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Procurement Strategies to Improve and Assure Higher Quality Soybeans

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This study compares purchasing strategies for meeting essential amino acid (EAA) requirements for soybeans in the Pacific Northwest export market. The analysis shows that specifying minimum EAA requirements in purchase contracts is the most reliable and cost-effective strategy and instills a sense of security and trust in meeting high-quality EAA end-user requirements. Additionally, purchasing based on minimum protein and oil specifications meets EAA requirements about 80% of the time, with the odds increasing to 93% when targeting origins based on soybean quality survey reports, albeit with added testing costs.

Key words: essential amino acids, export markets, global competitiveness, market risk, optimization, simulation

Introduction

A significant challenge confronting trading in most agricultural commodities is 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 particular requirements they seek to meet with a high degree of certainty. These problems are further compounded if the buyer's end-use requirements are neither 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 agronomic decisions.

Due to the growing demand, Brazil and the United States have expanded their competition for soybean exports. US-origin soybean meal is usually preferred for its higher digestibility and critical amino acids relative to soybean meal from other exporting nations, but there are challenges due to variability in production (Thakur and Hurburgh, 2007). This presents a significant challenge to soybean suppliers and intermediate buyers in meeting end-user quality expectations.

The quality of soybeans in the Upper Midwest region of the United States has raised concerns due to lower and more variable protein levels, likely caused by adverse weather (Naeve and Miller-Garvin, 2019). This has led to increased feed costs, abnormal spatial flows, and concerns related to meeting the Chicago Mercantile Exchange soybean meal futures delivery requirements.

In addition to the US Grades and Standards (test weight, percent splits, percent damaged kernels, foreign material, and other colors), the primary nongrade factors usually reported in the soybean export markets include moisture, protein, and oil content (Guinn, 2002). However, recent studies (Hertsgaard, Wilson, and Dahl, 2019; Bullock, Wilson, and Thompson, 2024) provide evidence that some segments of the industry will reward soybean producers for quality factors, such as EAA5, that

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are not directly included in US grading standards. Soybean buyers traditionally use implicit protein premiums for soybeans exceeding a minimum crude protein content, with discounts for those falling short. While crude protein measures are not directly used to determine the essential amino acid (EAA) content, they are considered a proxy by the industry. However, crude protein content is a poor predictor of overall feed quality and may not accurately reflect the proportion of critical EAAs (Ravindran, Abdollahi, and Bootwalla, 2014; Medic, Atkinson, and Hurburgh, 2014).

This study aims 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 optimization model was developed to analyze and evaluate alternative purchasing strategies for a typical PNW soybean buyer based on the level of information (public and private) that the soybean buyer may acquire. The methods include buying from (i) minimum cost regions provided they meet current minimum crude protein and oil content export requirements, (ii) regions with highest survey-reported crude protein content, (iii) regions with highest historical survey-reported EAA5 composite measure, (iv) regions with highest current (crop year) survey-reported EAA5 composite measure, and (v) minimum cost regions, provided they meet minimum EAA and meal protein requirements directly measured in the soybeans at the purchase location. The model uses historical data from regional soybean quality surveys (crude protein, oil, and EAA content) and estimates of regional basis, transportation costs, and production from public and private sources.

This study makes two important contributions to the academic literature. First, it provides a better understanding of five potential origin procurement strategies for mitigating price and quality risk for a buyer concerned about the EAA profile of soybeans. Each strategy is based upon the quality information available to the buyer, from regional sample information to specific origin quality information, which comes with the additional cost of testing and segregation at the origin. This study employs stochastic efficiency with respect to a function (SERF) to illustrate the potential risk premiums buyers would be willing to pay to assure the procurement of these high-quality soybeans across a wide range of risk preferences.

Second, this study employs historical simulation techniques to provide the buyer with various plausible scenarios regarding quality, basis, and logistical costs. To better replicate the actual quality of the purchased soybeans, additional simulated noise terms are incorporated into the official quality survey data based on sample sizes. The buyer then optimizes their regional purchasing strategy using these presented values, including the noise elements. This approach is termed optimized Monte Carlo simulation (OMCS) to distinguish it from traditional risk-programming methods. It has recently been used to model optimal trade flows for the global soybean and corn markets, considering logistical cost scenarios (Kamrud, Wilson, and Bullock, 2023; Wilson, Lakkakula, and Bullock, 2024).

This study fills a significant gap in the existing literature as it focuses on strategies at both the aggregate (regional) and disaggregated (origin) levels. Additionally, the study focuses upon the level of quality information available to the buyer using unique Monte Carlo simulation techniques to replicate the level of information and uncertainty presented to the buyer, who must optimize their regional procurement strategy based upon the presented information.

Background and Previous Studies

The production of soybeans in the United States and Brazil has grown significantly over the years due to factors like increased demand from China, technological advancements, changes in farm policies, and expansion of export capacity (Wilson, 2016). Both countries have experienced shifts in soybean production regions, with Brazil's output increasing rapidly and challenging US market share. Brazil's soybean production has risen, allowing it to become a significant player in China's soybean purchases (Shurtleff and Aoyagi, 2004; Gale, Valdes, and Ash, 2019; Salin and Somwaru, 2020). The movement of soybean production northward in the United States has led to the Pacific

Northwest (PNW) port becoming a significant gateway for Chinese soybean imports. This growth in the soybean industry has strengthened the interdependence of the United States, Brazil, and China (Kamrud, Wilson, and Bullock, 2023; North Dakota Soybean Council, 2022).

Soybean Quality Premiums and Discounts

Soybean quality differences are one of the critical 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 Brazilian soybeans. For example, commodity brokerage firm R.J. O'Brien & Associates (2017) reported that

> 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 bushel 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 bushel discount (have seen as high as 30c discount). Argentina soybeans at 20-25c per bushel 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 \$5–\$10 premium per metric ton. The size of these discounts is a premium in a margin-based industry. Issues about quality differences were recently highlighted (Thompson Reuters, 2021), indicating that the higher average protein levels make soybeans from Brazil "more attractive." 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 for US soybean growers. Discounts on US soybeans can vary by year and are generally based on reported protein content but can include foreign matter discounts. These issues affect other buyers who typically would preclude specific origins (e.g., PNW) due to their perception of historically lower protein levels.

The crude protein content of soybeans exhibits considerable variation geographically (Breene et al., 1988), with northern locations (34°N latitude and above) exhibiting generally lower protein content when compared to southern locations. The effects related to oil content could have been more evident. Using Japan Oilseed Processors Association annual data from 1972 to 1988, Hurburgh et al. (1990) found that soybeans graded US 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 China; however, Brazil had overtaken the United States in the latter years of the study. The study also found considerable variation between northern/western soybean states and southern states when comparing crude protein content. Also, IOM soybeans contained about 1.5% higher crude protein compared to the US No. 2 grade. The genotype and environmental factors also play a significant role in determining crude protein content (Fehr et al., 2003). One of the challenges facing soybean breeders is the trade-off between yield and crude protein content (Helms and Orf, 1998).

The essential amino acid (EAA) content of soybeans and their resultant products are critical to some buyers and end users. While many EAA components exist, five—referred to as EAA5—are particularly important in livestock nutrition: sulfur amino acids (methionine and cysteine), lysine, threonine, and tryptophan (Karau and Grayson, 2014). Methionine and lysine are essential to nutritional quality (Hacham et al., 2007). The sulfur amino acids are crucial in protein structure, metabolism, immunity, and oxidation (Bin, Huang, and Zhou, 2017). Bullock, Wilson, and Thompson (2024) examined basis levels in eight North Dakota USDA crop reporting districts (CRDs) and, using a hedonic panel-regression model, found a strong positive relationship between EAA5 levels and local basis. This relationship was more robust and statistically significant than crude protein and was particularly strong concerning methionine, threonine, and tryptophan.

In a study comparing the quality of soybeans and soybean meals from non-US exporters (Argentina, Brazil, and India), Thakur and Hurburgh (2007) found that US soybean meal was more consistent, with higher digestibility, lower fiber, and better quality of protein (as measured by EAA 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 poor predictor of the 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 EAA5.

Testing and Risk

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

Wilson and Dahl (2008) analyzed the 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. The simulation results indicated that the probability of meeting end-use requirements increased substantially when the strategy included more end-use characteristics. A risk premium was derived from the results and interpreted as the value to the buyer for particular varieties.

The studies above focus on purchasing strategies after the commodity has entered the marketing system. In contrast, several studies analyzed the costs and risks of testing and segregating genetically modified (GM) commodities versus non-GM varieties (Wilson and Dahl, 2005, 2006; Wilson, Dahl, and Jabs, 2007). Each of these studies defined the supply chain to begin with the grower declaring the variety (i.e., whether it was GM) as it entered the supply chain. The models were specified using stochastic optimization and were used to determine optimal testing strategies. The model assumed the existence and truthfulness of the grower declaration. The handler was assumed to segregate, test, and comingle the commodity lots at multiple points (i.e., country elevator when receiving and shipping and export elevator when receiving shipping) in the marketing chain. Risks in the model included adventitious comingling, the integrity of the grower variety declaration, testing accuracy, and costs. The results were generally consistent across countries and indicated that, with various declarations, the marketing system could utilize testing and segregation strategies, resulting 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 have been accepted).

Issues related to many controls and regulations in Canada have prompted further studies regarding testing and quality control. Traditionally, the Canadian marketing system had extensive regulations regarding handling, cleaning, blending, and varieties. Over time, a gradual effort to relax these regulations significantly impacted buyers' risk landscape. 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 developing optimal and efficient wheat quality testing strategies was possible, underscoring the importance of understanding and adapting to the regulatory environment in the Canadian wheat supply chain.

Recent studies analyzed quality differences in soybeans and derived optimal strategies to mitigate the quality heterogeneity effects on expected end-use requirements. Due to the heterogeneity of quality across spatial markets, traders face risks for implicit and explicit discounts applied to regions commonly thought to have lower protein and the risk of rejected shipments (Hertsgaard, Wilson, and Dahl, 2019). They found that traders confront the risk of implicit and explicit discounts applied to whole regions commonly thought to have lower protein and the risk of rejected shipments. Wilson, Dahl, and Hertsgaard (2020) analyzed spatial quantity and quality risk differences. Their model analyzed how traders can arbitrage discrepancies in quality and shipping costs to mitigate risks of meeting end-user requirements.

Data and Methodology

The model utilized in this study assumes that the primary decision-maker is an agency (or company) that buys soybeans on behalf of an international end user. The soybeans come from delivery origins tributary to the Pacific Northwest (PNW) export market. The decision-maker purchases the soybeans in shuttle train (110 or more railcars) units from the origin facilities. The decision-maker furnishes the transportation and is responsible for all transport costs 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").

The end user (whom the decision-maker represents) is assumed to buy soybeans for use in a high-quality hog ration. Their primary concern is the meal characteristics of the processed soybeans. In particular, they desire to purchase soybeans processed into meals that meet the minimum five essential amino acids (EAA5) requirements in the Merck Veterinary Manual (Cromwell, 2016) for growing pigs between 75 and 100 pounds. The minimum standards, defined as percentages for a 90% dry matter ration, are 0.50% sulfur amino acids (methionine plus cysteine), 0.84% lysine, 0.56% threonine, and 0.15% tryptophan. In addition, a primary assumption is that the end user desires the meal to meet the minimum protein requirement (44%) for soybean meal. These specifications are equivalent to the "high-quality" definition that previous studies (Hertsgaard, Wilson, and Dahl, 2019; Wilson, Dahl, and Hertsgaard, 2020) used for soybean marketing and EAA5 requirements.

Data Sources

The primary source of origin quality data was provided by the US Soybean Export Council, which contains sample data over 7 crop years (2013–2019) summarized by USDA crop reporting districts (CRDs). The University of Minnesota developed this data 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, oil content, and percentages for 18 amino acids. The reported values are all on a 13% moisture basis, including the number of samples per CRD. The annual soybean production by CRD was obtained from the Quick Stats database (US Department of Agriculture, 2024).

Figure 1 shows a map with the primary origin draw area for PNW soybeans. This map identified 27 CRDs in North Dakota, South Dakota, Nebraska, Minnesota, Iowa, Kansas, and Missouri as origins for procuring soybeans. Only CRDs for which quality data were reported for all 7 years (2013–2019) were retained. These criteria eliminated the western CRDs 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 westernmost CRDs were retained, as the eastern two-thirds of the state is dominated by the Mississippi River system. Northwestern Missouri and northeastern Kansas were also retained as they occasionally 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 chosen by visually examining

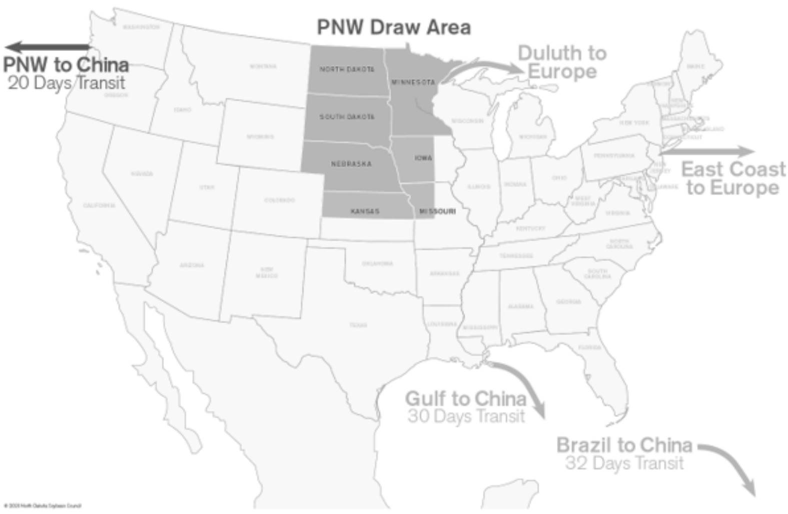

Figure 1. Principal Soybean Origination Area for PNW Soybean Exports

Source: North Dakota Soybean Council (2022).

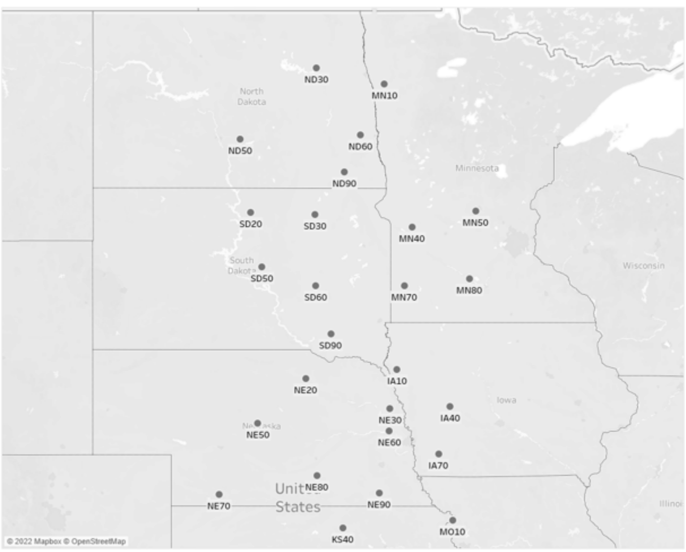

Figure 2. Pricing Locations by Crop Reporting District (CRD)

the Burlington Northern Santa Fe (Burlington Northern Santa Fe, 2024) rail facility map. Figure 2 contains a map with the locations used in this study.

Historical daily basis data for each location were obtained from DTN ProphetX (Data Transmission Network, 2023). If available, the exact location of each facility was used; if the data were incomplete or missing, an area close to the facility was used. The basis was reported in a nearby futures month format, and the daily values were rolled up into a marketing year (MY) (September through August) average. The daily nearby futures price for Chicago Board of Trade (CBOT) soybeans was obtained from ProphetX and similarly rolled into a MY average.

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 the mechanical designation code "LO" and a 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 central market locations was calculated from USDA-AMS (2024) data. The monthly values were converted to MY averages and applied to each origin based on estimated rail miles from the origin facility to the PNW. For the daily car values, weekly data from TradeWest Brokerage's Daily Market Report was converted to dollars per bushel and rolled up into market year average values. The daily car value does not vary by origin location as it is a flat national rate per railcar.

Modeling Methodology

The model used in this study was an optimized Monte Carlo simulation (OMCS), which differs from more traditional approaches, such as Monte Carlo Optimization and linear/quadratic risk programming models.[1] A key difference is that OMCS assumes that the decision-maker conducts a deterministic optimization at each iteration of the 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 critical decision metric or metrics (e.g., profit per unit, total cost), 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 model iterations have been completed), the optimal decisions are summarized using the moments and percentiles of the distribution of decision variable responses. This summary provides an overview 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 traditional approaches, which assume the decision-maker operates under risk and uncertainty, the OMCS approach assumes the decision-maker has access to deterministic information before making decisions. This approach has been used to model global trade flows in corn (Wilson, Lakkakula, and Bullock, 2024) and soybeans (Kamrud, Wilson, and Bullock, 2023), aiming to minimize logistics costs. In both cases, it was assumed that the market participants observe market prices (basis) and transportation costs (rail, barge, and ocean) before making optimal decisions. This assumption is reasonable as most participants in commodity marketing do not operate in an informational vacuum and have ready access to market-related information.

In this study, Monte Carlo simulation is applied to make random draws from a historical dataset of quality (surveys at a CRD level) measures, basis, and logistics costs data covering 7 years. Additional randomness, in the form of a normal residual term, is added to the survey quality data to reflect the differences in quality between the actual soybeans purchased at the origin and the survey results. The information revealed to the buyer from the simulation is based on the scenario assumptions. From this information, the buyer optimizes the regional (CRD) buying plan by allocating shuttle trains to minimize their total costs. This procedure is the OMCS portion of the model since it is a deterministic optimization of values presented to the buyer at each simulation iteration.

To compare strategies, the total iterations of the OMCS simulation are rolled up to calculate the sample statistics on the net price paid by the buyer. In particular, the mean and variance from the simulated values are extracted to construct the risk-adjusted price (mean price plus constant absolute risk aversion [CARA] premium), given different assumptions regarding the buyer's level of risk aversion.

Because the historical dataset used is quite broad in terms of the number of random variables (27 CRDs multiplied by 10 variables per CRD plus 2 global variables, or 272 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.[2] This method randomly chooses a year (2013–2019, with

[1] The OMCS methodology is novel in logistics and trade modeling. Figueira and Almada-Lobo (2014) discuss the details of the model, which they referred to as sequential simulation-optimization (SSO) models. These methods are also described and compared in Hardaker et al. (2015, chap. 9).

[2] A table with summary statistics on all 272 random variables is available from the authors on request.

equal probability assigned to each) and then looks up the actual CRD and global variable values that match 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 needs to 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.

Suppose an iteration of the model randomly drew 2015 as the crop year as an example of how this would work. The historical data for each CRD are organized 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 the number of survey samples from the third row of the CRD's lookup table. Additional values pulled from this row include the CRD's total production (in bushels), market year average basis, and rail tariff plus fuel surcharge (MY average). The third row provided the values from the remaining 26 CRDs in the model. Row 3 of the lookup table would also give the global variables (MY average nearby futures price and daily car value).

The quality variables (protein, oil, and EAA5) from the lookup tables represent the average values based on a limited number of sample observations in the quality survey. While this is representative of the sample survey, it may not wholly represent the valid average values for the entire CRD. To account for potential variability, a sampling error was simulated around the average survey value to determine the actual mean value for the delivered soybeans. The sampling distribution of the mean is normal, with the mean equal to the sampled mean and the standard deviation equal to $\sigma/\sqrt{n}$, where σ is the sample standard deviation and n is the sample size. Unfortunately, the sample standard deviations were not reported in the database, so the standard deviation of observed sample mean values across the 7 years was used as a proxy. The number of samples reported in the database was used for the value of n. Therefore, the model generates two sets of quality variables for each CRD: (i) the reported survey mean values and (ii) 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 offered prices to farmers, it is necessary to add elevator handling to get an on-track delivered equivalent for the buyer. These charges vary over time due to changes in the cost components of 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 15–65 cents per bushel, with a modal range of 30–40 cents as the most likely values. Note that the same simulated handling cost was applied to all CRD origins for each iteration, so the variation is purely an intertemporal rather than a geographic effect.

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

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

where p is the delivered PNW price, f is the nearby CME soybean futures 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. All variables are in dollars per bushel, with the tilde (~) indicating a random simulated value and the k subscript ($k = 1, \ldots, 27$) indicating the origin CRD. Note that the tariff (t) is a fixed, nonrandom measure based on current rates.

For determining the protein content of soybean meal (12% moisture basis) based on the raw soybean characteristics, the following equation from Updaw, Bullock, and Nichols (1976, equation 4) 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 expressed in decimal format). This is the same formula used by Hertsgaard, Wilson, and Dahl (2019) and in more recent agronomic literature (Barr, Hurburgh, and Mosher, 2021; Chiluwal et al., 2021; Capelin et al., 2022; de Camargo et al., 2023).

To convert the survey-reported essential amino acid (EAA) contents of the raw soybeans into a meal equivalent, it was assumed that the ratio of each EAA to protein was the same in the raw soybean and the meal (Hertsgaard, Wilson, and Dahl, 2019). The EAA was transformed into meal equivalents by multiplying their survey percentage values by the calculated meal percentage (Z). This transformation 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 (0.12/0.10).

The model assumes that the primary decision-maker aims to buy enough soybeans to fill one 70,000 metric ton Panamax vessel annually, approximately seven shuttle trains (110 cars each), 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 seven shuttle trains across the 27 origin CRDs. This lumpiness required integer programming to solve the optimization problem. An additional supply constraint added to the model stipulated that the total decision-maker purchases from any CRD could not exceed 10% of total reported production. This constraint is incorporated to account for competition from other regional buyers and capacity constraints at the origin shuttle facility.

A set of five alternative purchasing strategies were evaluated using the OMCS model. Strategy 1 (BASE) assumes that the decision-maker sources the soybeans at the minimum cost provided the delivered soybeans meet the minimum export requirements for protein (greater than or equal to 34%) and oil content (greater than or equal to 18%). 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 left to chance.

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

Strategy 3 (MAX HISTORICAL EAA5) assumes that the decision-maker purchases the soybeans from CRDs 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 does not 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 CRDs with the highest long-term average sample values.

Strategy 4 (MAX SURVEY EAA5) assumes that the decision-maker purchases the soybeans from CRDs with the highest annual reported sum of EAA5 regardless of price. This strategy is similar to Strategy 3 except that the decision-maker waits until the quality reports are released and then buys from the highest reported CRDs with supply constraints applying.

Strategy 5 (RESTRICT ORIGIN EAA5) assumes that the decision-maker 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% protein. This strategy requires the decision-maker to have the deliveries tested at the origin to meet the EAA5 and meal protein requirements at an additional cost. The decision-maker would use the survey information to find the CRD's highest probability of meeting the specifications and buying under the strict EAA5 and protein constraints. This strategy assures the decision-maker of receiving soybeans meeting the Merck hog ration requirements at the minimum possible cost. This strategy would be

Table 1. Numerical Stochastic Efficiency with Respect to a Function (SERF) Results by Strategy

	Risk-Adjusted Delivered Soybean Cost (π in \$/bushel)				
Risk Aversion Coefficient (λ)	**Strategy 1**	**Strategy 2**	**Strategy 3**	**Strategy 4**	**Strategy 5**
0.0000	$11.303	$11.607	$11.508	$11.637	$11.247
0.0500	$11.393	$11.698	$11.623	$11.728	$11.334
0.1000	$11.483	$11.790	$11.738	$11.819	$11.422
0.2500	$11.751	$12.064	$12.083	$12.091	$11.684
0.5000	$12.199	$12.521	$12.658	$12.545	$12.120

similar to Strategy 1, except the raw protein and oil constraint would be replaced by the ration EAA5 and meal protein constraints.

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

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

where π is the risk-adjusted net delivered price, λ is the decision-maker's risk aversion coefficient, $\boldsymbol{p}'$ is a $1 \times m$ vector of optimal weighted-average delivered prices with m as the number of simulation iterations, $\mathrm{E}[\cdot]$ is the expectation operator, and $\mathrm{Var}[\cdot]$ is the variance operator. The weighted-average delivered prices for each optimization were calculated using the following formula:

$$p'_j = \left(\sum_{i=1}^{27} \tilde{p}_{i,j} \cdot q'_{i,j} \right) / \left(\sum_{i=1}^{27} q'_{i,j} \right), \tag{4}$$

where j is a subscript indicating the simulation iteration number ($j = 1, \ldots, m$), $\tilde{p}_{i,j}$ is the simulated price, and $q'_{i,j}$ represents the optimized quantity (in bushels) purchased from CRD i for iteration j. Five values for λ (0,0.05,0.1,0.25, and 0.5) were used to illustrate the risk-adjusted delivery price across a range of decision-maker risk preferences. These range from totally risk neutral ($\lambda = 0$) to extremely high risk aversion ($\lambda = 0.5$). In addition to the risk-adjusted delivery prices, the probability of any or all of the quality constraints was calculated for each strategy, and the average percentage share (total quality purchased) by each origin state (sum of CRDs in-state).

The OMCS model was constructed using Palisade's @Risk (Palisade Corporation, 2023a) simulation add-in to Microsoft Excel.[3] The Palisade Evolver (Palisade Corporation, 2023b) optimization add-in to Excel was used to conduct the iterative optimizations in the model (as defined in Table 1). The application of convergence criteria suggested that 500 model iterations were sufficient to ensure 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 6–7 hours. A fixed random number seed assured comparability of the results across all simulations.

Results

Figure 3 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 1. The results show that Strategy 5 (RESTRICT ORIGIN EAA5) stochastically dominates the other strategies as the lowest cost to the decision-maker. On average, it is approximately 6.45 cents per bushel below the next lowest strategy (Strategy 1, BASE) ranging from 5.63 cents for the risk-neutral

[3] Screenshots of the complex Excel model and additional details are available from the authors on request.

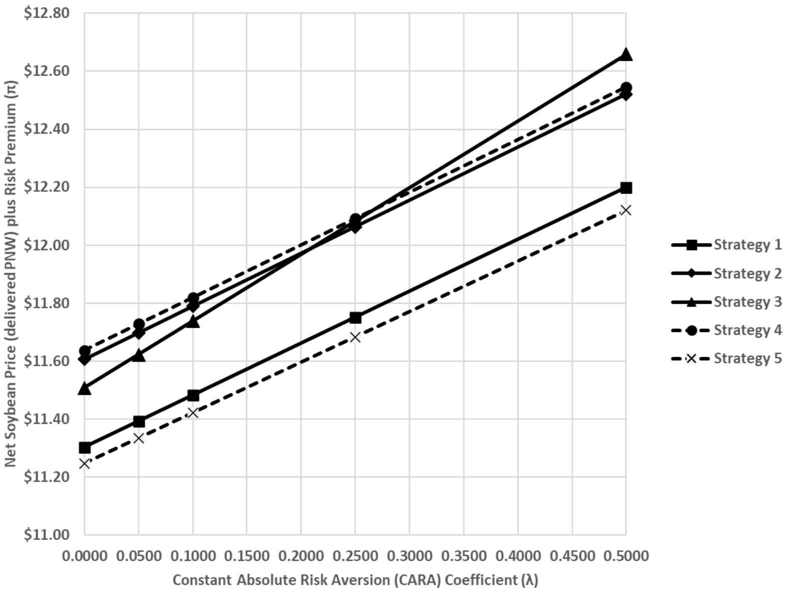

Figure 3. Stochastic Efficiency with Respect to a Function (SERF) Results Based on Procurement Strategy

Table 2. Optimal Procurement Results by State of Origin

	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%

($\lambda = 0$) to 7.92 cents for the extremely risk-averse ($\lambda = 0.5$) soybean buyer. While seemingly minor, this difference can significantly impact the overall cost of soybean purchasing.

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 5.63 cents per bushel (risk-neutral premium). Based upon a phone conversation (Killam, 2015), Hertsgaard, Wilson, and Dahl (2019) reported that testing for 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, Strategy 5 would be the dominant strategy from a risk-adjusted cost perspective.

Strategies 2–4 demonstrate notably higher risk-adjusted values, with prices 26–54 cents per bushel higher than Strategy 5. This is attributed to the absence of cost minimization in their respective objective functions. Strategy 4 (the highest annual surveyed EAA) stands out with the highest cost, except for the more risk-averse decision-maker. Meanwhile, Strategy 3 (higher long-term average EAA) presents a cautionary note due to the substantial variability in price (i.e., higher risk premium) under this strategy.

Table 2 shows the average volume share by state for each of the five strategies. Given its location, North Dakota is the lowest-cost state for a delivered price to the PNW; therefore, it has the largest share for both cost-minimization strategies (1 and 5). However, each plan must require diversification

Table 3. Simulation Constraint Summary

	Percentage of Time Constraints Are Met[a]				
State	**Strategy 1**	**Strategy 2**	**Strategy 3**	**Strategy 4**	**Strategy 5**
Protein ≥ 34.0%	100%	100%	85.2%	100%	75.2%
Oil ≥ 18.0%	100%	100%	97.0%	100%	98.4%
Lysine ≥ 0.84	100%	100%	100%	100%	100%
Threonine ≥ 0.56	100%	100%	100%	100%	100%
Tryptophan ≥ 0.15	96.6%	99.4%	96.0%	100%	100%
Cysteine + methionine ≥ 0.5	83.8%	92.4%	85.6%	92.8%	100%
All EAA met?[b]	80.4%	91.8%	81.6%	92.8%	100%
Measurement	**Average Protein of Delivered Soybean Meal[c]**				
Meal protein average (12% moisture basis)	44.3%	45.5%	44.7%	45.6%	44.3%

Notes: [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).

across origins. South Dakota and Nebraska also have relatively low costs for delivering soybeans to the PNW; therefore, they also figure prominently in the two cost-minimization strategies. In both cost-minimization strategies, the decision-maker has to reach into the more eastern to southern states (Minnesota, Kansas, and Missouri) less frequently (10%–12% of average volume) due to supply and quality requirement constraints. Western Iowa has significant soybean processing capabilities, resulting in more vital local basis values and Iowa soybeans being priced uncompetitively for shipment to the PNW.

For Strategy 2 (MAX PROTEIN), Kansas CRD 40 typically has the highest reported sample protein of all CRDs in the dataset. Nebraska CRD 80 also has a high average reported protein; however, it exhibits more year-to-year variability than Kansas. The same can be said for South Dakota CRDs 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 decision-maker's supply constraint (max 10% of total production); however, approximately 43% of the time, the supply constraint is binding, meaning it is not met, and the decision-maker 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 CRDs can deliver a more consistently high EAA5 value and, therefore, have the highest share under this strategy, followed by Nebraska, South Dakota, and Missouri.

Table 3 shows the percentage of the time (out of 500 iterations) that the quality constraints were met along with the average meal protein (based upon formula in equation 2) content on a 12% moisture basis. Strategy 1 involves 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 Strategy 1, all the individual EAA5 minimum requirements were met 80.4% of the time. The average protein content of the meal was 44.3%.

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

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

Buying from the CRDs with the highest reported sum of EAA5 (Strategy 4) resulted in a 100% probability of meeting the minimum protein and oil requirements. The EAA5 requirements were completely met 92.8% of the time. As with the previous three strategies, the limiting EAA was the sulfuric amino acids (cysteine and methionine), with tryptophan slightly limited under Strategies 1–3.

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

Summary and Conclusions

The issue of quality heterogeneity is a significant challenge in the commodity trading sector, particularly for grains and oilseeds. It has become a crucial problem for the US industry, especially in the face of competition from Brazil and other regions. Quality heterogeneity in US soybeans results in high variability among non-USDA-grade quality attributes (crude protein and EAA content), which varies across origins and time. As a result, both buyer and seller face risks, making it a common problem in commodity trading and a significant challenge in supply chain strategy.

This study takes a unique approach to analyzing and comparing alternative purchasing strategies to meet end-use minimum EAA requirements for soybeans grown in regions of the United States that contribute to the Pacific Northwest (PNW) export market. The study used a stochastic optimized Monte Carlo simulation (OMCS) model to evaluate five alternative purchasing strategies for a soybean buying agency that procures soybeans for a quality-conscious international end user. The mode specifications assume that the end user purchases the soybeans to crush into a high-quality meal for hog rations based on the soybeans' five essential amino acids (EAA5) content. The purchased soybeans are for export out of the Pacific Northwest (PNW) ports of exit.

The SERF analysis results clearly show that the dominant purchasing strategy, which involves buying the soybeans at the origin with the binding constraint that the delivered soybeans meet the minimum EAA5 and meal protein requirements, offers significant benefits. This strategy, conditional upon the cost of origin EAA5 testing being less than 5.63 cents per bushel, ensures compliance with the provisions in most situations. The 5.63 cents per bushel threshold is a crucial factor in determining the cost-effectiveness of the strategy. The findings of this research should reassure soybean buyers that a cost-effective and reliable strategy is within reach.

These implications can enlighten and empower soybean buyers, commodity traders, and international end users in the Pacific Northwest (PNW) export market. In particular, the following observations can be made:

- Soybean buyers can meet end-user EAA requirements by specifying minimums in origin contracts. Buyers serving the PNW export market can ensure this by waiving the bean's crude protein and oil requirements in favor of minimum meal protein requirements. This approach is cost-effective, with the lowest delivered price and risk premium, as long as added expenses are under 5.63 cents per bushel.
- 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% of the time. Targeting specific origins based on reported quality survey results can increase these odds to 92%–93%.
- These results are essential for various market participants as they show that PNW origins can meet the high-quality feed market's needs for EAAs. This suggests the need to establish a mechanism for origin testing to meet end-user contractual requirements.

- Most of the time, the western soybean-producing states (North Dakota, Nebraska, and South Dakota) can meet the minimum EAA5 requirements, with North Dakota usually holding the largest share. Only about 12% of the time do buyers need to purchase from eastern states like Minnesota, Kansas, and Missouri, which usually have higher costs due to the Mississippi River system and higher transportation costs to the PNW.

The model developed in this study is highly adaptable, and future research could examine the application of this methodology to other commodities and markets. There is a greater demand for precision in quality and performance characteristics as competition intensifies and processing and feeding technology becomes more sophisticated. Furthermore, the model used in this study is predominantly grounded in historical data regarding quality, basis, and logistical costs at a regional level. External macro factors, including geopolitical shifts, currency fluctuations, and evolving trade policies, are not included in the analysis. Modifying the model to include these external factors in a predictive context would be beneficial and would assess the sensitivity and robustness of the results across scenarios.

Another important area for future research involves the development of on-site testing infrastructure for essential amino acids (EAA) and other non-grade quality attributes in soybeans. Although the model results indicate that origin testing for EAA is effective, this is not yet reflected in real-world practices. One possible explanation for this discrepancy could be the widespread belief that protein testing serves as an adequate proxy for EAA. Additionally, there may be structural and cost-related barriers to establishing the necessary infrastructure for origin testing. While tests for EAA currently exist, it is vital to create standardized tests, methodologies, and protocols to facilitate their adoption within a commercial marketing system. In contrast to commodities such as wheat and barley, which have well-established testing and contracting protocols, such practices are not yet commonplace in the soybean industry.

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