The Implications on Price Relationships when Quality Adjusting Commodity Prices

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Selected paper prepared for presentation at the Southern Agricultural Economics Association (SAEA) Annual Meeting, San Antonio, Texas, 6-9 February 2016

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Abstract: Commodity markets work well in the U.S. because they standardize the products being sold. Using hedonic pricing models, this paper investigates the quality attributes that make soybeans differentiated across the U.S. and the possible implications that quality adjusted prices may have in today's markets. A hedonic model was tested using soybean prices from 2004 to 2013 to adjust for quality. A test was then conducted to show the price change over time due to quality changes in soybeans. Results show that quality-adjusted pricing may affect forecasting and hedging with stronger correlations computed between futures prices and quality adjusted prices than futures prices and observed prices.

Keywords: *soybean, hedonics, quality-adjusted prices*

The Implications on Price Relationships when Quality Adjusting Commodity Prices

The definition of commodity follows from (Rhodes, Dauve, and Parcell, 2015 p.351) as, "An economic good such as corn or wheat that can be legally produced and sold by almost anyone. A commodity contrasts with a differentiated product, which belongs to a specific seller and may often be trademarked as her exclusive property". Common application of agricultural commodities, as a standardized set of quality attributes, has significant implications for agricultural economists. The assumption of commodity production and commodity trading allows for the convenient theory that actors involved in the production, aggregation, and processing of agricultural commodities behave in a purely competitive environment. Economists then use the competitive economic environment assumption as a baseline when evaluating models of imperfect competition. Furthermore, in economic models of price discovery, price forecasts, price asymmetry and derivative hedging, the commodity assumption allows for individual actor behavior to be shaped by a horizontal demand curve.

At the same time, economists recognize the role of the firm to respond to economic incentives, or economic disincentives. Therefore, the realization that commodities change form over time and space should not be surprising. For example, in 2000 when the value of soybean oil was relatively low to soybean meal there was an industry effort to lower the percentage oil content in the soybean and increase the percentage protein content. Later, with the dramatic increase in vegetable oil prices following 2008 the industry priority changed to increasing the percentage of oil in the bean seed. This strategy is not unique to grains and oilseeds. In the 1990's the National Cattleman's Beef Association placed prioritized to make beef more like chicken by increasing leanness (i.e., more select quality grade animals). This decision was

followed by the early 2000's consumer change toward a desire for marbling and a more tender steak. The data for commodity quality attribute levels clearly indicates these trends.

What is the implication of economic models of market and market price behavior when historical price behavior is reflective of not only supply-demand shifts, but also of changes in the level of commodity attribute levels over time? Also, do firms behave in such a way that commodities are regional competed for based on the implicit levels of attributes?

If we assume a monopsonistic competitive market where inputs procured are not homogeneous, then there will be different values placed on different quality characteristics of the input, i.e., different buyers prefer a different level of an input attribute. For example, as buyers realize that a commodity (e.g., soybean) is associated with geographical differentiation in attribute levels (i.e., weather and soil vary), buyers are willing to compete for the intrinsic quality characteristics that allow for firms to achieve the highest level of profits. Firm competition drives up the value of the commodity in the region because of desire to purchase an input with the highest attribute level (i.e., a soybean crushing plant co-located with a biodiesel plant prefers to crush soybeans with 19% oil content to soybeans with 17.5% oil content).

Soybean quality for the U.S. is changing over time. Figure 1 shows the trend of protein and oil content in U.S. soybeans. Soybean quality in the U.S. can also differ greatly from one state to the next. This can be caused by many factors such as soil fertility, growing season, or climate. Figure 2 shows the reported differences in soybean price and average protein percentage for each state in 2010 and 2011. Average protein percentage for some states can differ by over five percent from one state to the next, and over five percent from one year to the next. This can come as a shock to certain firms that specifically use more of one characteristic of a soybean. A firm that uses soybean oil in its production will want to buy for that specific

intrinsic attribute. The same can be said for protein. This can lead to firms attempting to compete for these intrinsic attributes. By focusing on a certain quality characteristic, the firms place a separate value on protein and oil content that shifts price by more than stated premiums and discounts in the market place.

The quality-price relationship in soybeans opens up further studies in the U.S. soybean market. The soybeans grown today are not the same as the soybeans grown five years ago. Can quality-adjusted prices increase the accuracy of forecasting futures prices? Will hedging become more effective with prices that better reflect what a buyer is willing to pay? Do commodity prices across the U.S. react better to each other with quality-adjusted prices? If different firms need protein or oil content at different levels, will market competition be better explained when the quality of the soybeans are known? These questions have yet to be researched.

Quality Adjusting Historical Price

The Bureau of Labor Statistics has employed hedonic modeling for years to separate out the change in price over time due to quality attribute level changes and pure price change. Accounting for quality attribute changes over time is important for BLS when indexing prices over time. A price index is used to track historical prices for understanding inflation trends, by policy makers to make regulatory changes, and by business decision makers to make strategic planning recommendations or to benchmark a business. The classic example here is of the change in computer technology over time. Is it fair to compare the cost of the current 24.1" Dell AH-IPS resolution 1920 x 1200 to the cost of the Dell monitor from a decade ago? A monitor a decade ago would have had a 17" screen, much less resolution than today's monitor would, and likely two to three times the cost of today's monitor. Ideally, one would want to know the

decade ago cost of a monitor with today's attribute specifications. The hedonic model is particularly of importance in separating out price changes due to quality versus pure (e.g., supply-demand) price change in the absence of sufficient knowledge of industry costs for incremental quality changes (e.g., the industry cost of making a monitor 1920 x 1200 resolution versus 1700 x 1040 resolution).

By using the hedonic model methodology and specifying a hedonic model for soybeans, we are able to test whether historical market price changes have the presence of a quality price adjustment or simple pure price change. Market models assume commodity price changes over time and space are due to pure price differences.

Theoretical Framework

Ladd and Martin developed the multi-input multi-output production process hedonic model. A firm maximizes profit by choosing from a variety of inputs containing different levels of characteristics. The focus of this analysis is to develop the Ladd and Martin model using soybean (w) as a single input. Let v_{iw} represent the ith bushel of soybean used for soybean processing, p_w represents the output price received from soybean processing, q_w is the quantity of soybean processed, x_{jiw} represents the amount of characteristic j in the ith bushel of soybean entering soybean processing, and $x_{j \cdot w}$ is the total amount of characteristic j used for soybean processing. Subscript i refers to a bushel of soybean produced in a state. Using these definitions the production function for soybean processing can be written as:

(1) $$q_s = F_s(x_{1 \cdot s}, x_{2 \cdot s}, \ldots, x_{m \cdot s}).$$

Equation 1 states that the quantity of soybean processed is a function of the total amount of each input used in processing. The total quantity of each characteristic used in soybean processing can be expressed as:

$$x_{j\cdot s} = X_{js}\,(v_{1s}, v_{2s}, \ldots, v_{ns}, x_{j1s}, x_{j2s}, \ldots, x_{jns}). \tag{2}$$

Thus, the production function for soybean processing can be defined as:

$$q_s = G_s\,(v_{1s}, v_{2s}, \ldots, v_{ns}, x_{11s}, x_{12s}, \ldots, x_{mns}). \tag{3}$$

The profit function derived from 3 for a soybean processing firm is given as:

$$\pi = p_s F_s(x_{1\cdot s}, x_{2\cdot s}, \ldots, x_{m\cdot s}) - \sum_{i=1} S_i v_{is}, \tag{4}$$

where S_i denotes the price of the ith bushel of soybean. Soybean processing firms are assumed to maximize profits and are perfectly competitive. For convenience, the subscript s is dropped for the remainder of this section. Differentiating the first part of the right hand side of equation 4 with respect to v_i produces:

$$\partial F/\partial v_i = \sum_j (\partial F/\partial x_{j\cdot})(\partial x_{j\cdot}/\partial v_i). \tag{5}$$

Using equation 5, the differentiation of equation 4 with respect to v_i is given as:

(6) $$\partial\pi/\partial v_i = p \sum_{j=1} (\partial F/\partial x_{j.})(\partial x_{j.}/\partial v_i) - S_i = 0.$$

Solving equation for S_i yields:

(7) $$S_i = p\sum_{j} (\partial F/\partial x_{j.})(\partial x_{j.}/\partial v_i).$$

Equations 6 or 7 can be used to generate first-order conditions for profit maximization for each ith bushel of soybean. The interpretation of equation 7 is that $\partial x_{j.}/\partial v_i$ is the marginal yield of characteristic j used in soybean processing from a marginal change in the quantity of the ith bushel of soybean; $\partial F/\partial x_{j.}$ is the marginal change in soybean processing from a marginal change in the input of characteristic j. Therefore, $p(\partial F/\partial x_{j.})$ is the value (marginal implicit price paid) of the marginal product of the jth soybean characteristic used in soybean processing. Using the example of protein levels in soybean, this represents the incremental change in the price of the ith bushel of soybean from an incremental increase in the level of protein. Following Ladd and Martin, let $p(\partial F/\partial x_{j.})=T_j$. Thus, equation 7 can be expressed as:

(8) $$S_i = \sum_{j} T_j(\partial x_{j.}/\partial v_i),$$

where $T_j(\partial x_{j.}/\partial v_i)$ is the value of the marginal change in soybean characteristic j from the input of the ith bushel of soybean. Equation 8 states that price paid for the ith bushel of soybean is equal to the sum of values of the marginal yield of each characteristic.

Following Ladd and Martin, assume $\partial x_{j.}/\partial v_i = x_{ji}$ is constant. Using protein as an example, this implies a change in the amount of protein provided by the ith bushel of soybean

changes the total protein available for soybean processing by exactly the amount of protein in that bushel. Equation 8 can then be written as:

$$S_i = \sum_j T_j x_{ji}. \tag{9}$$

Numerous analysis have employed a non-constant marginal implicit value (T_j). Specifically, a quadratic functional form has been used to show optimal levels of characteristics exists. The quadratic functional form derived by Ladd and Martin is:

$$S_i = \sum_j x_{ji}\beta_1 + \sum_j x^2_{ji}\beta_2 = \sum_j x_{ji}(\beta_1 + x_{ji}\beta_2), \tag{10}$$

where x_{ji} is a constant. By letting $T_j = (\beta_1 + x_{ji}\beta_2)$, T_j is not constant and changes with the level of x_{ji}. Using the protein example, the marginal implicit price of protein for the ith bushel of soybean changes for different levels of protein and an optimal marginal implicit value may exist.

Empirical Model

The first paper that proposed that quality and price were coordinated was Taylor (1916) where he suggested cotton quality attributes could influence cotton prices. Waugh (1928) and Court (1941) followed with Court being the first to use the term "hedonic" in his analysis. Lancaster (1971), Rosen (1974), Ladd and Martin (1976), and Ladd and Suvannunt (1976) later set the groundwork for the use of hedonic models in agriculture.

Cain and Parcell (2014) developed a two-stage hedonic model for U.S. soybeans to show there is quality-price relationships. They were able to show that buyers recognize differences in

quality and are willing to pay different amounts for different quality soybeans, but there have not been any studies that focus on the potential of using quality-adjusted prices in today's markets.

This research is focused on showing the possibilities for a quality-adjusted market price. As observed from viewing Figure 1, soybean quality differs from state to state. To test whether or not quality-adjustments will make a statistical significance, we must first adjust prices using a hedonic model. We will be following the same hedonic model as presented by Cain and Parcell (2014) to apply separate values to soybean oil and soybean protein.

The hedonic model being used is:

(11)

$$\begin{aligned} Price_{it} = \sum_{i=1}^{n} \delta_i State_i + \alpha_1 Protein_{it} \\ + \alpha_2 Protein_{it}^2 + \alpha_3 Prt\_ADJ_{it} \\ + \alpha_4 Prt\_OTH_{it} + \alpha_5 Oil_{it} + \alpha_6 Oil_{it}^2 \\ + \alpha_7 Oil\_ADJ_{it} + \alpha_8 Oil\_OTH_{it} + \varepsilon_{it} \end{aligned}$$

The data used in this analysis is weekly data gathered from eight different states. (IA, MO, OH, MI, IN, IL, NE, and MN) The subscript *i* refers to the ith state. Definitions of variables can be found in Table 1. By running this model, we standardize the commodity even though it is not a homogeneous product.

There are four variables for each quality attribute. The first two variables for protein are the average protein content in state *i* at time *t* and the average protein squared, which is used for accuracy. The third variable is used to account for the possibility of any adjacent soybean producing states having an effect on state *i* at time *t*. By using the harvest-weighted average protein content of all adjacent states, we can rule out certain regional effects that may skew the

data. The last of the four variables accounts for any effect that may have affected the whole U.S. soybean population. These variables are then repeated for soybean oil in state *i* at time *t*.

After adjusting prices, we will be testing the proportion of price change due to pure price change, such as supply and demand, versus price change due to quality changes. Using the first-stage estimates from Cain and Parcell (2014) and choosing 2012 and 2013 as the base for oil and protein content for each region, we are able to compute the expected quality-adjusted price for each location and year, and then the quality-adjusted price for each attribute of the base period. By taking the difference of those two, we get the price change due to changes in quality. This gives us the price change due to supply and demand as the difference between the total change and the change due to quality. The following steps are used to calculate the price change due to quality changes.

1) Insert base period (2012 and 2013 marketing year) quality attribute levels averages into equation 1 to predict a quality-adjusted price for the base period ($\hat{P}_{base\ period}^{quality\ adjsuted}$).
2) Insert actual quality attribute levels from the year and location into equation 1 to predict a quality adjusted price for state i ($\hat{\hat{P}}_{i,t}^{quality\ adjsuted}$).
3) Compute the price change due to quality change, as $\Delta P_{quality\ change,i,t} = \hat{P}_{base\ period}^{quality\ adjsuted} - \hat{\hat{P}}_{i,t}^{quality\ adjsuted}$.
4) Compute the quality adjusted price as, $\widetilde{P_{i,t}} = P_{i,t} + \Delta P_{quality\ change,i,t}$

Firms make future decisions based on historical relationships. If the historical price, after adjusting for quality is statistically and significantly different from the observed price ($\widetilde{P_{i,t}} \neq P_{i,t}$) and the quality adjusted price has superior statistical properties (e.g., correlation with futures

prices is stronger), then a firm using historical data to make future decisions may choose to quality adjust prices as historical prices.

Data

The data to run the hedonic model was from Cain and Parcell (2014). The hedonic model had already been created. The main concerns with the panel data on price, protein content, and oil content had already been tested by Cain and Parcell so there was no reason to run these test a second time. The only addition we made to the model was that we added protein and oil squared to strengthen the regression.

We gathered weekly soybean prices from GeoGrain on eight different states from 2004 to 2013. This data is by marketing year so the data ends in the 2012 marketing year. After adjusting for missing prices, we ended with 464 observations for each state. Our adjustments left us with anywhere between 87% and 90% of the total observations. If there was one week missing we averaged the previous and following weeks to fill in the data. If there was more than one week missing, we established a trend using the previous week and the next known week to accurately represent the changing prices.

If we had perfect data, we would have weekly quality data along with the weekly price data. The data we have is annual data captured at the time of harvest. Because harvest quality is highly correlated with the quality from soybean bushels sold throughout the marketing year, the lack of data only erodes the power of statistical tests but does not bias the estimator.

Results

Table 2 gives the results of the first stage regression of the hedonic model. As can be seen, the data points are all statistically significant along with each of the variables except for protein and oil squared. The coefficient's signs are also as expected. One would expect protein and oil content to both have positive impacts on price while the coefficients of regional affects are negative. We expect this because if adjacent states have higher quality then that will raise the price of that state's soybeans while lowering the price of the state in question.

After adjusting price for quality, we compared the actual price against the adjusted prices. Figure 2 and 3 show the actual and adjusted prices between 2004 and 2013 for Michigan and Iowa. These figures show that over that nine year period there was rarely a time where prices reflected the true value based on the quality of the soybean harvest.

The differences in the average price and the standard deviation were also noticeable. Figure 4 shows these differences, and while a couple cents does not seem like much, when that couple of cents is multiplied by how many bushels of soybeans are being sold, the money that is being lost, or that could be gained, is a large amount.

Tables 2 and 3 give the calculated averages and standard deviations before and after quality adjustments. As can be seen in table 2 there are times throughout the nine year period where the quality adjusted prices show that, on average, the market both undervalued and overvalued the price of soybeans in a given year. The standard deviations in table 3 did increase, but that is to be expected when prices are adjusted to fit a more differentiated product. We expected standard deviation to go up because by quality adjusting prices we raised the price of certain soybeans and lowered the price of others depending on their previous value causing a larger price spread.

Table 5 gives one of the better explanations for the importance of quality-adjusted prices in the soybean market. The correlation between state price and futures price increases in every state data series after quality adjustments to the original price series. The increase in correlation due to quality adjustments suggests that more accurately forecasted prices could result.

Another example of using quality-adjusted prices would be to increase efficiency of hedging. Brorsen, B.W., D.W. Buck, and S.R. Koontz (1998) developed a model for optimal hedge ratio:

(12) $$\beta^* = \frac{X_f^*}{-X_c} = \frac{\sigma_{cf}}{\sigma_f^2}$$

where β* is the cross-hedge ratio, $\frac{X_f^*}{-X_c}$ is the correlation between futures prices and cash prices. The higher the correlation the closer the cross-hedge ratio is to one. Therefore, by increasing the correlation (i.e., numerator) through quality adjusting the historical cash price series, we strengthen the hedge ratio of today. That is, the hedge ratio used today is determined by cash-futures historical price relationships of similar quality levels.

Conclusion

With so much forecasting and hedging occurring in today's markets, being one or two cents off the actual worth of a commodity can cost someone a lot of money. Markets are starting to realize that the soybeans being produced today are not the same soybeans we had five years ago. The genetics are changing and so are the characteristics of the soybean. Protein and oil content are changing every harvest. With this kind of change occurring, there cannot be a standardized market without quality adjustments.

One of the goals of commodity trading in the U.S. is to provide a standardized value for each commodity based on a model of supply and demand for that commodity. In other words, a

market with perfect competition where every firm is selling the same quality product, but in competitive markets such as the U.S., there are no two products that are exactly the same because commodities are grown all across the country in different climates, weather, and conditions.

Our research found that after quality adjusting historical price series for soybean protein and oil content, we found that the correlation between futures prices and quality-adjusted prices was much higher than the correlation before quality adjustments were made. The results of these tests indicate that there could be better ways to forecast futures prices. It also shows that by adjusting price for quality, buyers may be able to hedge more accurately and reduce risk. This indicates that there is more research that can be done in the field of quality adjustment for soybeans to possibly make the market and buyers work more efficiently.

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Table 1

Hedonic Model Variables

Variable	Description
i	State (i = 1, 2, …, 27)
t	Year (t = 2003, 2004, …, 2012)
$Price_{it}$	Average soybean price in state i and time t
$Protein_{it}$	Average soybean protein content in state i and time t (%/bu)
Prt_ADJ_{it}	Interaction term: average protein content in state i (%/bu) multiplied by the harvest-weighted average of soybean protein content in all adjacent states at time t
Prt_OTH_{it}	Interaction term: average protein content in state i (%/bu) multiplied by the harvest-weighted average of soybean protein content in all other states (besides own and adjacent states) at time t
Oil_{it}	Average soybean oil content in state i and time t (%/bu)
Oil_ADJ_{it}	Interaction term: average oil content in state i (%/bu) multiplied by the harvest-weighted average of soybean protein content in all adjacent states at time t
Oil_OTH_{it}	Interaction term: average oil content in state i (%/bu) multiplied by the harvest-weighted average of soybean protein content in all other states (besides own and adjacent states) at time t

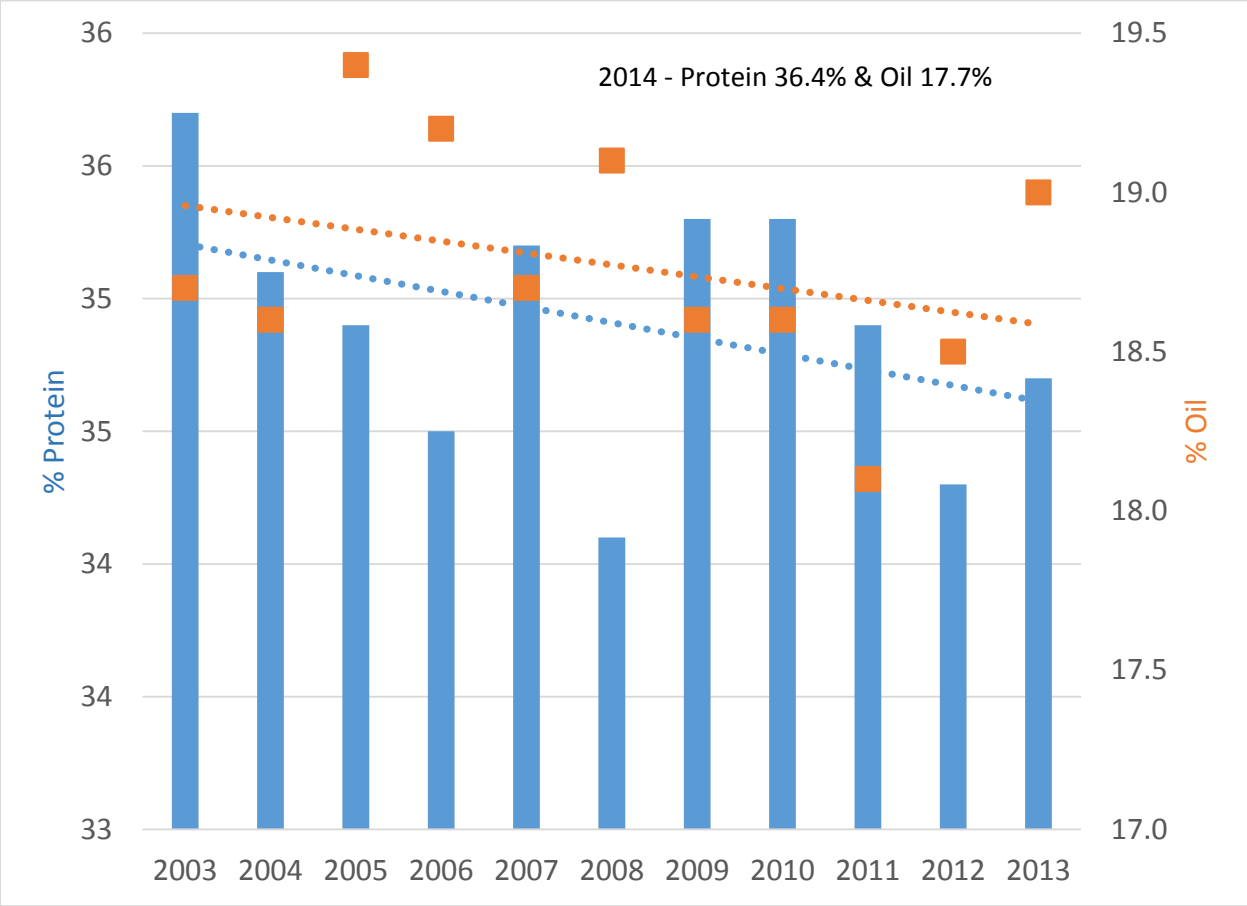
Table 2

Hedonic Model Results

Explanatory Variables	Dependent Variable
$Protein_{it}$	3.40 ***
$Protein_{it}^2$	–0.02
Prt_ADJ_{it}	–0.01 ***
Prt_OTH_{it}	–0.04 ***
Significant data points	100%
Mean	1.60
Oil_{it}	4.01 **
Oil_{it}^2	–0.02
Oil_ADJ_{it}	–0.03 ***
Oil_OTH_{it}	0.15 ***
Significant data points	100%
Mean	0.57

Notes: Significant data points refers to the percentage of marginal implicit prices that are statistically significant and of the expected sign. Also included in the regressions but not shown are state dummy variables. Number of samples: 270 (27 states, 2003 to 2012).

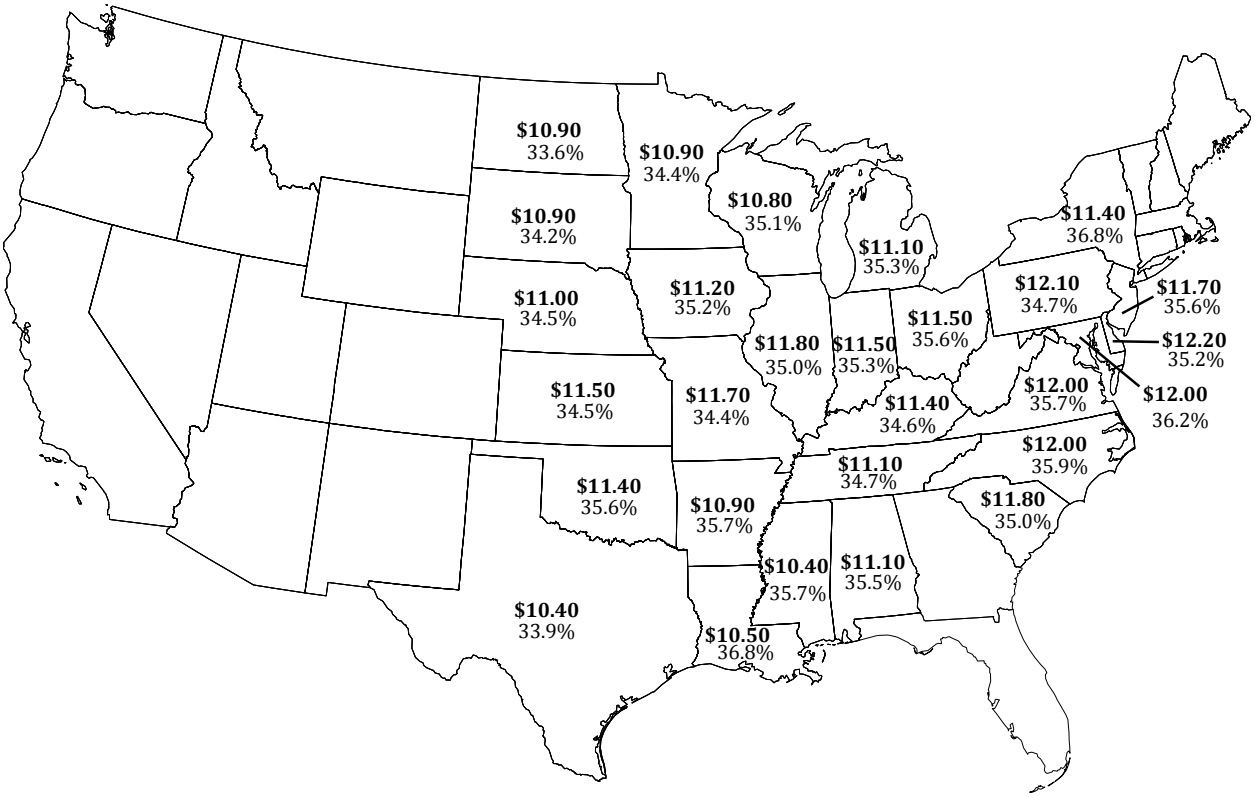
Figure 1 Weighted Average Soybean Qualty, % Protein and % Oil, by Year



source: United States Food Soybean Quality (various years) Naeve, Orf, and Miller-Garvin (Univesity of Minesota)

Figure 2

2010 Soybean Price and Protein Content



2011 Soybean Price and Protean Content

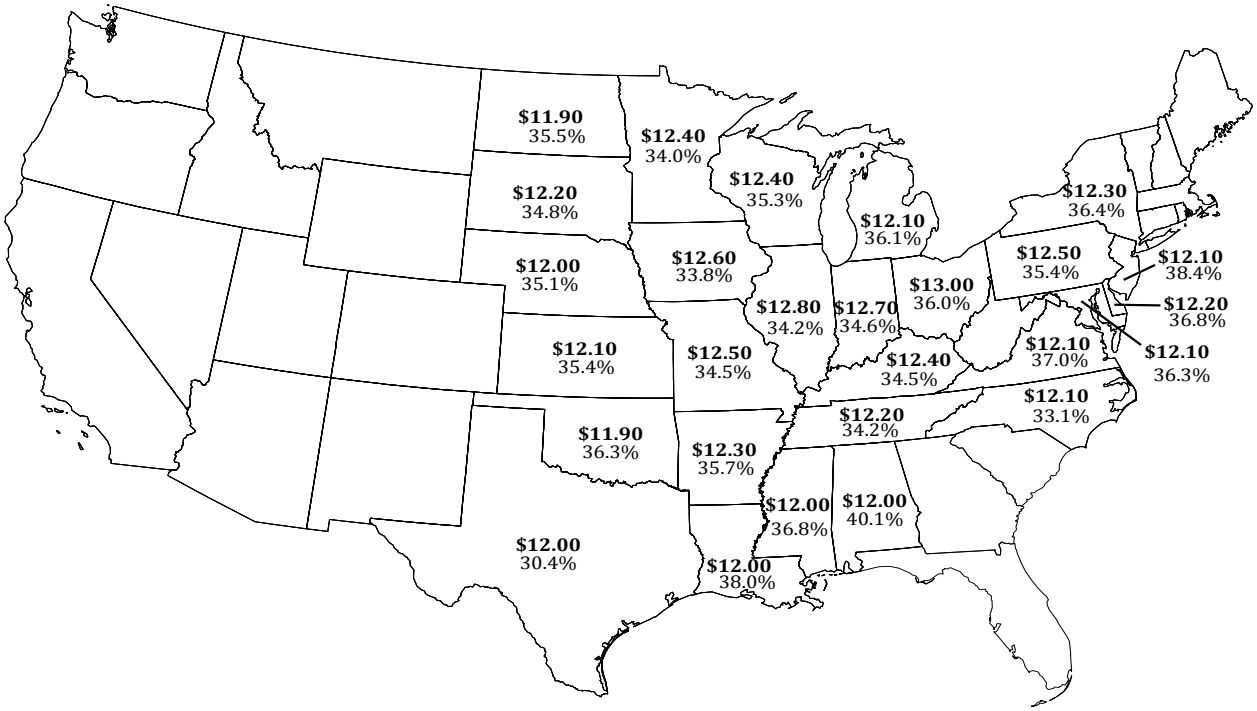


Figure 3. Michigan Prices Before and After Quality Adjustments

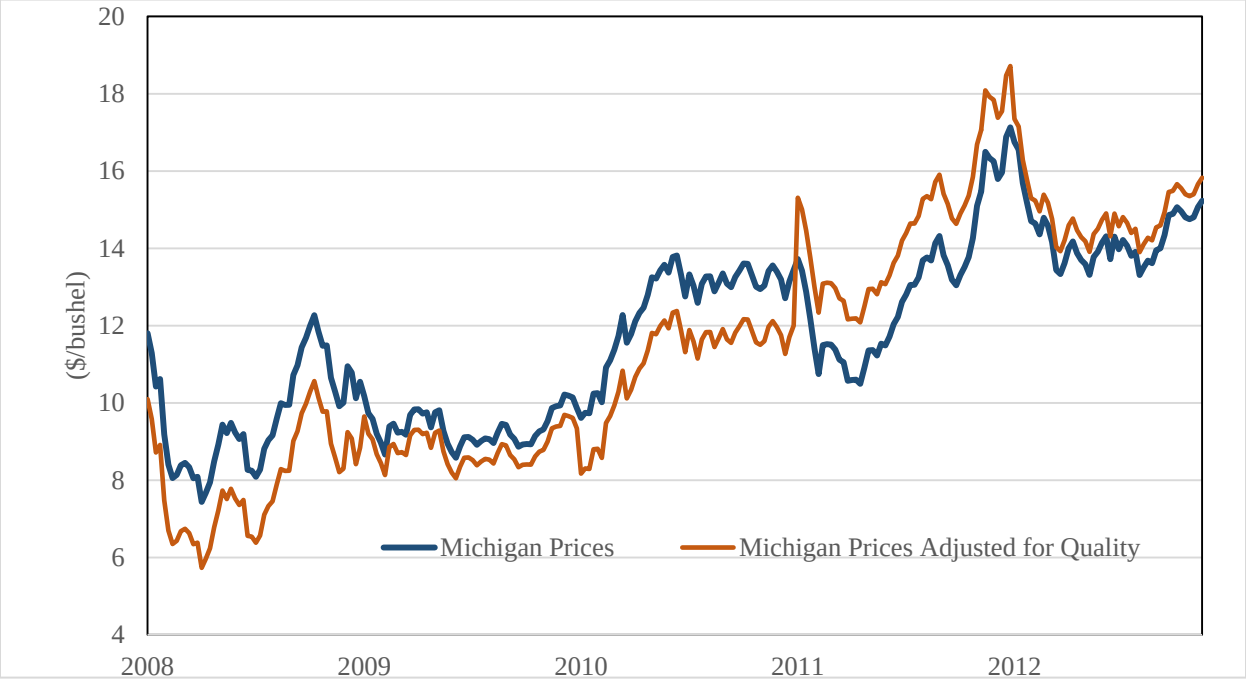


Figure 4. Iowa Prices Before and After Quality Adjustments

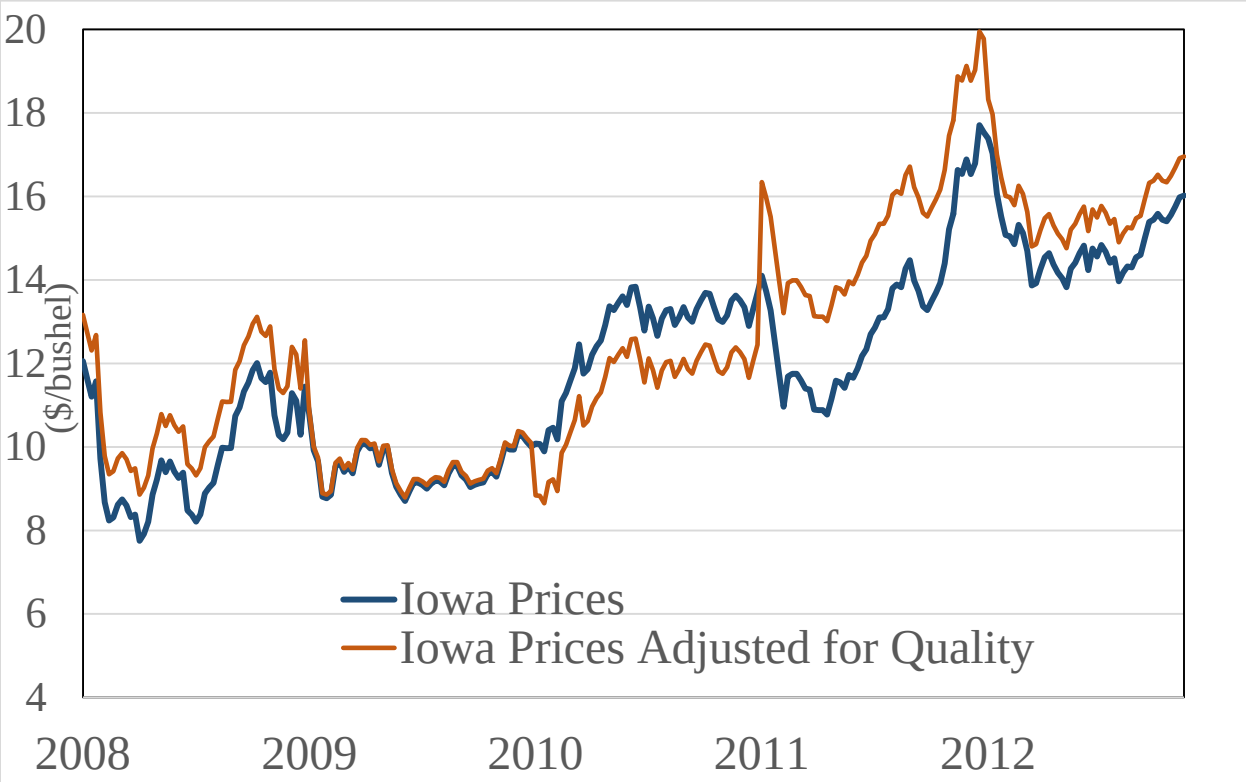


Figure 5. Difference, by State, between Average Price & Standard Deviation of Price Before and after Quality Adjustments

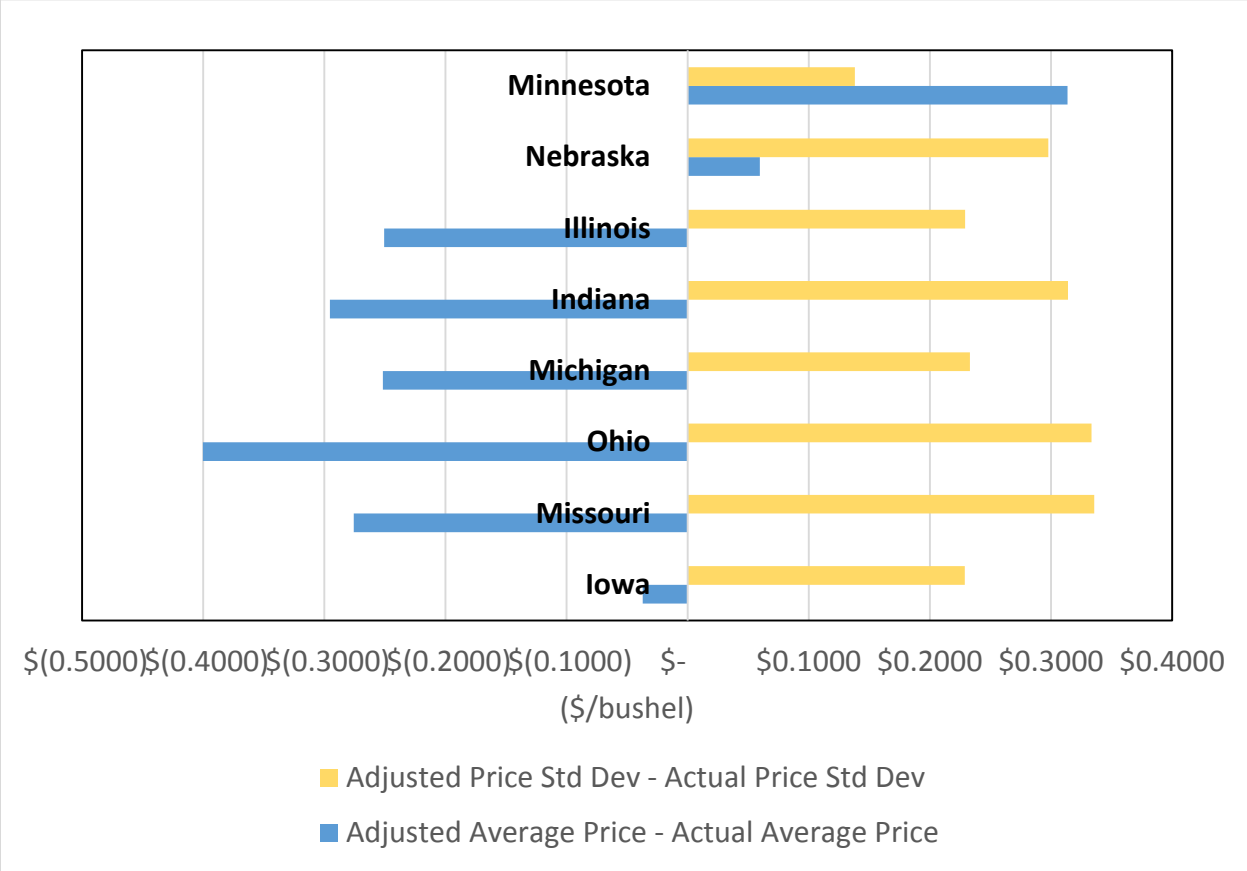


Table 3. Average Price Before and After Quality Adjustments

Location	Average Price Before	Average Price After	Difference
Iowa	$ 11.96	$ 12.58	$ 0.62
Missouri	$ 12.01	$ 12.06	$ 0.05
Ohio	$ 12.10	$ 11.47	$ (0.63)
Michigan	$ 11.73	$ 11.41	$ (0.32)
Indiana	$ 12.17	$ 11.85	$ (0.31)
Illinois	$ 12.13	$ 11.90	$ (0.23)
Nebraska	$ 11.64	$ 12.90	$ 1.26
Minnesota	$ 11.76	$ 13.17	$ 1.41

Table 4. Standard Deviation Before and After Quality Adjustments

Location	Std Dev Before	Std Dev After	Difference
Iowa	$ 2.38	$ 2.80	$ 0.42
Missouri	$ 2.41	$ 2.82	$ 0.42
Ohio	$ 2.31	$ 3.46	$ 1.15
Michigan	$ 2.28	$ 3.11	$ 0.82
Indiana	$ 2.32	$ 3.29	$ 0.97
Illinois	$ 2.38	$ 2.63	$ 0.25
Nebraska	$ 2.32	$ 2.74	$ 0.42
Minnesota	$ 2.33	$ 2.93	$ 0.60

Table 5. Correlation between Price and Futures Price Before and After Quality Adjustments

Location	Correlation Before	Correlation After
Iowa	0.8122	0.8679
Missouri	0.8087	0.8479
Ohio	0.8021	0.8184
Michigan	0.8025	0.8186
Indiana	0.8064	0.8243
Illinois	0.8132	0.8432
Nebraska	0.8098	0.8766
Minnesota	0.8113	0.8236