NCCC-134
APPLIED COMMODITY PRICE ANALYSIS, FORECASTING AND MARKET RISK MANAGEMENT

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Suggested citation format:

Bullock, D. W. and W. W. Wilson. 2019. "Managing Risk in Ethanol Processing Using Formula Pricing Contracts." Proceedings of the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. Minneapolis, MN. [http://www.farmdoc.illinois.edu/nccc134].

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Paper presented at the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management
Minneapolis, Minnesota, April 15-16, 2019

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Managing Risk in Ethanol Processing Using Formula Pricing Contracts

Manufacturers of ethanol face considerable pricing risk from both an input (corn and natural gas) and output (ethanol, distillers dried grains, and corn oil) in addition to the fluctuating value of the ethanol renewable identification numbers (D6 RINs) attached to each gallon of ethanol produced. Additionally, ethanol plants face technical risks related to their physical plant extraction rates for ethanol, DDGs, and corn oil along with their efficiency in using natural gas (or an alternative heat source). The purpose of this study is to examine the risk characteristics of a fixed margin, formula pricing contract applied to the ethanol industry using Monte Carlo simulation and sensitivity analysis. The margin model is set up for a typical South Dakota dry mill plant that has corn oil extraction capabilities in addition to dry DDGs. The results indicate that there are benefits to both the buyer and seller from utilizing the proposed contract. Under the average pricing scenario, the buyer can expect to pay a marginally lower mean ethanol price with a slightly lower probability of paying a high price and a slightly higher probability of paying a low price when compared to paying the spot ethanol price at delivery. At the mean, the buyer could feasibly save approximately 30 cents per gallon (on an average $1.43 delivery price) through perfect timing on setting the price components. For the seller, the gain from the contract is primarily due to a substantial reduction in margin volatility and better 5% value-at-risk (VaR) values when compared to the delivery benchmark under all three buyer pricing scenarios. The ethanol seller can also achieve gains in margin through increased ethanol extraction efficiency with an approximate 2% gain in margin for each 1% increase in the extraction rate.

Key Words: margin contracting, formula pricing, ethanol, Monte Carlo simulation

Introduction

Ethanol manufacturers confront substantial risk in the normal course of crushing including risks related to input prices (corn and natural gas), output prices (including ethanol, DDGs, and other residual by-products such as corn oil), in addition to D6 RIN (Renewable Identification Numbers) prices, and extraction rates for ethanol and by-products. Risks attributed to these variables are substantive and are typically absorbed by the ethanol manufacturer. While hedging mechanisms exist for some of these input and output prices, there is a notable amount of risk that is absorbed by the seller in terms of margin risk.

Alternatives to conventional hedging strategies involve varying types of contracting. One of these involves fixing each, or some, of the components of the underlying price independently (e.g., DDGs, ethanol, etc.); or contracting for the margin and fixing each of the elements of the ethanol price independently. In processing industries, this is sometimes referred as ‘component’ or ‘formula’ pricing. Simply, the ethanol price would be specified as a formula, whereby the buyer has the option to fix each element, however, the margin and extraction rate would be negotiated between the buyer and seller. While formula, or, component, pricing may appear novel to this industry, the approach has been adopted in other agricultural processing industries. As examples, component pricing is used for most of the semolina sales to pasta manufacturers, between brewers and malting companies, and between flour millers and bakers, as well as with some soybean and oilseed crushing companies for sales to their customers. These are all quite mature industries with larger and sophisticated principals and agents, making such contracting strategies readily implementable.

The literature in this sector has evolved though it is somewhat limited. Most of these studies investigate varying hedging strategies where by long or short positions in the processed product are hedged in futures contracts. To our knowledge, there is limited, if any, studies that have sought to quantify risks associated with alternative contracting strategies, despite that they are fairly common in these sectors. The purpose of this study is to analyze the use of a component-based, formula pricing strategy between ethanol manufacturers and buyers that is similar to those used in semolina and other processing industries. It is highly relevant. Ethanol, compared to the other agricultural processing industries, is relatively new, is high scale, and has substantial indigenous risk. The buyers and sellers are large and otherwise would have sophisticated approaches to pricing and risk management. There is substantial risk which can be partially absorbed through traditional mechanisms. However, the ethanol seller absorbs a consequential amount of residual risk and may be compensated by a risk premium for doing so. Component pricing, though not now used, is very relevant and would allow another way to mitigate risks, ultimately shifting a portion of the risk to the buyer.

We develop a Monte Carlo model of a hypothetical ethanol dry mill plant located in South Dakota (due to price availability) who buys corn and energy in the form of natural gas to produce ethanol and related byproducts in form of dry distillers' dried grains (DDGs) and corn oil. It is implicitly assumed that the D6 renewable identification number (RIN) value is embedded into the price of the ethanol. The proposed ethanol formula pricing equation is derived and simulated using a 72-day pricing window in which the buyer can choose to fix each of the price components (corn futures and basis, natural gas formula based upon daily Henry Hub prices, DDGs, corn oil, and D6 RINs). The ethanol 'crush' margin is fixed in the contract along with the extraction rates for corn to ethanol, DDGs and corn oil; and the usage rate for natural gas per gallon of ethanol produced. The simulation model examines both the statistical properties and the price sensitivities of the component-based formula price. This provides a profile of the risks and returns of entering this type of contract from the buyer's perspective.

To examine the risk characteristics and sensitivities to the ethanol processor, the formula price is then plugged into the plant's actual 'crush' margin, which is simulated, and the statistical and sensitivity properties derived. The seller's crush margin implicitly assumes that the seller will buy corn futures at the same time the buyer fixes the corn futures component and buys natural gas futures when the natural gas formula price (Henry Hub based due to lack of daily local price series) is fixed by the buyer. The D6 RIN value is fixed by the buyer in the formula price so the ethanol processor is assumed to absorb the price risks related to corn and natural gas basis (fixed at $2.00 in the formula), local DDG cash price, local corn oil price, and the actual extraction/usage rates versus the contracted rates.

The simulation results will be examined under three different assumptions regarding the buyer's skill or luck in fixing the pricing components. An 'optimal' scenario assumes that the buyer fixes the margin output prices (DDGs, corn oil, and RINs) at their maximums and the input prices (corn futures, corn basis, and natural gas formula) at their minimums in order to achieve the lowest formula price for ethanol over the 72-day window. A 'worst' scenario assumes the buyer fixes the margin output prices at their minimums and the input prices at their maximums which results in the highest formula price for the 72-day window. An 'average' scenario assumes that all of the price components were fixed at their average daily values during the pricing window. In addition, a 'benchmark' value is calculated for the ethanol price and actual 'crush' margin that would occur at contract maturity in the absence of the component-based, formula price contract. The contract prices / margins are compared to their benchmark values to ascertain their potential utility to both the buyer and seller.

Related Studies and Background

Processor Operations and Risk

Functions of processors differ from other hedgers, notably growers and traders. Processors buy inputs, transform the inputs and sell products. Typically, they would have one or more inputs and one or more outputs, and, importantly, active futures markets typically function in one or a couple of the prices which are at risk. As a result, there are other sources of risk which are not easily hedgeable and as a result, typically, the processor absorbs this risk.

A number of authors provide a description of the primary functions of processors. Hieronymus (1971) describes the flour milling industry as well as the soybean crushing industry, as does the Chicago Mercantile Exchange (2015). The crush spread is used by crushers to lock in margins. It is important that the soybean crush, normally refers to a futures crush. These are easily traded, and highly transparent and liquid. The cash crush differs in that basis values for each of the soybean, oil and meal are included in addition to a 'kicker' for non-reported or measurable attributes (e.g., protein). The focus of these are on ultimately how these firms hedge in futures.

Earlier studies described traditional hedging mechanisms in soybean processing (Andreas 1978; Peck and Nahmias 1989; Chicago Board of Trade 2006; Hieronymus 1971; Kolb and Overdahl 2007; Williams 1978) and flour milling (Bean 1978; English 1978; Lake 1978; Peck and Besant 1985) as well as later studies by Wilson and Preszler (1992 and 1993). These traditional approaches or models are of operational hedging (Working 1962). Inputs are bought or outputs sold, and the net position is hedged using a common transformation rate.

For ethanol manufacturers, corn is the primary input, in addition to natural gas, and the outputs are ethanol, corn oil, distillers' dried grains (DDGs) and RINs. Corn, ethanol, and natural gas are traded on futures markets and provide a mechanism to reduce exposure to risk on those components of the ethanol price. But the other components are important and result in risk that is not easily mitigate. As a result, managing risk in ethanol manufacturing is substantial.

Risk Management Studies on Agricultural Processors

There is a fairly extensive literature using analytical models to determine optimal hedge ratios for processors of agriculture commodities. These studies use varying forms of portfolio models to determine optimal hedge ratios for the hedgeable commodities. The focus on risk using hedging as a strategy is as if the only strategy pursued is that of hedging in futures.

These models have been applied in the bakery industry (Wilson, Nganje and Wagner 2006), soybean crushing industry (Dahlgran 2005), canola and western barley industry (Mann 2010), and cross-hedging of DDGs (Brinker et al. 2009). Others use varying forms of expanded mean-variance (EV) analysis including Gloy and Baker (2001), Sanders and Manfredo (2002), Pritchett et al. (2004), and Wilson, Nganje and Hawes (2007). Wilson et al. (2006) derived hedging strategies for food processors and illustrated that the optimal hedge ratios (HRs) were highly dependent on a complicated set of interrelations and duration. Bullock, Wilson and Dahl (2007) analyzed the efficiency of using futures and/or options as a hedge for processors with mean-variance preferences and correlated input-output prices using an approach originally developed by Bullock and Hayes (1992) where the analytical moments (mean and VCV) matrix were derived for truncated and/or non-smooth functions of a random variable (as is the case with options).

Wilson (1984) did one of the earlier studies on cross-hedging in the wheat sector. Chen et al. (2016) evaluated hedging for wheat flour millers, using EV models with copula distributions which are more flexible. He analyzed three scenarios for a wheat flour milling firm, depending if they were long or short cash wheat or flour. Their measure of risk was the value-at-risk (VaR) and derived the hedge ratio (HR) for a mean / value-at-risk (E-VaR) modeling approach which is becoming increasingly more adopted in these processing industries. Results indicated the HRs were typically less than one in value. The hedge ratios assuming copula distributions were in most cases less than the non-copula specifications, suggesting that models without copula may overstate risk.

There have also been a number of studies to determine optimal hedging strategies for soybean crushers. Simon (1999) found the crush spread reverts to its 5-day moving average and proposed trading rules to exploit this relationship. Others explored varying trading strategies using the soybean crush (Rechner and Poitras 1993; Johnson et al. 1991). Mitchell (2010) showed the profitable trades were shorter than losing trades. There are a number of other studies that discuss optimal hedging strategies for soybean processors (Farrell and Blas 2010; Lapan and Moschini 1994; Lence and Hayes 1994) using EV, expected utility (EU), and other modeling approaches.

More recent studies have analyzed varying aspects of canola crushing and contracting (Wilson and Dahl 2014). They analyzed preplant contracts in terms of risk and return for growers and processors. Their goal was to compare fixed price, variety specific and act-of-God provisions, in addition to an oil-premium contract.

Studies on Risk Management in Ethanol

Ethanol is a newer industry than others discussed above. James (2008) provides a review of energy trading. Dahlgran (2009) evaluated the effectiveness of hedging ethanol inventories and corn crush. Chang et al. (2012) explored asymmetric adjustments for spot and futures prices in numerous commodities and the ethanol futures price. Results indicate the spread adjustment with corn has the strongest long- run widening adjustment.

One of the few studies on risk management in ethanol (Awudu, Wilson and Dahl 2016) determined optimal hedge ratios and markets for different instruments and distributions. That study used EV models and VaR to evaluate optimal hedging strategies and derive measures of risk. They used more flexible distributions and quantified risk under different hedging strategies. The model was specified with copula dependencies which are more flexible when dealing with asymmetric distributions and correlation structure. They evaluated optimal hedging strategies for several scenarios. These include strategies for an ethanol processor purchasing corn and selling ethanol, corn oil, DDGs, and RINs. The optimal hedge ratios were derived using an E-VaR specification. This study assumed that the only strategy used by an agricultural processor was hedging and/or cross-hedging in futures. Hence, the goal was to use varying forms of the EV model (including EV, E-VaR, EV with copula, and E-VaR with copula approaches) and, as expected, the derived hedge ratios varied substantially by approach. The results indicated the best strategy would be short cash corn. The E-VaR with copula had the greatest utility indicating that other specifications misstate risks.

Component Pricing, Processor Hedging, and Risk

It is important that commodity processors pursue a number of strategies for risk management. Hedging is one, but it only reduces the futures price risk, which is only one element of risk confronting a firm. Hedging is attractive to hedge inventories (presumably when basis is weak such as arbitrage hedging), or to offset forward product sales, or in general to offset risks of a net cash position. For these reasons, hedging is common. However, hedging in futures is only one of a number of risk mitigation strategies. One alternative is component-based formula pricing, which is described in this section, and developed further in the following section.

The remainder of this section is based on our working with these industries in the development and application of processing contracts. Component-based formula pricing is an important alternative: 1) as industries mature, 2) when buyers are sophisticated (i.e., already active in hedging component inputs), 3) if the buyer is concerned about margins and extraction rates, and 4) when buyers want to buy further forward than actively traded instruments allow. Indeed, in the flour milling business, millfeed and other components are typically only tradeable 2-3 months forward, yet some buyers seek coverage 9-12 months forward and millers typically want to lock-in capacity utilization. In these cases, component-based formula pricing is attractive.

Component-based formula pricing has evolved to be an important alternative that is used, particularly by large bakers (in addition to being used in semolina flour processing and malting as indicated above). Traditionally a miller will buy wheat, hedge it and subsequently sell flour, millfeeds, and other byproducts; or they may sell flour, buy futures, and buy cash and sell millfeeds over time and as logistically attractive. Traditional hedging would have the miller taking offsetting positions (long or short) in futures, depending on their net cash position. However, the miller would be exposed to other components of price risk not mitigated by the wheat futures position. These other sources of risk or components of price are the wheat basis, millfeed values, extraction rates, and shipping costs. The residual of these would be the margin which would be random due to the variability of these other components.

Increasingly, the milling industry is selling to large corporate bakers. Typically, these firms are already hedging wheat prices, i.e., the wheat component of the flour price, but, are exposed to risk of the other components. While cross-hedging may be possible, these strategies are mostly ineffective. Hence, the seller is exposed to a larger component of risk due to these other components of risk which are not hedgeable; and, the buyer (i.e. baker) is similarly exposed to these risks. Component-based formula pricing is also common in markets which are not very transparent, or liquid, including durum, malting barley, etc., for the reasons cited above.

'Component pricing' would be executed in a contract that would specify a formula deriving the final price of flour, and how it relates to the components. The contract fixes margins, and extraction rates. All the other components are to be determined, normally, or, always at the option of the buyer. The mechanism on how this works varies by components. Futures are easy as both the buyers and sellers know the futures, so, at any time, they could concur on a futures price. At any time, the buyer would indicate the price level to be fixed, at which time 1) that component of price would be fixed; 2) the miller would either offset by buying futures if they are short cash wheat; or 3) selling futures if long cash wheat. There are no futures for the other elements (i.e., wheat basis, millfeeds), so the seller who knows these values (at which trades could occur), would routinely provide information to the buyer at which values can be fixed. It is important that the seller provides values for these components that are tradable or executable, else there would be a deviation in transaction prices which would exacerbate the distribution of risk. At any time, or with negotiated temporal limits, the buyer would indicate or accept a price for that component. The components of price may or may not, but typically would not, be fixed concurrently. The process of using a component-based formula pricing strategy reduces the risk for the seller (miller) and locks in a portion of forward capacity for processing. Ultimately, in some cases this would be referred as strategic purchasing.

In component-based formula pricing, the only risky variables are the extraction rate, or, e_a^* - e_c where e_a^* is the realized (or actual) extraction rate, and e_c is the contracted extraction rate. Ultimately, extraction rates are negotiable, but are fixed or non-random in the contract. The problem with extraction rates is the miller wanting to have autonomy on this component, and, due to difficulties of monitoring these values. Under component-based formula pricing, the components of price are to be determined at the option of the buyer, and are presumably (normally) offset concurrently by the buyer. Hence, from the buyer perspective, these are not risky.

The impact of component pricing for the mill is that risk is reduced substantially. Ultimately the only risks are execution risks and the difference between actual and contracted extraction rates. For these reasons, being there is less risk, the miller may be willing to negotiate a lower margin. The risk to the buyer depends on how they execute the trade. If they actively hedge and fix inputs strategically, their cost and risk should be reduced.

The problem for ethanol is more complicated for a number of reasons. Most important are that there are more components to the ethanol price including, prices for corn (futures and basis), DDGs, RINs, corn oil, and natural gas. However, we are of the view that at this moment it is probably not practical in pricing ethanol that all of the components of price could be treated as above. Instead, only the more liquid components are included in the formulae pricing below.

Conceptual Model

Consider a normal dry-mill ethanol plant with the ability to produce dry distiller's grains (DDGs) and corn oil as by-products of producing ethanol. The operating margin (M_t) for a particular plant in time period t can be represented as:

$$M_t = P_t^E + \boldsymbol{\beta}_t \cdot (P_t^{DDG} + P_t^{CO} + P_t^{RIN} - P_t^C - P_t^{NG}) + \varepsilon_t, \tag{1}$$

where P_t^i is the particular output or input price in period *t* with the *i* superscript equal to E for ethanol, DDG for local distiller's dried grains, CO for local corn oil, RIN for D6 Renewable Identification Numbers, C for local corn, and NG for local natural gas. The error term (ε) represents the other plant operating cost factors (direct and indirect) not accounted for in the equation. The vector β represents the technical operating characteristics of the particular plant in question for converting the corn and natural gas inputs into ethanol and byproducts (DDG, corn oil, and RINs). Note that the corn and natural gas input prices can be further broken down as:

$$P_t^C = F_t^C + B_t^C, \quad P_t^{NG} = F_t^{NG} + B_t^{NG}, \tag{2}$$

where *F* is the futures price and *B* is the basis component of the local cash price.

The fixed-margin ethanol formula pricing contract for a terminal delivery time period *T* is structured as follows:

$$\bar{M}_T = P_T^E + \bar{\boldsymbol{\beta}}_T \cdot [P_*^{DDG} + P_*^{CO} + P_*^{RIN} - (F_*^C + B_*^C) - (F_*^{NG} + \bar{B}^{NG})], \tag{3}$$

where the bar accent indicates the value is fixed in the contract and the star subscript indicates that the value can be fixed by the ethanol buyer at the current market at any time between the current time period (*t*) and the contract maturity date (*T*). Note that the contract assumes the natural gas price is a fixed basis formula price agreed to by the buyer and seller.

By rearranging the terms in equation 3, the contract ethanol formula price can be represented as:

$$\tilde{P}_T^E = \bar{M}_T - \bar{\boldsymbol{\beta}}_T \cdot [P_*^{DDG} + P_*^{CO} + P_*^{RIN} - (F_*^C + B_*^C) - (F_*^{NG} + \bar{B}^{NG})]. \tag{4}$$

Note that the formula price in equation 4 has a positive first derivative with the buyer-fixed input prices and negative first derivatives with the buyer-fixed byproduct and RIN prices. The buyer's objective is to minimize the ethanol formula price by maximizing the fixed byproduct and RIN prices while minimizing the fixed input prices.

For the ethanol plant, their actual margin at contract maturity (M_T) is determined by substituting the component-based ethanol formula price in equation 4 for the ethanol price in equation 1 and setting the time to maturity T. This results in the following equation:

$$\begin{aligned} M_T = \bar{M}_T &+ \beta_T^{DDG} P_T^{DDG} - \bar{\beta}_T^{DDG} P_*^{DDG} + \beta_T^{CO} P_T^{CO} - \bar{\beta}_T^{CO} P_*^{CO} + P_T^{RIN} - P_*^{RIN} + \ldots \\ &\bar{\beta}_T^C (F_*^C + B_*^C) - \beta_T^C (F_T^C + B_T^C) + \bar{\beta}_T^{NG} (F_*^{NG} + \bar{B}_T^{NG}) - \beta_T^{NG} (F_T^{NG} + B_T^{NG}) + \varepsilon_T. \end{aligned} \tag{5}$$

The ethanol plant margin risk is primarily based upon differences in technical efficiency (contract versus actual plant), or simply contracted versus actual extraction rates; and differences between the price set by the buyer and the actual prices paid and received for the inputs and byproducts respectively. Normally, these would be the same as described above; though it is possible for them to differ if there is execution risk.

Note that, by definition, the RIN technical factor is equal to one in both the contract and actual; therefore, the RIN risk is completely removed from the seller's margin equation since $P_T^{RIN} = P_*^{RIN}$ by definition in the contract. The ethanol plant can eliminate the risk of the futures component price differences for both corn ($F_T^C = F_*^C$) and natural gas ($F_T^{NG} = F_*^{NG}$) by buying the respective futures at the same time that the buyer fixes those prices. This strategy will be implicitly assumed in the simulation modeling of this study. Therefore, the reduced seller's margin equation can be represented as:

$$M_T = \bar{M}_T + \beta_T^{DDG} P_T^{DDG} - \bar{\beta}_T^{DDG} P_*^{DDG} + \beta_T^{CO} P_T^{CO} - \bar{\beta}_T^{CO} P_*^{CO} + \ldots$$
$$\bar{\beta}_T^C B_*^C - \beta_T^C B_T^C + \bar{\beta}_T^{NG} \bar{B}_T^{NG} - \beta_T^{NG} B_T^{NG} + \varepsilon_T. \qquad (6)$$

Therefore, the risks to the seller's margin are equivalent to the interactions between the technical extraction rates (contract and actual) with the byproduct prices (DDGs and corn oil) and the input basis values (corn and natural gas).

Methodology

To evaluate the risk profile of the proposed margin formula price contract, a Monte Carlo simulation model was set up using the @Risk™ application by Palisade Software[2] which is an add-in to Microsoft Excel. Two simulation models were set up: (1) a model of the contracted ethanol formula price that would be paid by the buyer to the seller (equation 4), and (2) the seller's (ethanol producer) actual margin using the component-based formula price contract (equation 6). The model was set up to reflect a typical South Dakota dry-mill ethanol plant producing dry DDGs and corn oil as the primary by-products and using natural gas at its primary heating source. The contract parameters used in the simulation are given in Table 1. The contracted margin is fixed at the calculated 'crush' margin at the initiation of the contract (5/8/2018).

Table 1. Parameters of Ethanol Margin Contract

Factor	Value	Units
Today's Date	5/8/2018	
Contract Delivery Date	8/15/2018	
Business Days Until Expiry	72	
Ethanol Technical Factor	2.80	gallons per bushel of corn
DDGs Technical Factor	17.25	pounds per bushel of corn
Corn Oil Technial Factor	1.50	pounds per bushel of corn
Contract Fixed Margin	$0.543	per gallon of ethanol

The buyer has the option of setting the corn futures (CME September 2018), local corn futures basis, distillers' dried grains (DDG) local price, corn oil local price, D6 RIN price, and a natural gas formula price which is set at $2.00 over the daily quoted Henry Hub price (in $/MMBtu). The price can be fixed by the buyer at the end of any business day between 5/8/2018 and

[2] www.palisade.com

8/15/2018. Since the buyer can fix the price at the close of any day during the 72-business day window, the entire daily time path of the pricing variables needs to be simulated. To project the daily time path of the price variables, daily values of the following price series (Table 2) were downloaded from Bloomberg for the relevant cash price series. Daily closing futures prices (ZCU18) were downloaded from DTN ProphetX and used to calculate the daily basis values using the daily SD cash price series. Daily Henry Hub natural gas prices were obtained from the Federal Reserve Bank of St. Louis' FRED online database. The data obtained covered the daily (business day) range from 8/16/2017 through 5/8/2018.

Table 2. Price Series Downloaded from Bloomberg

Series	Description	Bloomberg Key
Corn Cash Price	South Dakota Daily Ethanol Plant Corn Bid	ETDKNO2C Index
Ethanol	South Dakota Daily Ethanol Plant Ethanol FOB	ETDKETHP Index
Dry Distillers Grains	South Dakota Daily Ethanol Plant Dry Distillers	ETDKDDGP Index
Corn Oil	South Dakota Daily Ethanol Plant Corn Oil	ETDICOSD Index
D6 RINS	Daily D6 RIN Price	RIN6Y 18 STRF Index

To model and simulate the future time series behavior of the futures and cash price series, the @Risk time series fitting procedure was used to fit the historical data to the best fitting time series model (using the Akaike Information Criterion). To remove any bias in the model results to the prevailing trend in the data, the intercepts in all of the models were constrained to zero. Table 3 shows the best fitting model parameters for all of the daily price series. The price series were log-differenced to prevent negative forecasted values while the corn basis, which can be negative or positive, was just first differenced. Only the Box-Jenkins family of models (AR1, AR2, MA1, MA2, ARMA11) were included in the candidate model set. The AIC fitting criterion chose the MA1 model for all of the price series which is consistent with a mean-reverting stochastic process.

Table 3. @Risk Best Fitting Time Series Models Based on AIC Criterion

Series	Transform	Intercept (Trend)	MA(1)	Resid St Dev
Corn Futures Price (ZCU18)	Log Difference	0	-0.0570	0.0070
Corn Basis	Difference	0	-0.6952	0.0355
SD DDG Price	Log Difference	0	-0.1371	0.0098
SD Corn Oil Price	Log Difference	0	0.0000	0.0058
NG Formula Price	Log Difference	0	0.2761	0.0494
D6 RIN Price	Log Difference	0	0.1209	0.0505
SD Ethanol Price	Log Difference	0	-0.0185	0.0111

To account for potential correlations across the price series, the @Risk copula fit procedure was applied to the transformed (log- and first-differenced) price history. The best fitting copula, based upon the AIC criterion, was the Gaussian copula with a rank order correlation matrix shown in Table 4.

Table 4. Rank-Order Correlation (Spearman) Matrix for Gaussian Copula Fit

	Corn Futures	Dry DDG	Corn Oil	RINS	Corn Basis	Ethanol Price	NG Formula
Corn Futures	1.000						
Dry DDG	-0.193	1.000					
Corn Oil	-0.135	0.129	1.000				
RINS	0.005	0.147	-0.075	1.000			
Corn Basis	0.703	-0.168	-0.203	0.047	1.000		
Ethanol Price	-0.214	0.034	0.601	-0.140	-0.287	1.000	
NG Formula	0.056	0.006	0.101	0.166	0.081	0.116	1.000

Since the ethanol margin formula pricing contract essentially transfers all of the pricing decisions to the buyer, the final formula price reflects the ability of the buyer to optimally lock in all of the pricing components. Therefore, the simulation calculated three formula prices depending upon the buyer's ability to optimally time his/her pricing decisions:

1) an ***optimal scenario*** where the buyer fixes the input prices (corn futures, corn basis, natural gas) at their minimum values and the output prices (DDG, corn oil, RINs) at their maximum values over the 72-day pricing window which results in the lowest possible formula price,

2) an ***average scenario*** where the buyer fixes all of the prices at their average values over the 72-day pricing window, and

3) a ***worst scenario*** where the buyer fixes the input prices (corn futures, corn basis, natural gas) at the maximum values and the output prices (DDG, corn oil, RINs) at the minimum values over the 72-day pricing window resulting in the highest possible formula price.

The three scenarios place bounds upon the ability of the buyer to optimally time his/her pricing decisions within the contract. The first scenario represents the best that the buyer could accomplish via the timing of pricing while the third scenario represents the worst that the buyer could do via price timing. The second scenario would represent the price the buyer could expect if their timing decisions were essentially random or average in nature. A buyer with good timing skills could expect to achieve a price between the optimal and average scenarios while a buyer with poor timing skills could expect to achieve a price between the average and worst-case scenario.

From the seller's (ethanol producer) perspective, the risks of the contract are the deviation between the contracted margin and the actual plant operating margin using the ethanol formula price. This risk is directly related to three categories of factors:

1) the deviation between the contracted technical plant factors (extraction and usage rates) and the actual realized extraction and usage rates,

2) the deviation between the actual price received and the buyer fixed price for the byproducts (DDGs and corn oil), and

3) the deviation between the basis at maturity, and the buyer fixed basis for corn or the contract fixed basis ($2.00 in the simulation model) for natural gas.

With regards to the first category of factors, if the plant actually operates in a more efficient manner (higher extraction rates for ethanol, DDGs, and corn oil; or lower usage rate for natural gas), then the actual margin will be higher than the contracted value holding all other factors constant. With regards to the byproduct prices for DDGs and corn oil, the actual margin will be higher if the actual byproduct prices exceed the buyer-fixed values. With regards to the input basis values for corn and natural gas, the actual margin will be higher if the actual basis at maturity is weaker (lower) than the buyer-fixed basis in the contract.

In the Monte Carlo model, it is assumed that the seller buys corn and natural gas (Henry Hub) futures at the same time the buyer fixes those price components, thus effectively eliminating the futures component of price risk for both inputs. Therefore, the seller still has to absorb the basis risk in both markets. The natural gas formula price has a fixed basis of $2.00 per MMBtu; therefore, the seller absorbs the risk of the actual basis deviating from this contracted value. Likewise, it is assumed that effective hedging markets do not exist for the byproduct markets, so the seller absorbs the full price risk of these components.

Table 5. Distribution Assumptions for Technical Factors and NG Basis

Variable	Distribution
Actual Ethanol Extraction Rate	Uniform(2.66,2.94)
Actual DDGS Extraction Rate	Uniform(16.39,18.11)
Actual Corn Oil Extraction Rate	Uniform(1.43,1.58)
Natural Gas Basis	Normal(2.02,0.40)

Table 5 shows the additional distributional assumptions for the seller's margin model. It is assumed that the seller will receive the time series simulated byproduct prices and corn basis on the terminal date (day 72). The minimum and maximum parameters for the actual technical parameters represent a 5% deviation (above and below) from the contracted values. The natural gas basis represents the mean and standard deviation of the historical spread between the monthly average South Dakota industrial user price (as reported by the Energy Information Agency of the Department of Energy) and the Henry Hub spot price (as reported by the Federal Reserve Bank of St. Louis FRED online database) over the previous two years.

Monte Carlo Simulation Results

To examine and rank the risk factors impacting both the ethanol formula price and seller margin, the Monte Carlo simulation model was run for 5,000 iterations with the formula price and seller margin values for the optimal, average, and worst cash buyer scenarios tracked as outputs. For benchmarking purposes, the simulated ethanol delivery price and seller margin at delivery (day 72) were also tracked. Additionally, sensitivity analysis was conducted on the simulation results with the model inputs ranked based upon their percent contribution to the variance of the tracked output variable.

Ethanol Formula Price Results

Figure 1 shows the formula price distribution for the average price scenario (solid red) with the benchmark terminal delivery ethanol price (blue dots) overlaid on top. The mean price under this scenario ($1.427 / gallon) is approximately 1 cent per gallon lower than the mean benchmark price ($1.438 / gallon). However, a two-sample one-tailed t-test [Ho: μ(formula) < μ(benchmark)] produced a t-statistic of -4.15 which has a p-value of less than 0.0001 – an indication that the mean formula price is significantly lower than the mean benchmark price at delivery under the average pricing scenario.

In terms of variability, the standard deviations are almost equal (12.6 versus 13.3 cents per gallon). Where the price distributions seem to differ most significantly is in the tails. The probability of a formula price below $1.20 a gallon is slightly higher (4.1%) for the formula price when compared to the benchmark (2.6%). Likewise, the probability of a higher price (greater than $1.60 a gallon) is higher (11.4%) for the benchmark when compared to the formula price. A two-sample one-tailed F-test [Ho: σ^2(formula) < σ^2(benchmark)] produced an F-statistic of 0.8915 with a p-value less than 0.0001 – an indication that the difference in variability is statistically significant.

When examining the spread between the formula price and the benchmark price, pricing under the formula saved the buyer an average of approximately 1 cent per gallon with a 90 percent confidence interval between an extra cost of 32.8 cents per gallon and a savings of 28.3 cents per gallon. Therefore, the buyer with average pricing skills could expect to just about break even on the formula pricing contract when compared to just waiting to price at delivery. Therefore, the benefits of the formula pricing contract would primarily benefit the seller as described below (which is the intent of component pricing). In addition, it would benefit primarily buyers with superior (better than average) pricing skills while those with inferior skills are likely to do worse.

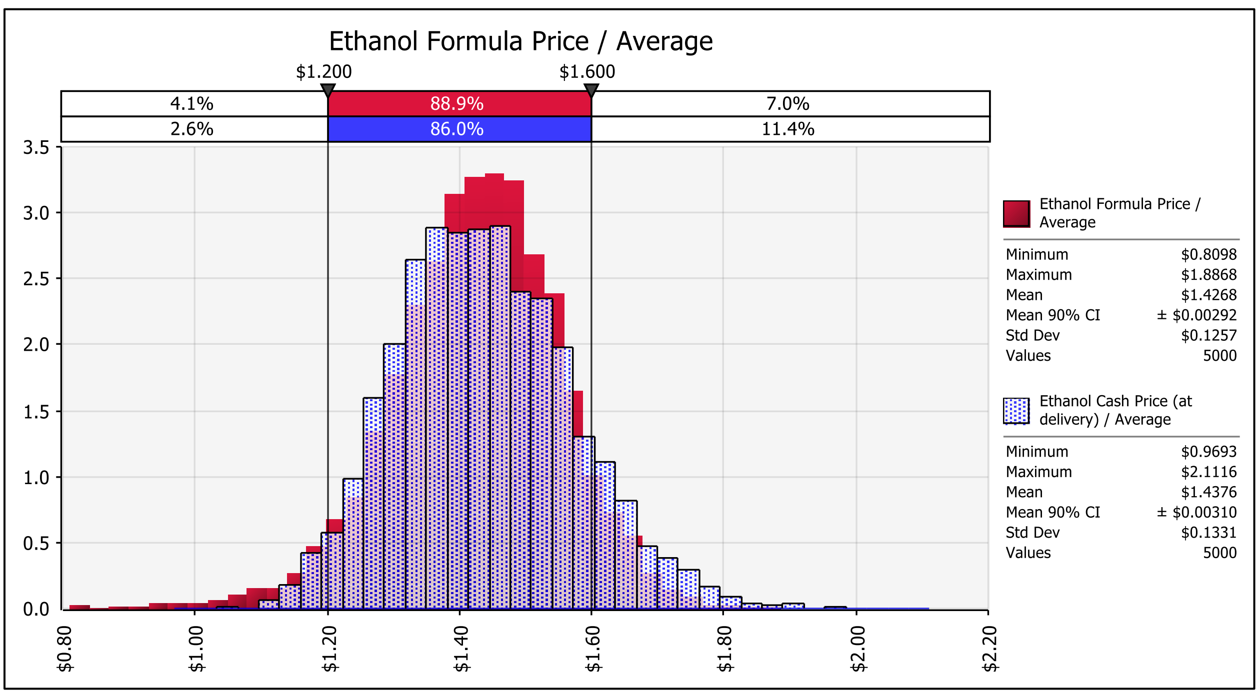

Figure 1. Formula Price Simulation Results from Average Scenario

Summary statistics for the formula price scenarios and benchmark delivery price are shown in Table 6. The results show that for the optimal timed buyer, the average price is approximately

$1.104 per gallon, a savings of over 30 cents per gallon relative to the benchmark price. For the worst timed buyer, the average price is approximately $1.7375 per gallon which is slightly over 30 cents per gallon higher than the benchmark. So, at the mean value, the price timing skill of the buyer can save or lose up to 30 cents per gallon under this particular simulation scenario.

Table 6. Summary Simulation Statistics for Formula Prices and Benchmark Delivery Price

Simulation Statistic	Formula Pricing Contract Scenarios (Buyer's Perspective)			Benchmark
	Optimal Scenario	Average Scenario	Worst Scenario	Delivery Price
Average	$ 1.1039	$ 1.4268	$ 1.7375	$ 1.4376
Standard Deviation	$ 0.1770	$ 0.1257	$ 0.1297	$ 0.1331
5th Percentile	$ 0.7901	$ 1.2096	$ 1.5600	$ 1.2351
95th Percentile	$ 1.3155	$ 1.6229	$ 1.9683	$ 1.6660

The sensitivity tornado for the average price scenario is shown in Figure 2. Almost half (48.9%) of the variability in the formula price is due to fluctuations in the average RIN price. Almost a third of the variability (28.6%) is due to fluctuations in the corn futures price while a little less than one-fifth (17.6%) of the variability is explained by fluctuations in the natural gas formula price. The remaining prices (local DDG's, corn basis, and corn oil) make up less than 5% of the formula price variability.

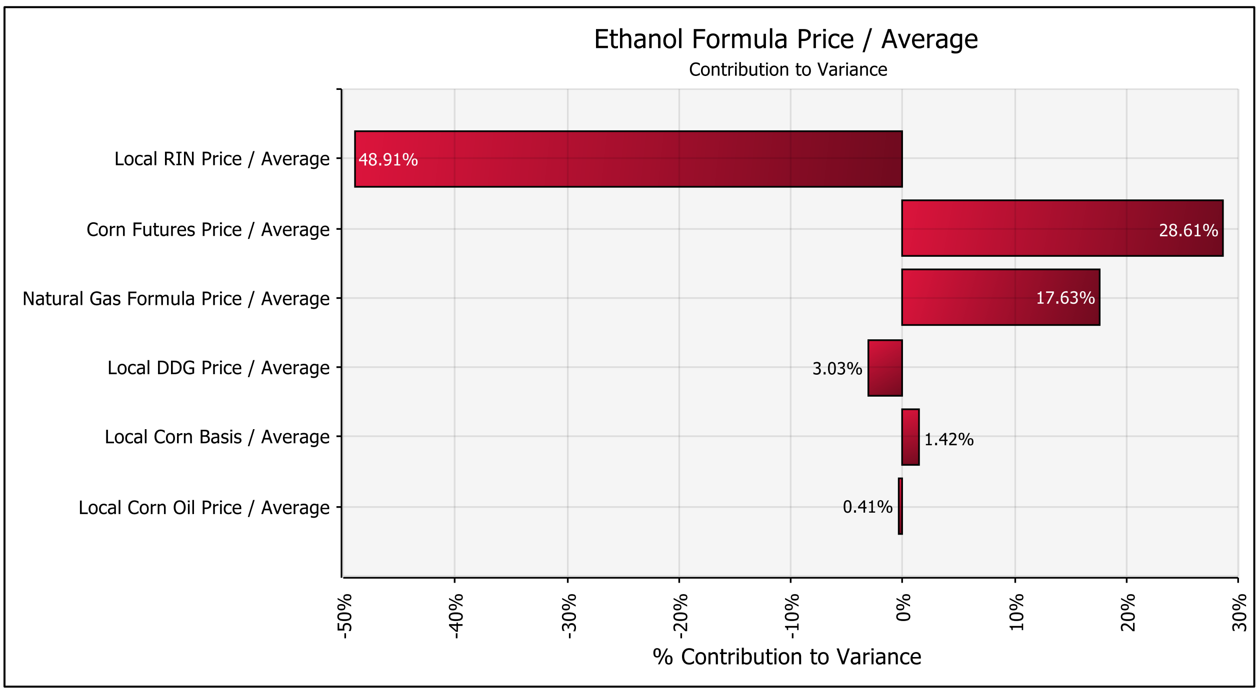

Figure 2. Formula Price Sensitivity Tornado for Average Scenario (% Contribution to Variance)

The sensitivity results for all of the formula pricing scenarios is shown in Table 7. For the optimal pricing scenario, the same ranking holds when compared to the average scenario. The main difference is the higher proportion of variance explained by the optimal RIN price (76.9% versus 46.8%) with all of the other variables shifted lower. In the worst scenario, the RIN price falls to 3rd in the ranking while the natural gas formula (46.3%) and corn futures (28.0%) prices occupy the top two slots.

Table 7. Sensitivity Results for All Formula Pricing Scenarios (% Contribution to Variance in Parentheses)

	Formula Pricing Contract Scenarios (Buyer's Perspective)		
Rank	**Optimal Scenario**	**Average Scenario**	**Worst Scenario**
#1	RIN Price (80.2%)	RIN Price (48.9%)	Nat Gas Formula Price (47.7%)
#2	Corn Futures Price (13.9%)	Corn Futures Price (28.6%)	Corn Futures Price (28.2%)
#3	Nat Gas Formula Price (2.8%)	Nat Gas Formula Price (17.6%)	RIN Price (19.5%)
#4	DDG Price (2.0%)	DDG Price (3.0%)	DDG Price (2.6%)
#5	Corn Basis (0.9%)	Corn Basis (1.4%)	Corn Basis (1.7%)
#6	Corn Oil Price (0.3%)	Corn Oil Price (0.4%)	Corn Oil Price (0.3%)

Overall, the simulation sensitivity results indicate that most of the variability (risk) present in the ethanol formula price contract is primarily concentrated in the two input prices (corn futures and natural gas) and the RIN price. Two of these components are directly hedgeable in the commodity futures and option markets (corn and natural gas) which cover almost half (48 – 49%) of the risk under the average and worst pricing scenarios. There is no liquid hedging mechanism for D6 RIN prices; therefore, if this is a feature of the margin contract, the buyer would absorb all of the risk / opportunity of the fluctuating RIN price.

Ethanol Plant Margin Results

A graphical summary of the simulation results for the ethanol plant margin under the average pricing scenario is shown in Figure 3 (along with comparison to benchmark margin at contract maturity). Under the average pricing scenario, the ethanol seller can expect to earn a slightly lower average margin (54.2 cents / gallon) when compared to benchmark delivery value (56.4 cents / gallon). A two-sample one-tailed t-test [Ho: μ(formula) < μ(benchmark)] resulted in a t-statistic of -5.64 which has a p-value of less than 0.001 – an indication that the difference in means is statistically significant.

However, in exchange for the slightly lower average margin, the seller gains a substantial reduction in margin variability as the standard deviation of the margin is significantly lower (5.0 versus 26.8 cents per gallon) for the formula price margin versus the benchmark. A one-tailed F-test [Ho: σ^2(formula) < σ^2(benchmark)] of 0.0352 had a p-value of less than 0.0001 – an indication of a statistically significant difference in variability between the two simulation samples. This illustrates the major purpose of component pricing, that being to reduce risk to the sellers. Here, it is reduced substantially through the hedging of the two components, corn and natural gas futures along with fixing the RIN value in the margin contract.

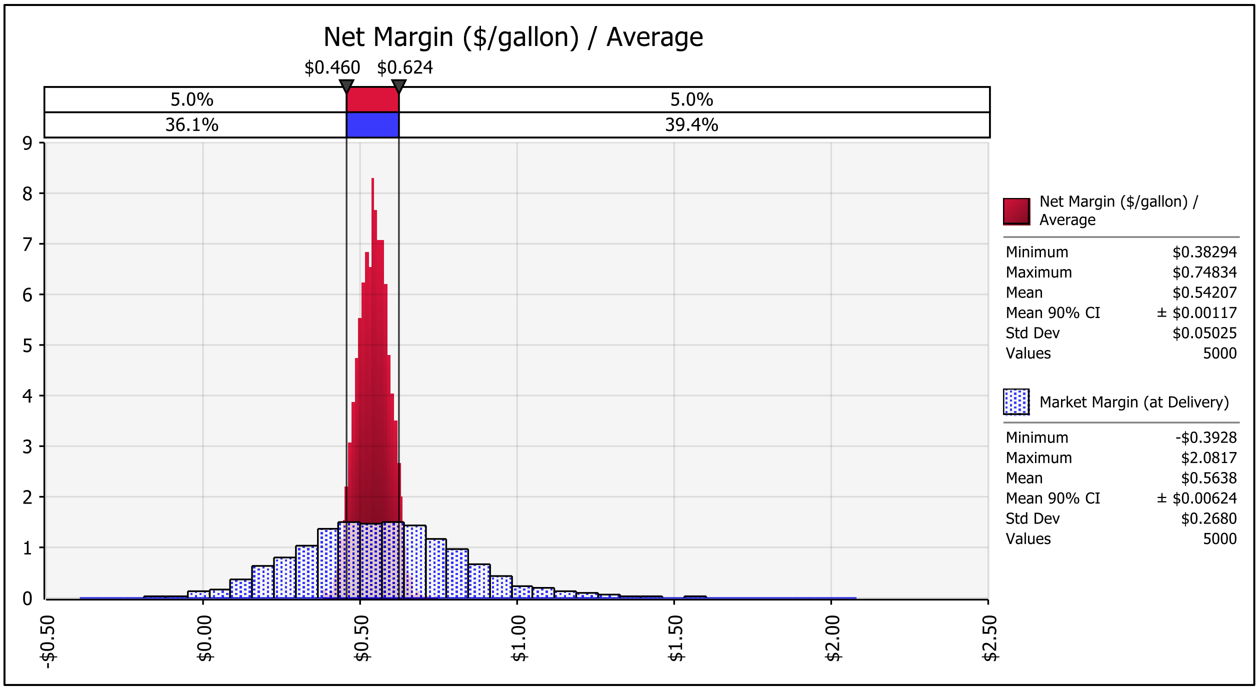

Figure 3. Ethanol Margin Simulation Results from Average Scenario

A summary of the sample statistics for all of the formula pricing scenarios and the benchmark is contained in Table 8. The final row of the table contains the simulated probability that a negative plant margin would occur. Under all of the formula pricing scenarios, the probability of a negative margin is effectively nil while there is a 1.3% probability of a negative margin under the benchmark. Also, note that the 5% VaR value under the optimal (buyer) pricing scenario of 38.1 cents per gallon is still substantially and materially higher than the value under the benchmark (14.6 cents). Therefore, the benefits of the contract to the seller for margin risk management entail essentially risking a dime at the mean (46.6 versus 56.3 cents per gallon) in exchange for a 23.5 cent gain in 5% VaR under even the highly unlikely optimal (buyer) pricing scenario.

Table 8. Ethanol Margin Simulation Results for All Scenarios and Benchmark

Simulation Statistic	Formula Pricing Contract Scenarios (Buyer's Perspective) Optimal Scenario	Average Scenario	Worst Scenario	Benchmark Delivery Margin
Average	$ 0.4663	$ 0.5421	$ 0.6159	$ 0.5638
Standard Deviation	$ 0.0488	$ 0.0503	$ 0.0536	$ 0.2680
5th Percentile	$ 0.3810	$ 0.4596	$ 0.5295	$ 0.1461
95th Percentile	$ 0.5425	$ 0.6236	$ 0.7060	$ 1.0071
Odds | Negative Margin	0.0%	0.0%	0.0%	1.3%

The sensitivity tornado graph for the net ethanol plan margin under the average pricing scenario is contained in Figure 4. The margin between the RIN price set by the buyer and the final delivery RIN price is the dominant contributor to the variance of the plant margin under this scenario (just over 80% of the explained variance). Also, of significance are the plant efficiency in ethanol extraction (actual rate versus contract rate) and changes in the corn basis at delivery. An examination of the sensitivities under the optimal and worst buyer pricing scenarios show an identical ranking in these top three factors with slight differences in the percentage shares.

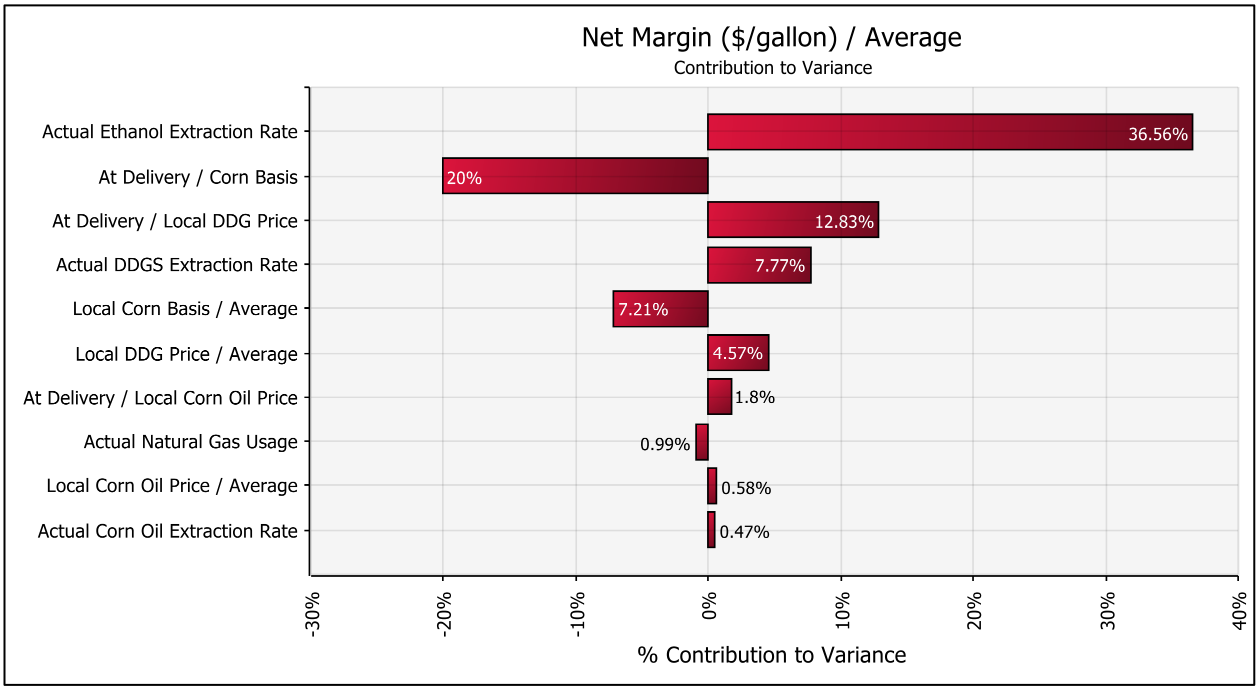

Figure 4. Sensitivity Tornado for Ethanol Margin under Average Pricing Scenario (% Contribution to Variance)

Overall, these sensitivity results indicate that, from the perspective of the ethanol plant, the primary remaining risk in the margin contract after accounting for hedging out the corn and natural gas futures price risk is mostly attributed to the variability in the ethanol extraction rate (36.6%) followed by the corn basis at delivery (20.0%), and the DDG price at delivery (12.8%). For the ethanol extraction rate, the sensitivity analysis on the mean margin (average scenario) indicates that, for a 5% variation above and below the contracted rate 2.8 gallons per bushel (minimum of 2.66 and maximum of 2.94), the mean net ethanol margin varies between 49.2 to 58.6 cents on a baseline margin of 54.2 cents per gallon. So, the potential losses / gains on the margin range from -5.0 to +4.4 cents per gallon based upon a 5% variability in ethanol extraction efficiency. So, the results indicate that any percent gain or loss in ethanol processing efficiency would likely translate into double that percentage impact upon the margin.

Table 9. Ethanol Margin Sensitivity Results for the Three Buyer Scenarios (% contribution to variance)

	Formula Pricing Contract Scenarios (Buyer's Perspective)		
Rank	**Optimal Scenario**	**Average Scenario**	**Worst Scenario**
#1	Ethanol Extraction Rate (33.5%)	Ethanol Extraction Rate (36.6%)	Ethanol Extraction Rate (37.1%)
#2	Delivery Corn Basis (20.4%)	Delivery Corn Basis (20.0%)	Delivery DDG Price (19.4%)
#3	Delivery DDG Price (10.7%)	Delivery DDG Price (12.8%)	Delivery Corn Basis (12.5%)
#4	Optimal Corn Basis (8.9%)*	DDG Extraction Rate (7.8%)	DDG Extraction Rate (7.4%)
#5	DDG Extraction Rate (8.7%)	Average Corn Basis (7.2%)*	Worst Corn Basis (7.2%)*
#6	Optimal DDG Price (7.0%)*	Average DDG Price (4.6%)*	Worst DDG Price (4.8%)*

*Price fixed by buyer in contract (per scenario).

The sensitivity results for all three buyer pricing scenarios are summarized in Table 9. The ethanol extraction rate is the top factor across all three scenarios accounting for approximately one-third of the variability in the seller's margin. While the composition of the top six factors is the same across all three buyer pricing scenarios, the rankings shift slightly for the 2, 3, 4, and 5 spots although the top three remain ethanol extraction rate, corn basis at delivery, and DDG price at delivery. This indicates that there is a strong incentive for tools to manage corn basis and DDG price risk in order to further reduce the variability of the plant margin.

Buying corn on either a fixed price or a basis contract could be used to manage the corn basis risk component. For DDGs, the potential mechanisms for managing price risk include forward sales contracts (to feedlots), an over-the-counter (OTC) derivative contract, or the use of a cross-hedge using corn and/or soybean meal futures. Note, however, that the timing of placing these positions (relative to the buyer's timing of fixing the component) is critical for the hedge to be effective.

Summary and Conclusions

Ethanol manufacturers confront substantial risk in the normal course of crushing including risks related to input prices (corn and natural gas), output prices (including ethanol, DDGs, and other residual by-products), in addition to RINS (Renewable Identification Numbers), and extraction rates. The risks associated with these variables can be substantial and are typically managed and/or absorbed by the ethanol manufacturer. Management typically entails a combination of futures hedges, over-the-counter (OTC) derivative contracts (when available), and traditional forward contracting mechanisms.

A common risk management tool utilized by many other processing industries facing multiple input and output pricing and technical risks involves a component or formula pricing approach whereby the technical aspects and processing margin are fixed while giving the buyer the option to 'fix' the remaining price components at the market at any time up until the maturity of the contract. These contracts are currently used in flour / semolina milling and related processing industries; however, they have not found use in the ethanol industry. These contracts essentially transfer much of the price risk from the seller to the buyer whereby the buyer can receive a superior price through skill in market timing while the seller can reduce its margin risk to essentially the technical performance of the processing plant (i.e., the actual extraction rates versus those specified in the contract).

This study examines a potential implementation of this type of fixed-margin, component-based formula pricing contract for a prototypical South Dakota ethanol dry mill with corn oil extraction capabilities. The proposed contract would fix the ethanol processing margin and the technical crush factors related to ethanol and byproduct production (per bushel of corn) and natural gas usage. The input components to be fixed by the buyer included corn futures and basis, and a natural gas formula price (based upon Henry Hub spot). The output components included distillers' dried grains (DDGs), corn oil, and optionally, the ethanol renewal identification number (D6 RINs) prices.

A Monte Carlo simulation model is set up to measure the ethanol formula price and the actual ethanol processor's margin if such a contract was implemented over the 72-day time window from 5/8/2018 to 8/15/2018. The relevant price series are modeled using stochastic MA(1) time series with three assumptions implemented regarding the timing of the buyer fixing the relevant prices: (1) an optimal scenario (relevant to the buyer) whereby the buyer fixes the prices at the minimum or maximum values within the time window in order to minimize the formula price, (2) an average scenario where prices are set at the average over the time window, and (3) a worst-case scenario whereby the prices are set to maximize the formula price. The ethanol seller is assumed to offset the corn and natural gas futures price risk by buying futures at the time at which the buyer fixes those components. The RIN value (contract and delivery) is fixed by the buyer who absorbs all of the risk of the price fluctuation. This feature is optional to the contract but would provide the buyer with an additional opportunity to enhance their price while not providing any additional risk to the seller.

The simulation results indicate that the buyer could potentially achieve a cost savings (at the mean) of 30 cents per gallon (over the price at delivery) under the optimal pricing scenario. Even under the average pricing scenario, the results indicate some benefits to the buyer in a slightly lower average ethanol price with some slight gains in terms of the price distribution (i.e., slightly higher probability of low ethanol price and slightly lower probability of a high ethanol price). In terms of sensitivity, under the average pricing scenario, the highest source of variability is the RIN price (close to half) followed by variability in the corn futures and natural gas formula (Henry Hub) prices. The same ranking essentially holds under the optimal pricing scenario; however, under the worst-case, the natural gas formula price has the highest ranking followed by the corn futures and RIN prices.

For the seller of ethanol, the results under the average pricing scenario show that while the mean margin value is slightly lower when compared to the benchmark, there is a substantial gain in the reduction of margin volatility. Also, the 5% VaR under even the optimal buyer pricing scenario is still significantly higher than under the benchmark scenario. The primary source of variability under all three buyer pricing scenarios is the ethanol extraction rate (approximately 1/3 of total margin variability) followed by the corn basis at delivery and the DDG price at delivery.

The results have a number of implications for the implementation of these types of contracts in the ethanol industry. First, the contract provides substantial benefits to ethanol buyers who are adept at market timing but even for those who only achieve average prices, there is a small but statistically significant benefit in terms of the net ethanol formula price. A considerable portion of the risk / opportunity to the buyer is through the local RIN price (almost 50% of variability under average pricing scenario and over 80% for the optimal scenario). The other two major sources of price variability are the corn futures and natural gas formula price which can be effectively managed by the buyer through the adept use of corn and natural gas futures and option contracts.

Second, the contract provides an effective margin risk management tool to the ethanol seller with a substantial reduction in the variability and downside risk (VaR) of the net margin while sacrificing a small amount of return at the mean under the average pricing scenario. The contract provides an opportunity for the ethanol seller to realize additional margin through achieving a higher ethanol extraction rate than the contracted value with each 1% increase in efficiency resulting in an approximate 2% increase in net margin. The seller can also achieve additional material reductions in margin variability and risk through the availability and use of risk management tools related to the corn basis and local DDG price.

A third and more minor observation is that the factors related to corn oil extraction and pricing are essentially not material to either the buyer's formula price or the seller's margin under all three pricing scenarios. Therefore, the results indicate that having a price risk management tool for corn oil is not material to the success of the contract.

References

Andreas, D. 1978. "Commodity Markets and the Processor." In A. Peck, ed. *Views from the Trade*. Board of Trade of the City of Chicago, pp. 177–182.

Awudu, I., W. Wilson, and B. Dahl. 2016. "Hedging strategy for ethanol processing with copula distributions." *Energy Economics* 57:59–65.

Bean, A. 1978. "The Miller and the Commodity Market." In A. E. Peck, ed. *Views from the Trade*. Board of Trade of the City of Chicago, pp. 149–154.

Brinker, A.J., J.L. Parcell, K.C. Dhuyvetter, and J.R. Franken. 2009. "Cross-hedging distillers dried grains using corn and soybean meal futures contracts." *Journal of Agribusiness* 27(1–2):1–15.

Bullock, D.W., and D.J. Hayes. 1992. "Speculation and hedging in commodity options: A modification of Wolf's portfolio model." *Journal of Economics and Business* 44(3):201–221.

Bullock, D.W., W.W. Wilson, and B.L. Dahl. 2007. "Strategic use of futures and options by commodity processors." *International Review of Economics & Finance* 16(4):578–591.

Chang, C.L., L.H. Chen, S. Hammoudeh, and M. McAleer. 2012. "Assymmetric adjustments in the ethanol and grain markets." *Energy Economics* 34(6):1990–2002.

Chen, S., W.W. Wilson, R. Larsen, and B. Dahl. 2016. "Risk management for grain processors and 'copulas.'" *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* 64(2):365–382.

Chicago Board of Trade. 2006. "Soybean Crush: Reference Guide."

Chicago Mercantile Exchange. 2015. "CBOT Soybeans versus DCE Soybean Meal and Soybean Oil Crush Spread." Available at: https://www.cmegroup.com/trading/agricultural/files/pm374-cbot-soybeans-vs-dce-soybean-meal-and-soybean-oil.pdf.

Dahlgran, R.A. 2009. "Inventory and transformation hedging effectiveness in corn crushing." *Journal of Agricultural and Resource Economics* 34(1):154–171.

Dahlgran, R.A. 2005. "Transaction frequency and hedging in commodity processing." *Journal of Agricultural and Resource Economics* 30(3):411–430.

English, E. 1978. "The Use of the Commodity Exchange by Millers." In A. E. Peck, ed. *Views from the Trade*. Board of Trade of the City of Chicago, pp. 143–148.

Farrell, G., and J. Blas. 2010. “Hedging helps foodmakers through uncertainty.” *Financial Times* 12(8).

Gloy, B.A., and T.G. Baker. 2001. “A comparison of criteria for evaluating risk management strategies.” *Agricultural Finance Review* 61(1):38–56.

Hieronymus, T.A. 1971. *Economics of Futures Trading for Commercial and Personal Profit*. New York: Commodity Research Bureau.

James, T. 2008. *Energy Markets: Price Risk Management and Trading*. John Wiley and Sons.

Johnson, R.L., C.R. Zulauf, S.H. Irwin, and M.E. Gerlow. 1991. “The soybean complex spread: An examination of market efficiency from the viewpoint of a production process.” *Journal of Futures Markets* 11(1):25–37.

Kolb, R.W., and J.A. Overdahl. 2007. *Futures, Options, and Swaps* 5th ed. New York: Wiley-Blackwell.

Lake, F. 1978. “The Millers Use of the Commodity Exchange.” In A. E. Peck, ed. *Views from the Trade*. Board of Trade of the City of Chicago, pp. 155–162.

Lapan, H., and G. Moschini. 1994. “Futures Hedging under Price, Basis, and Production Risk.” *American Journal of Agricultural Economics* 76(3):465–477.

Lence, S., and D.J. Hayes. 1994. “The empirical minimum variance hedge.” *American Journal of Agricultural Economics* 76(1.):94–104.

Mann, J.M. 2010. “The Role of Long Memory in Hedging Strategies for Canadian Agricultural Futures.” In *8th OxMetrics User Conference at George Washington University*. 8th OxMetrics User Conference. Washington, DC.

Mitchell, J. 2010. “Soybean futures crush spread arbitrage: Trading strategies and market efficiency.” *Journal of Risk and Financial Management* 3(1):63–96.

Peck, A.E., and L. Besant eds. 1985. *Readings in Futures Markets: Views from the Trade*. Chicago, IL: Chicago Board of Trade.

Peck, A.E., and A.M. Nahmias. 1989. “Hedging Your Advice: Do Portfolio Models Explain Hedging?” *Food Research Institute Studies* 21(2):193–204.

Pritchett, J.G., G.F. Patrick, K.J. Collins, and A. Rios. 2004. “Risk management strategy evaluation for corn and soybean producers.” *Agricultural Finance Review* 64(1):45–60.

Rechner, D., and G. Poitras. 1993. “Putting on the crush: Day trading the soybean complex spread.” *Journal of Futures Markets* 13(1):61–75.

Sanders, D.R., and M.R. Manfredo. 2002. "The role of value-at-risk in purchasing: an application to the foodservice industry." *Journal of Supply Chain Management* 38(1):38–45.

Simon, D.P. 1999. "The soybean crush spread: Empirical evidence and trading strategies." *Journal of Futures Markets* 19(3):271–289.

Williams, R. 1978. "How a Soybean Processor Makes Use of Futures Markets." In A. E. Peck, ed. *Views from the Trade*. Board of Trade of the City of Chicago, pp. 173–176.

Wilson, W.W. 1984. "Hedging effectiveness of U.S. wheat futures markets." *Review of Research in Futures Markets* 111(1):64–79.

Wilson, W.W., and B.L. Dahl. 2014. "Contracting for canola in the Great Plains states." *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* 62(1):89–106.

Wilson, W.W., W.E. Nganje, and C.R. Hawes. 2007. "Value-at-risk in bakery procurement." *Review of Agricultural Economics* 29(3):581–595.

Wilson, W.W., W.E. Nganje, and R. Wagner. 2006. "Hedging strategies for grain processors." *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie* 54(2):311–326.

Wilson, W.W., and T. Preszler. 1992. "End-use performance uncertainty and competition in international wheat markets." *American Journal of Agricultural Economics* 74(3):556–563.

Wilson, W.W., and T. Preszler. 1993. "Quality and price competition in international wheat trade: A case study of the United Kingdom wheat import market." *Agribusiness* 9(4):377–389.

Working, H. 1962. "New concepts concerning futures markets and prices." *The American Economic Review* 52(3):432–459.