costs. However, Rostek and Weretka (2015) attempted to identify the implications of market power shifts by creating a model that tries to simulate a market where agents know the impact of their actions on price, finding that better information still creates imbalances between price and the ability to trade. Haddock and McChesney (1991) recognized bargaining as the primary trading mechanism in thin markets, revealing problems of having counter-incentives of revealing information to attract other parties, but also to hide information to gain an advantage over other parties, too. They find that even with high bargaining costs, the method of bargaining is still desired by most market agents and should be optimized through allowing more bargaining freedom. From these papers, the principle aspects of thin markets lead to high transaction costs that greatly amplify the costs of searching and negotiating due to poor information, few market participants, and less trade opportunities.

Thin Markets – Information

In the thin market literature, the lack of reliable information has a key impact on market performance. Glaeser and Kallal (1997) advises against sellers purposefully restricting product information in a thin market, because it negatively affects liquidity, which arises from information asymmetry and hidden undesired traits. Thin markets that have few agents will lead to price manipulations and inefficiencies until trading rules are established, according to Saleth et al (1991). Saleth et al (1991) state that thin markets will see efficiency and social gains from complete information and establishing bargaining rules, reducing the incentives to strategically bargain. In looking at cap and trade markets, Liski (2001) reinforces the idea that trading is more

costly the thinner the market is in volume, which results in trading costs and decreases in productivity. Liski also states that a thin market that was previously thick will not have transaction costs that are as high as a traditional thin market, and that future research needs to see the specific levels of harm placed on buyers versus sellers. Gray (1960) proposes that a market's usefulness depends on its usage and growth, stating that a thin market will have less information compared to a thick one, thus causing problems for traders, but suggesting they are used anyway due to optimism towards future market growth.

Some of the literature also covers simulated measures of information and price efficiency in thin markets to hypothetically measure information costs on market performance. Cason and Friedman (1996) used a laboratory experiment on four types of trading institutions characterized by high and low levels of trading opportunities and information exchanges, finding that having multiple opportunities to trade and high trading volumes are the keys to increasing efficiency in a thin market situation. Gan and Li (2004) modeled efficiency levels in thin and thick job markets, finding that the thicker markets have better odds of filling a position with a well-fitting candidate compared to a thin market of limited choice and information.

Thin Markets – Other Costs

Other thin markets like financial and trucking have shown there are levels of price uncertainty and transaction risk that are affected by relationships, value capture methods, contracts, and reputation. Bossaerts and Plott (2002) find that only eight agents were needed to reach a competitive equilibrium in a simulated thin financial market, where the presence of substitute markets reduced competitive pressure further. Bossaerts and Plott also state that market thinness leads to slow price adjustments over time, which contributes to greater trade

completion uncertainty and risk, making participants hesitant to trade, especially if there are no substitute markets. Thin trucking markets that become twice as thick are said to contain 30 percent more spot transactions compared to contracts, which leads to cost savings, better scale economies, and specialization as transaction costs and resulting reduced value stealing (Hubbard 2001). Hubbard said that if thin markets lead to higher opportunistic behavior, then contracts and reputation are two tools to fight that.

Thin Markets – Agriculture

Adjemian, Brorsen, Hahn, Saitone, and Sexton (2016) noted that the concentration of agriculture in general is increasing and thinning out markets. The authors mentioned how thin markets are defined by low levels of participants, trading volume, and liquidity, with product sellers having an information advantages that distort prices. The authors proceeded to state that buyers have poor information due to the low amount of trades, and thus cannot measure the market well. In response to this, the authors see that these markets are moving towards contracts and vertical coordination over spot transactions. However, once Adjemian et al conducted empirical tests, they found that the price impacts were not significantly large. They concluded bilateral contracts helped in reducing production costs and opportunity costs of inputs, while increasing information and returns for both parties. So while producer contracts reduced some long-run trade concerns, the authors still warned that transaction and contracting costs would still exist and leave room for opportunistic behavior. Ultimately, they emphasized that standardized contracts and improved data information systems are the best methods to counter thin markets (and product differentiation and vertical integration if feasible, too). The authors also stated that

there needs to be more empirical work on market power and thinness, but is difficult due to limited data.

Thin market literature covers agricultural topics more than other industries. Gordon (1984) looked at thin futures markets, and identified the difficulty in studying them since there are low amounts of data. Gordon compares pricing data on rice and sunflower thin futures markets to the estimates of a predictive model, and he finds that price changes were random in nature and to a high degree. In addition, Gordon observed that price forecasts were inaccurate, which made the markets unattractive to producer-buyers. Pennings and Meulenburg (1997) noted that agricultural thin futures markets are subject to significant liquidity issues and basis risks in hedging. As a solution, Pennings and Meulenburg point to using new information technologies to help counter this issue in the future. Thompson and Sonka (1997) looked into using information technology and the internet to counter the low levels of pricing accuracy, volume, market agents, which would reduce communication difficulties and thus lower transaction costs. Anderson, Hudson, Harri, and Turner (2007) restated the issue of poor price discovery, stemming from low transaction volumes in thin markets. In this thin market scenario, Anderson et al bring attention to price volatility and an incentive to manipulate the market, though they conclude other characteristics help define thin markets, such as levels of contracting, vertical integration, and degree of similarity between spot and contract prices. Mattos and Garcia (2004) looked at the levels of trading activity in Brazilian agricultural spot and futures markets, finding that higher levels of trading activity leads to long-term relationships between spot and futures markets.

Thin market literature has focused on cattle markets, too. Nelson and Turner (1995) create a simulated livestock market of eight and 22 traders, finding that the “thinner” market of 8 players actually saw a slightly lower price variation, although the results did not find statistical

significance and also did not establish what how large is a “thin market.” In the choice steers market, market prices greatly changed when the number of sales did over a steady rate of time, according to Tomek (1980). Using Chebyshev’s inequality to define a thin market, Tomek said the above results match with thin market concepts. Koontz (2013) uses Chebyshev’s inequality to observe price errors and discovery in the fed cattle market. In the stocker cattle futures market, the low level of contracts (despite a greater number of cattle) has led to low levels of information and thus poor analyses, according to Diersen and Klein (2000). To model cross hedging, Diersen used feed price, cattle price, and seasonal factors, and as the market is seen as illiquid and risky, they suggested future research to be about volatility and more factors in a model.

Domestic thin markets Franken and Parcell (2012) used Chebyshev’s inequality to look at the thinness of hog markets to establish price confidence levels and ranges, finding that in contracting versus spot exchange, price differences were small, but there were lower quality trades in the spot market. Nadolnyak and Fletcher (2006) described the U.S. peanut market, saying that the thinness of market distorted supply and demand, making prices and program payments distorted, too.

Thin Markets – Additional International Considerations

Ariff and Finn (1989) studied market thinness in equity markets in Singapore, stating that announced changes in the market happen very quickly all at once, and then stop. Noor (2014) states that with the population increase in Indonesia and the world by 2050, crop byproducts will be key in providing cheaper livestock feed and thus increasing supplies of human food. Futures markets come into discussion in Easwaran and Ramasundaran (2008), finding that soy, cotton, and pepper are some of the thin markets in India that have low levels of volumes, trades,

participants, grading quality, spot market quality, and transportation, leading to a poorly-functioning futures market.

Thin Markets – Summary

In all, the literature on thin markets covers their main attributes as a lack in volume, players, and price stability, leading to issues ranging from information asymmetry and market power imbalances, to high general transaction costs and bargaining costs (e.g. Anderson et al 2007; Rostek and Weretka 2008). As seen in the information discussion, low liquidity and unforeseen consequences turn into decreases in social benefit and efficiency because of the lack of trades and the information behind them (e.g. Saleth et al 1991; Glaeser and Kallal 1997). These information issues increase the search costs and even the bargaining costs, which in turn means the transaction costs are higher compared to thicker markets. In addition, the lack of volume and number of players hurts the options a market participant has in either buying or selling in the market. This means that these will become even greater transaction costs for these thin markets in terms of finding trading partners. Other types of transaction costs stem from dealing with or avoiding opportunistic behavior exerted by the other partner, given the difficulty in finding other agents to trade with alternatively

In many types of markets, the literature has a common theme that showed even with the presence of market tools such as contracts, business relationships, reputation, and bargaining rules such as policy, thin market nature still led to levels of uncertainty and risk behind not only the price in a trade, but if a trade is to even ultimately occur (e.g. Hubbard 2001; Bossaerts and Plott 2002). Agriculture in general saw the same issues, with contracts attempting to fight and balance out the transaction costs, as sellers exert power over buyers (e.g. Anderson et al 2007;

Adjemian et al 2016). With crop and livestock markets suffering from thin market concerns, the same issues on having poor information has led to a call for more detailed and complete data sets to be used in future research, and help measure and tie thin market aspects to consequences (e.g. Diersen and Klein 2000; Franken and Parcell 2012).

Byproducts

Byproduct literature does not support economic evaluation as much as it does on their nutritional components, as there is a good amount of disregard to cost feasibility, and instead many articles focus on the optimal nutrient compositions in feed. Chenost and Sansoucy (1989) stated that energy, protein, and other nutrients are the most important nutritional factors that are ideal in using crop residues. Aregheore (2000) spoke of how the nutritional impacts of byproducts seem to be well known, but that determining optimal usage amounts remains challenging. Doerr (2011) had a very extensive amount of content on the optimal nutrient goals for a variety of livestock using different byproducts, but very limited mentions of prices and the overall market implications. Weber (2012) looked at the combinations of different residues and byproducts to achieve nutrient content goals, and while there are mentions of cost savings through replacing higher-cost ingredients, he did not provide any quantitative measures.

Byproducts – Distiller’s Dried Grains with Solubles (DDGS) and Ethanol Production

Due to the growth of biofuels in recent years, there has been an increase in biofuel byproduct research. Bista et al (2008) explains the use of DDGS in replacement of corn and soybean meal in terms of nutrient content (also affirming that protein and energy are the largest influences on price). Ferris (2006) also used price estimates to forecast the price and production

of ethanol and its byproducts against alternatives using protein and energy as guidelines, but states that more accuracy is needed for future estimates. Using DDGS as a lower cost alternative to the traditional feed option of corn is covered in Urbanchuk (2003), where the author saw the importance of protein in the livestock feed, but called for more information on more nutrients and usage information. Lindahl (1952), while outside of biofuels, looked into the possibility of altering ethanol-processing techniques in an effort to have better tasting byproducts with better nutrient content, too.

Egbenwe-Mondzozo, Swinton, Izaurralde, Manowitz, and Zhang (2011) explains crop residues as a similar alternative to byproducts and commodity crops, talking about the wide variety of usable biomass. Wisner and Gidel (1977) confirm that DDGS have competed with soybeans and soybean meal in livestock feed markets in the past, with livestock price, supply of livestock, supply of byproduct feeds and oilseed meal, corn prices, and time trends as important in forecasting the prices of feed. Non-byproduct crop residues are still seen as a way to increase the value of a crop through sales, as well as being difficult to forecast their supply (Graham 2007). Along similar lines, Szulczyk (2007) presented an analysis on biodiesel and ethanol, stating that technology advances will generally limit the need for byproducts, but if byproducts become cheaper, then demand will increase instead. Egbenwe-Mondzozo, Swinton, Kang, Post, Binfield, and Thompson (2015) looked at how grain crop byproducts in the Great Lakes region are about 20 to 35 percent the price of corn, making them a possible source of profitability if implemented in a cost effective manner. De La Torre Ugarte, English, Chad, Hellwinckel, and Walsh (2007) mentioned corn and soybean meal as possible replacements for non-byproduct crop residues in terms of animal feed.

Much of the discussion on DDGS has involved some insight to price discovery, shaping the market competitiveness of DDGS as a feed alternative, and how viable its usage is from a more economic standpoint. Hoffman and Baker (2011) focus on DDGS as feed competing alongside corn and soybean meal, and though there are concerns about price discovery and consistent nutrition (protein and energy content changed from new technologies), they acknowledge that supply and consumption have increased alongside rapidly growing ethanol production. Hoffman and Baker found that corn gluten feed production was estimated at 9.0 million metric tons in 2011, and U.S. exports fell from 86 percent in 1992 to 9.9 percent in 2011. Hoffman and Baker also state that there is little research on price discovery, but note that plants primarily base price on corn futures and soybean futures, with little regard to USDA numbers. Hoffman and Baker also found that 64 percent of users apply risk management techniques to deal with price risk, such as contracts, finding price to be correlated highly with region. In conclusion, Hoffman and Baker state that there are concerns on “quality, consistency, handling, and feed safety,” and the continued international interest has led to a 75/25 ratio of U.S. to international usage. Hoffman and Baker state future research should cover more about corn and DDGS, other byproducts, and regional prices.

In their compilation of 26 papers on distillers grains, Liu and Rosentrater (2016) state that roughly 17 pounds of byproduct comes from 56 pounds of corn in 2012, and are about the same compared to the 1940s. Liu and Rosentrater argued that the sale of DDGS is critical to the success of an ethanol plant. Shurson (2005) goes over the marketing concerns of ethanol byproducts, like DDGS, stating definitions, content variability, no grading system, quality management, transportation, low amounts of research, and no producer organizations (possibly due to market size) for byproducts are the primary obstacles to maintaining a well functioning

market. While also recognizing the international interest in these, Shurson stated that exports are complicated due to concerns over GMOs and tariffs.

Papers on corn gluten feed addressed the importance of protein and nutrition in livestock feed, presenting how some of its costs establish its place in the market. Holden (1992) stated CGF, like other crop byproducts, can replace soybean meal and cereal grains to provide protein and energy, respectively. Boyd and Brorsen (1986) confirmed that corn gluten feed and soybean meal prices are closely tied in both in the United States and Europe, both as protein substitutes. Ramirez, Johnston, McAloon, Yee, and Singh (2008) explained corn gluten feed is used to fulfill the energy, protein, and fiber needs of beef cattle most typically, which makes it valuable to the point where ethanol byproduct sales cover over 34 percent of the operating costs for an “average” ethanol plant.

The mass of ethanol byproduct literature reveals information on a market that does not appear to be too thin. For instance, the presence of USDA supply and price figures, as well as export numbers (and the consequent increase of domestic usage from Hoffman and Baker 2011) point to an actual industry with a level of volume and players that have been recognized and quantified by the government. And with ethanol byproducts covering 34 percent of operating costs of the average ethanol plant (making up tens of millions of dollars, and referred to as a “coproduct”) (Ramirez et al 2008), this implicates that these types of byproducts are a thick market. Liu and Rosentrater (2016) also stated that byproduct sales were essential to the continued operation of a plant.

Byproducts – Other Types

Stock, Lewis, Klopfenstein, and Milton (2000) looked at corn processing byproducts outside of ethanol production, and mainly observed the energy and nutritional values of them. Toasa (2008) provided an overview of whey, a cheese byproduct, saying that though it is being increasingly used in human foods, it still faces a high level of price volatility. Stearns (1994) described potatoes and their byproducts, along with their many uses, while providing information on production, usage, and trade levels in North Dakota. Rice byproducts are featured in Brorsen et al (1985), where the authors used time series modeling to look at price effects and adjustments with the listed rice byproducts and corn as an animal feed substitute. Marshall, Champagne, and Evans (1993) looked at using rice byproducts to remove metals from water solutions, showing a non-feed use for the byproduct. Leng and Preston (1988) observed sugarcane nutrient impacts, and also focusing on the importance of protein, energy, nutrient, and microbial content, though neglecting to mention price.

Grasser et al (1995) reviewed survey data to look at 9 separate byproducts used in California dairy rations to see supply, usage, price, and nutrient composition to determine the economic value of those byproducts. King (1958) developed over 100 pages of observations on demand and prices for a great number of byproduct feeds, and he cited their use as 18 percent of all feeds in the early 1950s (unknown now). ElMekawy (2013) did a critical review of using cereal byproducts from biorefineries, recognizing corn as the most commonly used cereal in US ethanol production, while also looking into the usage of other crops across the world, as well.

Separate byproducts still face levels of price and nutrition uncertainty caused by a variety of factors, leading into risks and transaction costs. Belyea et al (1989) found that crop byproduct nutrient content finding from a 1978 study did not match up with their 1989 one, which the

authors attribute to changes in processing methods. Upon reviewing varying energy value findings across several types of organizations, Belyea recommended careful nutrient testing and measurement for feed byproducts, due to risky, uncertain, and problematic calculations. In creating a model to determine wheat midds price, Ambrose (1965) used animal unit count, domestic usage, and corn and soybean meal competitive ingredients to determine cost, finding that animal numbers had the highest correlation.

Byproducts – Focusing on Livestock Usage

Authors have discussed the dairy market in the literature, placing importance on the fact that the consistency of nutrition aspects is important as byproducts enter the mix. Staples (2007) argued byproducts simply replace the usage of typical feed ingredients, such as corn gluten feed and soyhulls replacing the starch needs provided by corn. Staples added that DDGS are low in starch but can replace energy needs through protein, fat, and fiber. However, this leads Staples' point that maintaining a consistent overall picture of nutrition is very important, with phosphorus, fat, and protein as the most important nutrients. Ipharraguerre, Ipharraguerre, and Clark (2002) noted that soyhulls can replace corn grain in dairy feed up to 30 percent without facing any negative nutritional effects, but leaves out any cost implications, which future research needs to address in the long-term.

The literature on the swine market reveals much about consistency, storage, uncertainty, and the costs that occur as a result. Stein (2007) discussed how byproduct replacements in feed are not perfect substitutes though, saying using DDGS to replace corn or soybean meal in swine feed will displace energy and digestibility level, causing other feed additives to be altered as a result. This reveals the complexity of obtaining consistent feed composition. Stein emphasizes

the type of livestock and cost considerations add to the consistent nutrition problem, requiring more research on the effects of these feeds on livestock. Neill and Williams (2010) looked at the use of DDGS and wheat midds in swine diets, finding that while they can decrease feed costs by replacing soybean meal, they warn of the variability of nutrient content due to processing, which can be solved by purchasing from the same source repeatedly. Neill and Williams also recommended that any diet switches should happen slowly and gradually over time. In terms of pork production, energy inputs are 85 percent of diet costs, and diet costs are 55 to 70 percent of total production costs, according to Patience (2013). Patience also said that with feed costs doubling between 2006 and 2013, the costs of corn, DDGS, wheat midds, soybean meal, and other byproducts all have tradeoffs in terms of price, energy, amino acids, and vitamins and minerals. Patience concludes that depending on the needs of the feed, there needs to be a careful selection on the combination in order to maximize profitability.

Cattle markets have also been a target of byproduct feed literature, showing byproducts' potential impacts on cost savings, but also raising concerns on storage, transportation, and other factors. DiCostanzo (2003) identified 20 different components and byproducts to be possibly used in beef cow feed, including corn, corn gluten feed, DDGS, wheat midds, and soyhulls. However, while identifying that byproducts can be good sources of protein, energy, and minerals, DiCostanzo stated that supplier location/processing positioning, purchase requirements, financial terms, storage, mixing, and transportation are the most important components of using byproducts. In Lalman (1996), he said feed costs are 40 percent of production costs for a cow/calf operation, and identified soyhulls, corn gluten feed, wheat midds, rice bran, whole cottonseed, and DDGS as important sources of protein, energy, and minerals. However, Lalman also stressed the importance of storage and transportation, which can be a

major source of costs, especially when trying to correct issues through pelleting. It is through these papers, that a problem of infrastructure comes about, showing that traditional commodity crops have storage, transportation, and other market systems in place that help reduce transaction costs and make trading arrangements easier to set up and execute. Thus, these crop byproduct markets face additional transaction costs that stem from several reasons.

Byproducts – Additional Considerations

A large level of interest has occurred in crop byproduct usage for feed in developing and African countries. Owen and Aboud (1988) stated the importance of using byproducts as feed, but difficulties from poor infrastructure in Ethiopia have prevented secure markets from forming, calling for more research on the economics and not the nutrition of crop residues. Magnan, Larson, and Taylor (2012) described the lack of byproduct markets making it difficult to estimate costs in Morocco. El Hag and Kurdi (1986) spoke of the difficulty of obtaining and using byproducts in Sudan. Preston (1986) and Kossila (1988) both looked at the possibility of using crop byproducts and residues in developing countries, discussing current unavailability and future prospects, respectively. Aregheore and Chimwano (1992) stated byproducts in Zambia are not always available, nor used the most efficiently. McDowell (1988) and Reed and Goe (1989) both looked at the nutrition aspects of using crop residues in African livestock feed, with McDowell expressing concern on maintaining consistent byproduct nutrient content.

Price forecasting has existed for other agricultural markets too, especially ones that are tied to crop byproducts the most. Meilke (1975) forecasted feed demand from a six-equation model that factors in quantity of grains feed, food, storage, and exports, along with price and relevant animal units. Forecasting prices in the agriculture sector can be seen across different

products, as Weimar and Stillman (1990) conducted livestock forecasts, adding as a testament to desire for market participants to reduce uncertainty in a volatile market.

Byproducts – Summary

Overall, there is a lot of a focus on byproduct nutrients in the literature. There is a special amount of attention on biofuel byproducts such as DDGS and corn gluten feed in the research area, as well. With so much discussion on their usage, as well as steady increases of supplies, biofuel byproducts may not suffer as big of thin market negative effects and transaction costs after all. However, some concerns on nutrient consistency, storage, transportation, technology, price, and regional variability still linger, these markets still share some thin market attributes, important to compare across substitutes.

Though there have been various mentions of several other agricultural byproducts used in livestock feed, as well as some interest in third world usage, papers still tend to focus on nutrient aspects disregarding cost feasibility on a regular basis. While some articles addressed some of the pricing and market implications of primarily DDGS, other types of byproducts have still not been looked at with a decent data set yet. Although the amount of substitutes decreases the level of specialization of the assets, concerns on location and obtaining needed feed ingredients can still lead into market failures and resulting inefficiencies.

Framing the Research Question

The crop byproduct markets are thinner than their traditional agricultural commodity counterparts, though the DDGS market is a different story, and are presumably much thicker than the other byproducts. As a result byproducts face great transaction costs that stem from low

trade volume and trade partner count, along with poor and limited information. Though the number of direct substitute goods may reduce asset specificity costs, the costs of switching can include high search costs, bargaining difficulties, location specificity, readjustment requirements, inaccurate information, inconsistent quality, and price uncertainty. These problems would make one believe contracting and effective locational positioning would be the best option to battling transaction costs incurred in the market.

Research needs to look at the commonly identified and so-called “technology processing changes” described in the crop byproducts markets, which allegedly have and will continue to alter their vital nutrition levels. In addition, there needs to be more studies conducted on the economics of these byproducts, especially in a thin market setting, looking at concepts such as levels of price uncertainty. The literature would also benefit from more studies that specifically address the totality of transaction costs in thin and thick agricultural markets. Specifically it would help to identify both the direct and indirect costs that the continually concentrating agricultural industry will bear on producers, processors, and other market participants.

The continued concentration of livestock markets will cause the byproduct markets to shrink in terms of agents, since the livestock producers are the buyers in this trade relationship. The fact that nutrient consistency is key for byproducts, this creates dependency and places even more power in the hands of sellers or buyers. However, it is unknown how the crop byproduct markets actually play out with these factors in effect. The literature has not shown how consistent trade levels have been over time. While one may predict the level of byproducts produced, knowing how much of them are actually collected and marketed is a different issue. Thin markets amplify transaction costs, which are high enough to keep thin markets thin and

drive market agents away. But would more contracting help solve the transaction cost problem and help producers discover a market that has cost saving potential for their most costly input?

Information problems are one of the most critical issues in thin markets, and the growing affordability of cheap nutrient testing and analysis helps eliminate some of the opportunistic behavior a seller can exert. While the livestock market may be concentrating, it is growing or at least maintaining in terms of overall production size. Thus, these animals will have to be fed somehow, and the role of byproducts may end up evolving into a more major source of cheap feed. Large operations will be held to demanding levels of production, which will require a consistent level of nutrients. To ensure a level of consistency, contracting seems to be an attractive choice. On the same line of logic, vertical integration would require an operation to control a later level of a different value chain in order to produce an input, a process that I assume too would be far too costly and inefficient. This would require an operation to move away from specialization and bear the costs of entering a new market simply to cover the input costs of their primary product.

With all of this in mind, the proposed research question is “how do firms deal with transaction costs in crop byproduct markets?” Underlying this question are several research objective questions that address this central question: 1) Finding out whether firms contract or not (and why). 2) Which transaction costs seem to have the largest effect (whether price discovery or others). 3) How accurately can the above information help predict price influences in this market (among other factors in an attempt to reduce uncertainty). The research question is missing from the literature, which has brought attention to the importance of crop byproduct utilization in feed. In addition, the thin market literature has been scarce in terms of empirical work that helps differentiate between thin and thick markets, as well as the effects it has on price

and market agent behaviors. By answering these research questions, this will provide insight to future livestock feed markets, as well as the function of thin markets in general, granting knowledge that can help avoid the transaction costs and other issues undergone in these markets.

Based on the above literature, I hypothesize that over time agents in the byproduct market will switch over to contracting. Given the number of substitutes for nutrients in livestock feed compositions, one may think that it would be easier for producers to simply switch to one of those substitutes and save themselves from the problems of their current one. However, there are some obstacles to switching. There are concerns on complementary nutrient, digestibility, and energy differences that have to be balanced in the blend of feed mixture. And beyond that, there are concerns on the actual feasibility, locality, and availability of those substitutes. A producer intending to switch feeds will have to consider issues such as transportation and storage, which relies on their external surroundings and internal capabilities, respectively. With such high costs, I predict that firms use contracts to ensure long-term deals that counter the negative effects of price uncertainty, low number of trade partners, bargaining issues, and readjustment complexities. Contracts will allow buyers to lock-in a certain price level and ensure more consistent nutrient content and quality, to be reinforced by improved testing, measurement, and data technology.

At the same time, I do not predict that contracts will be the exclusive mechanism of crop byproduct markets. After all, the literature pointed to general thin markets using spot bargaining as the primary method of dealing (Haddock and McChesney 1991; Saleth et al 1991; Liski 2001). But beyond that, it is important to remember that other substitutes of crop byproducts are the most common feed sources: corn and soybean meal. The fact that these are much more available and nutritionally consistent compared to the byproducts, this makes them much thicker

markets that see greatly reduced transaction costs compared to the thin byproduct ones. I believe many producers will avoid the crop byproduct market and instead opt in for using traditional commodity crops and face greater direct costs to avoid the numerous issues otherwise. However, as crop byproduct users decide to save on direct costs by bearing greater transaction costs, they will attempt to maintain consistency by contracting their purchases of them.

An optimal study would have to obtain data on or related to crop and crop byproduct prices, seasonality trends, location/state/region markets, nutrition and quality measures, supply counts, buying patterns, number of area agents, and contract decisions. The use of Chebyshev's inequality could allow me to use standard deviation probability calculations to observe market thinness, as well as price errors, discovery, and confidence levels (e.g. Tomek 1980; Franken and Parcell 2012; Koontz 2013). Limitations on the data and sufficiently tying it all together will be very likely, which will require some universal assumptions in the analyses.

Chapter Three – Interviews with Crop Byproduct Market Players

Background and Introduction

The literature review explored how byproduct markets are thinner than other feed options, and that transaction costs emerge from low player counts and low market information. My research question is “how do firms deal with transaction costs in byproduct markets?” Given nutrient demands for livestock diets, and trade difficulties emerging from searching, bargaining, distance, asset specificity, quality, and price levels, contracting or switching to substitute goods seemed to be the best options for addressing thin market effects. The literature was not clear in confirming any of these organizational practices in reality, only with several articles implying that contracting and reputation as tools to trade in thin markets (Hubbard 2001; Adjemian et al 2016). However, I also include my other objective questions of what organizational structure strategies exist, what transaction costs impact the market, and what influences byproduct prices. Without sufficient data relating back to help analyze these ideas further, I turned to the opinions of industry professionals to get an understanding of how crop byproduct markets play out in their minds. I asked them a variety of interview questions to arrive at answers for these research questions, covering the same topics of contracting, storage, transportation, and so forth.

Starting in April 2017, I interviewed a combination of people in various crop byproduct markets. These interviews involved six players in the DDGS, wheat midds, soyhulls, and soybean meal markets, in addition to several others, such as cottonseed hulls and sunflower meal (which are not as directly addressed in this paper). Interviewees consisted of both buyers and sellers of crop processing byproducts, specifically people from two ethanol plant facilities, three feed mill companies, and one pork producer. Thus, this gives insights from direct DDGS sellers from the two ethanol plants, three “middlemen” feed mill companies who further process various

byproducts to create a feed end product for livestock producers, and an end-user hog producer, who directly purchased and utilized DDGS to use in his own feed rations. The titles of the interviewees included grains purchasing, hog production, commodities merchandising, feed operations, grain operations, and feed purchasing.

The purpose of these interviews was to get a better grasp at some of the difficulties and transaction costs in byproduct markets. Each of these interviewees answered 40 different questions over seven separate topic areas of own byproduct production, pricing, contracting, interacting with buyers/sellers, regulation and byproduct testing, transportation and handling, and the overall general byproduct market. The full set of these questions is listed in Appendix Table 1, and the purposes of the questions will be apparent in the answers they provided. Each of the interviewees' personal identities and the firms that they work are kept confidential in this paper and outside of it, as was agreed upon in the consent form that the interviewees voluntarily signed to be a part of this study. Each interviewee is classified under a "Participant Nickname," which their general traits are defined in the chart below.

List of Interviewee Participants

Participant Nickname, Operation Type, Regional Location

Participant A, Commercial Feed Mill, Central Midwest

Participant B, Commercial Feed Mill, Central Midwest

Participant C, Commercial Feed Mill, Northern Midwest

Participant D, Hog Producer, Central Midwest, > 3000 Head of Production

Participant E, Ethanol Plant, Northern Midwest, > 50 Million Gallons Production

Participant F, Ethanol Plant, Central Midwest, > 50 Million Gallons of Production

Responses – Own Byproduct Production

Participants E and F, the two sellers/ethanol plants, processed only corn through their facilities, although Participant F noted that in very rare instances a small amount of alternatives like sorghum or milo would be utilized. As a result, DDGS were their primary feed byproduct that helped increase revenue for the facility, in line with generalized expectations of a typical ethanol plant in the United States.

The three feed mill buyers, Participants A, B, and C, utilized corn as the primary input, with byproducts of corn gluten, DDGS of different protein levels, wheat midds, soyhulls, soybean meal, cottonseed meal, as well as others that were considered smaller and not worth mentioning. The independent hog producer, Participant D, used corn, soybean meal, and DDGS. Participant B spoke about how the byproducts are still waste products and they only end up in the feed industry if no other industry has use for them. In addition, one of the other feed-mill customers noted that their purchases into smaller byproducts (like the cottonseed and sunflower seed markets) are purely dependent on the state of the market. They added that the number of byproduct options has greatly declined over the past 20 years due to a combination of regulation and growing non-feed uses of certain byproducts. As a result, Participant A said this has driven those former byproducts of other types out of the feed business, and continually limiting the selection and number of players in the overall byproduct feed market.

On the seller side of changing production methods, both ethanol plant Participants E and F talked about changing processing methods to separate, market, and profit from different aspects of DDGS to feed buyers and beyond. The main example would be the separation and independent sales of oil from DDGS, which as a result lowers the fat content of DDGS. This was

brought up as a specific challenge by buyer Participants A, B, and D, noting how despite the continued growth and availability of DDGS, it has not been the same product over the years.

Responses – Sales and Seller Pricing

In terms of selling patterns throughout the year, the two DDGS sellers Participants E and F said that production and availability of DDGS are consistent throughout an average year. Participants E and F said they saw rising DDGS sales (and higher prices) in the winter, with declining demand in the summer, which is in line with seasonality in cattle feeding especially, and that the price will also follow with what is happening to corn or soybean meal. However, Participant E from the larger firm had talked about exports, noting that export levels greatly alter prices. As a result, the Participant E said DDGS prices have been largely unstable over the past few years due to constantly changing trade policies from China and other nations. Regardless, Participants E and F mentioned that DDGS are a significant source of revenue, the percentage of revenue that a plant will receive from DDGS sales can range from 20 percent up to 35 percent based on what the export market is doing primarily.

In terms of the difficulties behind selling DDGS, Participant E mentioned the domestic market is simple for the most part, due to its high popularity and awareness across the United States. However, Participant E did say that issues could arise through handling problems, nutrition complaints, and general inconsistencies. Participant F said inconsistent color and particle sizes were different especially across facilities in the past, although still now, placing a constraint on moving forward with changing any processes that will interfere with DDGS quality. On an international level though, Participant E said the challenges were competing with

domestic substitute products, lower usage of DDGS in other countries, lack of familiarity in other nations, communication, and finding trade vessels to use.

Information technologies have eased transaction costs to some extent. With the advancement of computers in the past decade alone, nutritional testing, communicating internally and externally, and storage/capacity/handling management has been critical in maximizing the efficiency of existing capital and turning over product in a timely manner, rather than just buying more storage (a very costly process), according to Participants E and F. In addition, Participants E and F said providing key protein and energy information to a buyer has become much faster and more accurate with each passing year, which has helped stimulate buyer confidence in purchasing the product. Through this, the sellers Participants E and F said they are able to generally have more sold than they produce, keeping up with both daily spot buyers and buyers that have scheduled and arranged (contracted) pick-up loads on a weekly or monthly basis. However, exporting Participant E said international buyers complicate trades, as there are many more logistical aspects to account for, leading to purchases that are multiple months into the future, up to a half-year at a time.

In terms of pricing Participants E and F, the two sellers, immediately mentioned that it is simply a matter of supply and demand, but they specifically try to take into account what corn price is, as well as what prices customers are being offered from other, competitor plants, both locally and regionally. Internationally, Participant E added that it is more up to a broker to do the initial work, and then it is the same process of comparing distance to optimal transportation costs, according to one of the sellers. However, they did note that DDGS price levels are very volatile and have historically been a fraction of corn value, though other times above it, and thus has been much more variable than corn despite following in its trend (Participants E and F).

Participants E and F also noted that spot buyers versus long-term contract buyers are going to be dealing with two different prices, to the point where it is essentially two different markets in the end, with implied volatility increasing in cash markets. Participant E clarified that if big buyers change their purchasing habits, then that is going to drastically alter the price of that particular week, though it tends to balance out over time through the cycle of acquiring new buyers when losing old ones.

Both sellers counted their DDGS sales portion of their plant as a success, Participant F of smaller size markets only by truck (with 20 percent of DDGS being sold within the state, and the rest averaging a 4.5 hour drive away), and the larger Participant E markets their DDGS via all sorts of transportation methods, including truck, rail, container, and barge (and thus they have 40 percent local/state sales, 40 percent sales within the rest of the US, and 20 percent export sales).

Participants E and F as sellers defined quality as included protein, fat, moisture, color, flowability, toxins, and overall consistency. Ultimately Participant E concluded that quality is easy to determine in a general sense, and as “fairly complex” from a truly technical standpoint, even with the advancements in analysis technology available today. Lastly, Participants E and F said the impact of quality on price on DDGS is great, and the price is very sensitive to those quality measures. Each Participant E and F said that issues with just one measure will really hurt the product’s value, and cause either price discounts or even the entire rejection of the load. Smaller seller Participant F emphasized that consistent quality is important enough to large buyers especially, that the plant operators have to be very mindful about deciding what new technologies to install, and how that will impact sales.

Responses – Purchasing and Buyer Price Habits

Feed-mill-purchaser Participant A noted that volatility has increased over time, with changes occurring more rapidly now, and does not feel as impacted by supply and demand as byproduct markets used to be. Hog producer Participant D said their purchases were constant in terms of overall volume, changed based on what was cheapest at the time. Participant B stated they contract more when prices are better to act as basic price protection, with the other agreeing, resulting in forward purchasing at weeks or months at a time (Participant C).

As for how much the byproducts take up feed rations, the swine producer said that the DDGS he used were about 14.5 percent (Participant D). For the feed mills, one said byproducts were about 50 percent of the cost of the ration (and maintaining that level over time), though the “what” of those byproducts has changed regularly based on least cost ideals (with a declining use of DDGS most recently) (Participant B). Participant A said their byproduct percentage was at 75-80 percent cost (a majority as wheat midds), though was down to 60 percent in the past. Which the 60 percent is in line with what Participant C has consistently stayed at, with both talking about how a large portion of used byproducts have been wheat midds.

In terms of ease of purchase, the hog farmer said that purchasing DDGS is generally easy, with very few major difficulties (Participant D). Participants A, B, and C spoke of some difficulties, citing inconsistent byproduct specs, timing purchases to get the best price, and timing purchases to optimize on site supply. Technology advancements have greatly helped with the timing of delivery, managing storage/inventory, and formulating diets optimally, especially over time (one stating efficiency has increased twofold as a result over the past decade), according to Participant C. The feed mills said that feed product turnover is fairly quick, with daily sales and having anywhere from a few days to a few weeks’ worth of byproducts on hand,

fluctuating due to constant changes in demand and delivery (Participants A, B, and C). It seems that despite being a large part of the market, larger buyers face great struggles in securing large quantities of byproducts. And this schedule is shaped by many forces both in and out of their control, even in the face of great improvements over time and consolidation of byproduct options.

When it came to the importance of finding the best price, Participants B and C said their buying strategy primarily focused on what will save the most money while most closely trying to fit a target nutrient formula. Participant A also noted an importance on price, but put more weight on making sure that the feed itself is more consistent in terms of handling and nutrients, over pure cost savings. Participant D mentioned his hog operation's nutritionist provided solid data on the optimal feeding ingredients based on price, and then just goes with that.

Over time byproduct prices have fluctuated greatly, and much more so than corn (two to three times more volatile according to Participant B). Participant B also stated that byproduct prices are more affected by changes in substitute markets like corn, soybean meal, and other byproducts, than compared to changes in their own markets. As an example, Participant A pointed out how DDGS values have went from a fraction of corn cost, to over the cost of corn, and then back down, just like with how Participants E and F previously stated. Participant B also attributed price changes largely to technology advancements and the elimination of byproduct markets, as larger industries find better uses for them and can afford to pay more.

On the producer side of price changes over time, hog farmer Participant D mentioned that both he and fellow producers have been forced to adopt and purchase new byproducts due to the unavailability of previously used options. Participant D emphasized that this comes at a great capital cost, but has to be done when there are no other feed options in times of market stress,

highlighting the need for nutrition over price, especially in times of crisis, whereas a feed mill operator is not as worried about feeding animals that they do not own.

As for the “where” of a purchase, the swine producer Participant D said his DDGS have always just come from one plant due to the convenience and low transportation cost. The feed mills offered the same sentiment of using nearby sources to save on costs, but noted that it is not always possible due to availability and seller problems (Participants A, B, and C). Thus, Participants A, B, and C said that their strategy is to start by looking at options that are closest to their facility, and then increasingly branch out to anywhere else in the country as needed.

The buyer definition of quality seemed to mirror the sellers, in that it is based on specs of nutrient levels and toxin levels (Participants A, B, C, and D). While Participants B and D and one of the feed mills said that better quality is nice, Participants A and C greatly emphasized how quality is the most important aspect to them, and that paying extra for a high quality byproduct is much more preferable compared to paying a lot less for a low quality one. Participants A and C reasoned was it made the customer happy with a consistent product which moves well through physical systems, making a huge impact on sales over cutting costs from cheaper ingredients.

All buyers talked about using tests to measure quality (Participants A, B, C, and D). Feed mills Participants A, B, and C mentioned that they conduct tests with decent accuracy, which facilities perform immediately to measure nutrients and toxins, getting results within 30 minutes. While expensive, they place a lot of value on these tests and mention how much easier it makes it for them to make decisions based on quality, and that their large operation sizes greatly diminish the overall cost impact of performing these tests routinely (Participants A, B, and C). Participant D mentioned that for him, the price of testing is a bit more expensive, and has to rely on an outside lab that leads to a few days of waiting before receiving the test results, highlighting

a great inefficiency. He mentioned he will often simply call the DDGS source/ethanol plant and ask for their own in-house test results and trust in those numbers, rather than face the delay, inconvenience, and cost of performing his own (Participant D).

Responses – Contracting

When asked about forward agreements and long-term contracting though, Participant E (the larger operation that exports) said that 20 percent of contracts were for a month or longer, placing a good amount of focus on more immediate sales on a weekly basis. On the other hand, the second ethanol plant Participant F said that month-long contracts were the typical length, accounting for 90 percent of their sales. Which I assume given the size and the fact that Participant F coordinated multiple locations, I believed that this allowed them to better manage and plan sales and transportation due to the increased information the firm has as a result. With 10 percent of short-term sales now, Participant F stated that 10 years ago the short-term sales level was 20 percent, attributing this reduction to the decline of small farmers over the years.

As for what terms are contained in a typical contract, both Participants E and F had primarily the same terms. Naming off the critical ones of price, quantity, and nutrients, they also mentioned other important contract terms such as delivery point, transportation method, additional product specifications, byproduct origin, counterparty, and other general trade terms (Participants E and F). When asked about who requests to do a long-term contract, Participants E and F said that it is buyers who usually ask about the contracting, in order to lock in a continuous supply of byproducts over time. While sensible and straightforward, these contract terms have helped enforce agreements on these byproducts that have been perceived as volatile in terms of price, and inconsistent in terms of some physical traits.

When asked about specifically longer-term contracts, the three feed mill buyers discussed different habits. Participant C described short-term purchases as “very rare,” relying on long-term (one to six months in advance) contracts to ensure a specific volume of specific ingredients. Larger operation Participant B said that long-term contracting ranged from 50 to 60 percent depending on the prices, at an average interval of three months, at up to a year on certain ingredients (mentioning how this puts the operation at a greater risk of not receiving what is exactly agreed upon initially). Participant A said that purchases for their operation are only about 10 to 30 percent contracted in the long term, roughly in three to six month periods. Although Participant A also said he formerly worked at a large vertically integrated feed operation, which would contract 40 to 60 percent of annual purchases, to have a combination of guaranteed supply and flexibility to change with spot purchases. Overall contracting increased with operation size.

In regards to contract terms, the same terms that the sellers focused on and mentioned were the same as what the feed mill buyers spoke of, and mentioned that it is usually at their request, as they are to ones to reach out to a seller (Participants A, B, and C). Participants A and B said that even though it is rare to have the seller initiate a contract request, it is good news for them, because it means the seller has excess byproducts that they are wanting to get rid of at a discounted price.

The hog producer mentioned that all purchases are indeed through contracts, though his last for a shorter period of two weeks to a month (upwards up to two months in some cases) (Participant D). Participant D mentioned that there is not much complication in the long-term contracts though, speaking of price quantity, and nutrients, but then proceeding to say it is all fairly simple and straightforward, and does not feel much different from buying on the spot. Despite the individual’s smaller operation size in comparison to the feed mills, he noted that the

ethanol plant is the one who requests long-term contracts with him, instead of the other way around (Participant D).

Responses – Seller Experiences with Buyers

Both sellers mentioned that identifying potential buyers has been easy for at least the past decade (Participants E and F). With the internet, research, and related geographic technologies, it is simple to know who the large players are and who is close to the plant, according to Participant E. Smaller Firm Participant F mentioned just general national knowledge and widespread word of mouth about DDGS has brought customers to them automatically. In an international sense, Participant E said that it is a matter of simply working with the International Grains Council and utilizing the information provided by the organization.

Following up with the ease of initial buyer contact, buyer retention was said to be very high by Participants E and F. Participant E said 90 percent of sales totals are from repeat buyers who buy at all sorts of various intervals, but almost always at a consistent rate individually. The other mentioned that 100 percent of purchases are from repeat buyers, paralleling the consistency of purchases to the consistency of the product that their specific plant provides (Participant F).

In terms of further interaction, both sellers said that there are very few disagreements about quality, given that they will self-test the product and discount it if necessary (Participants E and F). Participant F said that this has also been less of a problem over time due to the improvements in third party testing and the increasingly common nature of DDGS and technology changes stabilizing out for now. According to Participants E and F, these types of communications are held primarily through email to provide a record of what was stated, and to be more flexible.

Both sellers heavily focused on their own continuity of supply and consistency of their nutrients for their DDGS (Participants E and F), claiming that this leads to the low amount of disagreements that stem from a transaction. Larger firm Participant E locality and price can be a fairly important factor too, but maintaining a certain level of color, handling, and other quality measure is what users want the most.

Responses – Buyer Experiences with Sellers

The employees of the three feed mills mentioned that it is easy to identify sellers (Participants A, B, and C), and Participant B said large in size is key to staying active in the market leading to easier time initiating contact with sellers. Participants A and C directly attribute the small size for everyone knowing each other, leading to the creation and sustainment of business relationships and even personal friendships, too, identifying reputation as a very important necessity in the industry. Participants A, B, and C stated repeat purchases are frequent, as relationships are built with everyone to diversify risk (to deal with unplanned seller production issues), and get superior service and quality.

For the hog producer, his process was much easier, as he bought DDGS from the same plant continually over many years (Participant D). For disagreements, there have not been many even throughout all of the years, and if so they were resolved through computer calculations of the load, which determined and applied an appropriate discount or refund (Participant D). Like the other, larger buyers, Participant D spoke of how all of his communication is done through phone, with everyone's verbal word carrying a lot of weight and reputation with it.

With Participant D, the choice to use DDGS also came from the combination of good personal handling capability and having enough storage (due to the larger size of his operation

compared to other individual producers), and then it fitting into the ration at low cost (which he attributed to its large available quantity). Since it is bulk meal that does not require and special materials, Participant D said that it flows well through the right feed systems, and that is why he maintains its usage.

Participant A stated that quality issues happen, but not often, and some quality measures are enforceable while a few are not. Participant B mentioned that problematic loads which have to be discounted or rejected represents 5 percent of volume on a good year, and upwards of 10 percent otherwise. Participant C said quality disagreements can happen, but most issues stem from toxin issues, which are tied more to the raw crop itself rather than the byproduct seller. Participants A, B, and C mentioned phone as the preferred option for relationship purposes.

Responses – Regulation and Testing

When talking to the two ethanol-plant-sellers, Participant F said that every single load must contain a tag that identifies the byproduct itself, its origin, and guaranteed nutrient values of all kinds. In terms of improvements over the past decade, Participants E and F stated the process has not gotten much cheaper or faster to perform, although never cost too much anyway.

When asked about any regulation that has been impactful to their operations in the past 10 years, one DDGS seller said domestically, both said nothing has influenced their sales (Participants E and F), though internationally, Participant E said foreign regulations involving GMO restrictions has caused difficulties.

When it came to the buyer commentary on byproduct testing and regulation, the hog producer said that he performs tests infrequently, although does more if there are reported toxin concerns in the area (Participant D). All three feed mill buyers mentioned that they do their own

relatively cheap tests for nutrient content, but most importantly for toxin levels (Participants A, B, and C). Participant B mentioned that roughly 10 percent of ingredients are rejected and sent back because of toxin problems. Participant A did note that the testing process has gotten faster over time, increased accuracy of the tests, and much quicker traceability compared to years prior.

Participants A and B said that after the mad cow disease incidents in the past, meat and bone meal are not allowed any more due to a government ban, though they noted they rarely purchased any of that anyway. However, Participant A spoke a lot on the Food Safety Modernization Act (FSMA), and how it has required a lot of tracking that has added many costs that are borne throughout the entire industry's value chain. As a result, Participant A claimed it was a significant source of market players leaving the industry. Thus, it appears the basic nutrient testing has requirements have been both a source of value in terms of information exchange, but also a source of some costs that have lessened over time, too.

Responses – Transportation and Handling

When reiterating what types of transportation methods a facility utilizes, the two ethanol-plant-sellers said it is simply based on where the customers are and the pricing and quantity behind the purchase (Participants E and F). Smaller Participant F facility had only truck capability, while larger Participant E could handle about anything from truck, rail, barge, and intermodal containers with its larger size and location. Both Participants E and F said deciding the mode with a seller is easily discussed based on the individual facility and preference.

On the buyer side of transportation and handling, the swine producer said given the size of his operation and the nature of DDGS, it is a simple bulk byproduct delivered by truck, with nothing else to it (Participant D). As for concerns, Participant D too only spoke of moisture

concerns, which were rare, and machines were simple. The transportation methods for the three feed mill buyers were described as primarily as truck, with some rail if the facility was equipped for it (Participants A, B, and C). While one of the buyers said rail was optimal for long-range transportation, they said truck is great because it is cheaper close range (Participant C). The other two criticized rail primarily because of the lack of timeliness on deliveries compared to truck, which they say is much more reliable for on-time delivery (Participants A and B). Participants A and B cited that since truckloads are one-tenth the size of rail loads, there is much more flexibility in fitting it into storage than rail, and that with rail, it never seems to arrive when needed, and always shows up when storage is already near capacity. Participant A pointed out that if rail transportation falls through, then it is delivered on truck anyway, and that the contract specifies a certain time, so truck is the preferred method to make sure the contract is fulfilled.

Each feed-mill buyers mentioned the potential of catastrophic possibilities from inadequate handling, but ensure that they have always maintained a good enough control over the risk factors to prevent any of it from actually happening (Participants A, B, and C).

Participant A discussed how that with the byproducts they use today, those primarily used the same standard storage bins as most other ingredients, although many years ago when there were more options, those older byproducts did need unique containers, coolants, and so forth. Participants B and C stated that while each ingredient uses the same type of bin with the same internal machinery, they are sure to be kept separated from one another to isolate potential contamination in separate bins.

Responses – Thoughts and Future Predictions

When asking the two ethanol-plant-sellers about future perceptions and predictions, I received an answer from larger Participant E saying that local byproduct business levels are regional and will affect all plants in different ways, and smaller Participant F believed that international growth will be a large boost to recent DDGS sales more than anything else. Participant F also said that the changing of the demand structure of DDGS will be key in increasing future profitability. He elaborated on this by saying that this will involve taking different components out of the DDGS, which will happen due to the continual improvements of ethanol production technology (Participant F).

On the buyer side of market opinions, the swine farmer also emphasized the largely regional nature of the different byproducts, too (Participant D). And Participant D mentioned that he too has noticed the separation of oil and other components of DDGS has occurred over time, but noted that ethanol plants cannot alter the DDGS too much, otherwise they will not be able to make any feed sales. As for future insights, the Participant D said the domestic byproduct will likely maintain itself into the short future, unless weather and equipment change drastically. Participants A, B, and C spoke of the regional differences in the current market, as well. Participant A said that the less popular byproducts will continue to decline like it historically has, while plants that handle more conventional byproducts will grow. And as for the byproducts of “most of the major crops,” Participant C said they believe those byproducts will maintain the same volume for at least the next 5 years, and the only attainable growth opportunity for the upcoming few years will be through exports.

Participant A said that the byproduct market is going to be influenced by whatever the government will require in the coming year, and on the consumer side, overall meat consumption

trends will also shape the market greatly. According to them, even outside forces like the extreme weather patterns of a given year can cause immediate, unexpected, and relatively lasting effects on the market, a combination of many forces (Participant A).

Insights Gained from the Interviews

Byproduct choices have declined substantially over the past 20 years, stemming from regulations, bans, and developing alternative uses for the byproducts, according to Participants A and B. Participants A and B also said that maintaining the using older and thinner byproducts meant facing high fluctuations in their pricing and available supply, and being forced to switch was difficult and expensive. This concept stems from specificity in the transaction cost literature (e.g. Williamson 1979). After all, the buyers mentioned there are frequent price and supply fluctuations that require a lot of adaptation around the year (Participants A, B, C, and D). Participants A and B said that by purchasing only byproducts that are more common, compatible, and less volatile, an operation can cut down on the indirect transaction costs by avoiding these smaller byproduct markets that essentially died out for feed. However Participant A stated that price and supply volatility has indeed increased over time still.

Participants A, B, and C stated earlier that they contract more during perceived future volatile times especially, just to lock in good prices. Participants A, B, and C also requested long-term contracts with the sellers to best ensure a future supply of that byproduct. Sellers said long-term contracting was increasing in frequency over the past decade, alongside the percentage of large buyer purchases, implying more unstable spot prices especially in comparison to contracted prices (Participants E and F). Contracts reinforce the emphasis on why buyers need a purchasing agreement for guaranteeing specific trade details. And how even more so,

Participants A, B, and C expect a timeline as concrete as possible, which keeps their feed supply and sales rotating at the increasingly swift pace.

Participants A, B, and C said purchasing can be difficult because they need to rely more on widespread consistency within a supply, along with obtaining, storing, and finding the best prices on those particular supplies. Participants A, B, and C also stated that even though general technology advancements have greatly helped with timing deliveries, managing inventory, and formulating diets, the rapid feed turnover means that demand and delivery of byproducts is one of the greatest challenges in operating at complete efficiency.

Participants A, B, and C did say their contracting habits involving purchases a month or more in advance were from “almost always,” to about half or more for another, and around 10 to 30 percent for the other one, moving from the smallest firm to the largest one. Participant A did say at his former vertically integrated operation, the percentage was around 40 to 60 percent, but in all these different practices show that long-term contracting has been important in the past and likely to continue into the future.

With the smaller ethanol plant contracting long-term at around 90 percent (Participant F), and the other larger one at 20 percent (Participant E), this can further reinforce this idea of regional differences, as those two were several states apart within the Midwest. This is paired with the hog producer stating the ethanol plant is the one who initiates a combination of long and short-term contracts with him regularly (Participant D). Regardless of the direct cause, each of these buyers’ and sellers’ contracting habits show that long-term purchases happen to at least some degree (Participants A, B, D, and E) while others heavily utilize them (Participants C and F). This level of asset specificity is exemplified through both the uniform specifics of the

byproduct, as well as the timing of its arrival that is sought after by buyers more than a cheaper price for the byproduct itself (Participants A and C).

For the DDGS sellers, they did say that byproduct revenue ranged from 20 to 35 percent of total revenue (Participants E and F). Participants E and F said the fluctuation was due to changing export levels at a given time, because domestically DDGS are easy to sell. Participants E and F said their product is available throughout the whole year, sales typically increased in the winter due to the higher demand, especially with cattle. Overall though, they said price can significantly change if a big buyer changes their habits, showing that price levels of the most highly popular byproduct still face notable uncertainty (Participants E and F).

With DDGS exports, Participant E cited tougher competition, unfamiliarity with the product, and difficult-to-procure transportation in foreign market, where deals are long-term in nature, putting the completion of the deal at risk. Since exports takes the issues of a relatively volatile domestic market and adds even more complexity into the grand price equation, this opportunity for growth is one that comes with its own set of serious transaction costs (Participants E and F).

Both buyers and sellers talked about a variety of transportation options, with truck and rail as the two most common ones (Participants A, B, C, E, and F). Participants A and B said rail has a tendency to either deliver large loads when there is no available storage space, or to not deliver when needed. Since sellers want to avoid discounting their product due to poor timing, this shows an importance on avoiding risk by choosing truck transportation (Participant B). Participant B reiterated that operations try to save on transportation cost for byproducts as much as possible in the first place, and so that will default more commonly to trucking. It also shows

how important it is for operations to utilize byproducts to most easily and readily interact with their types of storage and machinery (Participants A, B, and C).

On the more direct matter of storage, I want to repeat the earlier sentiments from interviewees, first in that any biological concerns such as infections or toxins are definitely on the radars of each operation (Participants A, B, C, D, E, and F). However, Participants C, E, and F mentioned how with their advancing technology over the years combined with their efficient storage management, monitoring and cleaning to prevent toxins, infections, and moisture issues are very easy tasks. Feed-mill-buyers said in recent years, most byproducts use the same type of generic bins, just separated from each other (Participants A, B, and C). Whereas in the past, Participants A and B mentioned more byproducts needed special containers and storage units of certain temperature control.

Thus, this returns again to the idea of reducing asset specificity (the importance of an asset's main purpose over possibilities) for these key ingredients in a feed mix, making the ability to deal in a transaction much easier when the product is compatible with current equipment (e.g. Williamson 1979). The patterns in these responses again indicate a push towards an ease of transaction for all involved parties (Participants A, B, C, D, E, and F) As illustrated by the reduction in byproduct options and the number of players in the market over the past 10 and 20 years, this trend of declining thinner markets and the survival of more commoditized byproduct choices show how important reducing these transaction costs is (Participants A and B). It makes sense that thinner markets either conform to the high efficiency demands of being compatible with on-site machinery and other feed ingredients, or disappear from the market.

The monitoring aspect exists as Participants E and F mentioned that not only are they required to tag their DDGS with nutrient guarantees, but also they routinely perform nutrient

tests anyway to make sure they are achieving the consistency expected by buyers. In terms of the buyer responses however, most noted that they regularly perform their own tests anyway, making sure that the nutrients are at an acceptable degree, and that toxins are at a safe and low-enough level (Participants A, B, and C). Participants A, B, and C said the tests are relatively quick at about an average of 30 minutes, but again they help in making the best decisions because of the confidence of having a consistent product that livestock producers will buy. Overall, this shows that some information costs have been reduced through these efforts.

With the level of care required in analyzing toxin contents, Participants A and B still reported that rejection rates of loads range from 5 to 10 percent typically. This reality led to additional transaction costs borne by both the buyer and the seller of a byproduct. Though these tests are an example of some of the transaction costs that operations have continually reduced over time (Participants A, B, C, and D). These costs are defined such as the asset specificity of byproducts, gathering information, enforcing contract terms, and so forth (Coase 1937), which have been reduced through those very information technology advancements originally predicted in the agricultural literature (e.g. Pennings and Meulenburg; Thompson and Sonka 1997).

Participants E and F mentioned how nothing domestic has affected their operations, though the exporter said that the GMO restrictions from larger trade partners such as China have been crippling on that end (Participant E). However Participant A stated that government policy has affected the byproduct industry through the banning of meat and bone meal in reaction to diseases stemming from their use in the past. Participant A said that the Food Modernization Safety Act (FSMA) has increased tracking requirements, which has lead to great costs for everyone throughout the byproduct industry, and a direct cause of a few plants closing down.

Participants A and B mentioned that byproduct prices are much more volatile compared to corn prices (with them giving the example that even DDGS have ranged from being a portion of corn price to well beyond it within years). Participant A added that byproduct prices feel more affected by competing markets rather than events and changes in their own, which even further reinforces the idea that value is captured from transaction efficiencies. Participant A took this further, in their belief that recent price changes have been amplified by the reduction of byproduct choices and market players.

Participants A, B, C, and D prefer to buy local to save on transportation costs, although A, B, and C elaborated that they have always been forced to do a combination to maximize efficiency. While Participants A, B, and C did note that everyone in the industry essentially knows each other due to the market's small size, both parties still test all byproducts regardless of any requirements to do so or not. And it is not like byproducts are a small deal for feed mills, either, Participants A, B, and C had rations ranging from 50 to 80 percent of byproducts. Participants A, B, and C stressed the benefits from quality and consistency equated to greater sales ultimately.

The concept of sellers having superior information to their buyers was a thin market concern in several past articles (e.g. Glaeser and Kallal 1997; Anderson et al 2007; Rostek and Werekta 2008). Since this concern has been alleviated with this technological advancements, however, is important to keep in mind that this trade obstacle has been continually overcome across recent years with the expansion of data technologies used by both parties in a trade (Participants A, B, C, D, E, and F). And thus, this again goes back to idea the reduction of transaction costs originating from information technology advancements, to help meet the

demands of a continually thinning market that places stricter trade schedules on the participating market agents (Participants A and C).

Participants A, B, and C attributed easing trades to the communication and information technology advancements in the industry, along with the familiarity that comes with large players interacting together in a limited-population market. This ties back to earlier discussions on “everyone knowing everyone,” and a large focus on business relationships, friendships, and reputation as expressed by each of the buyers to a degree, emphasizing that both “trust” and “following through with promises” hold a lot of weight and play right into the whole reputation aspect of the industry (Participants A, B, C, and D). These types of business show relationship ideals match the desire and need for the convenient, efficient, and consistent trades amongst each other.

Participants A, B, and C spoke about how handling and having available storage space are the most important. Participant A emphasized how storage and handling arrangements did not work out, that was the end of that trade discussion. However Participants A and B rejected or received discounts from 5 to 10 percent of all byproduct loads, though their satisfaction with the “good loads” was enough to accept this trend and maintain usage of their byproducts, showing that the enforced contract terms indeed lead to benefits.

Essentially, with the market being thin enough, both buyers and sellers have seemed to have arrived at a point where there is a lot of coordination and understanding amongst each other, although contracts remain present (Participants A, B, C, D, E, and F). Thus overall, a combination of contracting, technology improvements (physical and information), and reputation-determinant actions help shape the industry’s operation, and directly works towards the goal of reducing transaction costs (Participants A, B, C, D, E, and F). Through cutting down

on asset specificity, communication costs, price and compensation negotiation costs, and so forth, these combinations of increased efficiency speak a lot about the active efforts to implement improvements into the market (Participants A, B, C, D, E, and F). As with the literature review, the contracting and reputation findings align with Hubbard (2001) and Adjemian et al (2016), the information technology findings aligned with Pennings and Meulenburg (1997) and Thompson and Sonka (1997). Therefore, the theoretical predictions appearing in the literature was expressed through several interviewee responses, all about how market player could and do deal with transaction costs in byproduct markets.

In terms of the research question of how firms deal with transaction costs in crop byproduct markets, the answer appears to be contracting, substitute products, reputation, information technologies, and efficient handling (transportation and storage) as a complementary combination of factors. It is through these actions together that, despite the transaction cost issues of byproducts market survivors choose to continue their respective sales and purchases of these feed ingredients. And they identified impactful transaction costs as poor delivery timing, inconsistent product quality, and fewer options in terms of what and who to purchase from. In addition, these answers show that contracting choices have increased in these crop byproduct markets, with spot purchases declining at the same time. Also, participant responses believed that corn prices, soybean meal prices, and nutrients as the main determinants of byproduct prices. And so the respondents provided qualitative support for these topics relating to the research questions and related objective questions, however quantitative analysis is still missing.

Future Considerations and Desired Research Data

While many interviewee answers covered applied to transaction cost concepts to varying degrees, there are still a lot of questions that arise from before and after their newfound answers. I identify some of the areas of improvement for future studies like these, as well as develop some additional question for later studies, to facilitate a deeper understanding of byproduct markets.

One area of later focus would be some more exact numbers behind what some of the interviewee responses. It would be really helpful to know the levels of byproduct volume, costs, nutrients, and so forth, behind an operation and comparing across different ones. This would provide a better understanding on how the conceptual and theoretical experiences stack up against hard numerical figure. However, there are two critical components to include in its consideration.

In obtaining concrete numbers, the reality of doing such may be difficult to acquire. This type of information is very sensitive to any type of operation, and asking for such level of detail regarding this subject may be an unsuccessful endeavor. Given that the number of relevant operations is in a decline in terms of active market players (Participants A and B), any sort of information may become continually easier to trace back to study participants. And given the sensitivity of such figures, it makes sense for feed mills, farmers, processors, and other types of byproduct users to want to keep their operational statistics private.

The second critical issue in obtaining more data is about scope. The optimal way of observing and analyzing data would be to get as many observations as possible. A survey would probably function the most appropriately for this type of information gathering, and would cover as many participants as possible, across multiple regions of the country, and among a diversity of operation types. So there is a trade off in scope, as performing in depth interviews could become

infeasible if enough firms are included within the study. However such level of detail may be unnecessary if the initial qualitative findings are dependable enough.

Another improvement again goes back to the diversity of market participants in the study. Even after completing the interviews and receiving a helpful amount of insight, I can confirm the benefit of having additional viewpoints included in the discussion of the overall byproduct market, as they could further strengthen identified patterns from existing responses, as well as help uncover new ones. In total, this could capture a broader, and more representative, understanding of the byproduct and feed markets in relation to one another. This could again play into helping figure out regional differences between each player and byproduct type, as well as which livestock differences are relevant to the byproduct choices of a given operation.

I was not able to speak to any vertically integrated feed mill operations, which would be a specific goal in addition to the aforementioned recommendation. Vertical integration is fundamental to understanding the markets, since the practice is tremendously relevant in the literature on transaction costs. As a result, this would give a more complete analysis on the byproduct market by including additional avenues of trade.

There is also still need for increasing the variety of seller operation types in a study. For a follow-up survey regarding byproducts, conversing with more ethanol operations would lead to a greater level of information, especially if locations are from different geographic areas. When looking into sellers of other byproduct types, this would extend the findings to a new level of understanding that incorporates feed ingredients in the byproduct markets together.

There is still a need for having as much of a “time” aspect connected to any data. Getting an idea on these types of market movements and tendencies across historical phases of the industry will be important. Especially given the previous interviewee statements on the decline

of many byproducts (Participants A and B), and others on the unknown future of the current ones (Participants A, B, C, E, and F), these time differences are key in any study of the subjects involving feed, byproducts, or thin markets.

There needs to be more statistical data on the different byproducts, in a more public and overall sense beyond information stemming from individual operations, through a government or other third party organization. While the size of DDGS volume and popularity allows for some more concrete industry numbers, there is a need to continue for other byproducts, especially as older options have become phased out of the feed market. Examples would be different byproduct options, and how many are made, used, thrown away, unsold, discounted, utilized differently, rejected, nutritionally consistent, and so forth. This data can enhance analytical studies, which combined with the other recommendations, may get a much more in depth study on the causes and impacts of various transaction costs in thin byproduct markets.

Questions for Moving Forward with Research

The entirety of the market is an extensive network of assorted interactions between a diverse list of byproducts, sellers, and users, as displayed within the scope of my interviews (Participants A, B, C, D, E, and F). Whether future research approaches this topic from a more general or more specialized manner, the following ideas should prove to be a good starting point in determining how to better approach complications in comprehending the crop byproduct industry.

“Is there any interest in implementing quality standards for any types of byproducts?” is my first future research questions. While I can think of counters to this idea, it is one that fits differently into each of the byproduct markets. For example at least, both the literature and

several of the interviewees spoke of the byproduct nutrient and price variation across not only regions, but even across individual plants, as well (e.g. Belyea et al 1989; Neill and Williams 2010; Hoffman and Baker 2011) (Participants A, B, C, D, E, and F). Given this, it would make sense that trying to implement a quality standard might not be effective based on possible widespread product inconsistencies.

If a standard would be helpful for some buyers in the sense that a quality guarantee could provide some quick assurance on the content of the byproduct, this would only be presumably for smaller producer operations that may not be as concerned with detailed nutrients, but would still like to have an overall picture. However, even this statement has flaws at least based on the hog producer's interactions with DDGS supplier. Participant D had his seller provide him with nutrient information, and then he acknowledged that he sent samples to third party testing on occasion, too, in the event he felt it was necessary based on the market's quality climate, showing third party testing already exists. Regardless, the presence of a regulatory standard would likely be inconsequential to Participants A, B, and C who face strict, large-scale nutrient requirements and performed constant byproduct quality tests as a result. Participants A, B, and C also stated that they needed to test because even when byproduct loads displayed abnormally higher nutrients, the facility needed to adjust the feed diet composition in order to maintain its consistency. And it would make sense for this to be widespread across the industry given the increasing size of operations at fewer numbers according to Participants A and B.

Thus, in the case of standardization, I would hypothesize that the process of introducing, promoting, and implementing such an idea would introduce additional costs, in the form of inconveniences to achieve compliance, certification, and such as inspection, for example, while introducing a minimal benefits. However, I do recognize that if such a process were optimally

designed and actualized, they may have the potential to help facilitate exchanges of such goods. But given the levels of inherent byproduct variability and the level of testing needed (and presently fulfilled) by operations already, this proposition may simple be unjustifiable.

However, I would assume the idea of standardization would tie in strongest to the popularity of DDGS described by Participants E and F, and some of the recent history behind its market. One paper covers the creation of a DDGS futures market back in 2010 (Hoffman and Baker 2011), though Participant C briefly mentioned the phenomenon, revealing little attention to the subject despite its initial and historic tone around its conception. The Chicago Mercantile Exchange declared it as delisted in 2015, with “no open interest” in the product (“Product Delisting: Distillers Dried Grains Futures,” 2015). This is peculiar, as Participant F emphasized how in recent years DDGS have started to become more consistent across ethanol plants than compared to before. However consistency conflicts with how DDGS’ nutrient content has been recently changing through oil separation as an example according to Participants A, B, C, D, E, and F. This type of action has lead to the alteration of DDGS nutrients to the point of altering the purchasing habits of byproduct users of Participants A, B, C, and D.

I state another important question as “what are the purchasing levels for different feed mill types?” This question encapsulates both the time aspect and the concept of transaction costs especially, when factoring in the vertically integrated nature of very large-scale operations producing feed for themselves, as I highlighted in my recommendations prior. Overall, this could provide clues as to which direction the byproduct markets are headed in, and why.

“What were previously used byproducts that are no longer used by you or the feed industry today?” would be a more focused question to help determine more concrete effects and causes of transaction costs that shaped the market as such, as well as diet and other changes, too.

This would greatly round out some of the history and reasoning behind any major shifts in the byproduct markets, and how the surviving players and markets were affected, and how they adapted in a concentrating industry.

A fourth area of interest would be about “unused” byproducts. This could cover simply what happens when a seller is unable to find enough buyers to get rid of their byproducts, when a buyer rejects a load (due to nutrient preferences all the way to serious issues with the byproduct load), when one or more parties has insufficient storage space, and so forth. The source and the response of byproduct disposal are important. Whether a facility tries to further market an inferior product at a lower price, discards it as waste, or something else, knowing this type of information would understand possible difficulties in byproduct market exchanges, and how buyers and sellers respond to issues in trade deals.

Given the possible influences on interviewee experiences, many other possible questions could help further analyze transaction costs. Examples could include “why were contracting levels so different among each of the interviewees?” or “what is the potential for a widespread toxin issue, and how effectively could this be contained?” Another may be “how would the markets react if DDGS content drastically changed and their usage declined as a result?” or “what would it take for other countries to adopt more byproduct exports from the United States, or other countries of origin (as applicable)?” And one last important one would be “how have contracting and spot prices compared over time?” Contracting, transaction costs, thin markets, predicting trends, and all of the other associated thoughts relate back to the above questions.

Chapter Four – Chebyshev’s Inequality

Introduction to the Concept Background on Chebyshev’s Inequality Literature

The findings in the interview chapter indicated there were disappearing byproduct markets, thinner byproduct markets struggling with transaction costs, and increasing volatilities over time in terms of byproduct prices (especially on declining spot markets). While the interviewees answered the research question of “how do firms deal with transaction costs in byproduct markets?” along with questions on the impacts of transaction costs, on organizational structure choices, and on byproduct price influences, their answers lacked the context of larger scale market data. While such data remains limited in several regards, some byproduct sets do exist, and allow for statistical analysis on some of the statements from the interviewees.

Most notably, Chebyshev’s inequality addresses thin market concepts and looks at the volatility comparisons in prices both within byproduct markets and across alternatives, too. This method factors into some of the interviewee comments about market size and whether markets are influenced by thin production volumes, geographic region, livestock presence, and industry trends over time. This statistical technique attempts to show an approximate level of implied volatility across specific years for a variety of locations and byproduct markets. I use this approach to see to what extent the interview findings exist in terms of declining spot market usage over time, as well as the high variance expected of smaller volume byproducts, especially. Here I indirectly look at possible transaction cost market impacts and influences in byproduct market prices based off of the general findings and how they change in and across markets.

Chebyshev’s inequality was a tool used by various pieces of literature in past years, tying strongly into the concept of thin markets, (e.g. Tomek (1980), Ward and Choi (1998), Franken and Parcell (2012), and Koontz (2013)). The technique is about discovering the needed

transactions within a market to accomplish an arbitrary level of pricing accuracy (Tomek 1980). I utilized this method in order to draw conclusions about the volatility over time for byproducts. More specifically, I used Chebyshev's inequality to determine the "size" of these different byproduct markets with calculating a type of "number of market transactions" required to avoid thin market classification and implied price discovery obstacles.

Chebyshev's inequality is technical and straightforward estimation method, one which uses a combination of summary statistics for a given price series (Koontz 2013). But in the method I use specifically throughout this chapter focuses on rearranging the original formula to arrive at a desired measure of price discovery. A user starts by selecting wanted confidence levels and a desired level of price precision to then arrive a numerical measure of required transaction volumes (Koontz 2013). One of the main drivers for this calculation is the variance level of the prices (Koontz 2013). However, each component works together in order to determine this overall measure of "needed transactions" in the end (Koontz 2013).

I chose to run a year-by-year analysis for each of the crop byproducts. For each year, I run a set of four different levels of desired pricing precision to provide consistency for comparison, even when byproducts have different typical price levels. These components were based on a consistent probability (level of confidence) of 90 percent, which is in line with aforementioned historical papers across time using Chebyshev's inequality (Tomek 1980; Ward and Choi 1998; Franken and Parcell 2012).

Background on Chebyshev's Inequality, Earliest Literature

Each of these papers approached their markets in different manners as they utilized Chebyshev's inequality in thin market concepts, in livestock industries of cattle (Tomek 1980,

Ward and Choi 1998, and Koontz 2013), and hogs (Franken and Parcell 2012). Given that these livestock markets are not commodity crop markets, much less crop byproduct markets, there are bound to be some divergences in results, especially with differences in the publication years, too.

The components in Chebyshev's inequality did not change across papers, and so there is some consistency behind the main purpose of the methods (Tomek 1980, Ward and Choi 1998, Franken and Parcell 2012, and Koontz 2013). The following equations are the original and altered Chebyshev's inequality, and best described in detail in the most modern paper of Koontz (2013):

$$P(|X_n - \mu| \geq c) = (\sigma_n^2 / (c^2))$$

$$n = (\sigma_n^2) / ((1-P) * (c^2))$$

where:

P = Probability; Level of Confidence (Chosen)

n = Number of Needed Transactions to Achieve “c” using “P”

X_n = Random Variable; “Mean Reported Price”

μ = Mean of random variable “X_n”; Equilibrium (“True Mean”); “Underlying Market Price”

c = Given Level of Pricing Precision; Arbitrary Constant; Accuracy; Price Error (Chosen)

σ_n² = Variance of Prices; Variance of Distribution of the Mean

Tomek (1980) and Early Use of Chebyshev's Inequality

Tomek (1980) was a Chebyshev's inequality-central article that used cattle pricing data from 1955 to 1968. Tomek defined a thin market as one with few transactions to the extent that pricing errors occur as a possible result of information asymmetry, and the deliberate or unintentional non-equilibrium pricing practices of a seller (Tomek 1980).

Tomek also states that Chebyshev's inequality can help display the lack of market information, through the assumption that variance increases as fewer transactions occur (and the level and overall quality of information consequently decreases, too). When specifically using Chebyshev's inequality, the author asserted that its use is a way to measure market thinness. In doing so, Tomek introduces the same components and arrangements as others (Tomek 1980).

Tomek ran the expression in an effort to see if certain markets were thinner compared to one another, and discovered the levels of market thinness through the use of n-value equation. Noting like I did before, he states that since the levels of pricing confidence (P) and precision (c) are self-chosen, making those numbers subjective in nature, regardless of the logic used in order to shape those choices. According to Tomek, despite the findings drawn from the equation, the "approximation" nature of these values limits the degree of strength behind the results (Tomek 1980).

For one of those arbitrary probability and accuracy values though, Tomek sets the confidence level (P) to 0.9 for his Chebyshev's models. The 0.9 number means that the resulting error is 10 percent, and that there is 90 percent certainty behind the final values given based on the data's variance and the chosen, desired pricing range (c). And so, in terms of the pricing range, Tomek chooses 10 cents per hundredweight as the set pricing range in the model. This "10 cents" number means that a series' prices needs to fall within that range (above or below 10 cents of the average, like choosing a standard deviation in effect) at a 90 percent confidence level. 10 cents was about roughly one-fifth of the standard deviation of the prices during the time series (Tomek 1980).

Tomek established that the volume of sales within each of the cattle market locations was usually enough to fall within his desired quantities set up by the Chebyshev's inequality altered-

equation results. To better draw conclusions from the years of prices, Tomek compared the different market locations against each other. Ultimately, Tomek said this process would be worthwhile in identifying the actual causes behind those divergent findings across locations, beyond the assumptions gathered based on Chebyshev's inequality and other types of statistical analytic methods (Tomek 1980).

In conclusion, Tomek stated that while there are more intricate ways to observe market thinness through greatly sophisticated analytical techniques, Chebyshev's inequality provided a way to put separate markets into a common method of comparison with each other. Within this goal, the author identified this resulting "n-value" number as the sufficient trades needed to establish a stable price. Although he adds this claim in the end, the author noted that future improvements that most fittingly use Chebyshev's inequality might best stem from the increase frequency of data observations. In the end, Tomek said that at the very least Chebyshev's inequality can help support notions of lower numbers of trades leading to less accurate pricing, originating from poor quality information, as well as less information overall (Tomek 1980).

Other Academic Sources on Chebyshev's Inequality, Thin Markets, and Livestock

Ward and Choi (1998) and The Extension of Tomek's Work

The only other relevant paper written before 2000, although still published 18 years after Tomek's, is Ward and Choi (1998). Ward and Choi's work also looked at price discovery, accuracy, and thin market effects in cattle markets, as well. Specifically, the authors focused on the fact that over time cattle sales have become exchanged less on traditional markets, and have moved away from their cash market origins. As a consequence of this trend, Ward and Choi asserted that this decline in information disrupted the level of the reported market prices. And

just like with thin markets in general the two identified this type of inaccurate information as the source of poor price discovery, where supply and demand do not have as much of an effect on price as they typically should in a thicker market (Ward and Choi 1998). In terms of their actual process, Ward and Choi followed the same use of the n-value modified Chebyshev's inequality as in the Tomek (1980) paper, in order to get an idea on market transaction volume and the resulting levels of thinness that are associated with any such declines (Ward and Choi 1998).

In summary, the findings from Ward and Choi (1998) agreed with the previous sentiments that Tomek identified. Their conclusions were that as the number of transactions and observations of those transactions decreased in a market, then the variance of the price series increased, in an inverse relationship between those. In addition, they also supported the statement that price accuracy decreases as the number of transactions in a market falls, too (Ward and Choi 1998). Ward and Choi stated that the number of transactions and observations seemed to most strongly influence pricing precision, as well as the probability of attaining a set pricing precision level. Looking toward future research recommendations, they said that later studies should look more on a transactional basis within this market and others like it. In a more detailed sense, the authors should of course address the concerns before about comparing locations, quality levels, and so forth, too (Ward and Choi 1998).

Franken and Parcell (2012) and Branching Out to the Hog Industry

The next paper that addressed a thinning agricultural industry was Franken and Parcell (2012). This article observed data from swine markets though, instead of cattle markets like with the three other agricultural Chebyshev's inequality papers in this chapter. The authors cited the main driver of the paper as concentration of livestock markets in general, combined with the

declining use of cash markets specifically. In all, this meant that the available “official market prices” were only then a portion of the total prices offered in the actual industry, which made them inaccurate to the actual reality of true market’s prices. Citing Tomek (1980) multiple times, Franken and Parcell also credited thin markets as stemming from a low number of transactions (Franken and Parcell 2012).

The methods in Franken and Parcell (2012) regarding Chebyshev’s inequality were the same still. Unlike the other papers however, they applied calculations for multiple measures of pricing error, giving a variety of “desired precision” scenarios to compare against each other all at once (Franken and Parcell 2012).

In terms of their conclusions, the authors added that if a thin market can price based off of a larger market of essentially the same product, then the thin market should be able to “price match” that larger market. In this case, the authors show this means the thin market can still be reasonably priced, without having to arrive at its own set of accurate, self-determined prices from their particular and unique market conditions. Overall, the significance of this concept, basing the prices of one market off of another larger one, is the that though small market locations can arrive at an accurate level of pricing using the prices of the same markets of other locations. However, the specific example here is that a smaller market can still rely on the collective findings and prices of other markets instead, to determine what the larger-scale market equilibrium is. However, the authors at least indirectly indicate that this cross-locational pricing scheme still comes with the caveat that the product has to be quite similar across locations (Franken and Parcell 2012).

In the end, Franken and Parcell said that a complete data collection will be important for further understanding thin markets and their effects in future studies. Lastly, they asserted that

subsequent researchers will need to pay attention to specific product quality in order to price more accurately in future transactions. However, they admit that several formula components are still based on arbitrary values. In terms of their deeper findings, Franken and Parcell did see shrinking and thinning markets as sources of unreliable pricing due to less market information (Franken and Parcell 2012).

Koontz (2013) and Returning to Thinning Cattle Markets

Finally, the most recent academic publishing using Chebyshev's inequality for an agricultural livestock market was Koontz (2013). This was actually a PowerPoint presentation, yet it still covered the overall topic of thinning cattle markets extensively, with a combination of charts and explanatory slides to supplement the discussion on the topic. Koontz began by stating that cash markets feature bid and ask prices, leading to price discovery through the interaction process in these markets specifically. Koontz emphasized that such prices do not involve any type of price discovery, unlike the cash markets. Koontz displayed that trading problems were amplified in these thin markets from the decreased level of trading and the lower amount of information as a resulting consequence (Koontz 2013).

Getting into some of the sources towards the perception of market thinness, Koontz directly stated that the number of transactions in a particular market was inversely related with the ease of price discovery for players within that market. This statement behind transactions and price discovery followed the findings of the above-mentioned papers (Tomek 1980, Ward and Choi 1998, and Franken and Parcell 2012). Going back to the reality of the cattle market, Koontz proposed the possibility that lower cash market exchanges may have resulted in distorted prices, and thus greater volatility in the end (Koontz 2013).

Koontz finished his presentation by stating that he believed declining market volume changes were indeed a negative effect for those markets as they faced thinning trade numbers. Overall, the author called for enhanced public data gathering and its free disclosure from relevant entities, warning that volatile pricing is the largest threat to arise to each of these thinning markets (Koontz 2013).

Data and Procedures

The Overall Basics of the Components and the Strategy for Using Chebyshev's Inequality

The data set for the Chebyshev's inequality portion here was from the United States Division of Agriculture Agricultural Marketing Service (USDA AMS). The information contained within are weekly price series of the five byproducts of dried distillers grains (DDGS), corn gluten feed (CGF), wheat midds, soyhulls, and rice bran, in addition to the mainstream byproduct of soybean meal (SBM) to go along with it (given its importance to the price of feed). These prices were listed as a low bid and high bid for each data entry, and thus were combined and averaged into a single pricing point per time period for various locations. I completed this averaging effect in order to avoid the potentially large effects of the maximum and minimum price listings, and therefore arriving at a bit truer representative of the market.

Also because of its price influence on feed, I included national U.S. corn price for comparison too, since it has traditionally been a much thicker market than the others, and yet still competes with the byproducts to some extent of feed ration usage. However, the data for corn originated from a different USDA source and set, and was available in monthly values instead. For all of the data sets, they span 16 years, going from 2001 through 2016. This provides a complete price series of 192 observations as a result for each byproduct in question for each one,

making them more comparable to the corn market values. However, byproduct monthly calculations are as an addition to the weekly-frequency values.

In terms of my procedures using Chebyshev's inequality, I followed the process I outlined in the beginning of this subsection. That is, from the original formula of

$$“P(|X_n - \mu| \geq ((\sigma_n^2) / (c^2)))”$$

I rearrange that into

$$“n = (\sigma_n^2) / ((1-P)*(c^2))”$$

In doing so, this method rearranged Chebyshev's inequality in a way so that the resulting output of this new equation provides a measurable level of transactions needed to maintain accurate price discovery for that particular byproduct and location, as with the previous literature described above. Also, the “n =” equation was the one that most directly addressed the uncertainties behind market size since that is the “objective” of the formula.

However, I must state now that unlike several of the other papers, I myself do not have “actual” or “real” transaction data to compare the n-values (originating from my modified Chebyshev's inequality equation) to. I admit that such official data would be very advantageous in providing a more concrete picture on the actual level of thinness of the market in reality. Still, the process allows me to see what is “needed” in a market over time, which still has merit and worth in and of itself, too. This concept of low information tied into how most domestic byproduct trades and prices have generally been not as readily available (if at all) compared to some thicker agricultural markets. And so unlike corn, several of these byproduct are not as frequently featured on USDA reports, discussed on Agricultural website articles, or traded on futures markets.

Choosing the Specific Components to Utilize in Chebyshev's Inequality Calculations

In terms of the values I chose as my P-values (probability/level of confidence) and c-values (the level of pricing precision/accuracy), I consulted previous papers on an appropriate approach. With the P-values, I simply used the 90 percent value that was most common in the reviewed papers above (Tomek 1980, Ward and Choi 1998, and Franken and Parcell 2012).

The c-value (pricing precision/accuracy, and the desired price range I spoke of in the prior paragraph) was a little less straightforward. For example, the first three papers from before used the following c-values: Tomek (1980) at \$0.10/cwt for cattle (20 percent the standard deviation) Ward and Choi (1998) also for cattle at \$0.25/cwt (6 percent of the standard deviation), and Franken and Parcell (2012) at three displayed options of \$0.25/cwt, \$0.35/cwt, and \$0.45/cwt this time for hogs (2 to 4 percent of the standard deviation). As an additional note, each of these three papers featured these c-values at about 1 percent or less the average price of the product in question during the entirety of the time series (Tomek 1980, Ward and Choi 1998, and Franken and Parcell 2012). When it came to Koontz's paper from 2013, he placed the c-value at \$1.00/cwt for cattle (which was an unknown amount relative to the standard deviation, although this is more than the other papers at less than \$1.00/cwt, placing it at about 1 percent of the average price however) (Koontz 2013).

In my own work though, I aimed to have a series of c-values for each scenario I develop, in the same spirit as Franken and Parcell (2012). In establishing the pricing precision range c-values, I had to keep in mind that each of these different byproducts deal with different levels of price ranges based on their own typical rates compared to one another. Considering this, I applied the same percentage range to each individual byproduct set in order to give them all a consistent variance measure. I established the c-values (pricing error) at the three, six, nine, and

twelve percent levels of the average for the entire price series of that byproduct. I recognize that this is notably higher than what the authors the other papers set up, whose c-values were at around 1 percent or less of their average price (Tomek 1980; Ward and Choi 1998; Franken and Parcell 2012; Koontz 2013).

Supplementary Concerns Regarding Data and Procedure Selections

In terms of my frequency of data reporting, most of the other papers were dealing with fuller sets of multiple transactions and prices. And I ultimately discuss weekly and monthly-spaced data sets using just a single averaged price for each time period in a given location. Thus, ultimately these byproduct prices were still sourced from unknown sellers, although it was still unknown how many sellers were in respective areas. In addition, this process of using weeks of data still runs into the problem of missing data entries, which was an incentive to consolidate the data into monthly portions. It was not rare for any data set to be missing anywhere from just a few weeks of data, to a dozen or more for a specific year, which would then be inconsistent across each other. Regardless of the specific pattern, this general issue could disrupt the consistency across years within across locations.

Additionally out of the 17 locations of the USDA ARMS data set lists for corn, the sole single location with a full data set represented White Number 2 corn. White corn however has historically been far less prevalent than its Yellow counterpart within major corn producing states within the country (USDA National Agricultural Statistics Service, 2017). Also, white corn is ultimately used more for human food rather than livestock feed, unlike yellow corn, which was clearly much more relevant due to its widespread market size. As a result, I compared both yellow and white corn in the end.

Given the different number of price data observations from using either the monthly or weekly (then averaged annually) values, it is important to note that in basic statistics if the sample size is reduced, then the variance of the overall sample decreases, too. However, a lower number in terms of the data observations also generally indicates that the standard error should increase as a result though, also.

It was equally important to keep in mind that these crop byproduct data sets, which I chose for their large-scale of available data, were still representative of single city locations for some sets, and state-region, statewide, and national levels for the others. Because of this, one must recall though that given a byproduct seller may have very well been the only available seller in their particular area.

Also, I want to repeat that the full extent of the data still did not cover any type of quality information, and that consequently this lead to another assumption that each of the byproducts were nutritionally consistent across their respective markets. However, the quality within a single location may have changed over time. For the sake of simplicity, I assumed in this paper that the quality characteristics of each byproduct were the same across time and concerning separate physical areas when applicable.

Only some possible demand effects from the livestock inventory numbers may provide any additional context to the calculation outputs. USDA NASS does provide inventory numbers on livestock groups, and so the following Figure 1 provides an overview on the states within the following outputs. The assumption here is that cattle are the primary consumers of most byproducts, although swine and chicken play a role in consumption patterns, too.

Figure 1 – Livestock Inventory Numbers of Selected States

State	Beef Cattle Inventory	Milk Cow Inventory	Swine Inventory	Chicken Inventory
Missouri	2,052,000	88,000	3,100,000	15,464,000
Nebraska	1,920,000	60,000	3,350,000	10,660,000
Illinois	387,000	93,000	5,250,000	5,380,000
Tennessee	909,000	41,000	Unlisted	2,733,000
Minnesota	370,000	460,000	8,200,000	13,073,000
California	655,000	1,755,000	Unlisted	15,422,000
Texas	4,460,000	490,000	910,000	28,380,000
Arkansas	914,000	6,000	Unlisted	22,540,000

Source: USDA NASS Quick Stats *2017 Values *Swine is 2016

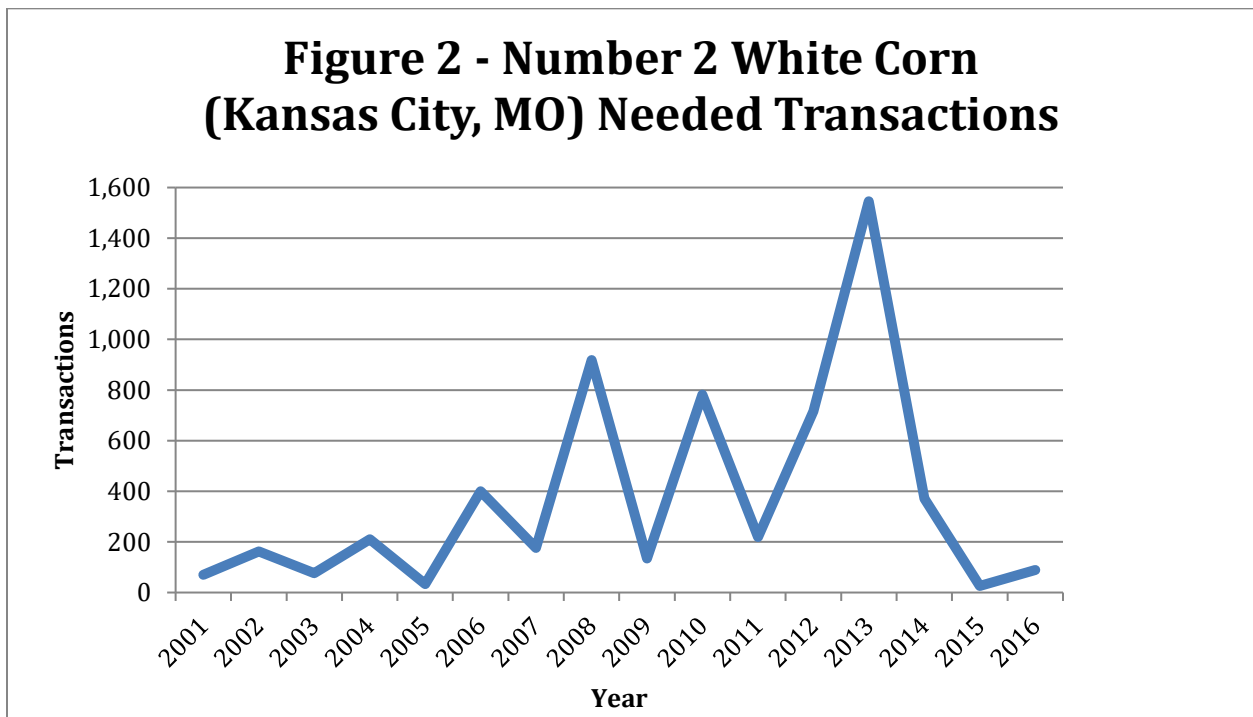
Findings from Chebyshev’s Inequality and Limited Crop Byproduct Market Data

Results from Calculations of a White Corn Market

I begin with corn due to its importance in the overall actuality of the standard animal diets in the U.S. industries. In terms of the weekly annual-averaged USDA AMS price series for the much smaller market of Number 2 White Corn, the Chebyshev’s inequality results varied a bit wildly depending on the specific year. Appendix Table 2 shows these differences on a per year basis to be quite significant, no matter which c-value column is observed. To begin, the values across each of the four columns of desired price error reinforce that the effectiveness of a market can be heavily influenced by this chosen c-value. As an example, the difference for wanting to be within +/- \$0.10 per bushel of a corn price compared to a much more “forgiving” range of +/- \$0.40 per bushel can easily require over a dozen times more present transactions in the market to achieve this aspiration, with all else held constant. However, one can easily assume that as least variation as possible would likely be the desired trait for any type of purchases.

With the Kansas City, Missouri White Number 2 Corn data, one striking observation is the level of price fluctuation across each of the years is relatively and highly variable, and does

not seem to follow any particular pattern or specific trend. Figure 2 visually displays the \$0.10 per bushel (the most precise confidence interval at roughly three percent of the data set's average), providing an overall view at the timing and magnitude of Chebyshev's inequality n-value outputs. As a reminder, each year of data relatively has the same number of observations with each other, regardless of which one. Almost all of them have 50 or more weeks, with only two of them in the 40's range (2014 and 2016), and both of those years do not have any extreme single-week values compared to the other ones. This makes the y-axis transactions per week, essentially per month, as the outputs were nearly identical. Also, I will focus on primarily this first column for any respective market unless otherwise noted.



Data Source: USDA AMS

Returning to the specific White corn findings, the three lowest years were spread out between 2001, 2005, and 2015 at around 25 to 75 transactions. On the other end of the spectrum, the three highest values were in the more around the middle years of 2008, 2010, and 2013 at

much higher levels between nearly 800 reaching to about 1,550 transactions. To detail the impact of the more liberal price error range of \$0.40/bushel though, this sole change in the formula caused the ultimate “needed transactions” results range as low as a two transactions, all the way to a maximum of 97 transactions. These trading volume levels at the least concentrated confidence interval are obviously much more easy to obtain by the market players compared to the opposite end. However, this would also assume that market players would be comfortable with an up or down \$0.40 price fluctuation per bushel. Given that corn during the timeframe averaged at about \$4.00 per bushel, this type of price difference would have been highly impactful, and likely a highly undesirable for anyone in the market (USDA NASS, 2017).

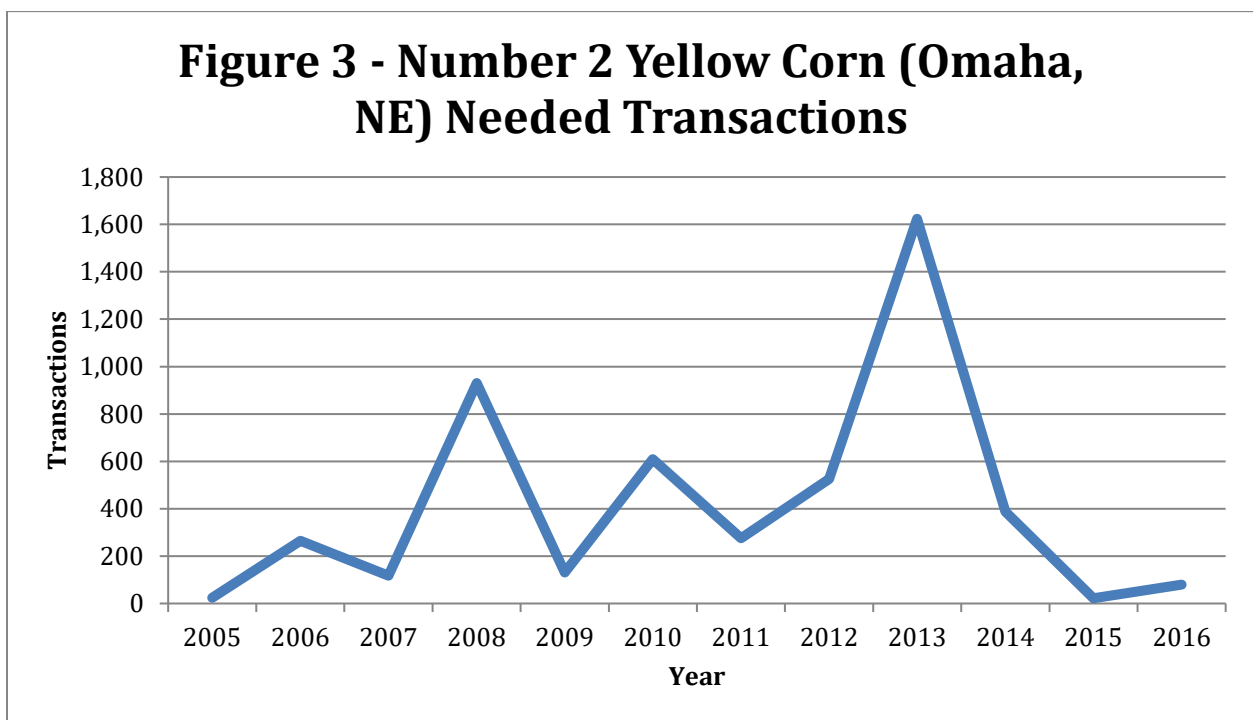
When viewed in its totality, Figure 2 shows that achieving stable market pricing in the white corn market is a volatile process. Considering that the white corn market is quite small in terms of volume (and likely small in regards the number of transactions as a result), these higher measures of transaction amounts might be implausible for the Kansas City market to attain. If true, then that would mean that the white corn market is indeed thin, and accordingly may comparable to smaller crop byproduct markets.

Results from Calculations of Yellow Corn Market

The USDA NASS yellow corn data set is in terms of monthly values for national prices, outside of the weekly level of data seen in the USDA AMS data set for white corn. The Daily Livestock Report numbers (of Omaha, Nebraska) are still in weekly figures though, so that is used as a decent comparison between the two sets of yellow corn data. Due to these differences in observation numbers, the variance should naturally decrease for the monthly-calculated annual averages, due to the simple fact that there are fewer observations per annual time frame.

Starting with the weekly yellow corn price data (originating in Omaha, Nebraska) of the Daily Livestock Report from 2005 to 2016, the results are strikingly similar to each other. White corn is a product of much less market size and entirely different human food use, and yellow corn is more prevalent nationally and used for mainly animal feed.

With weekly yellow corn data in Appendix Table 3, the years follow a similar data shape and direction over time with white corn, as seen visually with the representation of Figure 3. However the magnitude of “needed transaction volume” figures are the main differences.



Data Source: Daily Livestock Report (2017)

The three largest years of needed transactions and high price variance were in 2008, 2010, and 2013, at 610, 930, and 1,624 transactions, respectively. As for the years with low amounts of needed transactions, they were in 2005, 2015, and 2016 at 24, 22, and 80, respectively, too. Those values though were in terms of the most concentrated price error range. On the more extreme levels of the broadest price range though, the desired transaction counts ranged from a value of one to 101 during the entirety of those years. And so in comparison, it is

apparent that there is not too much differentiation between the overall trends of needed transactions, such as the large spike increase in 2013 (presumably stemming from the impacts of the 2012 drought), or the steep decline both 2005 and 2015 for both markets. And as for the notable n-value differences between the two, the primary examples of such are when the Kansas City White Corn market experienced higher increasing impacts in 2006 and 2010, where over 51 percent and 28 percent higher, respectively. Based off of these findings though, it is safe to say the white corn market faced some levels of increased volatility compared to yellow corn, while still mostly moving in the same directions, at the same time.

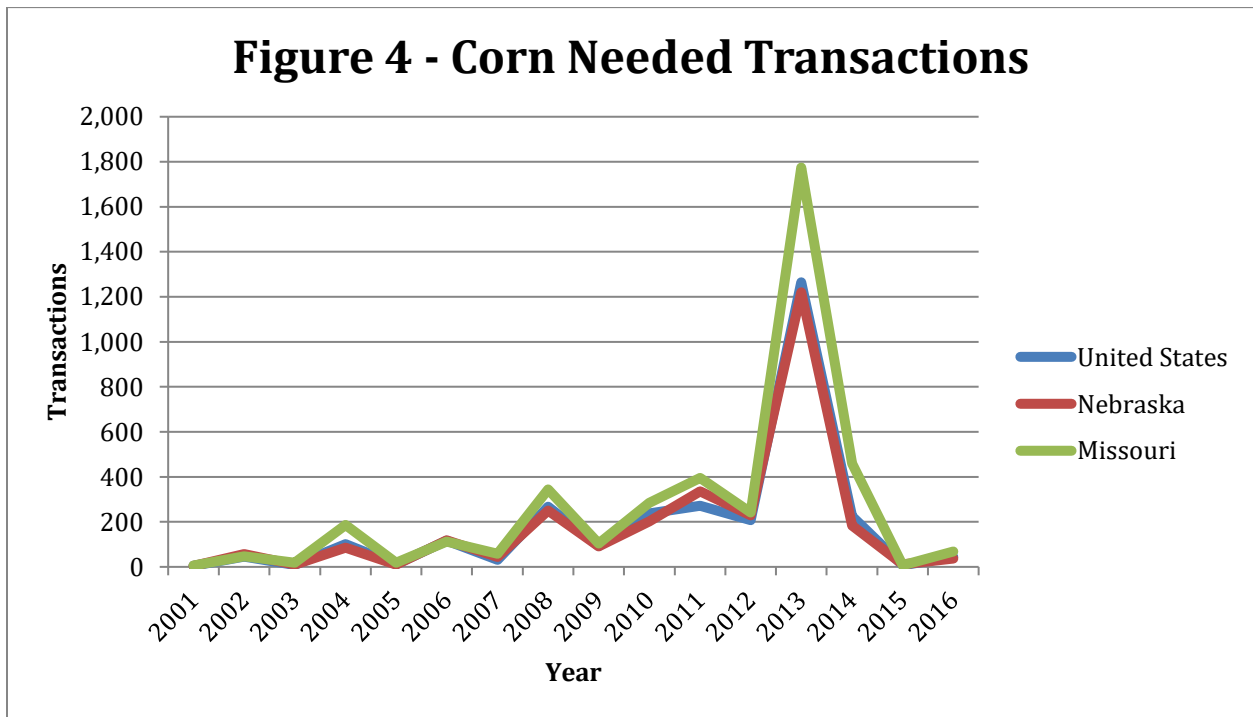
To add an additional layer of analytical comparison in this important discussion of corn price variance in different markets, I explored the other results of other corn markets to establish an even stronger basis for the findings. With the USDA NASS data sets, I expanded analysis out to three monthly comparison data sets between the national level, Nebraska on the state level, and Missouri on the state level, too.

The picture with the monthly national corn prices is much less volatile compared to the previous datasets above. Given the statistical nature of the variance measure, these values should be lower for the monthly dataset, because there are fewer observations to influence the ultimate output, and so I expected to see this. In addition to that, these values are presumably aggregated from a much large sample of prices, which should lead to more consistent prices as a result, too.

As seen numerically in Appendix Table 4, for the last 16 years of values of the \$0.10/bushel price error range, value for necessary transactions (to avoid thin market status) go as low as 5 in 2001 (with other single value digits in 2003 and 2015 as well). At the same time, the n-values are high as 1,264 in 2013 (following the same large drought impacts I mentioned in the previous paragraph). However, ignoring the 2013 data, the second highest transactions result

from Chebyshev’s inequality is at 272, which is noticeably lower compared to the average of around 400 in the Kansas City and Omaha markets (which were white and yellow corn, respectively). In fact, the average number of needed transactions for this national market was only at about 180, which is less than the others by over twice as much, implying a much more stable pricing.

In Figure 4, the U.S. yellow corn market graph is much more flat and tame compared to both Figures 2 and 3, holding only the same general up and down direction of the other values in a given year. In addition, the only main similarity is the data matching the same 2013 price variance spike as those other data sets (but to a lesser extent in terms of magnitude of around 20 percent less). These United States Chebyshev’s inequality values were particularly lower than the ones before, indicating less price fluctuations and a reduced need to have more transactions to reach a non-thin market status.



Data Source: USDA NASS

Another market is the Nebraska state monthly values from USDA NASS. To summarize briefly, the magnitude, shape, and overall outputs of Chebyshev's inequality results here are almost completely identical to the national corn prices from the same data set. As shown over time in Figure 4, the overall values between the two are effectively the same. The only primary difference was in 2011 where the Nebraska market experienced a noticeably (24 percent) higher level of needed transactions for the period. And the individual, detailed numbers behind this graph stem from Appendix Table 4.

Now the level of corn production in Nebraska is the third highest in the country, at around 1.7 billion bushels and accounting for over 11 percent of national production in 2016 terms (USDA NASS, 2017). It would make sense to believe that Nebraska is representative of the national corn market and their prices then. I assert that these two USDA NASS data sets are identical to each other. And so I follow the idea that if one market is identical to other ones, then those two will have similar price and pricing precision experience, despite the U.S. market clearly being much larger than a single state's. This previous statement originates as a loose extension of findings in Franken and Parcell (2012) involving a much larger, similar market could provide a price basis to another smaller one (Franken and Parcell 2012).

The Chebyshev's inequality results from the specific Missouri data set are a bit more different than the pair of findings from the Nebraska and U.S. national results. The average n-value from the Missouri calculations is around 260, which is noticeably higher than the average floating around 180 for both Nebraska and the entire country. The direction of where the price variance levels went is essentially the exact same. To highlight further, the lowest n-values of the Missouri set are very low like the others, at 6, 7, and 18 during 2001, 2015, and 2003/2005,

respectively. As for the three highest values of the set however, the needed transaction counts of 395, 460, and 1774 occurred in the years 2011, 2013, and 2013 respectively, too.

As it is shown in the graph of Figure 4, the Missouri corn market experiences price variance spikes that are simply just higher in magnitude than the other two USDA NASS monthly data sets. While still not as volatile as the weekly sets for Kansas City white corn and Omaha yellow corn, Missouri's trends and patterns definitely begin to move a little more towards those two. In Missouri 2013 output has a substantial increase exceeding all other values for any corn set, again showing it to contain more unreliable pricing in that year and others compared to the other locations. To put Missouri's level of corn production into perspective, it is decidedly lower than Nebraska's by several times, at about 3.8 percent of national production (or about a third of Nebraska's production) (USDA NASS, 2017). This may begin to show that price confidence may indeed be lower to some degree as the size of the market declines. However, knowing that the widespread usage and popularity of corn is high enough, achieving any of these Chebyshev's inequality n-value targets may not be an issue, considering that corn market participants could reach the target volume naturally.

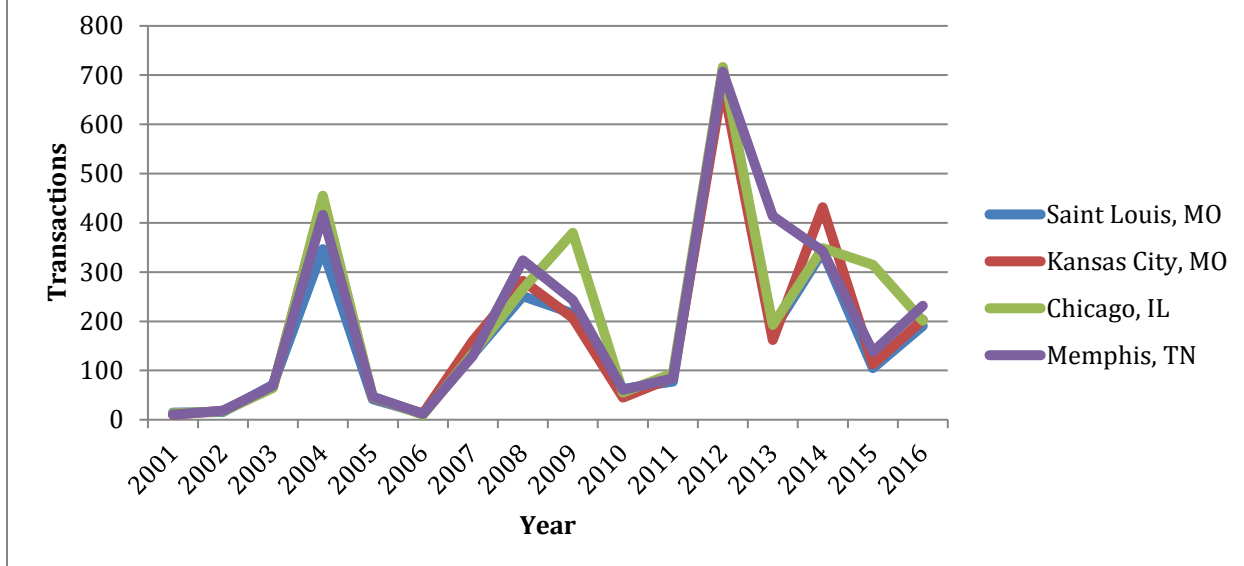
To repeat this in a broader framework in the context of the more wide-ranging price precision levels of primarily +/- \$0.40/bushel (though the +/- \$0.30 results did were not overly different compared to 40 cents, either), all of the corn data sets feature low values (usually below 100) regardless of any of the market traits. Again, these levels are representative of market participants' willingness to accept and be comfortable with these conditions, which ultimately must be based off of reality. At these wider levels of c-values, the n-values range from single digit results even as low as 0 or 1.

Soybean Meal (SBM) Results from Chebyshev's Inequality Calculations

With the soybean meal byproduct data, there are only minor differences when calculating the n-values based on either monthly or weekly-level data sets for these SBM calculations. Ultimately, there is less than a 3 percent difference in average n-values, and so for simplicity's sake I will only be discussing the weekly-level data set, since there are simply more data entries to factor in per annual n-value. For each data set I discuss in this chapter from here on out, I only mention any differences between weekly and monthly calculations as necessary from any large differences.

In the SBM results in Figure 5, the first primary observation is that the average overall “needed transaction counts” for this data set (the prices stem from Saint Louis, Missouri specifically) are overall comparable as the same as corn price sets of the country, Nebraska, and Missouri. However, the shapes and magnitudes for each year are ultimately quite different. Upon a closer look at Figure 5, the n-values for SBM compare to the yellow number 2 corn from Missouri in general, some variance spikes occur in unison at similar years, and others are inversely related and their lines of data move in opposite directions. The largest spike in SBM compared to corn is in 2012 rather than in 2013, and to a much lesser degree.

Figure 5 - Soybean Meal Needed Transactions



Data Source: USDA AMS

Regarding the concrete numbers in Appendix Table 5 for corn, the 2013 spike is nearly 1,800 transactions for that year with corn, while the SBM 2013 spike is a much lower at 713 transactions (but still the highest of its respective set). Comparing the reverse, the 2012 value for the corn market is 241 transactions, and the 2013 n-value for SBM is 181, thus the two markets are clearly apart from each other in both direction and magnitude during this particular time. So the entirety of the data’s shape for SBM is much more “tame” compared to corn’s, where graph movements appeared to be smoother, lower, and more gradual across the years. Although this main SBM data set still has values of 200 hundred or above for five of its years, it on average is still 33 percent lower compared to the corn price variances.

In order to confirm any location-based differences, I ran some preliminary Chebyshev’s inequality calculations for a few other locations, which are all distinct cities within the nation. Specifically, these are Chicago, IL, Kansas City, MO, and Memphis, TN. A quick comparison across each data set does not reveal anything too groundbreaking or important. This is strongest

inn comparison to the findings from the Saint Louis, MO market, in where Kansas City results very closely aligned here more than the others as shown in Figure 5. According to the outputs, the Chicago and Memphis markets did indeed experience some slightly larger overall average n-values for their results, and in a few particular years.

As for some of the overall conclusions of this data set, this seems to reinforce some of the findings with corn, in that a larger market will have much more stable price confidence and accuracy than smaller ones. While the corn market is much more larger than the SBM one, both should be sufficiently large enough to assure thick over thin market status, and ensure adequate price discovery. Given the high volume of SBM product and trade due to the simple fact of its very common usage next to corn, achieving anywhere from a dozen to a few hundred trades in the Saint Louis market is a very reasonable reality (USDA NASS, 2017).

While the SBM results were a bit less volatile than the Missouri corn market ones overall, both still point to the same ultimate considerations. Overall the market locations each follow the same widespread patterns for most years, but still face some critical differences. And it these differences appear to stem from possible time lags and other types of relationships within each other and their own respective geographic markets and locations.

The results from the SBM meal market fortify an idea from the corn markets, these two thicker livestock feed markets should indeed experience healthy market exchange motivated by high market product and trade volumes. These make up a majority of the market share of feeds in this paper at 75.4 percent, which is further broken up as corn consisting of 59.3 percent of this self-defined “feed” market, and SBM at 16.1 percent (USDA NASS, 2017; USDA Economic Research Service, 2017; Kahlon, n.d.; Agricultural Marketing Resource Center 2016; Commodity Specialists Company, n.d.; Soybean Meal INFO center; O’Brien 2010). The findings

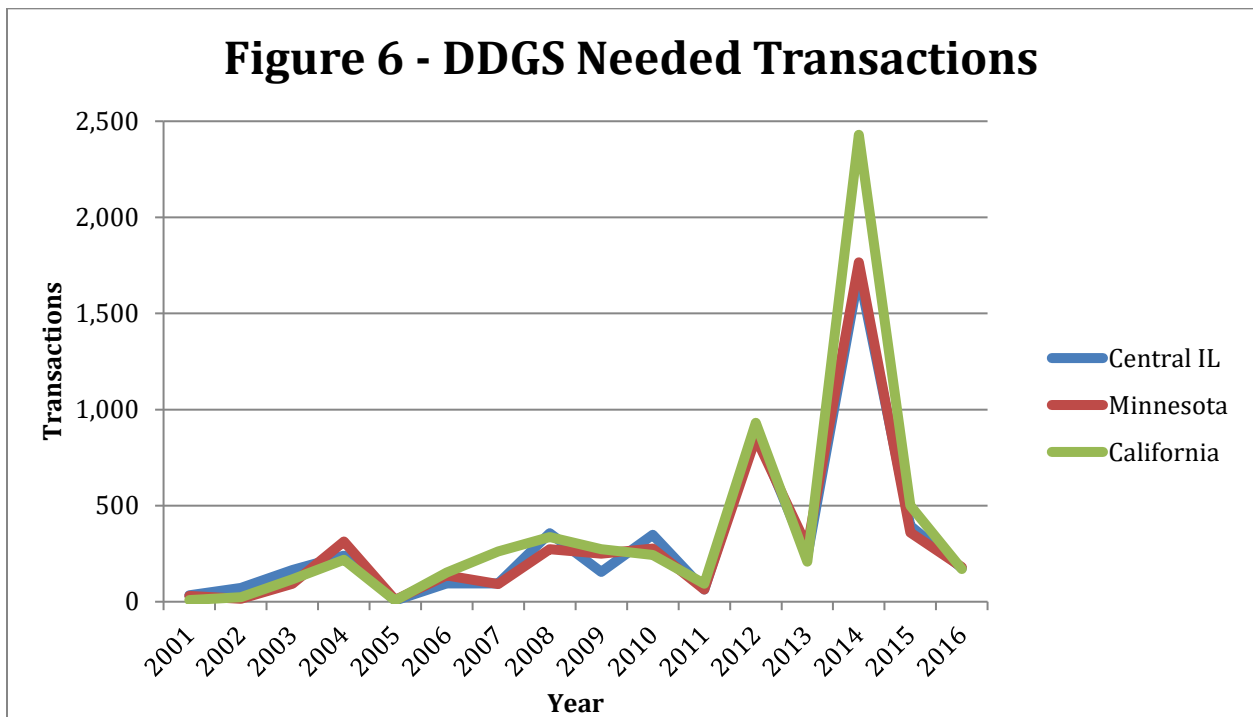
involving DDGS in the next subsection should also point to the same conclusions. The DDGS market is roughly as large as the SBM market, as confirmed through both market estimates (AMRC 2016; Soybean Meal INFO center), and directly one of the previous interviewees, too (Participant B). With SBM's more traditional and historical context versus DDGS' more "youthful" market of expansion over the past decade primarily, I expected to see some significantly different results than what was here (USDA Agricultural Marketing Service, 2017).

Dried Distillers Grains (DDGS) Results from Chebyshev's Inequality Calculations

The dried distillers grains (DDGS) market is a large market, roughly the same size as SBM, both feed staples (AMRC 2016; Soybean Meal INFO center). It has experienced much of its significant national growth in the past decade due to the rapid expansion of ethanol (USDA ERS, 2017). This ties back to the notion that corn is heavily tied to the prices of DDGS, and that SBM is tied due to the feed usage within the sheer span of its use (Hoffman and Baker 2011). One may expect DDGS prices to most heavily match corn trends, and still closely match SBM patterns, too. One issue though is that from the fast changes in the DDGS market size also incorporates the quality and nutrient changes to the products themselves across locations and years. And as result, this would presumably cause a much greater level of price variance, even in a single city market (as each location is still influenced by the overall macro-level DDGS market).

I chose the general "Central Illinois" regional data set to act as the representative market of DDGS, based on its greatest level of observation integrity, and the added scope of the specific high-trade nature of the location. Overall the series of results is not entirely distinct from the corn and SBM markets, but does experience some significant differences still. There is a decent

portion more volatility in the needed transaction results compared to corn and SBM. The average value is higher than any of the other previously discussed markets (higher than the most volatile monthly yellow corn market by nearly 22 percent at over 300 needed transactions). In Figure 6, and in Appendix Table 6, most years experienced slightly higher levels of price volatility in the early and mid-2000s compared to most of the corn markets. As the DDGS market would have been starting to really expand in terms of size during these years, and DDGS price changes following corn would make a lot sense in reality (Hoffman and Baker 2011). In a simple sense, this shows that regardless of the size, during these specific times of 2001 through 2009 the DDGS market faced similar price volatility compared to corn.



Data Source: USDA AMS

However, though it may appear that the different patterns are similar, this raises the question if the DDGS market was big enough to in terms of transaction volume in order to achieve the given “needed” level established by this formula. As an additional point, it is during this 2001-2009 year range on the graph is where SBM results patterns overall follow similar

trends in terms of direction and numerical weight. These separate points support the idea that these three markets were closely related to each other in terms of price volatility. Although in theory, the more specific and detailed movements of those actual prices may be different.

In 2010 however, that point is where a few major differences begin to emerge in the DDGS n-value results compared to the corn and SBM markets. Whereas the other corn markets experienced a massive volatility spike in 2013 that then rapidly fell in 2014, the DDGS market saw a moderately large volatility spike in 2012, a sharp decrease in 2013, and then an even larger spike in 2014 essentially equivalent to the 2013 ones in the corn market. The primary SBM market had a smaller, moderate increase in n-values in 2012, a sharp decline in 2013, and then an uneventful increase in 2014. Overall, this major difference reveals that despite the similarities in the initial origins and uses of these three staple feed ingredients, the markets are still subjected to their own unique conditions and events. After all, University of Nebraska researchers highlighted the heavy decrease of DDGS imports to China in late 2014 (a large potential primary player in DDGS trade, as recognized by a prior interviewee) (DeOliveira, Brooks, and Nogueira 2017; Participant E). During 2014, the export volumes rapidly fell in the beginning, fluctuated through the spring, and then began heavily declining midway through the year, and reaching zero at around the end of the year (DeOliveira et al 2017). This massive increase in demand would explain the rapid price increase that occurred at a time of the opposite effect for the corn markets.

To begin, the alternate location of the Chicago, Illinois DDGS market very closely compares to the Central Illinois discussed prior here. Due to the extreme similarities, I will not display the results. However this essentially concentrated version of the Central Illinois market, this outcome is expected.

The DDGS market for Minnesota is also very similar to the Central Illinois market. The graph shape and n-values of the Minnesota market so closely resembles the Central Illinois market, as seen in Figure 6, to the point that their average values are two only one transaction apart (313 versus 314 transactions, respectively). Since both are still within the large and ethanol-concentrated Midwest region, it appears that these markets are still shaped by the same forces to a basic same degree. When comparing the Chebyshev's inequality outputs for Central Illinois versus Minnesota, the earlier years of the market see some slightly different patterns. But overall across the years, and especially in 2010 and beyond, the general patterns in the data are very similar and reveal deep connections between the two market locations.

With the DDGS market, the California market housing six of the 204 ethanol plants within the United States, it is outside of the Midwestern markets (Ethanol Producer Magazine, 2017). As seen in Figure 6, the initial years experienced some different directions and sizes of the n-values and their movements across years. These distinctions may have spurred from the market size and location effects. After all, aside from the slightly different data shape, California's needed transactions are on average roughly 19 percent higher compared to the Central Illinois one. And in addition, California's price variance spike in 2012 is slightly larger in comparison, and is much larger at nearly 41 percent of a higher level, too.

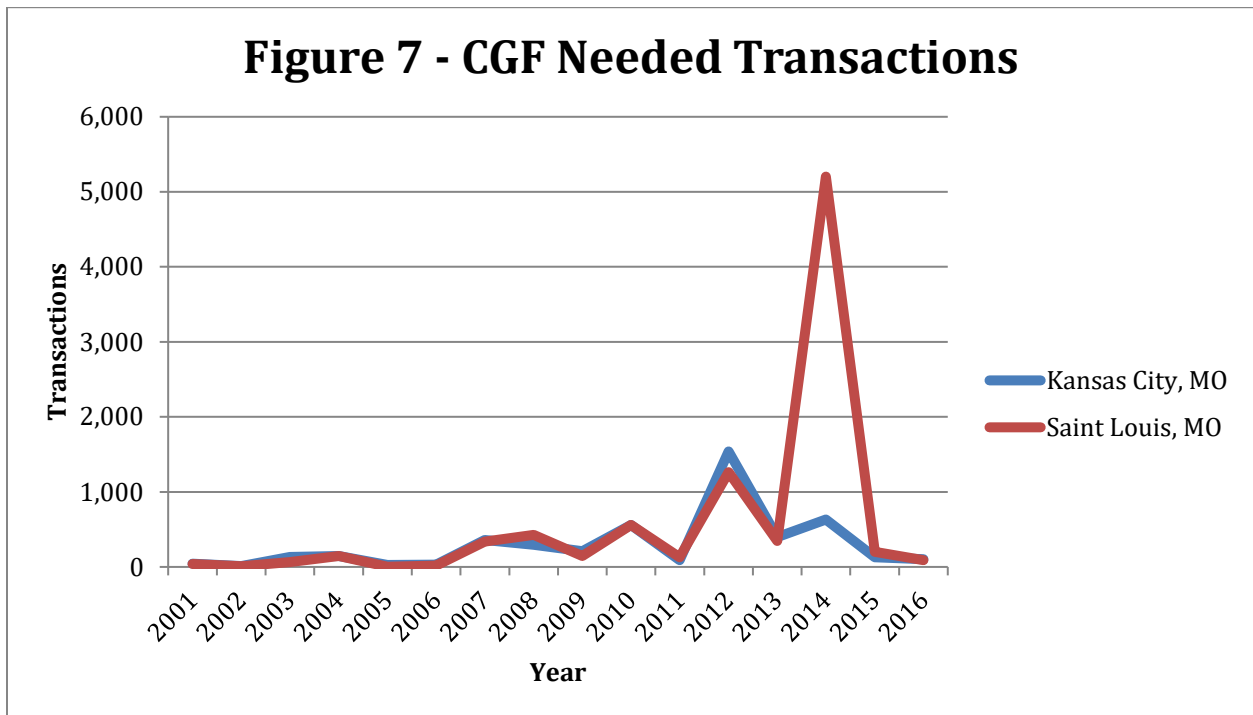
From the California DDGS market, it appears that volatility trends relatively resemble the much larger volume locations represented by the more dominant Midwest markets. Although the California market seems to have some greater levels of volatility that could reasonably stem from the fact that their individual market is much thinner compared to the Midwestern markets. Any effects from those states could also come from just having much larger numbers of ethanol plants, giving the markets a much thicker level of product supply and demand as a result, too.

The results of the Chebyshev's inequality DDGS n-values above indicate that despite some of the major market fluctuations differences, ultimately the timing and overall volatility between them still remain different. The size of the DDGS market changing over the 16-year span did not seem to directly affect the magnitude of the formula results to an extreme degree. Although the n-values are still assuredly higher than multiple and mainstream corn producing location price sets. The DDGS findings show that there are location-based varying volatility spikes across markets that face separate levels of impact. More specifically, there are unique market effects that can greatly affect each location at varying degrees. This is important to note, despite the common tie between the markets in terms of movement and feed usage, as these pricing relationships were established with the regression modeling work in the previous papers of Ferris (2006) and Hoffman and Baker (2011).

Corn Gluten Feed (CGF) Results from Chebyshev's Inequality Calculations

The corn gluten feed (CGF) results here stem from the Kansas City, Missouri market. To give a measure of national market size, the CGF market is roughly 22 percent the volume of the DDGS market, making it a great portion smaller and presumably thinner to that much of a degree (USDA NASS, 2017; AMRC 2016). When observing the n-values per year across years, the first observation is that even though the entirety of the price volatility is not substantially higher than DDGS, still higher overall at about 9 percent greater. These differences can be visually differentiated in Figure 7, and numerically in Appendix Table 7, by what magnitude volatility spikes occurred in specific years (both experiencing their greatest ones in 2012 and 2014, however). The main pattern difference is that the DDGS changes were fairly evenly spread

across initial years, and for CGF the very early years were very tame and consistent, and then both became much more highly variable in middle years of this 2001-2016 data set.



Data Source: USDA AMS

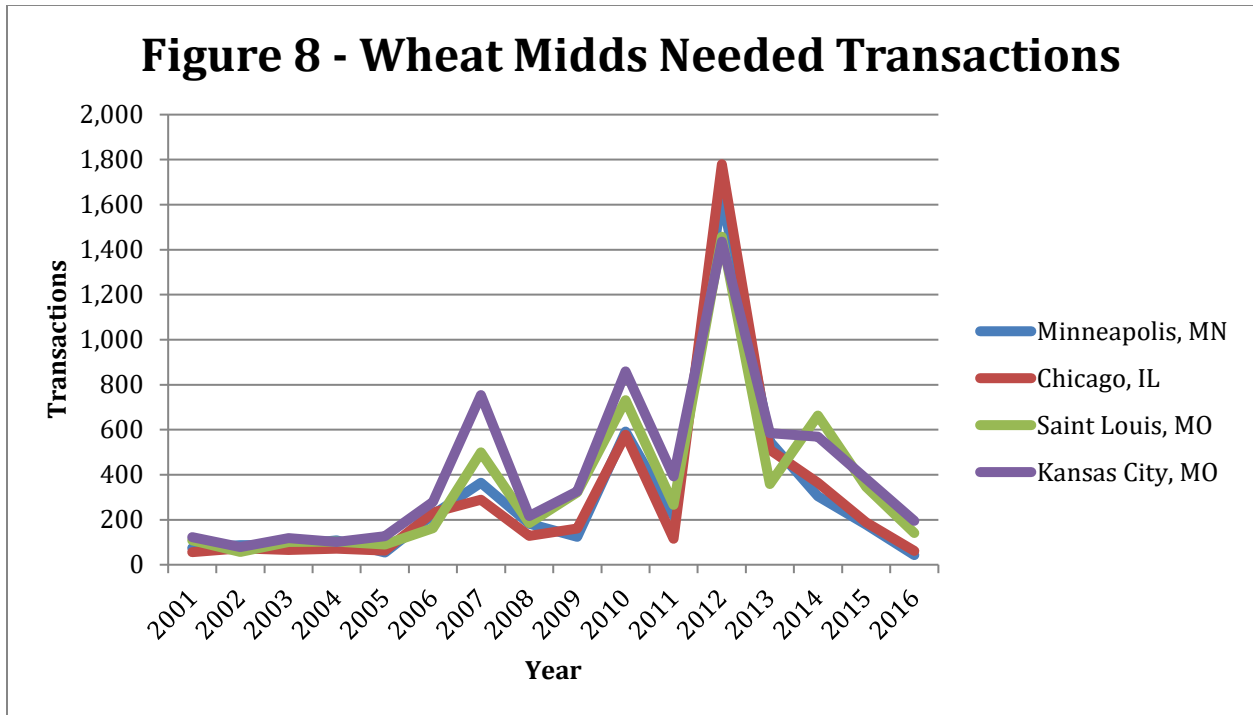
The CGF Saint Louis market is illustrated in Figure 7, too. Given the findings from the DDGS price volatility discussion, I initially expected the CGF market to act the same, especially when market location is within the same geographic region and state. While the size of both CGF markets for the two individual cities is unknown here, there are some notable differences that raise the question of why these two markets had such different volatility experiences. Though primarily caused by the much larger volatility spikes of the respective years, the overall Saint Louis CGF average volatility n-value measures at a 55 percent higher than DDGS. While both main spikes in the two markets occurred during 2012 and 2014, the Saint Louis market faced its second largest increase in 2012 (at 83 percent the value of Kansas City's during the same year). However, what was the largest impact was the fact that in 2014, Saint Louis had an extremely significant needed transaction value that exceeded Kansas City's by 241 percent, marking what

is a very tremendous period of instability at that time. Alternatively, these divergent volatility issues may have also arisen from the much smaller size of this byproduct industry compared to the prior ones that did not run into this immense variance to the same degree.

Wheat Middlings (Wheat Midds) Results from Chebyshev's Inequality Calculations

The wheat middlings (wheat midds) market is estimated to be about just 8 percent smaller than the corn gluten feed (CGF) market within the United States (Commodity Specialists Company, n.d.; USDA NASS, 2017). Despite any of these dissimilarities, the results from Chebyshev's inequality are similar and even more stable among each other compared to CGF, at around 11.5 percent lower n-values in comparison (which is just above 300 needed transactions).

In Figure 8, the overall shape of the data does not resemble anything too different compared to previous markets. None of the findings quite jump out in terms of any of the directions or sizes of the data. Displayed in Appendix Table 8 is that there is only a single large volatility spike, rather than the two seen in other ones. For this wheat midds market, the spike in 2012 was just like with all the other ones, and relatively to the same size as the other ones too. However, as some other markets experienced a second, additional spike in 2014, those were not as high as their respective 2012 ones (although still the second highest). With wheat midds, there was an n-value decline to around the average value of that same year, showing that prices remained relatively stable and consistent during 2014. And this stability was independent of what was happening in the corn byproduct markets (although not with corn or SBM however).



Data Source: USDA AMS

Looking at the following data chart from the Chicago, Illinois market, their graph in Figure 8 is very identical to the Minneapolis one in terms of the comprehensive timing, size, and shape. In fact, the average n-values of the two results sets are only three percent away from each other at around 300 needed transactions each. Simply put, these two markets are effectively identical in terms of their price volatility levels in their matching years of 2001 through 2016.

When comparing Minneapolis to the Saint Louis, Missouri market, some distinctions between the two begin to form though. In short, Saint Louis' three volatility spikes of 2007, 2010, and 2012 were a bit more pronounced in the Saint Louis area at the same time, as shown in Figure 8 once more. And in addition, while Minneapolis experienced a volatility decline in 2014 following one in 2013, Saint Louis saw a moderate-level spike during their 2014 year. Given that the average value in the Saint Louis location is about 15 percent higher in comparison, this reinforces that this market's variability in particular followed the Minneapolis one somewhat.

The Kansas City location reveals the same directional trends as Minneapolis (though it did not have the same sudden 2014 increase that Saint Louis had). The n-values in the Kansas City locations are much more pronounced especially during the large increases, as shown in Figure 8. In fact, these changes are significant enough that on average the Kansas City “needed transaction counts” are almost 35 percent higher. These distinctions support that the direction of prices across locations may follow that same basic patterns, though still maintain differences.

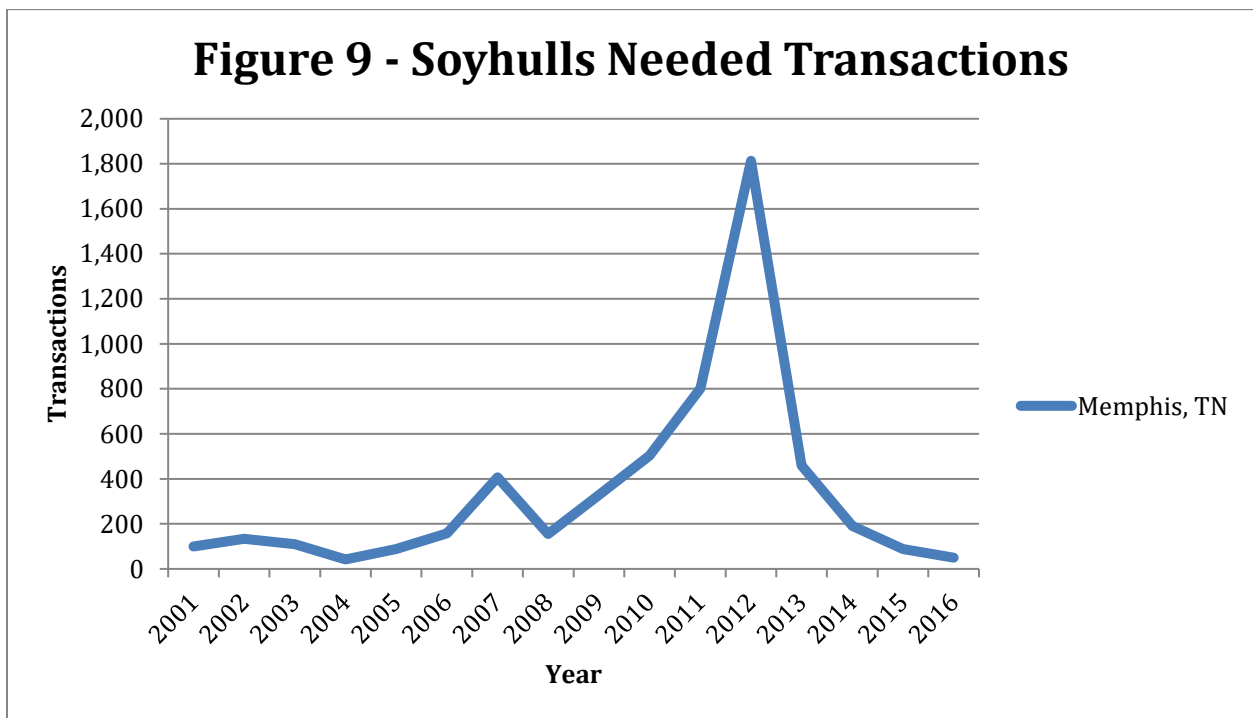
In total, the overall wheat midds market does not display any majorly unique trends compared to the other byproduct markets above. And in this case, despite the moderately smaller market size of this byproduct, it had little impact on the number of needed transactions for it to achieve reliable market pricing. The fact that this byproduct stems from wheat may be offset by the fact that it still ultimately used for the same animal feed purposes as the others.

Soyhulls Results from Chebyshev’s Inequality Calculations

The soyhulls (soybean hulls) market is much smaller in terms of production compared to each of the ration ingredients above, at an estimated 2.7 million tons (USDA ERS, 2017). In comparison, this places it at less than 40 percent the production size of wheat midds, and roughly just about 2 percent the size of the corn for feed market (Commodity Specialists Company, n.d.; O’Brien 2010). And so even on a national scale, this market is much smaller on a possible volume basis against most of these other byproducts (USDA ERS, 2017).

The Chebyshev’s inequality results from Memphis, Tennessee shows nothing that stands exceptionally. With the shape and direction of the data, this soyhulls one was a bit “smoother” compared to any of the other byproducts. As seen in Figure 9, the initial years were relatively stable with little variation in the n-values, but then had a couple of notable increases in 2006 and

2007, before dropping towards earlier levels in 2008. What makes this soyhulls market the most different is the fact that after 2008, the volatility steadily increased almost exponentially, culminating at the spike in 2012, and then heavily fell in the following years in a smooth and consistent line shape. This is different than the other byproducts, where multiple, large volatility spikes (generally two to three) occurred followed by immediate and noteworthy declines in the following year. In terms of the n-values, the average was around the usual 300 to 350 range of the other byproducts at 339 needed transactions, as seen numerically in Appendix Table 9.



Data Source: USDA AMS

There are unfortunately no other complete data sets locations to compare Memphis' soyhulls market with. It is as if the soyhull market's momentum would just continually shift in a given direction per year, which was much different than the other byproducts. It appears that the overall feed market affects the soyhulls market alongside the exclusive traits of the soyhull market, too. After all, the soybean meal markets above were much different where there were frequent increases and decreases, however to such short extents that they had a lower average.

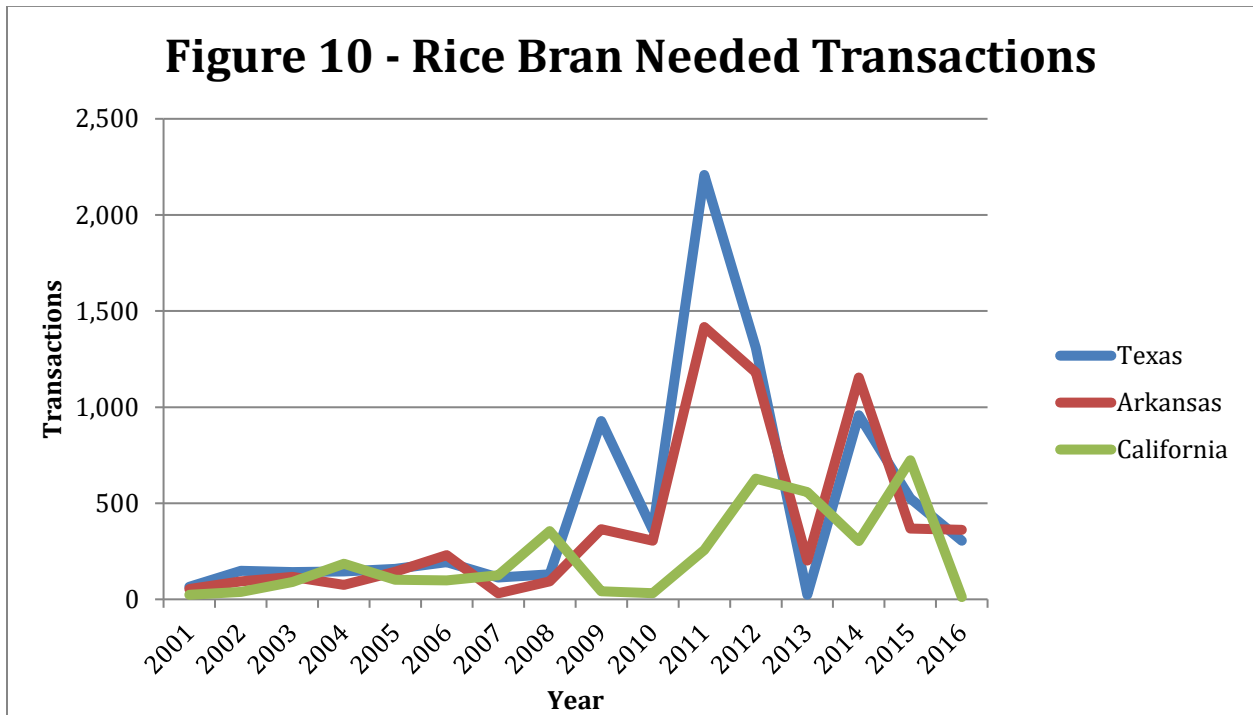
Along smaller impact variance spikes of SBM, this made the market much less volatile and more stable, despite the essentially back and forth shifts of earlier years. It is as if this soyhulls market has no type of immediate “recovery” or “stabilization” in terms of when the volatility started to increase in 2008 through 2012. This is despite the opposite happening in the SBM market during the same years. Whether this proves any effect on market size, and players not having sufficient information to price appropriately, is a question for the future. With soyhull price volatility beginning as stable and then rapidly shifting up and down over the span of a few years, it begs the question as to why this played out differently compared to the other byproduct markets.

With prices going from not moving much for a few years, to changing rapidly and increasingly over a number of years afterwards, this presents some contrast with some of the other byproduct markets. Given agriculture literature cites concerns that mainstream commodities are thinning over time, anything regarding byproduct markets especially thinning makes sense (e.g. Tomek 1980; Franken and Parcell 2012; Adjemian et al 2016).

Rice Bran Results from Chebyshev’s Inequality Calculations

At just around 1.1 million tons of annual U.S. production, rice bran is the definite smallest byproduct in terms of volume I focus on within this paper (Kahlon, n.d.). With such level of production, it is less than one percent the production volume of the national corn market. With rice as the smallest byproduct of this thesis, and since it is also sourced from rice (which is already a low volume agriculture product within its own right anyway), I expected it to see moderately different n-values (USDA NASS, 2017). With the state of Texas as the primary location, the initial numerical results revealed that it is a much more unstable market compared to the other byproduct markets before it.

When looking at the overall shape of the graph in rice bran’s Figure 10, the initial years (2001 through 2008) maintain a lower set of n-values usually between 100 and 200 transactions (except for 2001 where it was below 100 even). However in Appendix Table 10, the 2009 n-value greatly rose to over 900, fell back to less than 400 in 2010, spiked heavily to over 2,200 in the following year, and stayed above 1,300 during the next year. This alone was already a great deal of volatility that occurred in years differently from the other byproducts. In 2009, most of the other byproduct markets decreased needed transaction counts, while one maintained a moderate level during the same year, all while the Texas rice bran market acted much differently. Each of the other markets experienced their largest price spikes in 2012, while rice bran had its largest spike in 2011, while only decreasing (to what was still a large number) in 2012.



Data Source: USDA AMS

While most of the other byproduct markets essentially faced a lower measure of n-values during 2013, this downward spike for rice bran was so severe that it declined to a level that was only 24 necessary transactions. That deep of a trough was for the strictest confidence interval of

the Chebyshev's inequality formula. This measure is much less than any of the other markets, and considering the year before and after 2013 had an n-value of over 1,300 and over 950, respectively, this is a peculiarly momentous decline in volatility. Considering that decline was followed by an overly rebounded increase, the likes of which were only seen in the DDGS and CGF markets, this raises the question as to why the rice bran market reacted in the manner. After all this change was closer to those two byproduct markets, and not ones that were more in line with their nutrient profile, such as wheat midds or soyhulls (Beef Magazine 2017).

What happened in the overall rice bran market appears to be similar to what previously occurred in the soyhull market. Both of these smaller byproduct markets saw a very stable and consistent price volatility in the early and mid 2000s, and then proceeded to severely ramp up in terms of needed transactions after 2008. The soyhulls market the change is a very narrow eight-year bell curve, one that rises sharply for the first four years, and then suddenly drops for the last four, distinguishing it from the others. During this same time frame for rice bran, the n-value changes are large and almost always move in the opposite direction with each consecutive year. In summary, the rice bran market is much more volatile than any of the other byproduct markets before it, and exhibits unique variability patterns that are much more wild in size and direction.

I observe two additional locations from the previous data source. The n-values were so extreme in the second half of the data set, the average needed transaction number for the Texas market was at 482, which exceeds the typical 300 to 350 value of the other byproducts by a sizable margin. As shown in the Figure 10, the Arkansas location is fairly similar to the Texas one. However, the Arkansas market faces differences in terms of having one less volatility spike (absent in 2009), a lower-level highest spike for 2011, and an additional amount of movement during the initial 2001 to 2008 period. The average n-value is considerably lower than the Texas

location at 369 needed transactions for reliable price discovery, however still placing it a bit higher than some of the other byproducts. While the 2009 volatility spike is absent in the Arkansas location, the 2011 and 2014 ones occur at slightly lower and higher levels, respectively. Thus, Arkansas represents a bit more of a tame market in comparison to Texas, and is still one that encountered unique volatility patterns in unison, apart from the other byproducts.

The state of California's trade experiences reveal something actually far different compared to both the Texas and the Arkansas markets. The average volatility of the 2001 to 2016 data set was the second lowest (only behind SBM) at 223 necessary trades, a good portion below the 300 and above values originating from the other byproducts, shown in full with Figure 10. This lower level of variance stems from that spikes during the relevant years are simply lower than ones in the other rice bran markets especially. The California market did have stable levels of n-values in the early and mid-2000s, which helped keep the average value low.

The lower-level spikes of California still occurred in separate years compared to the other two locations. For California, the primary price increases happened in 2008, 2012, and 2015, whereas it was 2009, 2011, and 2014 in Texas (and as well as Arkansas, except not with 2009). Adding that there was a notable increase in the California market in 2008, altogether this raises the question as to why this market is so different from the other ones. Also, no such difference in patterns emerged when comparing locations across any of the other byproducts.

The rice bran market in California shows that perhaps across locations for really thin markets, there are indeed some larger differences that cannot simply be overcome by comparing it to a "larger, representative" market that effectively does not exist. This is based off of the fact again that no other byproduct had such differentiated Chebyshev's inequality results across locations. These locational differences make sense, if assuming the volatility of the price would

increase dramatically for such a thin byproduct, since rice bran is produced from a low-volume commodity crop within the U.S. in the first place already (USDA NASS, 2017).

However, the data from the California market shows that it may be a central market for rice bran, given its combination of significantly lower volatility spikes and the timing of the variability shifts being almost entirely unique. However, out of the six states that actually produce commercial rice within the country, California accounts for nearly 21 percent of that, while Texas is at almost 6 percent, and Arkansas produces the most at roughly 47 percent of national rice, according to the USDA ERS (USDA ERS, 2017). California's middle-ground production level supports the idea that volatility differences may have stemmed from geographic traits, more than on location volume alone. In addition, one note from Figure 1 earlier is that the state has a much larger milk cow inventory compared the others in this chapter, and Texas was less than a third in size in comparison, and Arkansas was only a small fraction of Texas inventory. This may be a significant hint that rice bran is highly utilized among milk cows, and California's high inventory count may be a critical demand impact on rice bran price and consumption.

Each of the geographic state locations shows the larger instability of the rice bran market in comparison to other byproducts. However, the lone California market actually had very low volatility measures compared to most other byproducts. And so not only is volatility high for many individual years, but quite erratic and unstable compared to most of the neighboring years, too. Perhaps rice bran is indeed a thin market based on the high number of transactions needed to maintain a thick market status. Since rice bran markets appear to be small enough in reality, I express doubt that there are sufficient players to achieve the target transaction volumes (Kahlon,

n.d.). Without the complete concrete data behind this though, such an assertion remains unsupported for now.

Overall Results and Conclusions from Chebyshev's Inequality Calculations

After applying the modified Chebyshev's inequality formula to several byproducts, I have displayed the resulting n-values for market sizes ranging from the largest in the feed industry, to one of the smallest. These n-values have defined what are the necessary transactions needed for a market to stay thick, and therefore provided insight into how volatile a market is on average during a given year. This information however, lacks the important piece of how many trades actually occurred within those areas during those times, in order to show if such measures were attained or not. As an example, no matter the size of the output or change in it, any of the markets here cannot be deemed thin or thick based on their results alone. However, trade volumes fluctuations still provide insight as to the occurrence of major market events.

To some extent, the price volatility tends to increase as the size of a market decreases. However, this trend is not always the case, and even when the magnitude of the effects tends to be on the lesser side, if not already a completely negligible level. To the most extreme comparisons, corn, soybean meal (SBM), and DDGS have some of the least volatile markets for their specific, weekly locations, sitting at the largest volume feed ingredients in the U.S. feed industry (O'Brien 2010; Soybean Meal INFO center; AMRC 2016). And in comparison, the white corn, soyhulls, and rice bran markets in their substantially lower production volumes face anywhere from minor to significant volatility increases compared to the others on average, respectively. Every byproduct in between those listed above (in terms of volume) sat at overall similar needed transaction volumes, at around 300 each. Still, locational differences here play

anywhere from a large to an insignificant effect, across all sorts of byproducts, calling for more location observations in future research.

This analysis still lacks a crucial component in the form of actual transaction volumes. There is additional insight that could have been sourced from more defined locations that are uniform across relevant cities, states, and regions as viable with available data. Again, the n -values only unremarkably increased (along with variance) across shrinking market sizes over time. Higher volume byproducts are at least more likely to be thick enough to attain price confidence, or at least thicker, where thinner ones probably struggle more to some degree. And any thin byproduct markets have to deal with poor price discovery that will drive away prospective and current market players alike (e.g. Easwaran and Ramasundaran 2008; Hoffman and Baker 2011). And the issue of having low transaction volumes and resulting poor price discovery was again an issue highlighted in Anderson et al (2007) and Rostek and Wernetka (2008).

Ultimately, the Chebyshev's inequality calculations in this chapter somewhat confirm my earlier hypothesis that smaller markets have greater volatility and poor price discovery as a consequence. This conclusion still comes with the caveat that the support for such a statement is still relatively weak based on the only the n -value (needed transactions) results alone.

Regarding observation frequency and count, the price volatility changes within a single month are generally unimportant to distinguish against the week-by-week movements of the same monthly time frame. The seasonal changes comparing monthly movements across an individual year are highly impactful in establishing substantial patterns. With data reporting frequency, the ensuing ultimate presumption is that seasonal effects in the crop byproduct markets are a strong force that maintains itself throughout individual markets. In addition, these

types of seasonal and other patterns relate across different locations and individual byproducts, even as those unique byproducts still face exclusive market traits and resulting effects.

In the end, every market faced some volatility and variance spikes to a degree. And usually that degree was a high level one, occurring anywhere from one to three years out of the 16 years on average. Coincidentally, even as nearly all of these markets spiked into the 1,000 or 2,000 range of needed transactions from formula outputs (the lowest maximum was SBM at a little over 700), each of these markets still experienced regular n-value measures in the hundreds, and at times in the double digit ranges, too.

The main point from these observations altogether is that each byproduct is subject to the realities of agricultural markets overall. Each market experienced at least some relative periods of relative price stability or consistency. However, in the end every market was affected by at least a couple years of tremendous price volatility, where the number of necessary transactions increased at such an instant, to a level many times higher than their average one. This pattern shows that a jump of price instability (such as poor weather, regulation, or other shocks) can have devastating effects on what the price of these feed ingredients. If a market was not already facing poor price discovery due to thin market sizes and trade volumes, this presumably further deters future trade for both current and future players.

Applying Chebyshev's inequality to find out variance and transaction values showed that volatility increased as market volume decreased (although not to the extent I previously predicted and envisioned). The resulting n-values exhibited seasonality trends that remained strong in each market across the years, regardless of which specific one. And finally, it revealed that that volatility occurs in each market to even commonly-shared extreme degrees, however the larger markets were assumed better equipped to deal with such changes on a surmised greater

volume and information basis. While these findings are indeed helpful in uncovering the question behind price discovery and thin markets for crop byproducts, alone they are still in need of outside context and support. In terms of the research question and related objective questions, it appears there is initial evidence that spot pricing has declined in crop byproduct markets and have led to more price variance, reinforcing the reason why interviewees would switch to contracting for byproduct transactions in response. And the calculation outputs also seem to reinforce there is merit to studying regional location livestock populations, and market volume differences in the future, to ultimately answer how firms deal with transaction costs.

However in the future, this type of research (specifically utilizing Chebyshev's inequality) would greatly benefit from the inclusion of what the volumes of byproduct transactions were, for measurement purposes. Also, the researchers could improve the results through including more uniform locations across markets for enhanced consistency across comparisons, as well as a greater variety of byproducts and geographic locations to solidify any possible data patterns. With even one of these improvements, that alone would lead towards much more robust and reliable results about this concept of thin agricultural market volume trends, the price confidence levels different ones face as a consequence, and how their markets react to such varying outcomes.

Chapter Five – Regression Models of Crop Byproduct Prices

Closer Review of Directly Relevant Literature

My thesis research question is “how do firms deal with transaction costs in crop byproduct markets?” The interviewees best answered that question in mentioning contracting and switching to substitutes, even more so during times of volatile prices. And the Chebyshev’s inequality confirmed implied volatility trends and increases, especially in smaller (Soyhulls and Rice Bran) byproduct markets over time, showing that for all markets there was a changing level of variance across years. The regression models in this chapter serve to deeper reveal the correlations in pricing movements, and to answer the underlying question of what influences byproduct prices and how those compare to each other. To add greater context to the main research question, the regression models best approach the research objective of finding out what influences byproduct market prices, and how those markets compare to one another. After all, it was both previous literature (Bista et al 2008; Neil and Williams 2010; Weber 2012), and Participants A, B, E, and F that pointed to corn and soybean meal as the largest price influences of a typical byproduct, in addition to nutrient content.

Much of the previous literature did not cover byproduct pricing beyond stating them as a source of cost savings. However, a few papers did address the pricing of these byproducts in one way or another through regression modeling, in terms of rice byproducts (Brorsen, Grant, & Chavas 1985), ethanol byproducts of DDGS, corn gluten feed, and corn gluten meal (Ferris 2006), and more on DDGS (Hoffman and Baker 2011). These papers are a bit spread out of publishing year, and variety of different byproducts. However, they each take some different approaches in estimating the price impacts behind these few crop byproducts, and thus arrive at distinct conclusions.

Brorsen et al (1985) regressed the prices of four rice byproducts (rice bran included), commodity rice prices, and corn prices. When using time series modeling to account for trends and seasonality, they concluded that each of the prices were weakly related to one another. In the end, they believed the products did not compete with each other, and that future research needs to look at other demand determinants of rice byproducts (Brorsen et al 1985).

Ferris (2006) focused on how the growing U.S. ethanol industry was going to affect the feed market. In his price-modeling portion, he took the prices of soybean meal, corn, and feed coarse grains to create “artificial values” of protein and energy, and then stacked those against the expected value of ethanol byproducts (corn gluten and DDGS) to their actual market costs. He finds that both the overall nutritional value of the byproducts of DDGS, soybean meal, corn gluten feed, and corn gluten meal have fluctuated in a pattern similar to their respective prices. However, the important piece of information he identifies, is that the gap between value and price has overall increased between 1995 and 2005, with general nutritional levels of these byproducts staying relatively steady, while the market price for them still going down. While noting flaws in his “value” calculations (location differences and inconsistent pricing methods for starters), the author’s pricing models had R-squared values between .96 and .98, showing the importance of the goods to each other, as well as nutrient levels (Ferris 2006).

In Hoffman and Baker (2011), their price forecasting section of their paper was only a small part of their overall article on the feed market changes from DDGS growth, and the model was very simple and straightforward, too. The authors simply used corn and soybean meal prices as the two coefficients in their regression model for DDGS prices. Through these models, they found out that those price variables account for much of the price variation at an R-squared value of .98, for both the periods of 1995-2006, and 2006-2010. They identify DDGS as both a protein

and energy product, but ultimately an energy byproduct primarily. The authors note that issues regarding consistent quality and handling affect heavy regional pricing, but note that corn, soybean meal, and other byproducts will remain important factors in determining DDGS prices (Hoffman and Baker 2011).

Design of New Regression Models with USDA AMS Data

I used publically available data from the United States Division of Agriculture's Agricultural Marketing Service (USDA AMS) as the data set for this analysis on byproduct pricing. It included weekly pricing data (in the form of high and low bid values) for the five byproducts of dried distillers grains (DDGS), corn gluten feed (CGF), wheat middlings (wheat midds), soyhulls, and rice bran. Weekly pricing data was also available for corn and soybean meal (SBM) (and technically a byproduct). However, the corn data was very limited. And so to keep the data consistent for each of the byproducts, I instead used monthly values from USDA National Agricultural Statistics Service (NASS) for the corn prices.

For the USDA AMS byproduct data sets though, these weekly price entries spanned anywhere from 5 to 19 locations across the United States. In addition, those price entries contain other data points such as transportation (e.g. truck, rail), pricing point (e.g. FOB, mills and processors), and delivery period (e.g. cash, 30 day delivery). I converted these weekly values into monthly ones to address the few gaps that existed across data sets (sometimes there was a week or two missing of missing data on occasion for either a year or a specific month). I covered data points between 2001 and 2016 so the set is complete and even across each price series.

With the difference in available years of data between the many locations, and to keep the model simple, I chose a single location for each of the byproduct pricing series in the USDA AMS data set. Each of these locations is unique from one another, with:

- Corn as national prices from NASS
- SBM from Saint Louis, Missouri
- DDGS from Central Illinois
- CGF from Kansas City, Missouri
- Wheat midds from Minneapolis, Minnesota
- Soyhulls from Memphis, Tennessee
- Rice bran from Texas

By using the monthly prices though taking the averages of a month's provided weeks (as well as taking the average of the high and low bid values for each price, this results in a single, consistent set of data. Averaged out this way, there were no missing observations for any coefficient between 2001 and 2016, for a total of 192 observations in total for each variable.

Using different feed prices is in line with how Hoffman and Baker (2011) simply ran a regression of DDGS price on corn and SBM price, though noted in their conclusion that future research should involve looking at other byproduct prices, too. Interviewees also mentioned the whole "pricing based on corn and soybean meal" as a strategy they utilize, as well (Participants A, B, E, and F). By including the other byproducts as well, this allows for a more complete look at the byproduct market beyond just DDGS. In addition, a corn and soybean meal basis also readdresses some of the findings in Brorsen et al (1985), since rice bran was one of the byproducts in that. Corn and SBM pricing ties back into Ferris (2006) too, because the model for

this paper multiplies the protein and energy percentage values to create prices that are on a protein or energy-equivalent basis, too.

In addition, I also multiplied the prices by protein and energy percentage and ran separate models, as a different way of interpreting the results. While I could also divide by percentages, the ultimate differences were minimal during initial regression test runs. In running each set of regressions, I initially placed the price of one of the five byproducts as the left-hand dependent variable, and all remaining price series on the right-hand side as the independent variables.

The information from the USDA AMS dataset consisted of a location (either a city or a state), and within that location were data entry categories on transportation method, pricing point, and delivery period. However, this leaves out specific locations of the buyer and seller, the transaction amount, the actual number of transactions, and other critical details. Without transaction-level data (and the comprehensive components that accompany that), it is much more of a stretch to make commentary and statements about transaction-level circumstances. That being said, I did run a series of simple regressions for the effects of the available variables on the price level. However, those coefficients proved to be statistically insignificant during several trial regression calculations, and thus were not included in subsequent regression model estimations.

Additional Modifications to the Model's Design

However, I will make one broad assumption, which are the nutrient levels of these byproduct feed ingredients. One crucial note about the protein-level price transformation (or energy-level depending on the byproduct, as shown later) is that I assigned a single percentage level of protein for each independent byproduct. And that protein percentage remained the same throughout each of the years, for a specific byproduct. And so while the interviewees may have

spoken about the changing fat and other nutritional content for DDGS for instance (Participants A, B, C, D, E, and F), I kept the percentage the same throughout all of the years. Beef Magazine's annual feed composition tables that covered crude protein levels for each year from 2009 to 2017, which was as much as I could find, and so I used that.

For protein values, I chose DDGS as containing 30 percent, CGF with 23 percent, wheat midds as 17 percent, soyhulls at 12 percent, corn with 9 percent, and soybean meal containing 49 percent. In an effort to keep the data consistent, I assign these as the protein levels for the byproducts across all years (2001 through 2016) of data (Beef Magazine 2017).

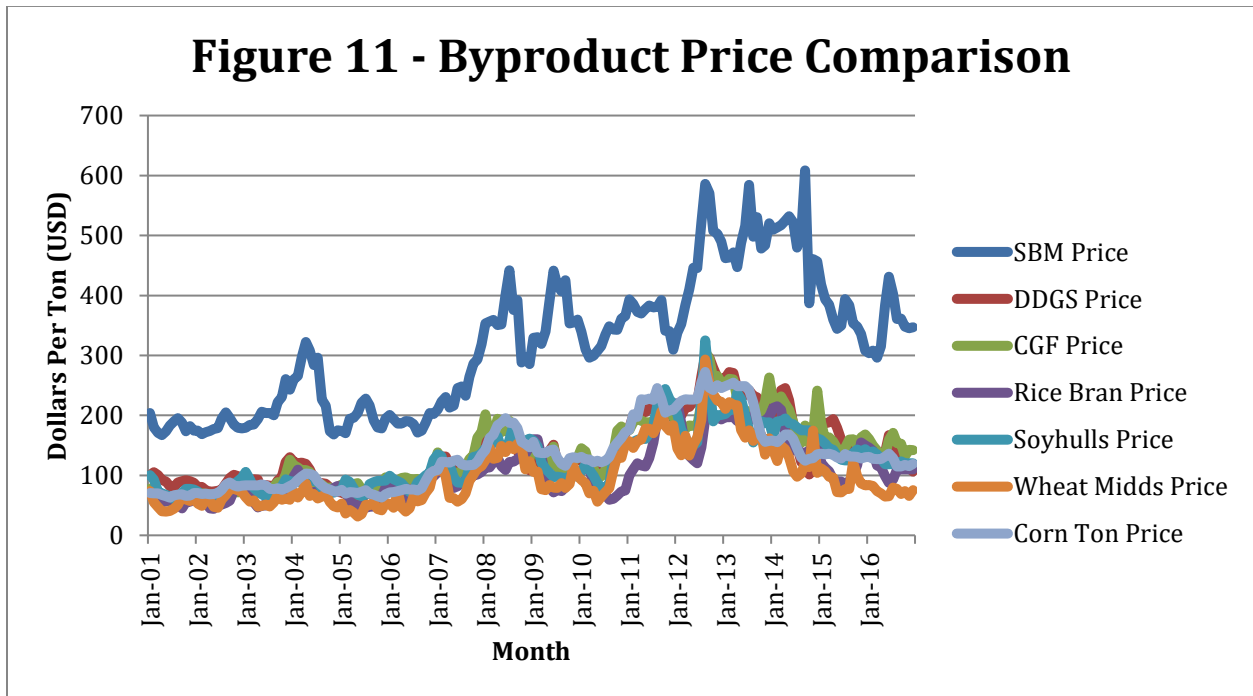
Again, I separate multiplied each feed ingredient price by their energy content, too. Authors in the literature mentioned that energy content can be important just like protein (e.g. Chenost and Sansoucy 1989; Stock et al 2000, Bista et al 2008; Patience 2013). Thus, in the like with the protein values, I used Beef Magazine's same annual data set to pull energy values (total digestible nutrients – "TDN"), matching their definition of "energy" in feed (Beef Magazine). I used energy values from the 2017 Beef Magazine nutrient composition tables, which had not changed compared to other years of data. The assigned TDN energy values are as follows: DDGS at 96 percent, CGF at 80 percent, wheat midds at 80 percent, soyhulls at 74 percent, rice bran at 71 percent, corn at 88 percent, and soybean meal at 87 percent, each set at that same level for all years of data (Beef Magazine 2017).

Further Modifications Based on Preliminary Results

One other approach in further shaping this model was the decision to either include or not include an intercept in the model, since each side of the variable was based on price. However, it had little effect when removed, and so I kept it.

I also combined multiple variables, with corn and SBM added together, and the remainder of the byproducts added together, too. Fundamentally, this helped isolate which variables had larger individual impacts, and attempted to address some of the multicollinearity or autocorrelation issues stemming from six related variables on the right-hand side of the equation. In addition, combining variables allowed me to see how individual byproducts interacted in price against the staple “corn and soybean meal,” too.

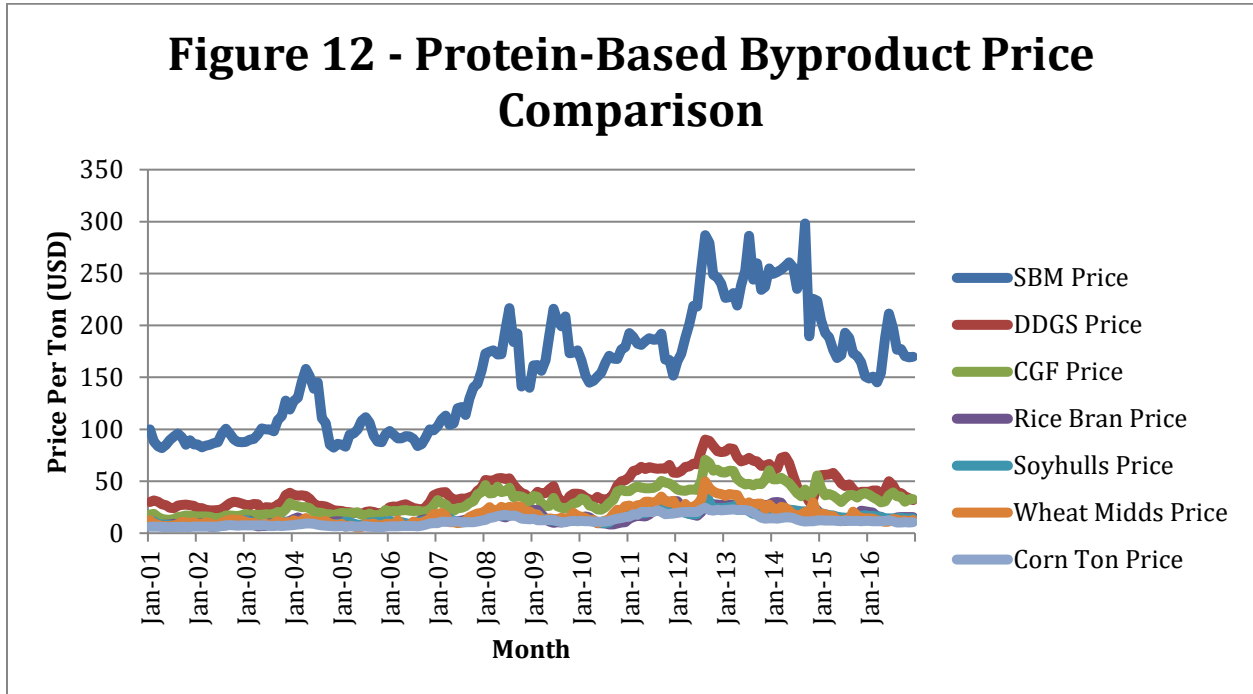
In order to better view the comparisons of the byproduct prices with one another, Figure 11 shows the change in the byproduct prices over time, with no nutrient basis, revealing that on a per-ton price a majority of these feed ingredients follow a similar range and general trend with one another. It shows that SBM costs a good portion more than another of the others.



Source: USDA AMS and USDA NASS

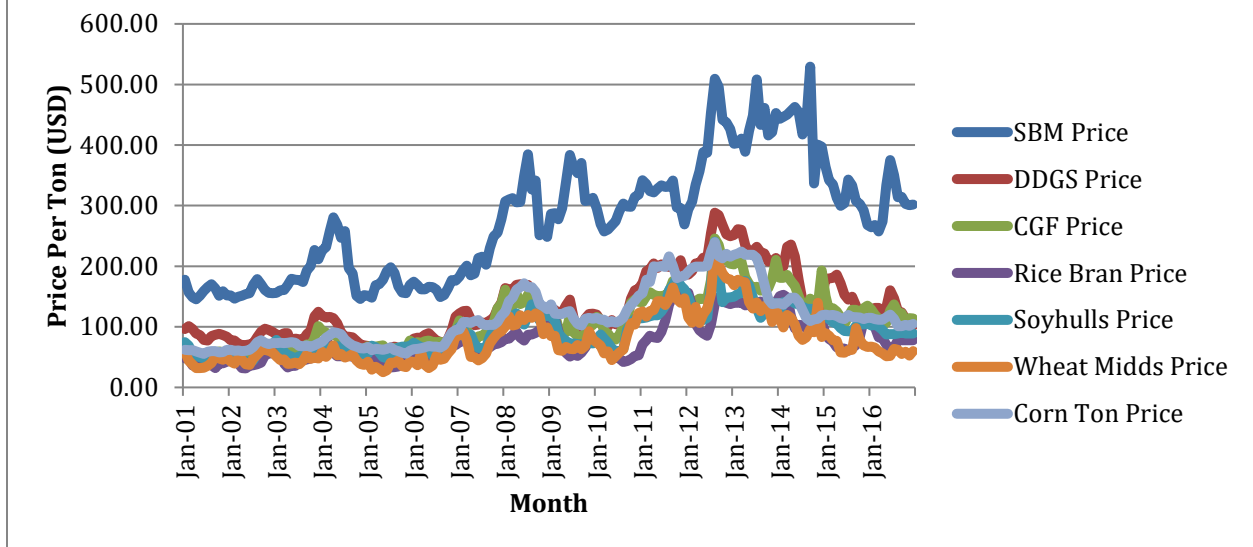
When observing these same prices on a Protein-Basis in Figure 12, and an Energy-Basis in Figure 13, they show the price of these byproducts when exclusively accounting for respective

protein and energy contents. These patterns reveals that basic trends maintain, there is less overlap in terms of protein prices, energy content is more closely aligned with one another, and that SBM's high cost is justified by the amounts of protein and energy that it uniquely provides.



Source: USDA AMS and USDA NASS

Figure 13 - Energy-Based Byproduct Price Comparison



Source: USDA AMS and USDA NASS

Another strategy and alteration that I performed at an earlier stage was the addition of a single-period lag independent variable of the dependent variable. However, this did not produce any level of significant improvement or noticeable changes to the coefficients themselves, and so I did not apply this change alone in the final results.

One more step I took in an effort to improve the model was including a trend variable within the model in order to address the effects of autocorrelation, multicollinearity, or both. Specifically, this trend variable is a time variable, simply a linear trend increasing by one for each month that passes. However, this is also combined with the “corn and soybean meal” combined variable, where the two values are multiplied by each other for each singular time period. Thus, this new variable overall covers both the influence of time and an increased impact of the primary feedstocks of corn and soybean meal, and I kept it within my final models.

One attempted addition to the model was my inclusion of seasonal variables, in order to help isolate and address the effects of autocorrelation. Crop production prices are shaped by the annual patterns of planting and harvesting practices, as identified by multiple interviewees (Participants A, B, E, and F). Thus, in order to directly address seasonality (which is what Brorsen et al (1985) attempted to confront), I included a series of dummy variables that spanned the relevant seasonal planting and harvesting patterns of corn and soybeans. I created four “season” dummy variables of planting, summer, harvest, and post-harvest. The seasonality dummy variables produced inconsequential changes to regression results on other coefficients, as well as their own parameter estimates, and I therefore removed them in the end, too.

Regression Results

Ordinary Least Squares (OLS) Models

“One Byproduct Price = Corn-SBM Price + Other Byproducts Combined Price
+ Corn-SBM Price Trend”

The initial models that incorporate the above modifications (absent seasonal dummies) are seen in Figure 14 for the five byproducts. Each model displayed relatively strong r-squared values between .793 and .941. One pattern from the data is that all main parameters of the different price series remain statistically significant. In terms of the parameter estimate values though, the trend with the Corn-SBM Price coefficient is that it was largest at .373 for DDGS (Energy), followed by .120 for CGF (Protein), and then .114 for Wheat Midds (Protein). Those estimates highlight that there is a relatively small, but positive correlation for when corn and SBM prices increase, the byproduct prices increase, too. The Soyhulls and Rice Bran models

were different though, in that they were negative at -.041 and -.183, respectively, showing through both magnitude and direction a disconnect with mainstream feed prices.

Figure 14 - OLS Regression Price Output						
Dependent Variable	Coefficient Parameter Estimates					
	Byproduct Price	Corn-SBM	Byproducts	Other Byproduct	D-W	R-Sq
DDGS (Energy)		0.373**	0.875**	-	0.395	0.892
CGF (Protein)		0.120**	0.865**	0.210** (DDGS)	0.764	0.941
Rice Bran (Energy)		-0.183**	0.771**	-	0.337	0.793
Soyhulls (Protein)		-0.408**	0.517**	-	0.677	0.892
Wheat Midds (Protein)		0.114**	0.661**	0.661** (Soyhulls)	1.120	0.912

Data Source: USDA AMS, USDA NASS **=Significant at 1 percent level, *=5 percent level

The combined “Byproducts” price coefficient was positive and statistically significant for all of the byproducts, with DDGS and CGF having the largest values of .875 and .865, respectively. However, the other three were still notable at values of .771, .517, and .452 for Rice Bran, Soyhulls, and Wheat Midds, respectively. In order to maximize the levels of significance though, I separated out the byproduct with the highest level of significance for specifically the CGF and Wheat Midds models, those being DDGS (.210) and Soyhulls (.661) for the two, respectively. Overall, each of these combined byproduct values show a moderately strong relationships between these byproducts at a level that consistently exceeded the Corn-SBM Price combination, especially in comparison to the thinner byproducts of Rice Bran and Soyhulls.

Autoregressive Conditionally Heteroskedastic (ARCH) Models

To address autocorrelation, I switched to an autoregressive conditionally heteroskedastic (ARCH) model in place of OLS. The Yule-Walker estimate results incorporate 13 lag periods, as recommended for monthly data observations in two instructional papers (McAllester 2002; SAS Institute 2014). After running an ARCHTEST to run the Q-stat and Lagrange Multiplier (LM)

test through lags 1 through 12, the p-values of every single byproduct data set was <.0001 for both tests and all lags. According to the SAS User’s Guide, this indicates the presence of heteroskedasticity, and justifies the use of ARCH models for these regressions. Also, the Durbin-Watson statistic increased for every model to ranges between .337 and 1.116 in OLS, to 1.747 to 1.983 in ARCH, placing it near the goal value of 2.000, which indicates a model free of autocorrelation (“Durbin Watson Statistic,” n.d.).

The first observation from the ARCH models, shown in Figure 15 for the five byproducts is that in comparison to OLS, the r-squared values consistently improved. All r-squared values increased anywhere from roughly three to 16 percent, making the ultimate results range between 94.0 to 97.3 percent with ARCH, from 79.0 to 94.0 percent originally with OLS.

Figure 15 - ARCH Regression Price Output					
Dependent Variable Byproduct Price	Coefficient Parameter Estimates				
	Corn-SBM	Byproducts	Other Byproduct	D-W	R-Sq
DDGS (Energy)	0.257**	0.711**	-	1.747	0.973
CGF (Protein)	0.098**	0.665**	0.340** (DDGS)	1.922	0.968
Rice Bran (Energy)	-0.128*	0.538**	-	1.800	0.953
Soyhulls (Protein)	-0.045*	0.510**	-	1.983	0.950
Wheat Midds (Protein)	0.120**	0.447**	0.524** (Soyhulls)	1.973	0.940

Data Source: USDA AMS, USDA NASS **=Significant at 1 percent level, *=5 percent level

In terms of the primary coefficients of Corn-SBM Price and Condensed Byproduct Prices, each one stayed significant for each model. However, the absolute values of these parameter estimates almost always decreased compared to OLS, presumably showing the weight of the seasonal patterns separate from the other feed ingredient coefficients. As seen in the Figure 15 for the ARCH models, and Figure 14 for the initial OLS models, the Corn-SBM price variable dropped when utilizing the ARCH model in absolute value for DDGS, CGF, and Rice Bran to varying degrees, but still remained similar. For Soyhulls and Wheat Midds, there were

very small changes. These prices all show that an increase in this primary feed ingredient of Corn and SBM will have lesser, positive increase in DDGS, CGF, and Wheat Midds by about 36 cents, 10 cents, and 12 cents per dollar of Corn-SBM, respectively. And with Rice-Bran and Soyhulls, these changes were that with a dollar increase of Corn-SBM Price, Rice Bran would fall by nearly 13 cents, and Soyhulls would go down by about 5 cents. Overall, these price impacts are a fraction of a uniform change, which is a bit counterintuitive to the expected larger price swings in the byproducts markets. Each of these prices are indeed on a nutrient per ton basis, which makes more sense when realizing that soyhulls and rice bran have less protein and energy compared to other ones (Beef Magazine 2017). After all, these smaller nutrient measures would mean that these ultimate nutrient shifts are indeed a large impact.

For Condensed Byproducts coefficients, each were a larger and consistently positive compared to the Corn-SBM price parameter estimates. Within the ARCH results seen again in Figure 15, the Condensed Byproducts coefficient was larger than the Corn-SBM by 2.77 times, 6.79 times, 4.20 times, 11.33 times, and 3.73 times for DDGS, CGF, Rice Bran, Soyhulls, and Wheat Midds, respectively. With this size difference, it makes sense to assume that the byproduct prices are more related to one another compared to corn and soybean meal. This relationship would be based on closer nutrient bases, as well as the feed ration mixture where some byproducts can fill different roles in the mixture. Again the CGF and Wheat Midds models, I separated highly significant byproducts out of the condensed parameter to account for its individual effect. With CGF it was DDGS, which had a higher value and impact over Corn-SBM. With Wheat Midds this was Soyhulls Price, which was actually larger than both Corn-SBM and even the remainder Condensed Byproducts. Again, this type of pattern shows that certain byproducts that may be closer in form and function than the overarching Corn-SBM price

combination, as shown by pricing behavior. In the end, Corn-SBM had the largest impact on DDGS, then Wheat Midds, followed by CGF, then Soyhulls, and the finally Rice Bran, which in total this makes sense in terms of looking at shrinking market sizes and the nutrient profiles of byproducts compared to each other and the mainstream Corn and SBM feeds.

As for the significant lags in each of the models, I applied 13 lags to the model. For shared patterns, each byproduct's first lag period was statistically significant. In addition, the second period lag as statistically significant between DDGS, Rice Bran, and Soyhulls. There were scattered statistically significant lags for only single models, which were lags on periods 3, 8, 10, and 12, at wheat midds, soyhulls, wheat midds, and CGF, respectively. These patterns show that present lags indeed have a strong seasonal impact and influence on the overall byproduct pricing patterns.

The Corn-SBM Trend variable, the last component of the model, was only present and statistically significant in the Rice Bran, Soyhulls, and Wheat Midds models. Overall it was a very small value, leaving the overall impact on the trend output as negligible.

In summary, the general byproduct price ARCH models showed a variety of patterns. Most importantly, these models pointed to that other byproduct prices consistently had the highest impact on the prices of the byproduct in question, anywhere from about two to twelve times the magnitude of the Corn-SBM price coefficients. Despite the differentiation of some models being based on energy, and others on a protein nutrient basis, these two categories appeared to have little effect. Still though, the Corn-SBM prices still have a notable, statistically significant impact on the larger, more closely related byproduct prices of DDGS, CGF, and Wheat Midds. The Soyhulls and Rice Bran results are more related to byproduct prices than the

others. After all, no interviewees mentioned rice bran previously, and they did not mention soyhulls beyond name, either. I assumed that this absence is because of a smaller market size.

Compared to the previously reviewed literature, Ferris (2006) approaches his model in a different way and displays his results in an unclear manner, and so there is little basis for comparison on that model. With Hoffman and Baker (2011) however, the findings in their DDGS model compared to the DDGS models here show that the impacts of corn and SBM are lesser when factoring in the other byproducts. After all, their corn and SBM estimates combined are .82 and .91 for their two models, while here they range from .257 in ARCH and .373 in OLS. Overall, this provides some early notions that despite the trends and connections with DDGS and corn and SBM, DDGS may be more closely priced with other byproducts when factoring in autocorrelation fixes and accounting for nutrient-based differences, which warrants further study.

Using Log-Log Models to Observe Elasticities

Specifically, these secondary regression sets are “log-log” copies of the previous calculations in question, following the exact same steps, except that the price values for every variable were converted to a natural logarithm basis on both sides of the model. This log-log distinction means they represent the price elasticities between the dependent variable and the independent variables. The interpretation is that a coefficient changes by one percent, then the dependent variable of that equation changes its price level by the estimated value in percentage terms, and in regard to a positive or negative direction. The coefficients of note and the dependent variable are in terms of price, converted by its listed nutrient values. Therefore, these price elasticities reveal two meaningful elements of information about the byproduct market

interactions on a pricing level. The fact that there is no quantity data in these models is a main reason why any actual cross-price elasticity analysis is unsuitable.

Log-Log Regression Models Using OLS

Comparing the general OLS log-log models in Figure 16 to the ARCH log-log models, several patterns emerged similar to OLS. The r-squared values started out strong overall, and then were each boosted to even higher values with the transition to the ARCH model form. As with the general price models, the log-log OLS r-squared values ranged between .810 and .930. With the ARCH transition though, the r-squared values range higher at .939 to .973, showing anywhere from a .030 to .136 increase depending on the byproduct. The ARCH approach further enhanced the fit of all models, with the Rice Bran model getting a similar level boost as in OLS and allowing it to catch up to measures of the other byproducts.

Figure 16 - OLS Regression Log-Log Output						
Dependent Variable Byproduct Price	Coefficient Parameter Estimates				D-W	R-Sq
	Corn-SBM	Byproducts	Other Byproduct			
DDGS (Energy)	0.623**	0.443**	-		0.345	0.895
CGF (Protein)	0.455**	0.428**	0.149* (DDGS)		0.537	0.931
Rice Bran (Energy)	-0.335**	1.149**	-		0.426	0.814
Soyhulls (Protein)	-0.185**	0.953**	-		0.701	0.920
Wheat Midds (Protein)	0.636**	0.319**	0.574** (Soyhulls)		1.122	0.911

Data Source: USDA AMS, USDA NASS **=Significant at 1 percent level, *=5 percent level

In terms of the first primary coefficient of the Corn-SBM Price variable, the OLS models of DDGS, CGF, and Wheat Midds were between 0.00 and 1.00 (at .623, .455, and .636, respectively), indicating that each have a weak relation with the Corn-SBM price variable. An example would be that for DDGS, as the average Corn-SBM Price increases by one percent, then the price of DDGS increases by .623 percent in response. However, the complexities of a feed ration stem from nutrient needs, physical limitations, availability, substitutability, livestock type,

and more, meaning that each of these feed products can be complements and substitutes to varying degrees among each other. This is further complicated that each byproduct has different average pricing points, and so even as these changes are in terms of percentage change, a percent price change in one byproduct may have a different impact than to another. These three larger-volume byproduct models show that they are moderately related to each other in price, sharing similar patterns with one another and corn and SBM as expected.

As for the Rice Bran and Soyhulls OLS Log-Log Models, their Corn-SBM price estimates were actually negative (-.335 and -.185, respectively), indicating an opposite movement in direction between the Corn-SBM price series and the two byproducts. The theoretical logic would point to these two byproducts as substitutes of Corn and SBM, however both can be either complements or substitutes depending on a wealth of variables. The production volumes of Rice Bran and Soyhulls are much smaller than the other three byproducts. And so market size may be the reason as to partially why the larger byproducts were more closely connected to Corn and SBM, and these two others had greater levels of disconnect.

With the principal coefficient of the Condensed Byproducts (the prices of all byproducts combined, aside from the left-hand variable), the patterns in the OLS models of DDGS, CGF, and Wheat Midds were that all were between 0.00 and 1.00, too (.443, .428, and .319, respectively). The price connections are weak, but in the same direction relationship as the other byproduct options, so their Corn-SBM variables were larger influences over the Condensed Byproducts coefficients in the end. However, based on previous initial results and findings, CGF and Wheat Midds had their most closely related byproduct separated out from their respective congregated byproduct coefficients, with DDGS and Soyhulls, respectively. DDGS was at a

lower value of .149, and Soyhulls was a much more moderate effect at .574. Thus, this showed the specific relationship between byproducts closer than the others.

In the Rice Bran and Soyhulls OLS models, their Condensed Byproducts were not only larger than their respective Corn-SBM coefficients in absolute value, but also positive. In addition, their Condensed Byproducts coefficient was also larger than any of the other three byproduct models, and in fact the Rice Bran one was the only one to exceed a value of 1.00 at 1.149, indicating a strong relationship. Soyhulls were close to a strong elasticity relationship however, at a value of .953. This indicated that these smaller market volume byproducts have a much closer relationship with the other byproducts rather than the larger corn and SBM markets. This makes sense, given that these smaller, nutrient-limited byproduct markets would more directly follow other byproduct options of similar nature, over mainstream corn and SBM.

As for the other coefficient with the Corn-SBM Trend, it was very small and had seemingly random patterns of being positive, negative, significant, and insignificant across the five models. Still, I originally included it in order to address issues of multicollinearity from the shared time trends, and hence that is why it remained included across most models, save for CGF because it distorted results (“Multicollinearity,” n.d.).

The OLS Log-Log model findings provided further support on the concept that larger byproducts of DDGS, CGF, and Wheat Midds, have strong and positive direct relationship with Corn and SBM, while still following the prices of other byproducts to a lesser degree. The Rice Bran and Soyhulls markets were much more closely related to other byproducts, and had an inverse, low-magnitude relationship with corn and SBM, too.

Log-Log Regression Models Using ARCH

Following the same methodology as before, the Log-Log ARCH model composition allowed for direction comparisons on the changes with the Log-Log OLS byproduct pricing models. Using ARCH provided minor to moderate r-squared increases for each byproduct model, but accounts for seasonality and resulting autocorrelation issues. In observing the output in Figure 17 a few main patterns reemerge, while some new ones take form compared to OLS.

Figure 17 - ARCH Regression Log-Log Output					
Dependent Variable Byproduct Price	Coefficient Parameter Estimates				
	Corn-SBM	Byproducts	Other Byproduct	D-W	R-Sq
DDGS (Energy)	0.638**	0.330**	-	1.870	0.973
CGF (Protein)	0.295**	0.318**	0.421** (DDGS)	1.837	0.972
Rice Bran (Energy)	0.050	0.687**	-	1.734	0.946
Soyhulls (Protein)	-0.093	0.851**	-	1.905	0.960
Wheat Midds (Protein)	0.687**	0.410**	0.391** (Soyhulls)	1.998	0.939

Data Source: USDA AMS, USDA NASS **=Significant at 1 percent level, *=5 percent level

In the Corn-SBM price coefficient, the ARCH model featured results similar to OLS for DDGS and Wheat Midd. In these ARCH models, the Corn-SBM prices remained between 0.00 and 1.00, at .638 for DDGS and .687 for Wheat Midds, both only marginally different from their OLS values. Given how CGF was grouped in with these two earlier, I anticipated their Corn-SBM coefficient to stay the same, and yet its Corn-SBM value dropped from .445 in OLS, to .295 in ARCH. This changed the Corn-SBM price from the largest magnitude coefficient of the model to the smallest. As for Rice Bran and Soyhulls, both coefficients became much smaller in magnitude, and even from statistically significant to insignificant. These results reinforce the connection DDGS and Wheat Midds have with corn and SBM markets. However it does bring into question why CGF declined notably. As for Rice Bran and Soyhulls, it supports previous statements on their disconnect to corn and SBM, with ARCH shifting the coefficient to the statistically insignificant.

As for the Condensed Byproduct Coefficients in the DDGS and Wheat Midds models, the value dropped from .443 to .330 for DDGS, and then increased from .319 to .410 for Wheat Midds, showing a weakening and strengthening corn and SBM price relationship for the two, respectively. The Wheat Midds model again includes a separated byproduct coefficient, soyhulls. The value of this parameter estimate actually shifted from .574 to .391 in the transition to ARCH this change shows Wheat Midds have a decent connection to many of its related feed products. With CGF though, its Semi-Condensed Byproducts coefficient fell from .428 to .318. However, the most notable change is that of the separate DDGS coefficient in the model, which went from a value .149 to .421, taking it from the lowest to the highest of the coefficients, showing the two share a moderate price relationship.

For the Rice Bran and Soyhulls models' Condensed Byproducts coefficients, their values also dropped in the ARCH versions of the models. In Rice Bran the value fell from 1.149 in OLS to .687 in ARCH, which is a notable decline indeed. For Soyhulls, the change was less impactful at falling from .953 to .851 in ARCH. This does weaken their relationships between the other byproducts, though. When combining this with the fact that Corn and SBM went from small to insignificant in these two models, it shows an overall lower price elasticity with each of these feed ration ingredients. Still, the magnitude and the direction with these Condensed Byproducts coefficients remained consequential and showed that there is still a moderately high price connection to other byproducts, much more than corn or SBM.

Just as with previous OLS models, the trend variable itself was still very small in absolute value, and had a seemingly lack of a pattern in terms of its significance or sign in the ARCH versions, either.

In terms of the lag patterns for the Log-Log ARCH models, all shared the first lag as a statistically significant one. DDGS, Rice Bran, and Soyhulls each had a second period lag that was statistically significant for each one of those, too. For any other statistically significant lag periods in a model, the only remaining ones were in Soyhulls, which had a period 8 lag, and Wheat Midds, which had lags during periods 3, 4, and 13. Overall, despite the moderate dispersion of the lag period patterns, the presence of statistically significant lags shows that accounting for such was an important inclusion in the models. Considering at the very least the importance of the first and second lags for models overall, this and highlights that the seasonal impacts in these markets are quite relevant indeed, and improved model outputs as a result.

In total, the ARCH Log-Log models showed the same overall relationships as the OLS ones. This showed that as Corn-SBM price changed, larger market volume and higher nutrient content byproducts of DDGS and Wheat Midds (and CGF to a lesser extent) would follow in the same direction at a low to moderate rate. It were these same byproducts that also followed the same pricing movements as their other byproduct alternatives to similar degrees, too. This all showed strong feed market pricing trends that followed each other regardless of nutrient-base (protein or energy), and seemed to be somewhat tied to having a larger market size. In terms of thin markets, the results from the Soyhulls and Rice Bran models revealed a solid disconnect with Corn-SBM patterns, and were connected to the other byproducts at a stronger, yet reduced, rate and direction of change to the other byproducts. As the ARCH methodology refined some of the autocorrelation concerns, it reinforced these findings captured from the OLS models.

These outcomes, in the overall scope of each regression model, support each other in saying that there is less pricing confidence in calculating larger market byproducts with smaller market ones, at least based off of the traditional measures of previous literature (e.g. Brorsen et

al 1985; Ferris 2006; Hoffman and Baker 2011). Overall, thinner byproduct markets appear to have a less reliable pricing than the thicker ones. Therefore, at a minimum the data points to that corn and soybean meal are still influences on crop byproduct markets, although other influences exist beyond previous statements. The findings here show that thinner markets follow corn and soybean to a lesser extent, and more so follow the trends of other, more price-volatile trends of other byproducts instead, reinforcing questions about substitutability and compatibility in feed ration mixtures. In addition, through the limited comparisons with protein and energy weights along with cross-locational results, there is merit that nutrients and livestock populations still have an important impact as previously alluded to, as well.

Remaining Issues for Future Modeling Procedures and Improving Outputs

Ultimate there were still several issues that distorted and disrupted the end results of the byproduct regressions in different ways, and at varying levels. These problems stemmed from limitations of the data set and modeling methods. The initial regression models all used the “ordinary least squares (OLS)” estimation method, and the ARCH models afterwards alone could not solve all of the emerging problems, either.

One of the problems that is simply the issue of choosing which regression models methods to use. Given the vast array of attempted changes that I performed throughout the development stages, there were many options to choose from. This was further complicated as I evaluated test runs when I combined different variable elements together or added them in and removed them as I deemed it appropriate. The sheer number of processes I ran and chose from is still a key consideration for future work.

The models that I display in this paper can still be overlooking or missing an important concept that stemmed from repeated modification of regression methods, and the attempts to fix any issue. Summarily, each of these will hold separate measures of relevance during the future of crop byproduct regression modeling work.

Autocorrelation issues still showed up in the final, chosen regression models for each individual byproduct, to varying degrees. This phenomenon was present throughout each of the steps taken in changing and shifting the model, however too. As a result, autocorrelation was a consistent issue from the very beginning, and then when continuously experimenting and applying the different steps from above. While the ultimate autocorrelation values across techniques and byproduct models were different, they were still present, noticeable, and impactful in the end in with OLS, and even with ARCH depending on the byproduct. Since this distorts parameter estimates due to the changing variances found with Chebyshev's inequality, this puts into question the meaningfulness of a given coefficient ("Autocorrelation," n.d.).

Another main complication arising from the nature of the variables was multicollinearity. This concept stems from the relationship the byproduct price series have with each other. Each of the byproduct buyer and seller interviewees asserted that these individual byproduct prices are influenced by corn, soybean meal, and each other so strongly (Participants A, B, C, D, E, and F). In addition, I want to point out again that other papers have displayed this kind of price link for some byproducts, too (e.g. Brorsen et al 1985; Ferris 2006; Hoffman and Baker 2011). Specifically, this powerful price pattern connection means that the related coefficients are influencing each other in an unstable manner, and therefore the parameter estimates are unreliable as variables concurrently affect each other. To observe the magnitude of this

circumstance among these byproduct price series, I view the correlation matrix between all of the price variables, absent any nutrient conversion effects.

Upon looking at a table full of correlation coefficients, there was a high degree of correlation between each of the variables across the entire chart. A majority of the values fell between .80 though .93, with very few of the values falling below that .80 level. In fact, the lowest value for the entire table was .75, which was the correlation between rice bran and soybean meal, the two smallest byproducts here. The highest level was at .936 between DDGS and CGF, which makes a lot of sense given how related the two regression model outputs were overall within this chapter, and how strong the DDGS parameter estimate grew in the ARCH Log-Log models. In comparison to Corn Price Per Ton, the closest correlated byproducts were at DDGS at .928, followed by Wheat Midds at .926, then CGF at .893, then Soyhulls at .886, and lastly Rice Bran .814, showing the limited, yet present, disconnect of these byproducts to some of the mainstream corn option for feed. As for SBM, the correlations were definitely weaker with the strongest correlation at .883 with CGF, and Rice Bran at .750, and everything else in between, showing not as strong as a connection with this mainstream byproduct, but a byproduct nonetheless. Overall, byproducts price relations were closer to corn compared to SBM, and yet for both, the pattern in total maintained that the lower volume byproducts of rice bran and soyhulls saw less correlation, although were still present and fairly strong, too.

As for the byproducts correlation matrix relationships amongst one another, most were quite notable at a range of .826 (DDGS and Rice Bran) through .936 (DDGS and CGF, as mentioned in the previous paragraph). In total, these correlations show that again each of these byproducts share decent price relationships with one another, at levels that are comparable to corn, and simultaneously a bit stronger than SBM (however still relatively strong and notable). In

terms of observing the impacts between byproducts of different market volume sizes, DDGS as the largest saw some correlation reductions when moving from larger volume byproducts to lower volume ones, as with CGF, and as well with Wheat Midds (save for soyhulls). When looking at the two smaller byproducts' correlations, soyhulls was more strongly correlated with the other byproducts compared to Corn and SBM. With Rice Bran, its strongest correlation was with Soyhulls at .898, and then reduced in size for the larger options at the mid and lower .80s range, although interestingly enough having the lowest correlation with SBM at .750.

In total, each of the outputs from the correlation matrix shows that overall these seven feed ingredient variables have relatively strong pricing relationships between one another. Despite any differences not being extreme in magnitude, overall byproducts that had a smaller market share had more of a disconnect with the larger size feed ration options compared to the other ones. This again supports the ideas of weaker pricing patterns in thinner markets, but the results from this correlation matrix also show the presence of multicollinearity. Therefore, this reinforces the importance of addressing this multicollinearity concept in future work.

With all different byproduct feed options, they are sourced from a primary product, and are only produced through specific processes involving raw crops being processed in a particular manner. For the supplies of a byproduct to change, this is more dependent on changes with the primary product itself and any market or processing alterations involving those. While there are complications in developing a ration with several factors to balance, protein and energy remain as the primary nutrients for the foundation of value of a feed component. With all of the available feed options for achieving nutrient goals and needs, buyers are able to shift between substitute options to varying degrees based on concepts such as distance, transportation, and storage. Regardless of which reasons, in the end the market effects on the primary crop products

will be a large influence on the overall shape of the byproduct markets. As a result, buyers are selecting from various options and substitutes framed by movements in the source product markets, rather than these byproducts markets alone having as direct of an effect on each other.

Ultimately, some of the remaining issues for future studies and researchers stem from a variety of possible refinements. Later studies should be focus on improving the consistency, detail, and the scope of the data first and foremost, such as including additional years of observations, nutrient content variables, and other byproducts to observe. Next, choosing the right model type and variables would be key to overcoming any complications arising from both autocorrelation (from the seasonal time trends) and multicollinearity (from the shared patterns across the different byproducts). Combining these general concepts together in a more complete and complementary data set and modeling structure would provide some robust findings that could arrive at new, measurable notions, as well as updated conclusions of old ones. After all, the ultimate coefficients in these models were time-invariant, and so if the interviews mentioned large price effects over time, accounting for this in future models would help further explore that, too. While surely complicated, such methods are surely possible to achieve as time passes. These advanced models could provide much more concrete and quantifiable deductions on thin markets, and even organizational structure on price discovery in commodity markets with the right data. Of course, such improvement would also apply to markets directly stemming from commodities, like with the byproduct markets analyzed here.

Chapter Six – Overall Summary, Sensitivities, and Conclusions

Returning to the Beginning Issues

The topic of crop byproducts facing price discovery issues, shaped by thin market traits, led to a search on how market volumes influence price stability within respective markets. The literature revealed discussion on how agricultural markets have been thinning, and how this trend may negatively affect their pricing variances (e.g. Tomek 1980, Franken and Parcell 2012, and Adjemian et al 2016). Literature also suggested future research should study additional products with more observations and greater detail within them (e.g. Brorsen et al 1985, and Ward and Choi 1998). In recent years though, these more complete and concrete studies have remained mostly missing, especially the byproduct market, despite its presence and influence in the livestock feed industry. From these general issues, my main research question formed around the ideas of thinning markets, price volatility, and organizational structure. Given the nature of thin markets in the first place, this leads to the problem of poor data in terms of amount and quality. Still, I asked the question “how do firms deal with transaction costs in crop byproduct markets?” and from there I investigated how contracting was present in different markets, what transaction costs affected players the most, and what factors shaped the price of byproducts.

I structured my main research question around how firms deal with transaction costs in crop byproduct markets, going into details about contracting, vertical integration, general transaction cost types, and volume effects on price uncertainty within byproduct markets. Issues stemming from a lack of data soon became apparent though. My data only involved bid price comparisons with each other and general, and time-invariant market volume and nutrient estimates. This lack of data caused me to seek outside perspectives from industry professionals in the forms of six interviews. I used their answers to develop findings discussion and future

recommendations on study methods, and then reinforced their statements with statistical analysis and regression modeling using the limited byproduct data available. I had originally hypothesized that as markets become thinner and the associated transaction costs increase, buyers will move towards contracting, vertical integration, and substitute products.

Individual Findings from the Main Chapters

The interviews were the only source of any information regarding specific byproduct transactions on the buyer and seller perspectives in several markets. The six interviewees were composed of three commercial feed mill buyers, two ethanol plant sellers, and a hog producer buyer across multiple states within the Midwest.

Participants A and B revealed that the number of byproduct options for feed had been reduced by a large number over the past two decades alone, caused by government intervention and changing demand based on non-feed usage. In terms of transaction costs problems though, Participants A and B included the fact that the increasing number of now-obsolete byproducts faced supply and price variance issues, which made market exchange difficult for buyers and sellers alike. Several interviewees said that current market byproducts still faced transaction costs issues where products and agreements were remain inconsistent, but avoiding smaller byproduct markets was currently best way to combat these same transaction issues (Participants A, B, C, and D). However, none of the interviewees were part of a vertically integrated business. Participants A, B, and C stated their contracting habits as revolving around future anticipations of price and supply volatility.

Participants E and F of the large-market-volume DDGS byproduct however, they said that long-term contracts have been increasing over time as the number of market players have

declined, citing price, quantity, product traits, and many more transactional attributes as the main agreements within a deal. Buyer Participants A, B, and C expressed that increasing operation speeds and efficiencies have caused a greater reliance on communication and product management technology, and then contracting specific terms more than ever before. However, across buyers and sellers alike, this percentage of large-term contracting (a month or more in advance) ranged anywhere from 10 to 90 percent roughly, indicating operations dealing with the aforementioned risks in much different manners (Participants A, B, C, E, and F).

As for transaction costs, each interviewee talked about how asset specificity (having the right types of storage, equipment, and cross-byproduct compatibility) was greatly present for any byproduct, and sticking to the mainstream byproduct options such as DDGS and wheat midds has been the most practical approach to easing transaction costs (Participants A, B, C, D, E, and F). Buyer Participants A, B, C, and D said that information technology on nutrient, storage, and transportation management has helped reduce some of these transaction costs (and when combined with contracts) over time, relating only to asset specificity and information gathering, however. Detecting an issue is one concept, and actually solving any critical issues is another though. And so despite the prevalence of legal contracting, Participants A, B, C, and D focused on the concepts of reputation, trust, personal promises, and favors as very important in business relations, even amongst the largest players.

The experiences from these interviewees showed that on a consistent basis transaction costs and the ability to overcome them has been an influence on which byproducts are used over others (Participants A, B, C, D, E, and F). In addition, the answers of Participants A, B, C, and D have reinforced the idea that in reducing transaction costs, simply making a trade work is primary goal. In order to control transaction costs, the operations of buyer Participants A, B, C,

and D have turned to contracting and reputation, while other smaller byproduct markets have been abandoned in times of demanding, large-scale feed production. This confirmed my hypothesis, that as byproduct markets thinned, this increased transaction costs to unsustainable levels and thus buyers increased contracting habits, and moved towards substitute byproducts, too.

The findings from the Chebyshev's inequality calculations pointed to the pattern that as market volume size decreased, price volatility increased. However, in terms of the actual magnitudes of each market's respective Chebyshev's inequality n-values, they were quite comparable. Although when comparing the two extremes of high-production-volume byproducts to low-volume ones, there were notable differences that fit the general trend of the inverse effect of market volume on price variance. The main issue involving this analysis though was that there just needs to be more overall detail with the data, both on an observation basis, as well as an extended amount of byproducts and locations for the number of data sets overall. Regardless, it confirmed my earlier hypothesis that smaller markets have increased price volatility that presumably leads to damaged price discovery within those independent markets, albeit to a weak degree as shown earlier.

In addition, the Chebyshev's inequality findings reinforced the concept that no matter the size of the market, all face price variance spikes at times, to notable degrees. These sudden surges highlight that market-wide changes, such as weather incidents, trade restrictions, and processing redesigns, can greatly influence price trends to various degrees. These are more problematic for thinner markets, which suffer from such problems to a greater degree initially.

With the regression modeling, both protein and energy-based pricing had significant effects impacts across feed ingredients. The differences between the two nutrient approaches

were not overly different when comparing them across byproducts, since both are presumably important to most livestock. As for the coefficients within any models, the combination of corn and soybean meal price as one parameter, and then a combination of the other byproducts prices together, proved to be very applicable in each byproduct model. Using ARCH over OLS to account for the autocorrelation of seasonal price trends was an effective way to refine parameter estimates by correcting for those time effects.

The implications of the ARCH model outputs in terms of these feed ingredient prices is that the byproduct prices have strong relationships with the other ones, to a greater degree than the corn and soybean meal combined price for each byproduct model. However, the corn and SBM price variable still had a moderate level impact that started out larger in higher volume byproducts of DDGS, Wheat Midds, and CGF, and then increasingly dwindled in smaller volume markets of Soyhulls and Rice Bran. Overall, these findings also lined up with my hypothesis that with the corn and SBM markets having the most stable prices, the thinner a market was, the less it followed corn and SBM trends and was presumably more unstable, too. Through the Log-Log regression models, the results displayed the elasticities of each price series compared to one another, and confirmed the same general patterns as the previous price models. Overall, these patterns again supported that the mainstream feed ingredients of corn and SBM have had a much more direct effect on byproducts with greater production and usage.

Implications of the Various Findings Together

As the three main chapters addressed how firms deal with transaction costs in byproduct markets, each could not answer this question fully alone. Even together, there are still some missing answers on how operations deal with transaction costs in crop byproduct feed markets.

However, the findings support one another overall, and help refine ideas related to the research question and similar ideas.

The interviewees confirmed the increasing prevalence of transaction costs in byproduct markets, citing inconsistent transportation timing, strict storage turnover, ingredient compatibility concerns, reduced number of market players, quality problems, and changes of outside-market demand as sources of difficulty in transacting in these markets now (Participants A, B, C, D, E, and F). In addition, Participants A and B described these costs as even more prevalent in previously existing markets, and ultimately what caused thinner byproduct markets to die out over time, therefore limiting available options today. According to each of them, these issues are still prevalent, despite technological advancements alleviating information efficiency issues (Participants A, B, C, D, E, and F). As a result, the presence of long-term contracting has increased to varying extents, with seller Participants E and F saying that the spot market has declined due to the simultaneous decline of smaller operations that utilized it. These responses align with my hypothesis that as thin market effects of high transaction costs intensify, then buyers will move towards long-term contracting more often or switch to substitute products.

The Chebyshev's inequality findings confirmed the findings from these interviews, as well as providing some additional context and detail. They that showed overall markets with high production volumes have more stable pricing patterns over time compared to ones with lower production volumes, supporting the idea that thinner markets do have greater levels of price volatility. I assume such pricing troubles to stem from the issues caused by the increased effects of transaction costs in thinner markets and the decline of the spot market that followed, shaped by high efficiency demands that require optimal transportation, storage, and nutrient balance arrangements. And with thin market effects amplified due to the nature of agriculture in

general, as well as the increasing concentration and thinning of it too, this view appears to be justified (Adjemian et al 2016).

The findings from the regression modeling showed that the larger-volume byproducts of DDGS, CGF, and wheat midds were more closely aligned with the patterns of the mainstream feed options of corn and soybean meal in a new manner compared to Chebyshev's inequality results. The Chebyshev's inequality findings showed corn and soybean meal that had lower levels of price volatility, and the regression results fit this with the notion that these thicker market byproducts of DDGS, CGF, and wheat midds experience less volatile pricing patterns, too. The thinner market byproducts of soyhulls and rice bran had weaker, inverse, and sometimes insignificant relationships to corn and SBM, this shows their disconnect with larger market price trends, shaped possibly by nutrient, location, and livestock demand differences.

Participants B, E, and F stated byproduct prices follow corn and SBM. Participant B also said that byproducts follow the same trends as corn and SBM, but are each much more volatile by several times. While the findings with Chebyshev's inequality did not reveal a pattern to quite that degree, the general sentiments hold true. In addition, previous literature used corn and SBM to also study byproduct prices (Brorsen et al 1985, Ferris 2006, and Hoffman and Baker 2011). With the models here utilizing the price series of other byproducts, and finding out that the other byproducts have a significant impact on each other (especially for the thinner ones), this creates new insight that certain pricing schemes have a bit more depth than previously alluded to.

The regression models reinforce the idea that thin markets have more price volatility as identified with Chebyshev's inequality. The results of both statistical approaches supported the beliefs of industry buyers and sellers, in that the byproduct market suffers from greater price volatility, causing an increase in long-term contracting as a result (Participants A, B, C, D, E, and

F). The original research question was “How do firms deal with transaction costs in crop byproduct markets?” and along with that included contracting habits compared to alternatives, what those different transaction costs are, and what is the uncertainty of a byproduct’s price compared to another. My hypothesis was that contracting and switching to substitute feed ingredients would be the main solutions to avoid transaction costs, and thus becoming the more common choices in the market, which the interviewees seemed to confirm. At the same time, the interviewees showed that nutrient information, quality analysis, efficient timing, and reliable equipment were necessary to deal with the transaction costs of asset specificity and arranging deals in a small market pool, in ultimately using byproducts to create an optimal feed mixture. Through Chebyshev’s inequality and the regression modeling, there was consistent evidence for thinner byproduct market characteristics leading to greater levels of pricing uncertainty compared to thicker byproduct markets. Together, the chapters show that these byproducts face these levels of volatility due to influences including corn price, SBM price, prices of other byproducts, geographic location livestock traits, nutrients, and other demand factors.

Areas of Focus for Future Research

Despite the above findings that the chapters arrived at, there are still a few flaws that future researchers should be mindful of moving forward. The main recommendation for each is to increase the scope and detail of the data. While the feasibility of is shaped by what data exists, finding more years of data for additional types of byproducts, with new location, quality, and quantity information included, will lead to much more telling results and conclusions. Regardless, more robust methods for regression and Chebyshev’s inequality work would allow for better controls on autocorrelation, multicollinearity, and any other identified problems.

Given the variety of findings from the interviews, the same concept on additional data applies too, with more interviews on a greater variety of interviewees in terms of size, role, location, as possible improvements. Also, a future study would benefit from a wide scale survey to gather more data on thinning markets and experiences with various transaction costs.

Overall, the work here provided a starting point for crop byproduct analysis, and has shown how later approaches may better build upon and move past the work done here. While the nature of the topic creates obstacles for performing research efforts right now, there is a lot more insight to gain in an industry related to the massive global meat consumption demand, and the feed inputs that are critical to the operation and success of livestock producers. With future work, one may be able to apply new findings and create a framework for studying other types of thin markets, organizational structure strategies, and other, broader topics important to overall economies, and some of the more specific parts of them.

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Appendix

Appendix Table 1 – Interview Question Sets

Interview Questions for Sellers (40 in Total):

1. Own Production:

1. What crops are processed through your facility, and what byproducts do they produce?
2. How much in volume of your byproducts do you produce in a given year, and how has that changed over time?
3. How have your production inputs and your processing methods changed over the years (such as the grain crops used or the technology installed), and why? How has that affected the byproducts and their sales?
4. How much ingredient mixing do you generally perform, as an alternative to giving standalone feed ingredients to buyers?

2. Pricing and Sales:

5. During what times of the year are your byproduct sales generally higher or lower? How does that align with your levels of byproduct production and availability throughout the year?
6. What percentage of revenue comes from byproducts?
7. What part about selling your facility's byproducts is the most difficult?
8. How helpful have information and data management technologies been in the operation of your byproduct sales portion of the business?
9. When are byproducts sold relative to production?
10. How is price determined?
11. In general, how much has the price of your byproducts changed and fluctuated over time?
12. Does the price change depending on how much a buyer purchases?
13. Do you do anything beyond general processing to alter the nutrient content of a byproduct or feed mix?
14. What percentage do you market locally, what do you do with the remainder?
15. What percentage of your byproduct production do you internalize and use for yourself, and what do you do with them?
16. How quality sensitive is your price, and how do you define quality?
17. How easy is quality to measure?

3. Contracts:

18. What percentage of byproduct deals are done through contracting?
19. How long do byproduct contracts last?
20. What are components are mainly covered in a typical contract (for example, price, quantity, nutrients, etc.)?
21. When a contract occurs, is it usually at your request, or the buyer's?

4. Buyer Interaction:

22. How do you identify buyers, and do you find this easy or difficult? For example, do you rely on advertising, word of mouth, or other means?
23. How much do repeat buyers make up your sales totals, and how frequent are their purchases?

24. At what point is the sale usually complete and the ownership of the byproduct transferred to the buyer?
25. On average, how close are your buyers to your facility in terms of distance? Is there a range you could provide/estimate?
26. How often are there disagreements about the quality?
27. What is the standard method of communication when interacting with buyers?
28. Do you know buyer motivations for choosing your specific byproducts? If so, what are some of the common answers that you hear?
29. On average, how large are buyer operations, what kind of storage do they have, and what types of livestock do they own?
30. Do you typically sell byproducts in different forms such as pellets or loose meal? Is this done automatically or at the request of a buyer?
31. Do you provide bags or other handling materials, and if so, at what cost?

5. Regulation and Testing:

32. Do you test and provide nutrient information about the byproduct? Are you required to? What specific nutrients are generally covered?
33. How costly is it for you to perform nutrient tests?
34. Has there been any regulation in the past decade that you believe was particularly impactful on your sales of byproducts?

6. Transportation and Handling:

35. What are the general transportation methods for your byproducts, and why?
36. How is the transportation method decided on within a trade deal?
37. How much of a concern is bacterial/fungal infection and moisture for byproduct production and storage? How costly is it to combat the issue?
38. Do storing your byproducts require special types of equipment and containers?

7. General Market:

39. What levels of production and usage of byproducts do you perceive at a local, state, and regional scale?
40. How do you think the byproduct market will change in the coming years? This could really refer to any perceived trend such as the popularity of a certain byproduct, byproduct usage overall, and so forth. This could also be in terms of a country or a certain livestock group within any particular region, or something else like that.

Interview Questions for Buyers (40 in Total):

1. Own Production:

1. What crops, byproducts, and other inputs are processed through your facility, and what additional byproducts do they produce?
2. What volume of byproducts do you produce in a given year, and how has that changed over time?

3. How have your feed production inputs and your processing methods changed over the years (such as the grain crops used or the technology installed), and why? How has that affected resulting byproducts and their sales?
4. How much ingredient mixing do you generally perform for feed, compared to purchasing mixtures from sellers?

2. Pricing and Purchases:

5. During what times of the year are your byproduct purchases generally higher or lower? How does that change during a given year?
6. What percentage of feed costs come from byproducts?
7. What part about purchasing byproducts is the most difficult?
8. How helpful have information and data management technologies been in facilitating byproduct purchases?
9. When are byproducts typically bought relative to feeding?
10. How do you determine what is an appropriate byproduct price?
11. In general, how much has the price of your byproduct purchases changed and fluctuated over time?
12. Does the price change depending on how much you purchase?
13. Do you do anything to alter the nutrient content of a byproduct or feed mix?
14. What percentage of your byproduct purchases are from local markets, from nonlocal markets?
15. What percentage of your byproduct production do you internalize and use for yourself, and what do you do with them?
16. How much does quality influence your purchase decisions, and how do you define quality?
17. How easy is it to measure quality?

3. Contracts:

18. What percentage of byproduct purchases are done through contracting?
19. How long do byproduct contracts last?
20. What are components are mainly covered in a typical contract (for example, price, quantity, nutrients, etc.)?
21. When a contract occurs, is it usually at your request, or the seller's?

4. Seller Interaction:

22. How do you identify sellers, and do you find this easy or difficult? For example, do you rely on advertising, word of mouth, or other means?
23. How much frequently do you repeatedly purchase from a single seller?
24. At what point is the sale usually complete and the ownership of the byproduct transferred to you?
25. On average, how close is your seller's facility in terms of distance? Is there a range you could provide/estimate?
26. How often are there disagreements about byproduct quality with the seller?
27. What is the standard method of communication when interacting with sellers?
28. What makes you choose a specific type of byproduct?
29. Does the size of your operation influence your decision to purchase byproducts over other alternatives?

30. Do you typically buy byproducts in different forms such as pellets or loose meal? Is this done automatically by the seller or at your request?
31. Are you provided bags or other handling materials, and if so, at what cost?

5. Regulation and Testing:

32. Do you test nutrient information about the byproduct, does the seller, or both? What specific nutrients are generally covered?
33. How costly is/would it for you to perform nutrient tests?
34. Has there been any regulation in the past decade that you believe was particularly impactful on your purchases of byproducts?

6. Transportation and Handling:

35. What are the general transportation methods for your byproduct purchases, and why?
36. How is the transportation method decided on within a trade deal?
37. How much of a concern is bacterial/fungal infection and moisture for byproduct storage? How costly is it to combat the issue?
38. Do storing your byproducts require special types of equipment and containers?

7. General Market:

39. What levels of production and usage of byproducts do you perceive at a local, state, and regional scale?
40. How do you think the byproduct market will change in the coming years? This could really refer to any perceived trend such as the popularity of a certain byproduct, byproduct usage overall, and so forth. This could also be in terms of a country or a certain livestock group within any particular region, or something else like that.

Appendix Table 2 – Number 2 White Corn (Kansas City, MO)

Year	<u>Needed Transactions</u>			
	<u>\$0.10/bushel</u>	<u>\$0.20/bushel</u>	<u>\$0.30/bushel</u>	<u>\$0.40/bushel</u>
2001	70	17	8	4
2002	162	40	18	10
2003	76	19	8	5
2004	210	52	23	13
2005	33	8	4	2
2006	400	100	44	25
2007	176	44	20	11
2008	918	229	102	57
2009	135	34	15	8
2010	782	195	87	49
2011	219	55	24	14
2012	716	179	80	45
2013	1,546	386	172	97
2014	371	93	41	23
2015	26	7	3	2
2016	89	22	10	6

Appendix Table 3 - Number 2 Yellow Corn (Omaha, NE)

Year	<u>Needed Transactions</u>			
	<u>\$0.10/bushel</u>	<u>\$0.20/bushel</u>	<u>\$0.30/bushel</u>	<u>\$0.40/bushel</u>
2005	24	6	3	1
2006	264	66	29	17
2007	118	29	13	7
2008	930	232	103	58
2009	131	33	15	8
2010	610	152	68	38
2011	276	69	31	17
2012	525	131	58	33
2013	1,624	406	180	101
2014	388	97	43	24
2015	22	6	2	1
2016	80	20	9	5

Appendix Table 4 - U.S. National Corn

Year	<u>Needed Transactions</u>			
	<u>\$0.10/bushel</u>	<u>\$0.20/bushel</u>	<u>\$0.30/bushel</u>	<u>\$0.40/bushel</u>
2001	5	1	1	0
2002	45	11	5	3
2003	8	2	1	1
2004	100	25	11	6
2005	11	3	1	1
2006	117	29	13	7
2007	31	8	3	2
2008	267	67	30	17
2009	93	23	10	6
2010	237	59	26	15
2011	272	68	30	17
2012	207	52	23	13
2013	1,264	316	140	79
2014	224	56	25	14
2015	7	2	1	0
2016	44	11	5	3

Appendix Table 5 - Saint Louis, MO Soybean Meal

Year	<u>Needed Transactions</u>			
	<u>\$9.50/ton</u>	<u>\$19.00/ton</u>	<u>\$28.50/ton</u>	<u>\$38.00/ton</u>
2001	14	4	2	1
2002	16	4	2	1
2003	71	18	8	4
2004	346	87	38	22
2005	42	10	5	3
2006	12	3	1	1
2007	133	33	15	8
2008	251	63	28	16
2009	216	54	24	14
2010	63	16	7	4
2011	78	19	9	5
2012	713	178	79	45
2013	181	45	20	11
2014	341	85	38	21
2015	105	26	12	7
2016	190	48	21	12

Appendix Table 6 - Central IL DDGS

Year	<u>Needed Transactions</u>			
	\$4.00/ton	\$8.00/ton	\$12.00/ton	\$16.00/ton
2001	33	8	4	2
2002	72	18	8	4
2003	199	50	22	12
2004	229	57	25	14
2005	9	2	1	1
2006	106	26	12	7
2007	95	24	11	6
2008	344	86	38	22
2009	171	43	19	11
2010	329	82	37	21
2011	77	19	9	5
2012	855	214	95	53
2013	223	56	25	14
2014	1,723	431	191	108
2015	378	95	42	24
2016	180	45	20	11

Appendix Table 7 - Kansas City, MO CGF

Year	<u>Needed Transactions</u>			
	\$4.00/ton	\$8.00/ton	\$12.00/ton	\$16.00/ton
2001	42	10	5	3
2002	16	4	2	1
2003	132	33	15	8
2004	142	35	16	9
2005	75	19	8	5
2006	37	9	4	2
2007	374	93	42	23
2008	472	118	52	29
2009	330	83	37	21
2010	548	137	61	34
2011	97	24	11	6
2012	1,527	382	170	95
2013	394	99	44	25
2014	967	242	107	60
2015	146	37	16	9
2016	155	39	17	10

Appendix Table 8 - Minneapolis, MN Wheat Midds

Year	<u>Needed Transactions</u>			
	<u>\$4.00/ton</u>	<u>\$8.00/ton</u>	<u>\$12.00/ton</u>	<u>\$16.00/ton</u>
2001	75	19	8	5
2002	86	22	10	5
2003	87	22	10	5
2004	108	27	12	7
2005	55	14	6	3
2006	222	56	25	14
2007	365	91	41	23
2008	182	45	20	11
2009	124	31	14	8
2010	591	148	66	37
2011	217	54	24	14
2012	1,639	410	182	102
2013	548	137	61	34
2014	304	76	34	19
2015	178	45	20	11
2016	43	11	5	3

Appendix Table 9 - Memphis, TN Soyhulls

Year	<u>Needed Transactions</u>			
	<u>\$3.75/ton</u>	<u>\$7.50/ton</u>	<u>\$11.25/ton</u>	<u>\$15.00/ton</u>
2001	100	25	11	6
2002	134	33	15	8
2003	110	28	12	7
2004	42	10	5	3
2005	89	22	10	6
2006	158	40	18	10
2007	407	102	45	25
2008	155	39	17	10
2009	328	82	36	21
2010	504	126	56	31
2011	803	201	89	50
2012	1,813	453	201	113
2013	459	115	51	29
2014	191	48	21	12
2015	88	22	10	5
2016	50	13	6	3

Appendix Table 10 - Texas Rice Bran

Year	<u>Needed Transactions</u>			
	<u>\$3.25/ton</u>	<u>\$6.50/ton</u>	<u>\$9.75/ton</u>	<u>\$13.00/ton</u>
2001	66	16	7	4
2002	148	37	16	9
2003	142	35	16	9
2004	145	36	16	9
2005	158	40	18	10
2006	193	48	21	12
2007	114	28	13	7
2008	131	33	15	8
2009	927	232	103	58
2010	362	91	40	23
2011	2,208	552	245	138
2012	1,309	327	145	82
2013	24	6	3	1
2014	958	239	106	60
2015	525	131	58	33
2016	304	76	34	19