Agribusiness and Applied Economics Report No. 815 September 2022

PROCUREMENT STRATEGIES TO IMPROVE AND ASSURE HIGHER QUALITY SOYBEANS

David W. Bullock, Ph.D.

William W. Wilson, Ph.D.

Department of Agribusiness and Applied Economics
Agricultural Experiment Station
North Dakota State University
Fargo, ND 58108-6050

Acknowledgements

The authors thank Drs. Erik Hanson and Frayne Olson for their helpful comments on an earlier version of this manuscript. The authors would also like to thank the North Dakota Soybean Council for providing funding support for this research.

Executive Summary

The purpose of this study is to analyze and compare alternative purchasing strategies to meet end-use minimum essential amino acid (EAA) requirements for soybeans grown in regions of the United States that are tributary to the Pacific Northwest (PNW) export market. A stochastic Optimized Monte Carlo Simulation (OMCS) model was developed to analyze and evaluate alternative purchasing strategies for a PNW soybean buyer who is sourcing soybeans for a quality-conscious international end-user. The model uses detailed historical data for 2013 through 2019 crops on regional soybean quality (crude protein, oil, and EAA content), basis, transportation costs, and soybean production. The results indicate that buyers can meet a high-quality EAA5 end-user requirement (i.e., Merck hog ration recommendation) with near certainty only by specifying minimum EAA5 requirements directly into the purchase contracts. This strategy also dominates from a cost-risk (SERF) perspective. Results also indicate that buying soybeans based upon a minimum protein (34%) and oil (18%) specification resulted in meeting minimum EAA5 requirements approximately 80% of the time. Targeting origins based upon soybean quality survey reports can increase the odds up to 93% but with added testing costs.

Table of Contents

List of Tables

List of Figures

Strategies to Improve and Assure Soybean Purchases for High Quality Markets

Introduction

An important challenge confronting trading in most agricultural commodities is that of quality heterogeneity. As buyers become more sophisticated, their demands for quality attributes become more specific, but at the same time, there is substantial inherent heterogeneity across supplies. Buyers typically have fairly specific requirements for which they seek to meet with a high-degree of certainty. These problems are further compounded if the buyer's end-use requirements are not customarily nor easily measured in the marketing system. Variability of quality occurs across geographic production regions, as well as across farms, and is also impacted by changes in climatic conditions and choices regarding agronomic decisions. The impact of this variability presents a challenge to buyers' procurement and supply chain strategies, and creates risks for suppliers. Indeed, an important element of supply chain strategy is having an adequate supply of commodities that conform to quality requirements.

This is true across many commodities. For example, buyers of hard wheats utilize farinograph measurements of quality characteristics, but these are not routinely measured in the marketing system. In malting barley, quality factors related to germination, fusarium, and ergot are important. For durum wheat, factors related to dough properties and pasta quality are important. More recently, end-users of soybean meal have placed more emphasis upon requirements regarding essential amino acid (EAA) measurements as it translates to feed ration quality for many livestock species. These important quality attributes are not commonly measured in the marketing system and it is typical for suppliers to use varying proxies to increase the chance that a commodity shipment conforms to these end-use requirements.

These issues are particularly important for soybeans since import demand has grown sharply as both Brazil and the United States have engaged in intense competition to meet this demand and quality differences are an important feature impacting this competition (Thakur and Hurburgh 2007). U.S. origin soybean meal typically has an advantage in digestibility and key amino acids when compared to other exporting nations (Brazil, Argentina, and India); however, given the geographic and temporal quality variability in U.S. soybean production, it is not unusual for a significant share of the crop to not conform to these additional end-use quality requirements. The result is that soybean suppliers and intermediate buyers confront the risk of not meeting end-user quality expectations, particularly if the requirements are not explicitly stated in buyer contracts.

Concerns about soybean quality related to crude protein and EAA have emerged as issues for producers, merchandisers, and agribusinesses in the soybean producing regions of the United States (Hertsgaard, Wilson and Dahl 2019). The importance of this issue has increased with the recent growth of soybean production into the Upper Midwest region of the United States. Soybeans grown in the Upper Midwest typically have lower and more variable protein levels compared with soybeans from other regions (Naeve and Miller-Garvin 2019). The importance of this problem was heightened with the 2017 crop, which had lower protein which was likely caused by adverse weather. This raised concerns related to the prospect for lower crude protein in the resulting soybean meal which caused suppliers to reduce their minimum protein guarantees in the raw soybeans. The effects of this event resulted in (a) increased feed costs, (b) abnormal spatial flows; and (c) concerns related to meeting the Chicago Mercantile Exchange soybean meal futures delivery requirements (i.e., minimum 48% protein, subsequently reduced to 47.5% in 2019) that have tighter specifications than most of the industry.

Soybean buyers have traditionally utilized implicit protein premiums for soybeans that exceed a specified minimum crude protein content with discounts for soybeans falling short of the minimum requirements. Soybeans are typically tested for crude protein content, which is determined by the amount of nitrogen within the resulting soymeal. Crude protein measures typically are not used to directly measure the EAA content of the meal, but are considered a valid proxy for this value by many in the industry. Sophisticated livestock feed rations will often require minimum EAA requirements for quality. The current problem is that the marketing system within the United States currently uses official USDA grades and standards that do not directly measure EAA content although some buyers will specify minimum soybean or soymeal crude protein levels that are a proxy for the end-user's EAA requirements. Furthermore, crude protein content has been found to be a poor predictor of overall livestock feed quality (Ravindran, Abdollahi, and Bootwalla 2014) and in fact, may be inversely related to the proportion of the five most critical EAA's (Medic, Atkinson, and Hurburgh 2014) which are lysine, cysteine, methionine, threonine, and tryptophan.

The purpose of this study is to analyze and compare alternative purchasing strategies to meet end-use minimum EAA requirements for soybeans grown in regions of the United States that are tributary to the Pacific Northwest (PNW) export market. A stochastic Optimized Monte Carlo Simulation (OMCS) model was developed to analyze and evaluate alternative purchasing strategies for PNW soybean buyers. The strategies include buying from 1) minimum cost regions provided they meet current minimum crude protein and oil content export requirements, 2) regions with highest reported (survey) crude protein content, 3) regions with highest historical reported EAA5 composite measure, 4) regions with highest current (crop year) EAA5 composite measure, and 5) minimum cost regions provided they meet minimum EAA and meal protein requirements. The model uses detailed historical data on regional soybean quality (crude protein, oil, and EAA content), basis, transportation costs, and soybean production. The data covers the 2013 to 2019 crop years for soybean production and quality, and the subsequent crop marketing years (2013/14 through 2019/20) for basis and cost variables. The geographic scope of the data covers the regions defined as USDA crop reporting districts (CRD's) that are tributary to the Pacific Northwest (PNW) export market. The model assumes that the primary decision-maker (DM) is a PNW-based soybean buyer who is purchasing raw soybeans for an international end-user who processes soybeans for a high-quality hog ration.

This paper contributes to a better understanding of supply chain management which has escalated in importance in recent years. Indeed, an important element of supply chain strategy is that of procurement. The goal of procurement and logistics management is to get the right product to the right customer at the right time at the lowest possible cost. If the product does not conform to the end-user's quality requirements there are drastic implications for the buyer. In agricultural commodity trading these implications could include: 1) having to sell the product to another buyer at a heavily discounted (i.e., fire sale) price, 2) producing an inferior product for the domestic market, or 3) placing product in storage for blending and later sale. All of these incur substantial costs to the buyer. This paper addresses a problem that is particularly important for those commodities needing to conform to specific quality specifications outside of traditional

USDA grades and standards. An analytical model is developed in the case of soybeans that optimizes the supply chain strategy under a variety of historical market and quality scenarios. The results are interesting and have implications for end-users, as well as traders and marketers seeking guidance in procurement strategy.

The organization of this paper is as follows. In the next section, additional background information is provided regarding the historical growth of soybean production in the United States along with a discussion of previous research related to the topics of soybean quality premiums, testing and quality risk management strategies. This is followed by a section discussing the data sources, database structure, and modeling methodology utilized in this study. The cost, geographic sourcing, and crop quality results from the OMCS model for each of the five alternative sourcing strategies are summarized in the next section. This is followed by a section summarizing the major results from the model and the resulting conclusions that can be drawn from these results.

Background and Previous Studies

Soybean production in the United States grew from 54 million metric tons (mmt) in 1990 to 126 mmt in 2022 (USDA-FAS *PSD Online* database[1]). Production in Brazil increased from 16 mmt to 149 mmt over the same period. Both of these markets grew in part in response to the growth of imports by China which is by far the dominant importer in the world (Wilson 2016). The growth in production was facilitated by technology, changes in farm policies, climate change, the development of more efficient transportation modes including shuttle rail shipments, and expanded export capacity.

Soybean production in the United States began as a wartime necessity during World War II (Shurtleff and Aoyagi 2004). During these early years, incredible amounts of research were put into optimizing feed rations using soybeans, harvesting and processing techniques. US soybean production was able to expand its output and move northward to the Great Plains due to breeding efforts and genetically engineered (GE) soybeans. GE soybeans were first planted for commercial use in 1996, and by 2020, 90 percent of planted area for corn, cotton, and soybeans in the United States comes from GE seed (USDA-ERS 2020). Early adoption of herbicide-resistant soybeans allowed US farmers to spray their fields with herbicides to kill weeds, more effectively manage rocks via rock rolling, decrease competition for the soybean crop, and increase yield. Soybean varieties bred to reach maturity in shorter-growing seasons such as those in the Dakotas allowed production to expand northward (Scheresky, Wilson, and Bullock 2022). States in the Upper Midwest once thought to be too cold to grow soybeans are now some of the top-producing states, and soybean production in the Deep South has decreased severely.

Brazil began its own meteoric production increases and became the second largest producer by 1975, producing over 11 mmt (Shurtleff and Aoyagi 2004). Between 2012 and 2016, Brazil's market share of Chinese purchases hovered below 50%, and in the 2017/18 crop year, both the United States and Brazil produced 120 mmt. For the 2028/29 market year, the USDA predicts that Brazil's production will surpass 160 mmt, whereas that of the United States will be lower

---

[1] https://apps.fas.usda.gov/psdonline/app/index.html#/app/home.

than Brazil by 34 mmt (Gale, Valdes, and Ash 2019).

Soybean cultivation crept northwards through Brazil, beginning in the southern states such as Paraná, Rio Grande do Sul, Santa Catarina, and Sao Paulo and expanding northward into the cerrado region which includes states such as Mato Grosso, Mato Grosso do Sul, Goiás, Minas Gerais, and Bahia as farmers create an increase in arable land. The soybean frontier was responsible for 65% of Brazil's soybean output growth from 1997 to 2017 (Gale, Valdes, and Ash 2019). During this time farmers continued to increase yields as well as practices improved. Additionally, double cropping with corn allows Brazilian farmers to have two harvests each year, taking advantage of the tropical climate.

Brazil's rapid soybean output increase has played a large role in the United States/Brazil competition. Brazilian soybeans have been cutting into US market share since the 1990's. Brazil became the most dominant soybean exporter in 2013, and US market share in 2019 was 32 percent compared to 66 percent in 1992 (Salin and Somwaru 2020). Brazil has increased production dramatically, but an increase in transportation efficiency has been an equally important factor in Brazil establishing itself as a key player for China's soybean purchases. Brazil has also proved to be competitive due to higher oil and protein content, and the country's arable land and production abilities that are unique to its geography.

The movement of soybean production northward in the United States simultaneously as China's demand grew has led to the Pacific Northwest (PNW) port being a gateway for Chinese buyers to procure U.S. soybeans (North Dakota Soybean Council 2022). The PNW port is extremely reliant on Chinese soybean imports. Clearly, exports to China are a main driver in the growth of the soybean industry, and these three countries as being interdependent on one another.

Soybean Quality Premiums and Discounts

Soybean quality differences are one of the important features in the grain trade between China and its trade partners. It is common knowledge that international grain traders and buyers regard US soybeans as deficient in quality relative to the Brazilian soybeans. For example, on May 23, 2017, commodity brokerage firm R.J. O'Brien and Associates reported the following in their daily *Market Report*:

> *…, Brazilian soybeans tend to sport higher protein and oil content than soybeans in the US as well as Argentina. Basis Brazilian soybeans at quality par in the eyes of Chinese and EU industrial crushers: US Gulf soybeans at 10c per bu discount (but subject specific seed fill weather in a specific year… have seen this discount has high as 25c). US PNW soybeans at 15c per bu discount (have seen as high as 30c discount). Argentina soybeans at 20-25c per bu discount (have seen has high as 35c discount).*

These discounts are widely regarded and have persisted in recent years. Plume (2018) described how Brazilian soybeans often receive a premium of $5 to $10 per mt. The size of these discounts is a premium in a margin-based industry. Issues about the quality differences were recently highlighted (Thomson Reuters 2021) indicating that the higher average protein levels make soybeans from Brazil “more attractive”.[2] It is common for PNW soybeans to be discounted up to 40 cents per bushel relative to the US Gulf on a China delivery basis (Wilson 2016) which translates to about $3.5-$4.0 billion a year to the United States soybean growers. Discounts on U.S. soybeans can vary by year and are generally based on reported protein content but can include foreign matter discounts as well. These issues affect other buyers who more typically would preclude specific origins (e.g., PNW) due to their perception of historically lower protein levels.

Crude protein content of soybeans exhibits considerable variation geographically (Breene et al. 1988) with northern locations (34 degrees N latitude and above) exhibiting generally lower protein content when compared to southern locations. The effects related to oil content were less clear. Using Japan Oilseed Processors Association annual data from 1972 to 1988, a study found that soybeans graded U.S. No. 2 and those from Indiana, Ohio, and Michigan growers (IOM) had a slight advantage in protein when compared to competing soybeans from Brazil, Argentina, and the Peoples Republic of China (Hurburgh et al. 1990); however, Brazil had overtaken the U.S. in the latter years of the study. The study also found considerable variation between northern / western soybean states when compared to southern states when comparing crude protein content. Also, IOM soybeans contained about 1.5 percent higher crude protein when compared to U.S. No. 2 grade. The genotype and environmental factors also play a major role in determining crude protein content (Fehr et al. 2003). One of the challenges facing soybean breeders is the tradeoff between yield and crude protein content (Helms and Orf, 1998).

The essential amino acid (EAA) content of soybeans and their resultant products are of particular importance to some buyers and end-users. While there are many EAA components, there are five of particular importance (referred to as EAA5) in livestock nutrition. These are the sulfur amino acids (methionine and cysteine) along with lysine, threonine, and tryptophan (Karau and Grayson 2014). Methionine and lysine are of particular importance to nutritional quality (Hacham et al. 2007). The sulfur amino acids play a crucial role in protein structure, metabolism, immunity, and oxidation (Bin, Huang, and Zhou 2017). Bullock, Wilson, and Thompson (2021) examined basis levels in eight North Dakota USDA crop reporting districts (CRD’s) and using a hedonic panel-regression model found a strong positive relationship between EAA5 levels and local basis. This relationship was stronger and more statistically significant than crude protein and was particularly strong with regards to methionine, threonine, and tryptophan.

In a study comparing the quality of soybeans and soybean meals from non-U.S. exporters (Argentina, Brazil, and India), Thakur and Hurburgh (2007) found that U.S. soybean meal was more consistent with higher digestibility, lower fiber, and better quality of protein (as measured by essential amino acid levels) even though Brazil held an advantage in terms of crude protein content. Ravindran, Abdollahi, and Bootwalla (2014) found that crude protein levels were a

---

[2] Details regarding FM in soybeans are included in: https://www.soyquality.com/farmer-resources/ which demonstrates how farmers can FM, and, provides some background in to the FM issue between the U.S. and China.; https://www.aphis.usda.gov/aphis/newsroom/news/sa_by_date/sa-2017/soybean-exports-to-china which describes U.S. soy’s commitment to lower weed seeds and FM in exports.; https://www.aphis.usda.gov/publications/plant_health/faq-soybeans-to-china.pdf describes China’s concerns in weed seeds found in U.S. soybean exports; and, https://www.aphis.usda.gov/publications/plant_health/fs-soybeans-to-china.pdf describes the responsibility of “participants in the U.S. grain supply chain” to implement a systems approach to lowering presence of weed seeds in U.S. soy exports.

poor predictor of overall feed quality of soybean meal while Medic, Atkinson, and Hurburgh (2014) found that lower crude protein soybeans tended to have a higher proportion of the five critical essential amino acids (EAA5).

Testing and Risk

Earlier studies analyzed quality uncertainty and procurement strategies in the case of hard red spring (HRS) wheat. Johnson, Wilson, and Diersen (2001) analyzed procurement strategies where the focus was on mitigating risks of vomitoxin. Wilson, Dahl, and Johnson (2007) was one of the first studies to recognize issues related to quality heterogeneity and that buyers could pursue alternative procurement strategies to manage their risks and costs. In this study, they used data on grade, protein and end-use performance for HRS wheat planted across 22 origins and developed an optimization model to minimize costs of procurement to meet end-use requirements of a typical end-user. Their base case was a naive strategy which allocated purchases across origins to minimize costs. In that case, the probability of meeting end-use requirements was 61 percent and purchases were allocated across most of the 22 origins indicating the importance of geographic diversification. An alternative was for functional end-use requirements to be met 90 percent of the time, but the buyer could be opportunistic. In this case the probability of meeting requirements increased to 90 percent and costs increased slightly.

In a related study Wilson and Dahl (2008) analyzed costs and risks of different strategies using a stochastic simulation model. The results showed that, when using conventional contracts, there was a substantial risk of not meeting functional trait requirements. When more specific characteristics were specified into the strategy, the simulation results indicated that the probability of meeting end-use requirements increased substantially. The results were used to derive a risk premium which was interpreted as the value to the buyer for particular varieties and farinograph tests.

The studies above are focused on strategies for purchasing after the commodity is within the marketing system. In contrast, several studies were conducted to analyze costs and risks of testing and segregating genetically modified (GM) commodities versus non-GM varieties (Wilson and Dahl 2005; Wilson and Dahl 2006; Wilson, Dahl and Jabs 2006). Each of these studies defined the supply chain to begin with the grower declaring the variety (i.e., whether the variety was GM) as it enters into the supply chain. The models were specified using stochastic optimization and were used to determine optimal testing strategies. The model was based on the assumption of the grower declaration, as well as its probably of being truthful. The handler was assumed to segregate, test, and co-mingle the commodity lots at multiple points (i.e., country elevator when receiving and shipping, and export elevator when receiving a shipping) in the marketing chain. Risks in the model included adventitious co-mingling, veracity of the grower variety declaration, testing accuracy and costs. The results were generally consistent across countries and indicated that, with variety declaration, the marketing system could utilize testing and segregation strategies which resulted in a relatively low cost and risk to buyers. In addition, Wilson and Dahl (2006) quantified risks accrued to buyers (i.e., of accepting a shipment that should be rejected) and sellers (i.e., of having a shipment rejected that should be accepted).

Issues related to variety controls and regulations in Canada resulted in further studies regarding testing and quality control. Traditionally, there were extensive regulations regarding handling, cleaning, blending and varieties within the Canadian marketing system. Over time, there was a gradual effort to relax these regulations. The impact of this relaxation was to instill greater risks on buyers. Ge et al. (2016) developed an optimization-simulation model to analyze the Canadian wheat supply chain under the new regulatory regime and to find efficient strategies for testing varieties of Canadian. The results supported the hypothesis that optimal and efficient wheat quality testing strategies could be developed under the new regulatory regime.

Recent studies analyzed quality differences in soybeans and derived optimal strategies to mitigate the quality heterogeneity effects on expected end-use requirements. Due to heterogeneity of quality across spatial markets, traders face risks for implicit and explicit discounts that are applied to entire regions that are commonly thought to have lower protein and the risk of rejected shipments (Hertsgaard, Wilson, and Dahl 2018). They found that traders confront the risk of implicit and explicit discounts that are applied to whole regions commonly thought to have lower protein and also the risk of rejected shipments. Wilson, Dahl, and Hertsgaard (2020) analyzed spatial differences in quantity and quality risk. Their model analyzed how traders can arbitrage differences in quality and shipping costs as a strategy to mitigate risks of meeting end-use requirements.

There have been other related studies of interest. Lakkakula, Bullock, and Wilson (2020) developed a Monte Carlo simulation model that used blockchain technology to manage documentation risk in soybean export markets. The results suggested that implementing a blockchain documentation system could reduce average costs by about 2.3 cents per bushel and reduce documentation and shipping time by 41 percent. These results are significant for agribusinesses that are exploring alternative supply chain strategies. Lakkakula, Bullock, and Wilson (2021) analyzed the impact of blockchain technology on asymmetric information between buyers and sellers regarding crude protein content in soybeans for PNW export. Decision trees were used to model the asymmetry of alternative strategies. The results suggest that substantial premiums of 40 to 60 cents per bushel can be realized by using blockchain technology to alleviate information asymmetries related to crude protein content in high quality soybeans.

Data and Methodology

The model utilized in this study assumes the primary decision-maker (DM) is an agency (or company) that buys soybeans on behalf of an international end-user. The soybeans are purchased at origins for delivery to the Pacific Northwest (PNW) export market. It is assumed that the DM purchases the soybeans in shuttle train (110 or more railcars) units from origin facilities that have the capability to load-out shuttle trains. The DM furnishes the transportation and is responsible for all costs of transport from the origin facility to the PNW. These costs include the rail tariff, fuel surcharges (if any), and secondary railcar market values ("daily car values" or DCV).

The end-user (whom the DM represents) is assumed to buy soybeans for use in a high-quality hog ration. Therefore, they are primarily concerned with the meal characteristics of the processed soybeans. In particular, they desire to purchase soybeans that will process into meal that meets the minimum five essential amino acid (EAA5) requirements as specified in the *Merck Veterinary Manual* (Cromwell 2016) for growing pigs between 75 and 100 pounds. The minimum requirements, specified as percentages for a 90 percent dry matter ration are as follows:

Essential Amino Acid (EAA5)	**Percent (90% Dry Matter Basis)**
Sulfur Amino Acids (Methionine plus Cysteine)	0.50
Lysine	0.84
Threonine	0.56
Tryptophan	0.15

In addition, it is assumed that the end-user desires that the meal meet the minimum protein requirements (44 percent) for soybean meal. These specifications are essentially equivalent to the "high quality" definition utilized in previous studies (Hertsgaard, Wilson, and Dahl 2019; Wilson, Dahl, and Hertsgaard 2020) regarding soybean marketing and EAA5 requirements.

Data Sources

The primary source of origin quality data was a spreadsheet database provided by the US Soybean Export Council (USSEC) that contained sample data over 7 crop years (2013 to 2019) summarized by USDA Crop Reporting Districts (CRD's). This data was developed by the University of Minnesota for use in the United Soybean Board's *United States Soybean Quality* annual reports (Naeve and Miller-Garvin 2019). The quality measurements included average protein, average oil content, and average percentages for 18 amino acids. All were reported on a 13% moisture basis along with the number of samples per CRD. Annual soybean production by CRD was obtained from the USDA-NASS *Quick Stats* (https://quickstats.nass.usda.gov/) online database.

Figure 1 (in Appendix B) shows a US map with the primary origin draw area for PNW soybeans. Using this map, a total of 27 CRD's from the states of North Dakota, South Dakota, Nebraska, Minnesota, Iowa, Kansas, and Missouri were designated as origins for procuring soybeans. Figures 2 through 8 (in Appendix B) show the CRD regions used as origins (circled in red) on each state map. Only CRD's for which quality data was reported for all seven years (2013 through 2019) were retained. This eliminated the western CRD's in North Dakota, South Dakota, Nebraska, and Kansas. Southeast Minnesota (CRD 90) was also excluded from the origins as this region is dominated by the Mississippi River which serves the Gulf export market. In Iowa, only the western-most CRD's were retained as the eastern 2/3's of the state is dominated by the Mississippi River system. Northwestern Missouri and Northeastern Kansas were also retained as they have, on occasion, supplied soybeans to the PNW market (as indicated in Figure 1).

For origin basis and transportation costs, a single shuttle train loading facility with quoted tariffs to the PNW was selected within each CRD. These facilities were selected via visual examination of the Burlington Northern Santa Fe (BNSF) rail facility map[3]. Table 1 (Appendix A) lists the facilities by CRD and a map of the locations is shown in Figure 9 (Appendix B).

Historical daily basis data for each location was obtained from *DTN ProphetX* (Data

---

[3] Located at http://www.bnsf.com/mappingtoolbox/elevatorMap/elevatorsNf.html .

Transmission Network 2022). The exact location of each facility was used if available — if the data was incomplete or missing then a location close to the facility was used. The basis was reported on a nearby futures month format and the daily values were rolled up into a marketing year (September through August) average. The daily nearby futures price for CBOT soybeans was also obtained from *ProphetX* and rolled up into a marketing year average in a similar manner.

For rail shipping costs, the current BNSF railroad tariff schedule (BNSF 4044, Item 69105) was used to derive the rail tariff for all origin locations. The tariff for 100-120 car shuttles with mechanical designation code "LO" and cubic capacity greater than 5,001 cubic feet per car was used. For historical rail fuel surcharges (FSC), the per-mile average surcharge (per bushel) for major market locations was calculated from a spreadsheet file ("Table 7: Tariff Rail Rates for Unit and Shuttle Train Shipments") downloaded the USDA-AMS *Grain Transportation Report Datasets* web-page.[4] The monthly values were converted to marketing year averages and applied to each origin based upon estimated rail miles from the origin facility to the PNW. For the daily car values (DCV), weekly data obtained from TradeWest Brokerage's *Daily Market Report* was converted to a dollars per bushel basis and rolled up into market year average values. Note that the DCV does not vary by origin location as it is a flat national rate per railcar.

Modeling Methodology

The model used[5] in this study utilized *Optimized Monte Carlo Simulation* (OMCS) which differs from more traditional approaches, such as Monte Carlo Optimization and linear/quadratic risk programming models. A key difference is that OMCS assumes that the decision-maker conducts a deterministic optimization at each iteration of Monte Carlo simulation model based upon a realization of sample values from the random distributions in the model. The decision-maker is assumed to observe the realization of these random variables, conduct the appropriate calculations for the key decision metric or metrics (such as profit per unit, total cost, etc.), and then determine the optimal values for the decision variables using a deterministic mathematical programming approach. At the end of the Monte Carlo simulation (i.e., all iterations of the model have been completed), the optimal decisions are summarized statistically using the moments and percentiles of the distribution of decision variable responses. This provides a summary of the optimal deterministic decisions using Monte Carlo to generate a series of plausible scenarios (based upon either history, fundamental forecasting, or subjective estimation) that each present an optimization problem to the decision maker.

Unlike the traditional approaches which assume the decision-maker operates under conditions of risk and uncertainty, the OMCS approach assumes the decision-maker has access to deterministic information before making their decisions. This approach has been used to model global trade flows in both corn (Wilson, Lakkakula, and Bullock 2022) and soybeans (Scheresky, Wilson, and Bullock 2022) where the objective was to minimize logistics costs. In both cases, it was assumed that the market participants had the opportunity to observe market prices (basis)

---

[4] Located at https://www.ams.usda.gov/services/transportation-analysis/gtr-datasets.

[5] The OMCS methodology is novel in logistics and trade modeling. The model's details are discussed in Figueira, and Almada-Lobo (2014) where which they referred to as *sequential simulation-optimization* (SSO) models. These methods are also described and compared in Hardaker et. al., (2015), Chapter 9.

and transportation costs (rail, barge, and ocean) before making their optimal decisions. This is a reasonable assumption as most participants in commodity marketing do not operate in an informational vacuum and have ready access to market related information.

Because the historical dataset used are quite broad in terms of number of random variables (27 CRD's times 11 variables per CRD plus 2 global variables which equals a total of 299 random variables) relative to the number of years (7 from 2013 to 2019), the *historical simulation* method was used to simulate the CRD and global random variables. This method essentially randomly chooses a year (2013 to 2019 with equal probability assigned to each) and then looks up the actual CRD and global variable values that match for that particular year. The advantage of this approach is that it implicitly incorporates the historical distribution and correlation structure contained in the dataset. The main drawback is that it does not consider the possibility of values outside the historical range; however, since this is an OMCS model that examines optimal behavior across historically plausible scenarios, it is less of a drawback when compared to a traditional risk modeling approach.

As an example of how this would work, suppose an iteration of the model randomly drew 2015 as the crop year. Each of the individual CRD's historical data are set up in Excel lookup tables. Therefore, for CRD 50 in North Dakota, the model would pull in the quality survey values for average protein, oil content, cysteine, lysine, methionine, threonine, tryptophan, and number of survey samples from the third row of the CRD's lookup table. Additional values pulled from this row would include the CRD's total production (in bushels), market year average basis, and rail tariff (current 2022 value regardless of year) plus fuel surcharge (MY average). The third row would also be pulled for the values from the remaining 26 CRD's in the model. Additionally, for the global variables (MY average nearby futures price and daily car value), these would also be pulled from row three of their lookup table.

The quality variables (protein, oil, and EAA5) from the lookup tables represent the average values based upon a limited number of sample observations in the quality survey. While this is representative of the sample survey, it may not be completely representative of the true average values for the entire CRD. This additional potential variability was incorporated by simulating a sample error around the mean survey value to derive the actual mean value for the delivered soybeans. The sampling distribution of the mean is distributed as normal with mean equal to the sampled mean and standard deviation equal to $\sigma/\sqrt{n}$ where σ is the sample standard deviation and n is the size of the sample. Unfortunately, the sample standard deviations were not reported in the database so as a proxy, the standard deviation of observed sample mean values across the 7 years was used. The number of samples was reported in the database and was used for the value of n. Therefore, the model generates two sets of quality variables for each CRD: (1) the reported survey mean values, and (2) the actual mean value for the delivered soybeans which reflects the sample mean plus/minus a simulated sampling error based upon the 7-year standard deviation and the number of samples taken in the survey.

The cost of elevation at the origin elevators was also simulated in the model. Since the quoted basis values in the DTN ProphetX database are offer prices to farmers, it is necessary to add elevator handling to these prices to get an on-track delivered equivalent for the buyer. These charges vary over time due to changes in the cost components that compose the elevator handling charge. No reliable historical database exists for this variable; therefore, the model utilized a subjective distribution that summarizes discussions conducted with market participants. These discussions indicated that the elevator handling charge can vary from a minimum of 15 to a maximum of 65 cents per bushel with a modal range between 30 to 40 cents as the most likely values. Figure 10 (Appendix B) shows an illustration of the subjective distribution. Note that for each iteration, the same simulated handling cost was applied to all CRD origins — so the variation is purely an inter-temporal rather than a geographic effect.

To calculate the delivered price to the PNW from each CRD, the following formula was used:

$$\tilde{p}_i = \tilde{f} + \tilde{b}_i + \tilde{h} + t_i + \tilde{s}_i + \tilde{d}, \tag{1}$$

where p is the delivered PNW price, b is the origin farmer basis, h is the origin elevator handling charge, t is the railroad published tariff, s is the rail fuel surcharge (FSC), and d is the rail daily car value (DCV). All variables are in dollars per bushel with the tilde (~) indicating a random simulated value and the i subscript ($i = 1, \ldots, 27$) indicating the origin CRD. Note that for the tariff (t), the value is fixed at the current (June 2022) value are nonrandom.

For determining the protein content of soybean meal (12% moisture basis) based upon the raw soybean characteristics, the following equation[6] from Updaw, Bullock, and Nichols (1976) was used:

$$Z = -0.1343 + 0.6712 \cdot X + 1.3203 \cdot Y, \tag{2}$$

where Z is the pounds of protein content per pound of soybean meal, X is the oil content of the raw soybean, and Y is the protein content of the raw soybean (all are expressed in decimal format). For converting the survey reported essential amino acid (EAA) contents of the raw soybeans into a meal equivalent, it was assumed that the same ratio of each EAA to protein was the same in the raw soybean and the meal. Therefore, the EAA were converted to meal equivalents by multiplying their survey percentage values by the calculated meal percentage (Z). This resulted in the EAA for 12% moisture soybean meal. To convert EAA to the Merck ration equivalent (90% dry matter), the meal values were multiplied by the ratio of the moisture contents (0.12 over 0.10).

The model assumes that the primary decision-maker (DM) has the goal of buying enough soybeans to fill one 70,000 metric ton Panamax vessel per year. This equates to purchasing approximately 7 shuttle trains (110 cars each) per year or approximately 2.82 million bushels of soybeans per year. It is assumed that the soybeans are purchased from the origins in shuttle train units; therefore, the optimization problem involves allocating the 7 shuttle trains across the 27 origin CRD's. This lumpiness required use of integer programming to solve the optimization problem. An additional supply constraint added to the model stipulated that the DM's purchases from any CRD could not exceed 10 percent of its total reported production. This constraint is incorporated to account for competition from other buyers in the region and capacity constraints at the origin shuttle facility.

A set of five alternative purchasing strategies were evaluated using the OMCS model. These

---

[6] Equation 4 in Updaw, Bullock, and Nichols (1976).

strategies are described in Table 2 (Appendix A). The first strategy (Strategy 1 or BASE) assumes the DM sources the soybeans at the minimum cost provided the delivered soybeans meet the minimum export requirements for protein (greater than or equal to 34 percent) and oil content (greater than or equal to 18 percent). This would represent the standard strategy likely deployed by current soybean buyers who buy on international standards for protein and oil. Whether the soybeans meet the Merck EAA5 ration requirements is merely left to chance.

The second strategy (Strategy 2 or MAX PROTEIN) assumes the DM purchases the soybeans from CRD's producing the highest surveyed protein regardless of the delivered price. This strategy would represent the buyer assumption that protein is a valid proxy for EAA5 and buying from CRD's based upon maximum reported protein would represent the best strategy to meet the Merck EAA5 ration requirements.

The third strategy (Strategy 3 or MAX HISTORICAL EAA5) assumes the DM purchases the soybeans from CRD's that have reported the highest average sum of EAA5 over the 7-year sample period regardless of the average price. In this strategy, switching regional purchases from one iteration to the next would be based purely on whether supply constraints apply (based upon random production). This strategy would be followed by a buyer who doesn't wait for the annual quality data to be released and believes they can maximize their chances of meeting the Merck EAA5 ration requirements by buying from the CRD's with the highest long-term average sample values.

The fourth strategy (Strategy 4 or MAX SURVEY EAA5) assumes the DM purchases the soybeans from CRD's that have the highest annual reported sum of EAA5 regardless of price. This strategy is similar to Strategy 3 except that the DM will wait until the quality reports are released and then buy from the highest reported CRD's with supply constraints applying.

The fifth strategy (Strategy 5 or RESTRICT ORIGIN EAA5) assumes the DM purchases the soybeans based upon minimum average price with the constraint that the delivered soybeans must meet all of the Merck hog ration requirements and the mean meets a minimum 44 percent protein. This strategy requires the DM to have the deliveries tested at the origin for meeting the EAA5 and meal protein requirements at an additional cost. The DM would use the survey information to find the CRD's with the highest probability of meeting the specifications and would then buy under the strict EAA5 and protein constraints. This strategy assures the DM of receiving soybeans meeting the Merck hog ration requirements at the minimum possible cost. This strategy would be similar to Strategy 1 except the raw protein and oil constraint would be replaced by the ration EAA5 and meal protein constraints.

For each strategy, a risk-adjusted, weighted-average net delivered price was calculated. The formula for this price is as follows (based upon a constant absolute risk aversion or CARA utility function):

$$\pi(\lambda) = \mathrm{E}[\mathbf{p}'] + \frac{1}{2} \cdot \lambda \cdot \mathrm{Var}\left[\mathbf{p}'\right], \tag{3}$$

where π is the risk-adjusted net delivered price, λ is the DM's risk aversion coefficient, **p'** is a 1 x *m* vector of optimal weighted-average delivered prices with *m* as the number of simulation iterations, E[.] is the expectation operator, and Var[.] is the variance operator. The weighted-average delivered prices for each optimization were calculated using the following formula:

$$p' = \left(\sum_{i=1}^{27} \tilde{p}_i \cdot q_i^{'} \right) / \left(\sum_{i=1}^{27} q_i^{'} \right), \tag{4}$$

where $\tilde{p}_i$ is defined by equation (1) and q_i' represents the optimized quantity (in bushels) purchased from CRD *i*. A set of five values for λ (0, 0.0005, 0.005, 0.05, and 0.5) was used to illustrate the risk-adjusted delivery price across a range of DM risk preferences. These range from totally risk neutral (λ = 0) to an extremely high level of risk aversion (λ = 0.5). In addition to the risk-adjusted delivery prices, the probability of any or all of the quality constraints was calculated for each strategy along with the average percentage share (of total quality purchased) by each origin state (sum of CRD's in state).

The Optimized Monte Carlo Simulation (OMCS) model was constructed using Palisade's *@Risk* (Palisade Software 2022a) simulation add-in to Microsoft Excel (Microsoft Corporation 2022). The Palisade *Evolver* (Palisade Software 2022b) optimization add-in to Excel was used to conduct the iterative optimizations in the model (as defined in Table 2). Using convergence criteria, it was determined that 500 iterations of the model was sufficient to assure reasonable convergence in the mean results. Because each iteration required running a complicated integer-programming optimization in *Evolver*, the average runtime for each simulation was 6 to 7 hours. To assure comparability of the results, each simulation was run with the initial seed value (for random number generation) fixed to a value of '20220524'.

Results

Figure 11 (Appendix B) shows a *stochastic efficiency with respect to a function* (SERF) plot of the risk-adjusted delivered soybean prices for each strategy with the numeric values also presented in Table 3 (Appendix A). The results show that Strategy 5 (RESTRICT ORIGIN EAA5) stochastically dominates the other strategies as the lowest cost to the decision-maker (DM). On average, it is approximately 5.5 cents per bushel below the next lowest strategy (Strategy 1 - BASE). Origin inspection costs are not included in either strategy, so the dominance of Strategy 5 would hold provided that the additional inspection cost of testing for EAA5 at the origin was less than or equal to 5.6 cents per bushel. Hertsgaard, Wilson, and Dahl (2019) found that testing for all EAA in origin soybeans would cost approximately $10 per test or 0.12 cents per bushel (in addition to the 0.15 cents to test for protein and oil). Therefore, it can be concluded that Strategy 5 is the dominant strategy from a risk-adjusted cost perspective.

Strategies 2, 3, and 4 all have significantly higher risk-adjusted prices (26 to 54 cents per bushel more than Strategy 5) since cost-minimization was not part of the objective functions under these strategies. Strategy 4 (highest annual surveyed EAA) had the highest cost across all except for the more risk averse DM where Strategy 3 (higher long-term average EAA) is highest due to the greater variability in cost (i.e., higher risk premium) under this strategy.

Table 4 (Appendix A) shows the average volume share by state for each of the five strategies. North Dakota is the lowest cost state for delivered price to the PNW given its location; therefore, it has the largest share for both of the cost-minimization strategies (1 and 5). However, it is important that each strategy requires a diversification across origins. South Dakota and Nebraska are also relative low cost for delivery of soybeans to the PNW; therefore, they also figure prominently in the two cost minimization strategies. In both cost minimization strategies, the DM has to reach into the more eastern to southern states (Minnesota, Kansas, and Missouri) less frequently (10 to 12 percent of average volume) due to supply and/or quality requirement constraints. Western Iowa has significant soybean processing capabilities which result in stronger local basis values and result in Iowa soybeans being price uncompetitive for shipment to the PNW.

For Strategy 2 (MAX PROTEIN), Kansas CRD 40 typically has the highest reported sample protein of all CRD’s in the dataset. Nebraska CRD 80 also has a high average reported protein; however, it exhibits more year-to-year variability when compared to Kansas. The same can be said for South Dakota CRD’s 20 and 30.

For Strategy 3 (MAX HISTORICAL EAA5), Nebraska CRD 80 has the highest average sum of the EAA5 over the 7-year sample period. Kansas CRD’s 40 and 70 have the second and third highest averages followed by Missouri CRD 10. On average, Nebraska CRD 80 produces enough soybeans to meet the DM’s supply constraint (max 10% of total production); however, approximately 43% of the time, the supply constraint is binding, and the DM has to look to Kansas and Missouri to fill the remaining balance.

For Strategy 4 (MAX SURVEY EAA5), while the Nebraska CRD has the highest average, this result is skewed by the 2018 value. In terms of year-to-year results, the Kansas CRD’s are able to deliver a more consistently high EAA5 value and therefore, have the highest share under this strategy, followed by Nebraska, South Dakota, and Missouri.

Table 5 (Appendix A) shows the percent of time (out of 500 iterations) the quality constraints were met along with the average meal protein (based upon formula in equation 2) content on 12% moisture basis. For Strategy 1, which was buying the lowest delivered price soybeans provided the delivered (not survey) soybeans met the minimum protein (34.0%) and oil (18.0%) content requirements. Under this strategy, all of the individual EAA5 minimum requirements were met 80.4% of the time. The average protein content of the meal was 44.3 percent.

Buying from CRD’s that had the highest surveyed protein content each year (Strategy 2) resulted in the protein and oil requirements being met 100 percent of the time. For the EAA5 individual requirements, all were met 91.8 percent of the time which was an increase of 11.4 percent from the base strategy. The average meal protein content also increased by over a percentage point to 45.5 percent.

Buying from the CRD’s that had the highest 7-year average sum of EAA5 (Strategy 3) resulted in lower probability of meeting protein (85.2%) and oil (97.0%) requirements. Also, all of the individual EAA5 requirements were only met 81.6 percent of the time, only a slight improvement over Strategy 1. The delivered meal protein content was 44.7 percent.

Buying from the CRD’s with the highest reported sum of EAA5 (Strategy 4) resulted in a 100 percent probability of meeting the minimum protein and oil requirements. The EAA5 requirements were completely met 92.8 percent of the time. As with the previous three strategies, the limiting EAA tended to be the sulfuric amino acids (cysteine and methionine) with tryptophan as slightly limited under Strategies 1 through 3.

Buying from CRD's with the lowest delivered price provided the delivered soybeans met all of the EAA minimum requirements and also met the 44.0 percent minimum meal protein requirement (Strategy 5) resulted in all the EAA requirements being met 100 percent of the time by definition. The strategy had the lowest probability (75.2%) of meeting the minimum protein requirement of 34.0 percent. However, the protein content of the meal was 44.3 percent despite the soybeans themselves not meeting the 34 percent threshold.

Summary and Conclusions

Quality heterogeneity is an important problem in commodity trading, particularly for grains and oilseeds. It has emerged as a very important problem for the United State industry confronting competition, notably from Brazil, and other regions. Quality heterogeneity in United States soybeans is characterized as a high degree of variability among non-USDA grade quality attributes (crude protein and essential amino acid content) which varies across origins and through time. This is further compounded by the fact that specifying these additional quality attributes in purchase contracts is not a common practice in the U.S. soybean industry. As a result, there is both buyer risk of not meeting desired requirements, and seller risk of not being able to conform to buyers' requirements. These are common problems in commodity trading and a major challenge in supply chain strategy.

The purpose of this study was to analyze and compare alternative purchasing strategies to meet end-use minimum EAA requirements for soybeans grown in regions of the United States that are tributary to the Pacific Northwest (PNW) export market. A stochastic Optimized Monte Carlo Simulation (OMCS) model was developed to analyze and evaluate five alternative purchasing strategies for a soybean buying agency the procures soybeans to a quality-conscious international end-user. In particular, the end-user is assumed to purchase the soybeans for crush into a high-quality meal for hog rations based upon the five essential amino acids (EAA5) content of the soybeans. The soybeans are purchased for export out of the Pacific Northwest (PNW) ports of exit.

The objective of the OMCS model was to determine the amounts procured from the supplying origins (shuttle train facilities located in 27 crop reporting districts across the states of North Dakota, South Dakota, Nebraska, Minnesota, Iowa, Kansas, and Missouri) based upon varying objective functions and constraints. The simulation uses historical quality (crude protein, oil, and EAA5) survey data from each origin crop reporting district (CRD) for the 2013 through 2019 crop years. This data is supplemented with annual production, nearby basis, and transportation cost data from each CRD. At each iteration, the buying agency is presented with a set of randomly generated quality and market values, and then optimizes their decision based upon the procurement strategy objective function and constraints.

The optimized strategy results from the OMCS models were compared on the basis of their risk-adjusted net prices (delivered to the PNW) and the frequency (percent of iterations) that the delivered soybeans met the protein, oil, and EAA5 requirements. The risk-adjusted net delivered prices were calculated using a range of constant absolute risk aversion (CARA) coefficient values ranging from completely risk neutral to extremely risk averse. Strategies were evaluated for dominance using stochastic efficiency with respect to a function (SERF) as the decision criterion.

The SERF analysis results clearly show that buying the soybeans at the origin with the binding constraint that the delivered soybeans meet the minimum EAA5 and meal protein requirements was the dominant strategy. This dominance was conditional upon the cost of origin EAA5 testing being equal to less than 5.6 cents per bushel. Previous research (Hertsgaard, Wilson, and Dahl 2019) had found that EAA5 testing costs were around 0.12 cents per bushel; therefore, this condition should be met in most situations.

Constraint analysis on the dominant delivered cost strategy indicated that the buyer would have to be willing to relax the minimum protein and oil requirements for the raw soybeans (34.0% and 18.0% respectively) in order to meet all of the EAA5 requirements with certainty. Under this dominant cost strategy, soybeans would be procured from North Dakota most often (39.2%) on an average volume basis. Other major supplying states (in order of average volume) were Nebraska (33.3%) and South Dakota (16.0%). The remaining volume (11.5%) would come from the states of Kansas, Minnesota, and Missouri. Soybeans would be originated from Iowa under none of the simulated scenarios.

The second-best strategy was to relax the EAA5 requirements and to purchase the soybeans with origin constraints placed on the raw soybean's protein (34.0%) and oil (18.0%) content. Under this strategy, the risk-adjusted delivery prices were approximately 5.6 to 7.9 cents per bushel higher than the optimal strategy. Across the 500 iterations of the model, the minimum EAA5 requirements were met 80.4 percent of the time. Under this strategy, soybeans would also be procured from North Dakota with a higher average volume (52.3%) followed by Nebraska (24.7%) and South Dakota (12.1%). The remaining balance (10.8%) would come from Kansas, Minnesota, and Missouri with Iowa delivering none.

The remaining three strategies involved purchasing soybeans based solely on the highest reported survey values for either protein or the sum of EAA5 (7-year or annual average). These strategies all involved significantly higher risk-adjusted delivery prices (26 to 54 cents per bushel above the optimal strategy) and none completely met the EAA5 minimum requirements for all of the iterations. Two of the three strategies did meet with minimum protein and oil requirements for 100% of the iterations.

These results clearly show that soybean buyers concerned about EAA5 content can achieve 100% compliance with these requirements in a cost-effective manner by specifying minimums and testing at the origin if they are willing to relax the minimum protein and oil specifications. If they are concerned about meeting the protein and oil minimums, the results show that they should be able to still meet the minimum EAA5 requirements over 80 percent of the time. In both cases, the Northern Plains states of North Dakota, South Dakota, and Nebraska clearly have the capability of delivering soybeans meeting these requirements most of the time. Occasionally (11 to 12 percent of the time), the buyer will find it necessary to source soybeans at a greater distance in the more eastern states of Kansas, Minnesota, and Missouri.

There are a number of implications of these results for participants in the PNW soybean export market. First, buyers of soybeans can assure themselves of meeting end-user essential amino acid (EAA) requirements best by specifying the minimums directly in the origin contracts. In terms of a high-quality hog ration specification (Cromwell 2016), buyers of soybeans at origins serving the PNW export market can meet these requirements with near certainty each year if they are willing to waive crude protein and oil requirements for the bean in lieu of minimum meal protein requirements based upon technical formulas such as Updaw, Bullock, and Nichols (1976). This strategy also has the advantage of being the lowest cost (from a delivered price and risk premium perspective) among all of the strategies examined in this study as long as the added costs (inspection, premiums, etc.) are less than 5.5 cents per bushel.

Second, buying soybeans from PNW origins under traditional minimums for crude protein (34%) and oil (18%) in the raw bean will meet the high-quality EAA5 specification approximately 80 percent of the time. Targeting specific origins based upon reported quality survey results can increase these odds to 92-93 percent.

Third, these results have important implications for other market participants (i.e., farmers, commodity organizations, origin elevators, merchandisers, etc.) as they indicate that PNW origins can meet the end-user requirements of high-quality feed markets (in terms of essential amino acids). This is with the caveat that a mechanism must be created that supports origin testing for protein, oil, and EAA attributes to meet end-user contractual requirements.

Fourth, a majority of the time (over 88 percent), the minimum EAA5 requirements can be met by the western soybean producing states within the PNW tributary region (North Dakota, Nebraska, and South Dakota) with North Dakota typically holding the largest share under a minimum cost purchasing scenario. Only approximately 12 percent of the time does the buyer have to extend purchases into the eastern states (Minnesota, Kansas, and Missouri) which typically have higher costs due to Mississippi River system and domestic processing competition, and higher transportation costs to the PNW.

References

Bin, P., R. Huang, and X. Zhou. 2017. “Oxidation Resistance of the Sulfur Amino Acids: Methionine and Cysteine.” *BioMed Research International* 2017:1–6.

Breene, W.M., S. Lin, L. Hardman, and J. Orf. 1988. “Protein and Oil Content of Soybeans from Different Geographic Locations.” *Journal of the American Oil Chemists’ Society* 65(12):1927–1931.

Bullock, D.W., W.W. Wilson, and R. Thompson. 2021. “Impacts of Non-Grade Quality Factors on North Dakota Origin Soybean Basis Values: A Panel Regression Approach.” In NCCC-134 Conference on Applied Commodity Analysis, Forecasting, and Market Risk Management. Online, p. 26. Available at: https://legacy.farmdoc.illinois.edu/nccc134/conf_2021/pdf/Bullock_Wilson_Thompson_NCCC-134_2021.pdf [Accessed June 28, 2022].

Cromwell, G.L. 2016. “Nutritional Requirements of Pigs.” In *Merck Veterinary Manual*. Rahway, NJ: Merck and Company. Available at: https://www.merckvetmanual.com [Accessed May 31, 2022].

Data Transmission Network. 2022. *ProphetX*.

Fehr, W.R., J.A. Hoeck, S.L. Johnson, P.A. Murphy, J.D. Nott, G.I. Padilla, and G.A. Welke. 2003. “Genotype and Environment Influence on Protein Components of Soybean.” *Crop Science* 43(2):511–514.

Figueira, G., and B. Almada-Lobo. 2014. “Hybrid Simulation–Optimization Methods: A Taxonomy and Discussion.” *Simulation Modeling Practice and Theory* 46:118–134.

Gale, F., C. Valdes, and M. Ash. 2019. “Interdependence of China, United States, and Brazil in Soybean Trade.” No. OCS-19F-01, USDA Economic Research Service. Available at: https://www.ers.usda.gov/webdocs/outlooks/93390/ocs-19f-01.pdf [Accessed June 23, 2022].

Ge, H., J. Nolan, R. Gray, S. Goetz, and Y. Han. 2016. “Supply Chain Complexity and Risk Mitigation – a Hybrid Optimization–Simulation Model.” *International Journal of Production Economics* 179:228–238.

Hacham, Y., L. Song, G. Schuster, and R. Amir. 2007. “Lysine Enhances Methionine Content by Modulating the Expression of S-adenosylmethionine Synthase: Lysine Affects the Expression Level of SAMS and Methionine Content.” *The Plant Journal* 51(5):850–861.

Hardaker, J.B., G. Lien, J.R. Anderson, and R.B.M. Huirne. 2015. *Coping with Risk in Agriculture: Applied Decision Analysis* Third Edition. Boston, MA: CABI.

Helms, T.C., and J.H. Orf. 1998. “Protein, Oil, and Yield of Soybean Lines Selected for Increased Protein.” *Crop Science* 38(3):707–711.

Hertsgaard, D.J., W.W. Wilson, and B. Dahl. 2019. “Costs and Risks of Testing and Blending for Essential Amino Acids in Soybeans.” *Agribusiness* 35(2):265–280.

Hurburgh, C.R., T.J. Brumm, J.M. Guinn, and R.A. Hartwig. 1990. “Protein and Oil Patterns in U.S. and World Soybean Markets.” *Journal of the American Oil Chemists’ Society* 67(12):966–973.

Johnson, D.D., W.W. Wilson, and M.A. Diersen. 2001. “Quality Uncertainty, Procurement Strategies, and Grain Merchandising Risk: Vomitoxin in Spring Wheat.” *Applied Economic Perspectives and Policy* 23(1):102–119.

Karau, A., and I. Grayson. 2014. “Amino Acids in Human and Animal Nutrition.” In H. Zorn and P. Czermak, eds. *Biotechnology of Food and Feed Additives*. Advances in Biochemical Engineering/Biotechnology. Berlin, Heidelberg: Springer, pp. 189–228. Available at: https://doi.org/10.1007/10_2014_26.

Lakkakula, P., D. Bullock, and W. Wilson. 2020. “Blockchain Technology in International Commodity Trading.” *The Journal of Private Enterprise* 35(2):23–46.

Lakkakula, P., D.W. Bullock, and W.W. Wilson. 2022. “Asymmetric Information and Blockchains in Soybean Commodity Markets.” *Applied Economic Perspectives and Policy* 44(1):273–298.

Medic, J., C. Atkinson, and C.R. Hurburgh. 2014. “Current Knowledge in Soybean Composition.” *Journal of the American Oil Chemists’ Society* 91(3):363–384.

Microsoft Corporation. 2022. *Microsoft Excel 2019*. Microsoft Corporation.

Naeve, S., and J. Miller-Garvin. 2019. “United States Soybean Quality: Annual Report 2019.” Available at: https://28vp741fflb42av02837961y-wpengine.netdna-ssl.com/wp-content/uploads/2020/02/2019-US-Soybean-Quality-Report.pdf?segid=cecb10dd-9466-45e1-a5b8-5693ccfc9cdd [Accessed November 9, 2020].

North Dakota Soybean Council. 2022. “Everything You Need to Know About North Dakota Soybeans.” Available at: https://ndsoybean.org/soybean-stats/ [Accessed July 5, 2022].

Palisade Software. 2022a. *Evolver: Optimization Add-in for Microsoft Excel*. Ithaca, NY: Palisade Software, Inc.

Palisade Software. 2022b. *@Risk: Advanced Risk Analysis for Microsoft Excel*. Ithaca, NY: Palisade Software, Inc.

Plume, K. 2018. “Protein Plight: Brazil Steals U.S. Soybean Share in China.” *Reuters*. Available at: https://www.reuters.com/article/us-usa-soybeans-protein-insight/protein-plight-brazil-steals-u-s-soybean-share-in-china-idUSKBN1FE0FM [Accessed March 23, 2021].

Ravindran, V., M. Abdollahi, and S. Bootwalla. 2014. “Nutrient Analysis, Apparent Metabolisable Energy and Ileal Amino Acid Digestibility of Full Fat Soybean for Broilers.” *Animal Feed Science and Technology* 197:233–240.

Salin, D., and A. Somwaru. 2020. "The Impact of Brazil's Infrastructure and Transportation Costs on U.S. Soybean Market Share: An Updated Analysis From 1992-2019." USDA Agricultural Marketing Service. Available at: https://www.ams.usda.gov/sites/default/files/media/SoybeanMarketShare1992_2019.pdf [Accessed June 23, 2022].

Scheresky, G., W.W. Wilson, and D.W. Bullock. 2022. "Spatial and Logistical Competition for Shipments to China from the United States and Brazil." No. 812, North Dakota State University, Department of Agribusiness and Applied Economics.

Shurtleff, W., and A. Aoyagi. 2004. "History of World Soybean Production and Trade - Parts 1 and 2." In *History of Soybeans and Soyfoods, 1100 B.C. to the 1980's*. Lafayette, California: Soyfoods Center. Available at: https://www.soyinfocenter.com/HSS/production_and_trade1.php [Accessed June 23, 2022].

Thakur, M., and C.R. Hurburgh. 2007. "Quality of US Soybean Meal Compared to the Quality of Soybean Meal from Other Origins." *Journal of the American Oil Chemists' Society* 84(9):835–843.

Thompson Reuters. 2021. "Higher Average Protein Levels Make Brazilian Soybeans More Attractive for Crushers When Delivered Prices Are the Same." *Inside Commodities*.

Updaw, N.J., J.B. Bullock, and T.E. Nichols. 1976. "Pricing Soybeans on the Basis of Oil and Protein Content." *Journal of Agricultural and Applied Economics* 8(2):129–132.

USDA-ERS. 2020. "Recent Trends in GE Adoption." *Online Article*. Available at: https://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-us/recent-trends-in-ge-adoption/ [Accessed June 23, 2022].

Wilson, W.W. 2016. "China: The World's Largest Soybean Market: How Vital Is It to North Dakota?"

Wilson, W.W., and B. Dahl. 2006. "Costs and Risks of Segregating GM Wheat in Canada." *Canadian Journal of Agricultural Economics* 54(3):341–359.

Wilson, W.W., B. Dahl, and D. Hertsgaard. 2020. "Soybean Quality Differentials, Blending, Testing and Spatial Arbitrage." *Journal of Commodity Markets* 18:100095.

Wilson, W.W., and B.L. Dahl. 2005. "Costs and Risks of Testing and Segregating Genetically Modified Wheat." *Applied Economic Perspectives and Policy* 27(2):212–228.

Wilson, W.W., and B.L. Dahl. 2008. "Procurement Strategies to Improve Quality Consistency in Wheat Shipments." *Journal of Agricultural and Resource Economics* 33(1):69–86.

Wilson, W.W., B.L. Dahl, and D. Demcey Johnson. 2007. "Quality Uncertainty and Challenges to Wheat Procurement." *Canadian Journal of Agricultural Economics* 55(3):315–326.

Wilson, W.W., B.L. Dahl, and E. Jabs. 2007. “Optimal Supplier Testing and Tolerance Strategies for Genetically Modified (GM) Wheat.” *Agricultural Economics* 36(1):39–48.

Wilson, W.W., P. Lakkakula, and D.W. Bullock. 2022. “Logistical Competition for Corn Shipments from the United States and Ukraine to Targeted International Markets.” No. 811, North Dakota State University, Department of Agribusiness and Applied Economics.

Appendix A – Tables

Table 1. CRD Pricing Locations Used in Study

CRD	Elevator Number	Location	Elevator Name	Track Capacity
ND30	1024	Lakota, ND	CHS Inc.	120
ND50	2334	Sterling, ND	South Central Grain	110
ND60	918	Casselton, ND	Maple River Grain And Agronomy LLC	110
ND90	3373	Gwinner, ND	CHS Inc.	110
SD20	1328	Selby, SD	CHS Inc.	111
SD30	1251	Grebner, SD	Agtegra Coop	111
SD50	1290	Harrold, SD	ADM-Benson Quinn	110
SD60	1257	Alpena, SD	Agtegra Coop	113
SD90	2446	Beardsley, SD	Dakota Plains Ag Center LLC	112
NE20	796	O'Neill, NE	Cargill Inc.	110
NE30	800	Oakland, NE	Central Valley Ag	110
NE50	3243	Anselmo, NE	The Andersons Inc.	110
NE60	711	Fremont, NE	Interstate Commodities Inc.	112
NE70	3282	Culbertson, NE	Frenchman Valley Farmers Coop	125
NE80	736	Hastings, NE	Cooperative Producers Inc.	112
NE90	642	Beatrice, NE	Farmers Cooperative Inc.	110
MN10	312	Crookston, MN	CHS Ag Services	112
MN40	360	Holloway, MN	Western Consolidated Cooperatives	115
MN50	3257	St. Cloud, MN	ADM Benson Quinn	117
MN70	424	Ruthton, MN	CHS Inc.	110
MN80	5236	New Ulm, MN	Farmers Co-Op Of Hanska	115
IA10	164	Hinton, IA	Central Valley Ag Coop	111
IA40	195	Templeton, IA	Landus Cooperative	113
IA70	186	Red Oak, IA	United Farmers Cooperative	113
KS40	1690	Concordia, KS	Agmark LLC	120
KS70	1987	Topeka, KS	Cargill Inc. (Gordon/West)	110
MO10	492	St. Joseph, MO	Bartlett Grain Company LP	112

Table 2. Summary of Five Purchasing Strategies Analyzed in Study

Strategy Number	Strategy Name	Optimization Goal	Optimization Constraints
1	BASE	**Minimize** Delivered Average Price	1) Delivered Protein Content >= 34.0 percent, 2) Delivered Oil Content >= 18.0 percent, 3) CRD Purchased Quantity <= 10% of CRD Annual Production.
2	MAX PROTEIN	**Maximize** Delivered Average Protein based on Survey	1) CRD Purchased Quantity <= 10% of CRD Annual Production.
3	MAX HISTORICAL EAA5	**Maximize** Delivered Average EAA5 Based on 7-year Average of Surveyed	1) CRD Purchased Quantity <= 10% of CRD Annual Production.
4	MAX SURVEY EAA5	**Maximize** Delivered Average EAA5 Based on Annual Survey Results	1) CRD Purchased Quantity <= 10% of CRD Annual Production.
5	RESTRICT ORIGIN EAA5	**Minimize** Delivered Average Price	1) All minimum EAA5 hog ration requirements (Merck) met simultaneously in delivered, 2) Minimum meal protein content (Updaw et al. formula) >= 44.0 percent in delivered, 3) CRD Purchased Quantity <= 10% of CRD Annual Production.

Table 3. Numerical Stochastic Efficiency (SERF) Results by Strategy

Risk-Adjusted Delivered Soybean Cost (π)					
Risk Aversion Coef (λ)	**Strategy 1**	**Strategy 2**	**Strategy 3**	**Strategy 4**	**Strategy 5**
0.0000	$ 11.3034	$ 11.6066	$ 11.5076	$ 11.6374	$ 11.2471
0.0005	$ 11.3043	$ 11.6075	$ 11.5088	$ 11.6383	$ 11.2480
0.0050	$ 11.3124	$ 11.6158	$ 11.5191	$ 11.6465	$ 11.2558
0.0500	$ 11.3930	$ 11.6981	$ 11.6227	$ 11.7282	$ 11.3344
0.5000	$ 12.1995	$ 12.5212	$ 12.6584	$ 12.5454	$ 12.1203

Table 4. OMCS Results for Average Percent of Total Volume Procured by Origin State

	Average Percentage (by volume) of Soybeans Procured by Origin State				
State	**Strategy 1**	**Strategy 2**	**Strategy 3**	**Strategy 4**	**Strategy 5**
North Dakota	52.3%	0.0%	0.0%	0.0%	39.2%
South Dakota	12.1%	18.5%	0.0%	14.4%	16.0%
Nebraska	24.7%	13.6%	93.6%	16.7%	33.3%
Minnesota	4.4%	0.0%	0.0%	0.0%	3.7%
Iowa	0.0%	0.0%	0.0%	0.0%	0.0%
Kansas	6.0%	67.9%	6.3%	66.9%	7.3%
Missouri	0.4%	0.1%	0.1%	2.1%	0.5%

Table 5. Simulation Constraint Summary

	Percent of Time Constraints are Met[a]				
Constraint	**Strategy 1**	**Strategy 2**	**Strategy 3**	**Strategy 4**	**Strategy 5**
Protein >= 34.0%	100.0%	100.0%	85.2%	100.0%	75.2%
Oil >= 18.0%	100.0%	100.0%	97.0%	100.0%	98.4%
Lysine >= 0.84	100.0%	100.0%	100.0%	100.0%	100.0%
Threonine >= 0.56	100.0%	100.0%	100.0%	100.0%	100.0%
Tryptophan >= 0.15	96.6%	99.4%	96.0%	100.0%	100.0%
Cysteine+Methionine >= 0.5	83.8%	92.4%	85.6%	92.8%	100.0%
All EAA Met?[b]	80.4%	91.8%	81.6%	92.8%	100.0%
Measurement	**Average Protein of Delivered Soybean Meal[c]**				
Meal Protein Average (12% moisture basis)	44.3%	45.5%	44.7%	45.6%	44.3%

[a] Percentage out of 500 iterations of Optimized Monte Carlo Simulation model based upon delivered soybeans.

[b] Constraints on lysine, threonine, tryptophan, and sulfuric amino acids (cysteine plus methionine) all holding simultaneously.

[c] Based upon equation (4) in Updaw, Bullock, and Nichols (1976).

Appendix B – Figures

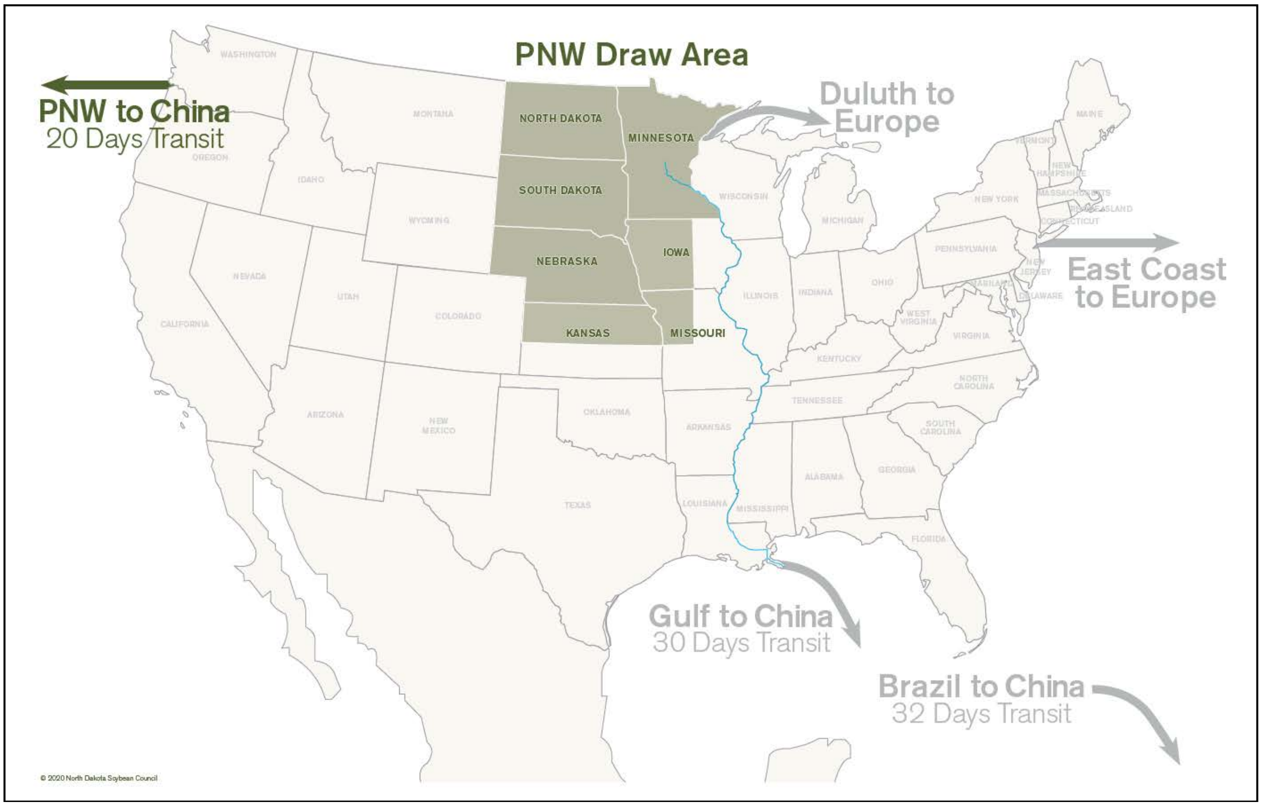

Figure 1. Principal soybean draw area (origins) for PNW soybean exports (source: North Dakota Soybean Council).

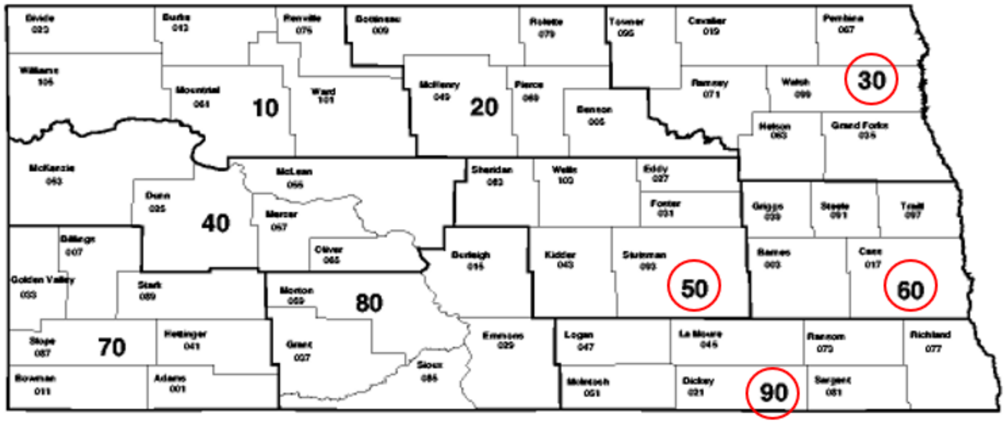

Figure 2. North Dakota crop reporting district (CRD) map with regions utilized in study circled in red.

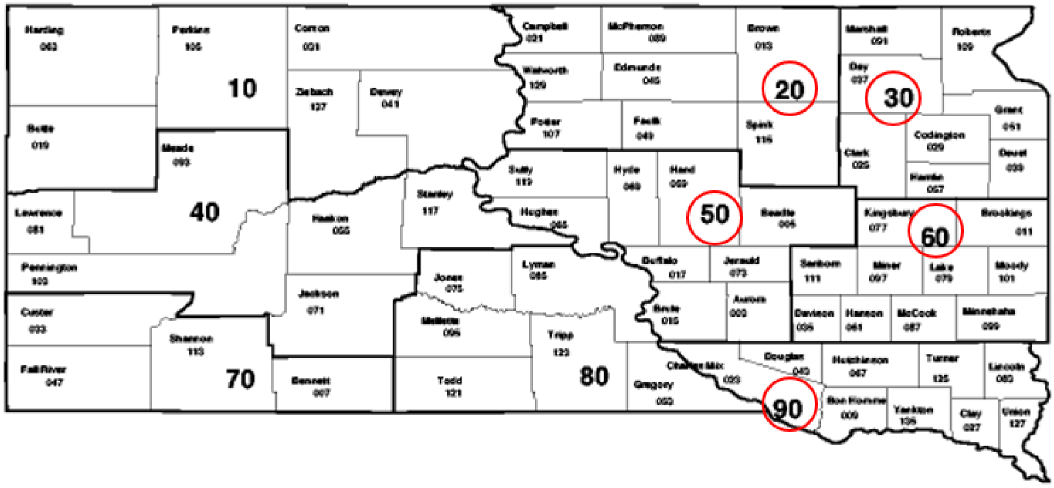

Figure 3. South Dakota crop reporting district (CRD) map with regions utilized in study circled in red.

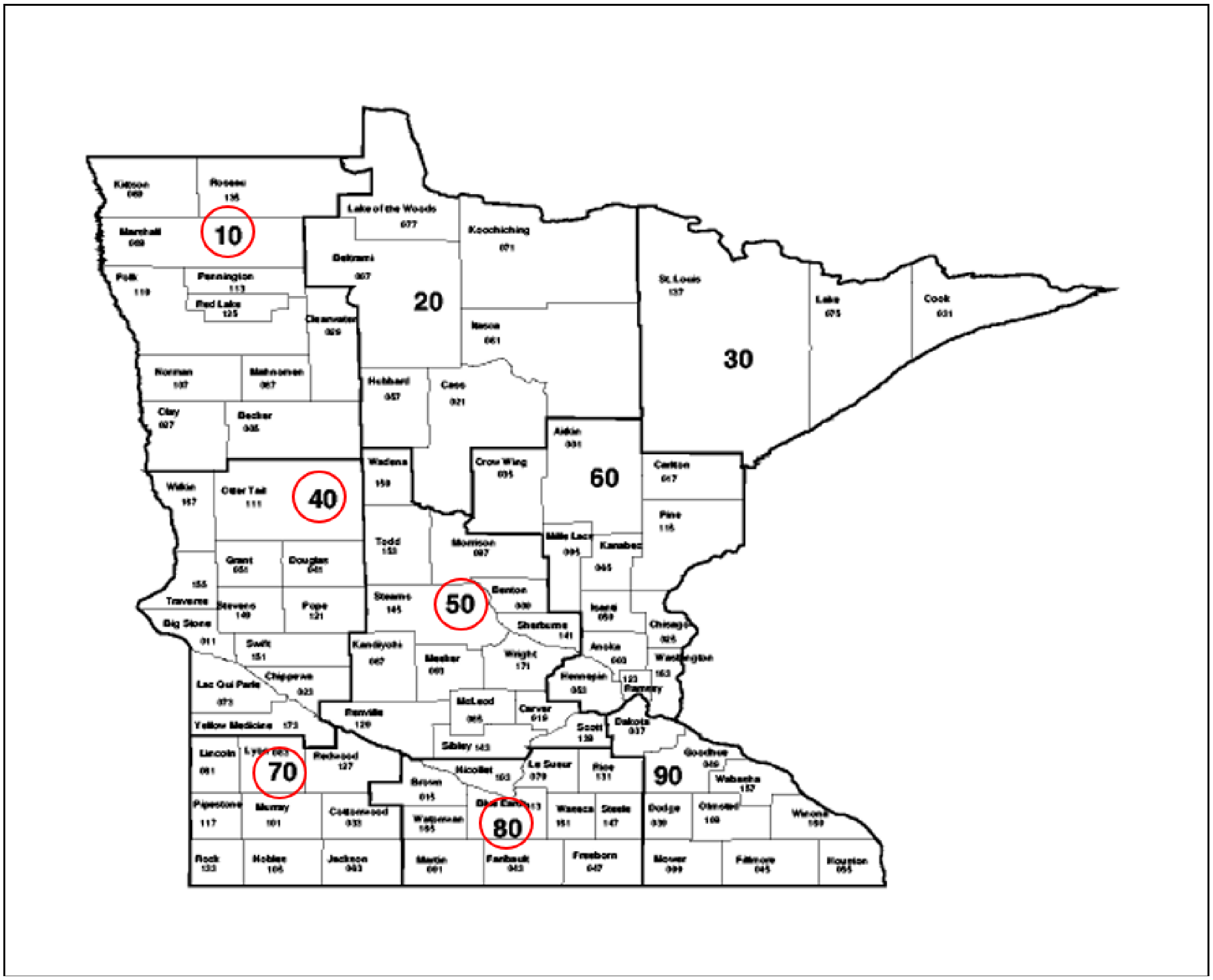

Figure 4. Minnesota crop reporting district (CRD) map with regions utilized in study circled in red.

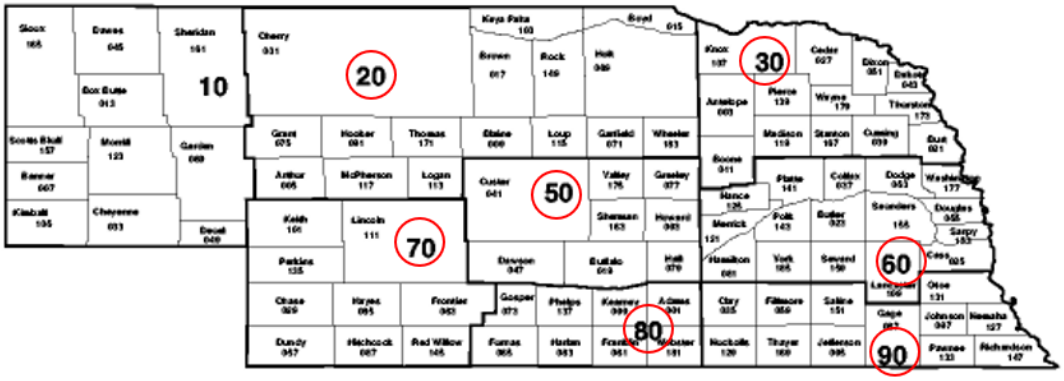

Figure 5. Nebraska crop reporting district (CRD) map with regions utilized in study circled in red.

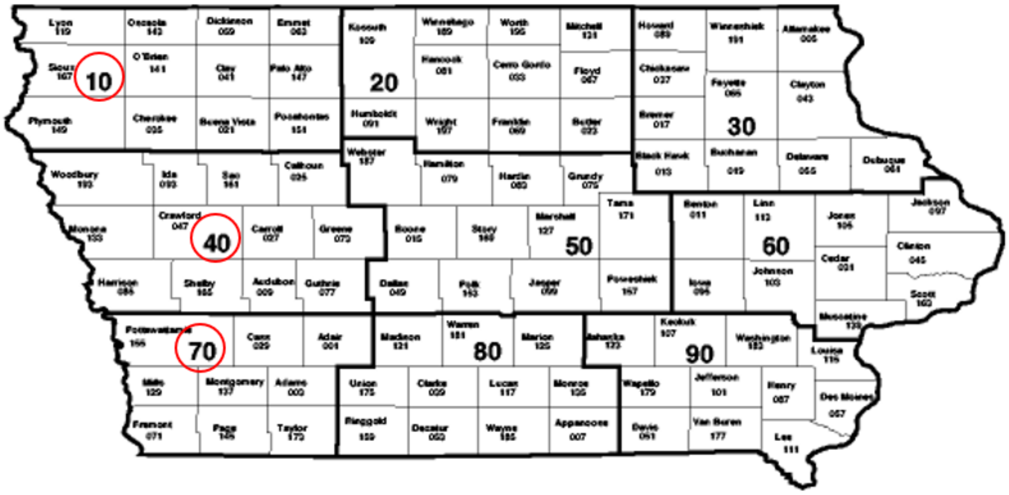

Figure 6. Iowa crop reporting district (CRD) map with regions utilized in study circled in red.

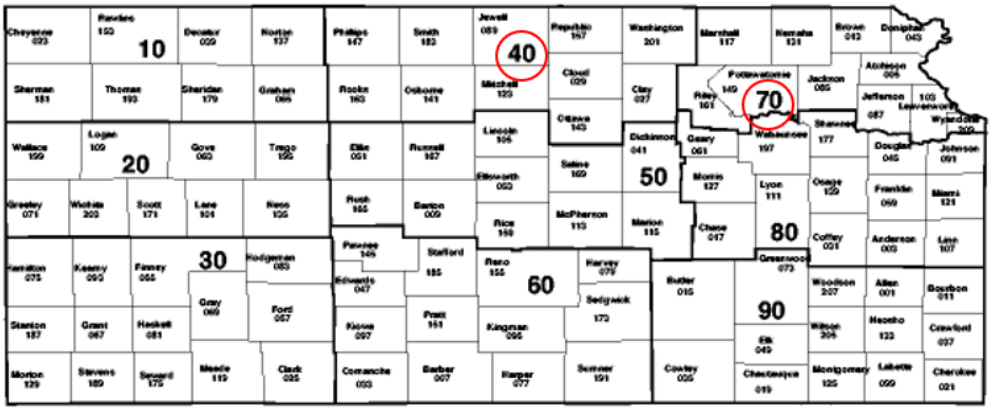

Figure 7. Kansas crop reporting district (CRD) map with regions utilized in study circled in red.

Figure 8. Missouri crop reporting district (CRD) map with regions utilized in study circled in red.

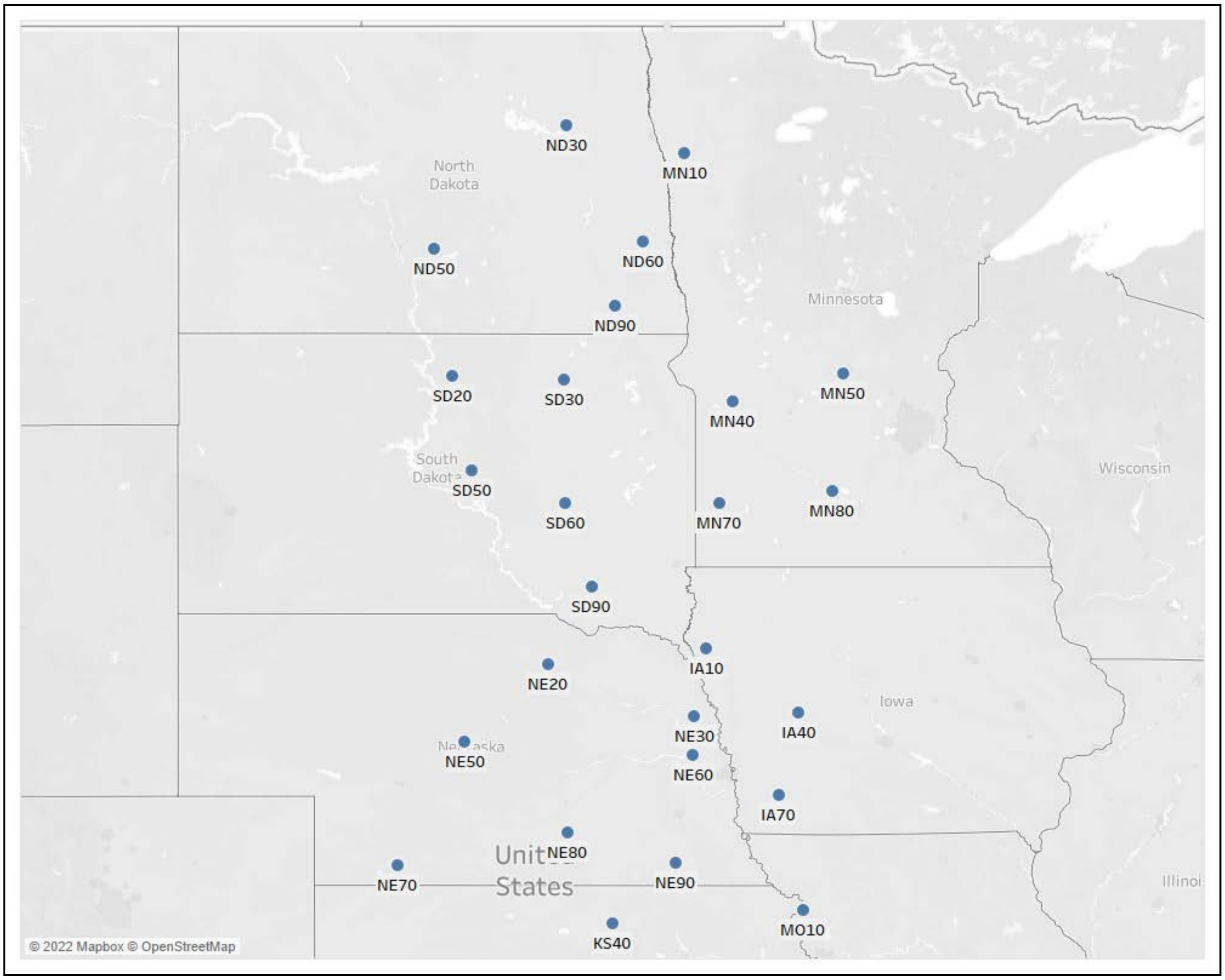

Figure 9. Pricing locations by Crop Reporting District (CRD).

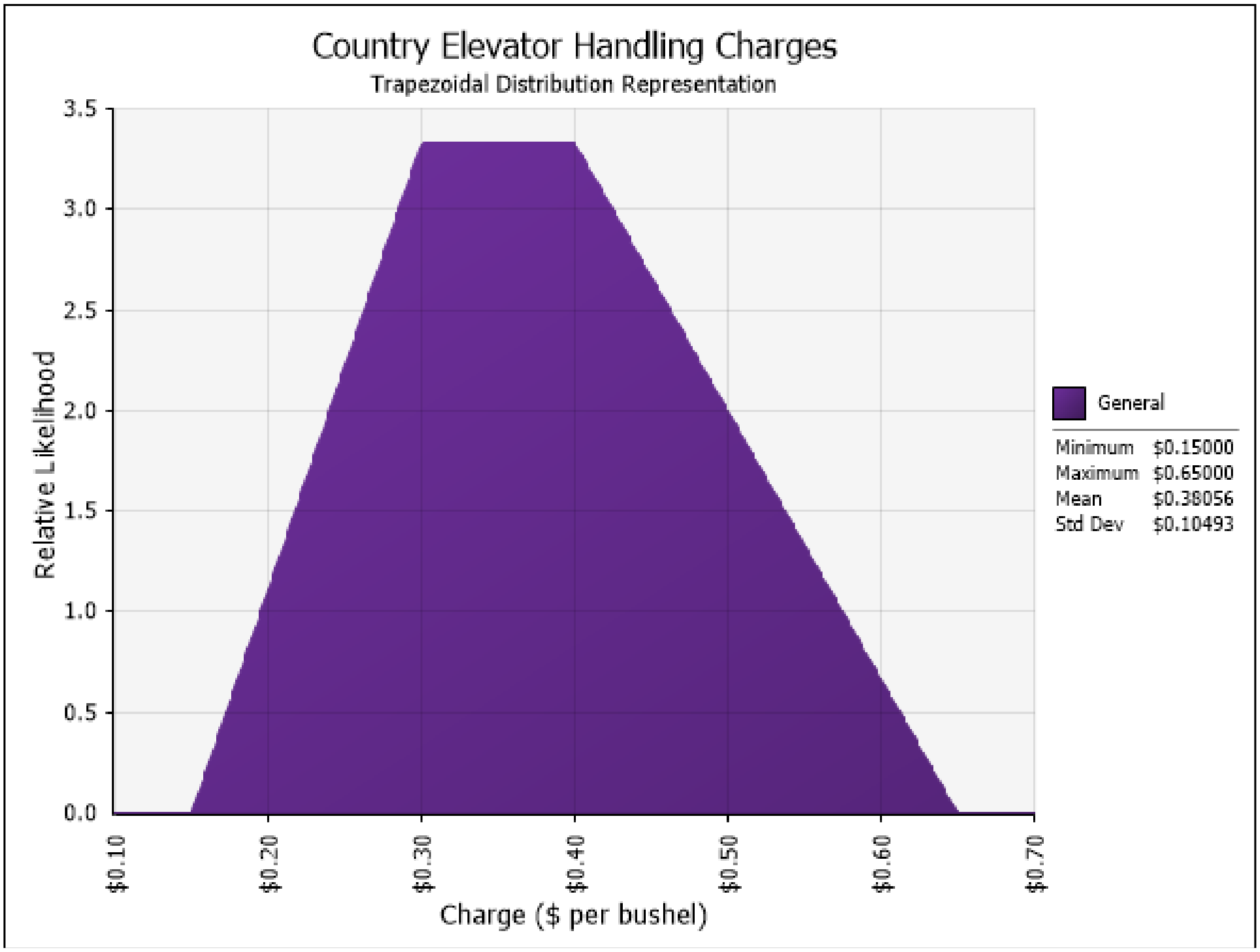

Figure 10. Subjective representation of elevator handling charges using Trapezoidal distribution.

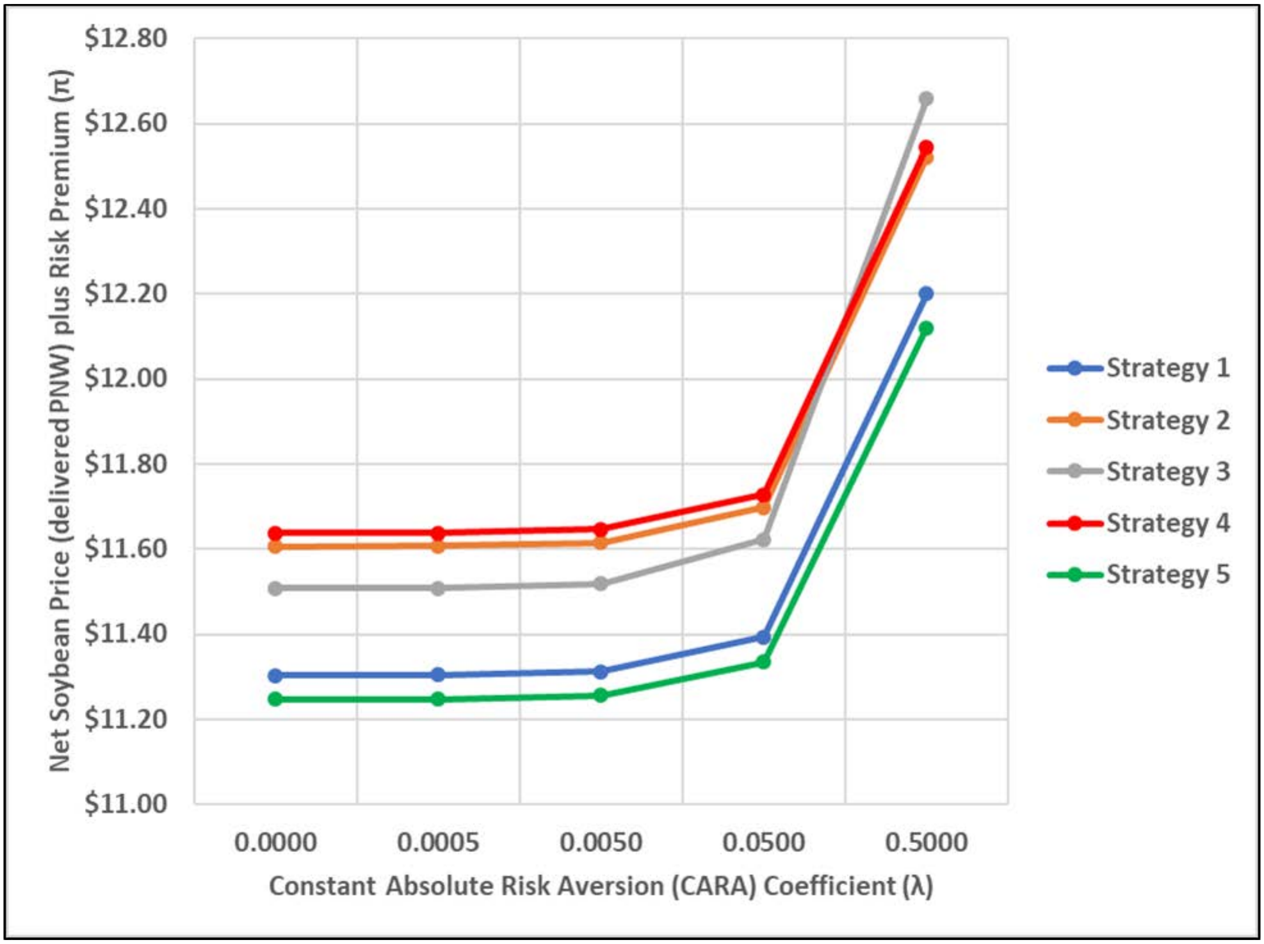

Figure 11. Stochastic efficiency (SERF) results by procurement strategy.