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Corn-Crush Hedging – Does Location Matter?

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Corn-Crush Hedging – Does Location Matter?

At the end of 2018, 200 ethanol refineries were operating in the U.S. and processing nearly 40 percent of U.S. corn production. These refineries are widely dispersed and the typical ethanol refining firm operates several plants. Hedging is widely used as a price risk management strategy. The dispersion of a given firm's plants leads us to ask the question posed by the title of this paper – should the plant's location be considered in constructing a hedging program?

We tested this notion by drawing a sample from the plants operated by a multi-state/multi-plant ethanol refiner. We interviewed plant managers to get information about input-output coefficients, inventory turnover, plant efficiency comparisons, and hedging horizons. This information informed our modelling. To test our premise, we sought plant location prices for corn, natural gas, ethanol, dried distiller gran, and distiller corn oil. Local corn prices were obtained but we had to use proxies and state averages for the other prices.

Standard hedging methodology was applied as we examined two hedging strategies: (a) hedging the crush margin, and (b) hedging individual commodity transactions then combining these hedges according to the input-output coefficients to hedge the crushing margin. Approach (b) produced better results but the data limitations hindered testing our main hypothesis. In addition to variations in hedge ratios for each location, we also discovered that (a) storage periods for input and output inventories are short (1 to 2 weeks), (b) input-output coefficient variability across plants creates opportunities for location specific hedging strategies, and (c) previous studies that are based on aggregated cash prices likely overstate the effectiveness of local hedging strategies.

Keywords: ethanol futures, hedging, cross hedging, corn crushing, processing hedge.

Introduction

Over the past two decades U.S. ethanol production has grown by fourteen percent per year so that currently almost forty percent of the U.S. corn crop is processed by ethanol refineries (figure 1). Initially, this growth was fueled by ethanol's substitutability as a fuel-octane enhancer for MTBE which was banned due to environmental pollution concerns (Raffensperger 2001). Energy policy (biofuels mandates and blending tax credits)[1], low interest rates that contributed to the financial viability of plant construction, and occasional gasoline price spikes have also contributed to the sector's growth.

This growth has required new mills as benchmarked by table 1. These new mills embody new technologies so while overall corn milling efficiency has increased, vintage differences result in efficiency differences among mills. In addition, local markets for modified (wet) distillers' grains have developed so each mill faces a local market for wet distiller grain while larger regional markets are important for dried distiller grain. These potentially important local variations are glossed over in the corn-crush hedging literature that utilizes U.S. average ethanol and corn

[1] The U.S. fracking boom and the resulting domestic abundance of crude oil has muted energy independence as a rationale for policies supporting the ethanol industry.

prices (CME Group, 2007a, 2007b) and industry-wide conversion efficiencies. In addition, natural gas is not considered as an input. In short, while hedging studies based on industry aggregates are illustrative, the results are less useful for specific locations.

We extend the literature on ethanol hedging by incorporating research on specific refinery operations into the hedging strategy. We utilize contacts with ethanol plant managers to incorporate detailed information about input-output coefficients and inventory holding periods. Our overall objective is to determine if local hedging outcomes can be improved by using local

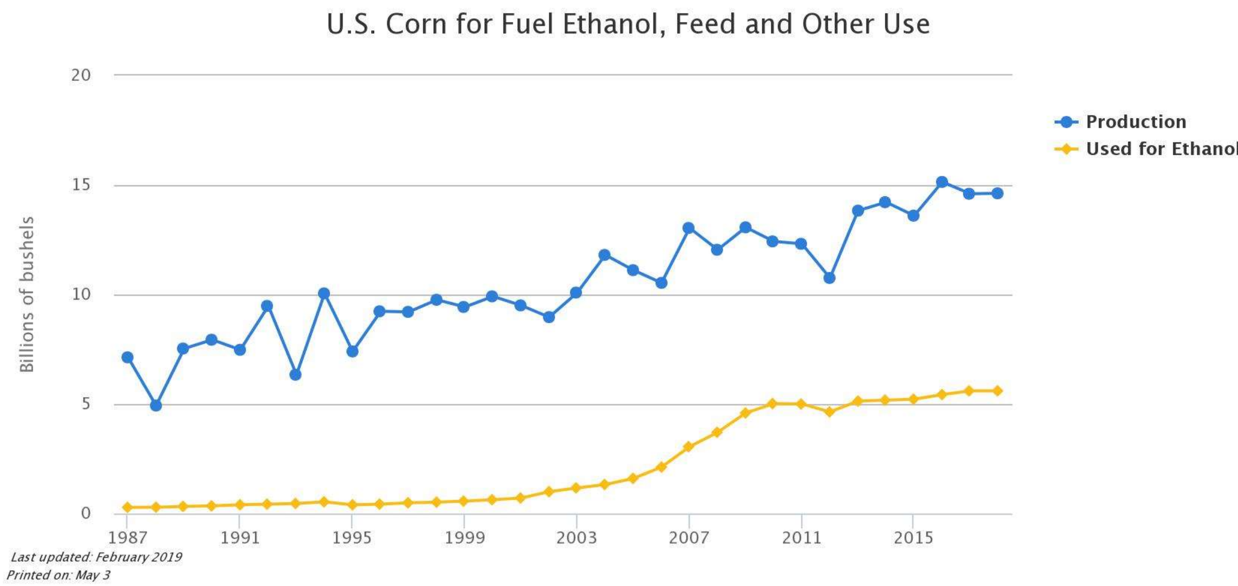

Figure 1. U.S. corn production and corn used in ethanol production. (Source: USDA)

Table 1. The structure of the U.S ethanol refining industry, 2018 vs 2006.

Year	2018	2006
Number of refineries	200	115
Capacity (bill gal /year)	16.3	5.75
Production (bill gal)	16.1	4.9
Production (tank cars/plant/year)	2,759	1,724

(Source: Renewable Fuels Association)

rather than aggregate data. Hypotheses to be tested include: (1) Do hedge ratios estimated from location-specific price data significantly outperform hedge ratios based on aggregated price data? (2) Do hedge ratios estimated from mill specific input-output coefficients significantly outperform those estimated from generic input-output coefficients? (3) Do correlations between corn and DDGs, and ethanol and natural gas exist and if considered, do they lead to hedge ratios significantly different from unity?

This study proceeds as follows. First, hedging methodology will be presented and its use in previous processing studies will be examined. This examination will reveal that commodity-processing price risk derives from two factors - time and product form. Accordingly price risks arise from inventory holding and product transformation. Hedging strategies will be analyzed by using cash and futures prices for corn, ethanol and natural gas to estimate hedge ratios and hedging effectiveness for standard inventory and transformation hedging horizons.

Literature Review

Johnson (1960) and Stein (1961) represent hedging as a portfolio-risk management problem. The portfolio consists of a required spot position (x_s) and an attendant futures position (x_f). Profit (π_h) from holding the portfolio is

(1a) $\pi_h = x_s (p_1\text{-}p_0) + x_f (f_1\text{-}f_0)$,

where p_0 and f_0 are initial spot and futures prices, and p_1 and f_1 are unknown ending-period spot and futures prices. The ending-period spot and futures prices are unknown at the outset so are treated as random outcomes where

(1b) $V(\pi_h) = x_s^2\, V(p_1\text{-}p_0) + x_f^2\, V(f_1\text{-}f_0) + 2\, x_f\, x_s\, Cov(p_1\text{-}p_0, f_1\text{-}f_0)$.

Setting x_f to minimize $V(\pi_h)$, gives the risk-minimizing futures position

(1c) $x_f^* = -\, x_s\, Cov(p_1\text{-}p_0, f_1\text{-}f_0) / V(f_1\text{-}f_0)$

and the hedge ratio (x_f^* / x_s), which is estimated by the negative of the regression slope of futures price changes against spot price changes. When $x_f = 0$, unhedged profits are $\pi_u = x_s (p_1\text{-}p_0)$ and $V(\pi_u) = x_s^2\, V(p_1\text{-}p_0)$. Hedging effectiveness (e) is the proportionate price risk reduction due to hedging,

(1d) $e = [V(\pi_u) - V(\pi_h)] / V(\pi_u) = (r_{\Delta p,\Delta f})^2$,

where $r_{\Delta p,\Delta f}$ is the correlation between spot and futures price changes (Ederington, 1979).

Anderson and Danthine (1980, 1981) generalized the portfolio approach by considering multiple futures positions and by assuming a mean-variance utility maximization objective. Under these conditions the agent's problem is

(2a) $\max U(\pi_h) = E(\pi_h) -(\lambda/2)\, V(\pi_h)$
wrt $\mathbf{x_f}$

where $\pi_h = x_s (p_1 - p_0) + \mathbf{x'_f} (\mathbf{f_1} - \mathbf{f_0})$, $\mathbf{x_f}$ is a vector of positions in multiple futures contracts and $\mathbf{f_t}$ represents the prices of those contracts at time t. The solution is

$$\text{(2b)} \qquad \mathbf{x_f^*} = \lambda^{-1}\boldsymbol{\Sigma}^{-1}_{\Delta f,\Delta f}[\mathbf{E}(\mathbf{f_1}) - \mathbf{f_0}] - \boldsymbol{\Sigma}^{-1}_{\Delta f,\Delta f}\boldsymbol{\Sigma}_{\Delta f,\Delta p} x_s .$$

Empirical applications proceed by assuming that either $\lambda = \infty$ (the agent is extremely risk averse) or $\mathbf{E(f_1) = f_0}$ (futures markets are efficient), so hedge ratios are estimated by the regression parameters in $\mathbf{\Delta p = \Delta f}\ \boldsymbol{\beta} + \boldsymbol{\varepsilon}$. The multiple regression R square estimates hedging effectiveness.

Time-varying hedge ratios have been incorporated into the above framework but "provide minimal gain to hedging in terms of mean return and reduction in variance over a constant conditional procedure" (Garcia, Roh, and Leuthold 1995, p1127). Consequently the Johnson, Stein, and Anderson and Danthine methods are typically employed in agricultural production and storage hedging.

This methodology has been used for hedging commodity processing. Tzang and Leuthold (1990) use weekly prices from January 1983 through June 1988 to investigate multi- and single-contract soybean-processing hedges over one- through fifteen-week hedging horizons. Fackler and McNew (1993) use monthly average prices to examine three soybean-processing hedging strategies: multi-contract hedges, single-contract hedges, and proportional crush-spread hedges. Dahlgran (2005) examined the relationship between transaction frequency and hedging effectiveness in soybean processing.

The multi-contract approach has recently been extended to cross hedging in the cottonseed-processing sector (Dahlgran 2000; Rahman, Turner, and Costa 2001). Franken and Parcell (2003) found that ethanol could be effectively hedged with unleaded gasoline futures contracts.

Dahlgran (2005) summarized various approaches applied by others to separately hedge inputs and/or outputs during overlapping time periods. The possibilities identified include a *one-to-one hedge* (a.k.a. *equal and opposite*), a *risk-minimizing direct hedge*, a *commodity-by-commodity cross hedge*, and a *multi-contract cross hedge*. Likewise product transformation hedging can be done with a *one-to-one crush hedge*, a *proportional crush hedge,* a *risk-minimizing direct hedge*, a *commodity-by-commodity cross hedge*, and a *multi-contract cross hedge*.

Empirical Model

Our model of physical ethanol refining is built on information gleaned from conversations with plant managers. Observations include:

- Ethanol yields vary by plant and over time. Yields have been consistently increasing because of improved yeasts and corn varieties[2] and yields differ among plants because of mechanical differences. Anecdotally, one refiner's plant yields ranged from 2.85 to 2.97gal/bu. in 2017. The productivity of all plants has been increasing over time due to improvements in mechanics and yeasts.

[2] A GMO variety of corn called Enogen (#2 yellow with alpha enzyme) has been formulated specifically to boost ethanol yields.

- When corn is crushed, and all byproducts are accounted for, the input mass and the output mass balance. Ethanol is the most valuable output so plants are tuned to maximize ethanol output. Because of this mass balance, plants with lower ethanol yields have higher yields of other co-products.
- Bechen (2011) estimates 2009-2010 energy costs between 15 to 21 cents per gallon of ethanol produced. Szybist and Curran (2015) report that conversion and drying requires 23,000 BTU of natural gas per gallon of ethanol produced. This requirement varies by type of plant. Eighty percent of natural gas usage is for ethanol refining and twenty percent for drying distiller grain.[3]
- Electricity is the third major input used by ethanol refineries. Usage ranges from 0.5 to 0.8 Kwh per gallon of ethanol produced.
- In addition to ethanol, a bushel of corn yields fourteen pounds of dried distiller grain. Converting wet distiller grain (55 percent moisture) to fourteen pounds of dried distiller grain (10 percent moisture) requires about 4,600 BTU from natural gas. Wet distiller grain is typically fed to livestock locally while the dried distiller grain can be shipped to other markets. Most refineries do not have the capacity to dry all of the distiller grain produced so having a local market for the wet product is critical. The mix of wet versus dry distiller grain sales varies by season.
- Distiller corn oil is the third coproduct from ethanol refining. Yields are typically near 0.8 lb of corn oil per bushel of corn.
- Ethanol refineries' storage is for buffer stocks that allow the mill to continuously operate at capacity. Plants typically have capacity to store 10-12 days of crushing and corn-to-ethanol conversion takes three days. Likewise, plants don't store their products for extended periods of time. The average U.S. ethanol refinery produces a unit train (100 cars) of ethanol about every two weeks. (table 2)

Considerations in formulating commodity processing hedges include (a) the processor has spot positions in both inputs and outputs and these positons are tied together by input-output relationships, (b) potential hedges of both input costs and output revenues exist and correlations between input prices and output prices will impact optimal hedge ratios, and (c) commodity processing involves the continuous production of overlapping batches of output.

The Tzang and Leuthold (1990) analysis of soybean crushing provides useful insights for modelling corn crushing. Tzang and Leuthold break the hedge horizon into an anticipatory period, when production is planned but inputs and outputs are not yet priced, and a storage period when output is stored. In soybean crushing, price risk in the anticipatory period is hedged with a long soybean futures position and short soy meal and soy oil futures positions. When the soybeans are purchased, the long soybean futures position is eliminated but the short soy meal and soy oil futures position are retained. Finally, when the soy meal and soy oil outputs are sold and the short soy meal and soy oil futures positions are closed.

Table 2 applies the Tzang and Leuthold transaction sequence to corn crush hedging by considering the action times (t_0, t_1, t_2) and the intervals between these times. Under model A, t_0 represents the beginning of planning for processing. No actions are taken in the spot commodity markets at t_0 but in anticipation of processing, corn and natural gas futures contracts are bought

[3] Plant manager comments.

and, assuming the existence of dried distiller grain (DDG) and distiller corn oil (CDO) futures contracts, ethanol, dried distillers grains, and distiller corn oil futures contract are sold. The anticipatory period lasts until t_1 when the physical inputs of corn and natural gas are procured and the short futures positions in these two commodities are closed. Once the physical inputs are procured at t_1, they are stored either in their input form or their output form until the ethanol, dried distiller grain, and distiller corn oil are sold at t_2. Hence the designation of the storage period from t_1 to t_2. When these inputs are sold at t_2, the corresponding futures contracts are bought to close the futures positions.

The model B refines model A by inserting perfectly offsetting spot and futures transactions for the outputs at t_1. While these transactions have no effect on the ultimate hedged outcome, they price the positions at t_1. This valuation allows us to consider different price risks during the anticipatory period (t_1 versus t_0) when output price risk might offset input price risk, and during the storage period (t_2 versus t_1) where the refiner faces only output price risk. This distinction also allows for the consideration of differing price risks created by differences in the length of the periods.

Model C refines model B by recognizing that futures contracts for dried distiller grain and distiller corn oil do not exist so that these transactions are replaced with cross hedges in related futures contracts. In our empirical analysis we will use soybean meal and corn futures to cross hedge dried distiller grain, and soybean oil to cross hedge distiller corn oil.

The corn crushing production function is a multi-input multi-output fixed-coefficients form. Due to multiple outputs, this function is expressed as an implicit function where inputs bear a negative sign and outputs bear a positive sign. We use a bushel of corn as the numeraire and divide the complete time horizon from anticipated processing to output sales into an anticipatory period and a storage period.

Let the vector $\boldsymbol{\gamma_a}$ represent the inputs and outputs for a bushel of corn applicable to the anticipatory period. Processing a bushel of corn requires 66,700 BTU of natural gas (23,000 BTU per gallon of ethanol x 2.9 gal /bu), and yields 2.90 gallons of ethanol, 14 pounds of distillers dried grains and .8 pounds of distillers corn oil. Thus

$$\text{(3a)} \quad \gamma_a' = \begin{bmatrix} -1 \text{ bu corn} \\ -66{,}700 \text{ BTU of natural gas} \\ 2.9 \text{ gal of ethanol} \\ 14 \text{ pounds of DDG} \\ 0.8 \text{ pounds of DCO} \end{bmatrix}, \text{ and}$$

$$\text{(3b)} \quad \pi_a = \gamma_a \, \boldsymbol{\Delta_a} \, \mathbf{S}$$

where π_a is the fluctuation in the processing margin per bushel of corn over the anticipatory period, S is a vector of spot prices in units compatible with the vector γ_a and the summation implicit in the cross product, and $\boldsymbol{\Delta_a}$ represents differencing according to the length of the anticipatory period. To get the total effect of price fluctuations on the plant's gross operating margin, we multiply π_a by the plant's anticipated corn crush (X_c) or

Table 2. Alternative representations of the corn crush hedge.

	t_0	… Anticipatory Period … t_1 … Storage Period …	t_2
		Model A	
Spot		Buy corn	
		Buy Nat Gas	
			Sell Eth
			Sell DDG
			Sell DCO
Futures	Buy Corn	Sell Corn	
	Buy Nat Gas	Sell Nat Gas	
	Sell Eth		Buy Eth
	Sell DDG		Buy DDG
	Sell DCO		Buy DCO
		Model B	
Spot		Buy corn	
		Buy Nat Gas	
		(Sell Eth / Buy Eth)	Sell Eth
		(Sell DDG / Buy DDG)	Sell DDG
		(Sell DCO / Buy DCO)	Sell DCO
Futures	Buy Corn	Sell Corn	
	Buy Nat Gas	Sell Nat Gas	
	Sell Eth	*(Sell Eth / Buy Eth)*	Buy Eth
	Sell DDG	*(Sell DDG / Buy DDG)*	Buy DDG
	Sell DCO	*(Sell DCO / Buy DCO)*	Buy DCO
		Model C	
Spot		Buy corn	
		Buy Nat Gas	
		(Sell Eth / Buy Eth)	Sell Eth
		(Sell DDG / Buy DDG)	Sell DDG
		(Sell DCO / Buy DCO)	Sell DCO
Futures	Buy Corn	Sell Corn	
	Buy Nat Gas	Sell Nat Gas	
	Sell Eth	*(Sell Eth / Buy Eth)*	Buy Eth
	Sell XDDG	*(Sell XDDG / Buy XDDG)*	Buy XDDG
	Sell XDCO	*(Sell XDCO / Buy XDCO)*	Buy XDCO

(3c) $\Pi_a = \pi_a X_c$

In the storage period, the input prices are no longer at risk so the storage period return is given by

(4a) $$\gamma_s' = \begin{bmatrix} \text{0 bu corn} \\ \text{0 BTU of natural gas} \\ \text{2.9 gal of ethanol} \\ \text{14 pounds of DDG} \\ \text{0.8 pounds of DCO} \end{bmatrix},$$

(4b) $\pi_s = \gamma_s \boldsymbol{\Delta_s} \mathbf{S}$, and

(4c) $\Pi_s = \pi_s X_c$

where $\boldsymbol{\Delta_s}$ represents differencing according to the length of the storage period.

With hedge targets defined by (3b) and (4b) we can now define portfolio returns for each period (p) as

(5) $\pi_p^h = \boldsymbol{\gamma_p} \Delta_{\boldsymbol{p}} \boldsymbol{S} + \boldsymbol{x_p^f} \Delta_{\boldsymbol{p}} \boldsymbol{F}$, where p = a (anticipatory period) or s (storage period).

The Anderson and Danthine solution in (2b) indicates the utility-maximizing futures positions during period p (anticipatory or storage period) as

(6) $x_p^{f*} = \lambda^{-1} \Sigma_{\Delta_p F, \Delta_p F}^{-1} \mathrm{E}(\Delta_p F) - \Sigma_{\Delta_p F, \Delta_p F}^{-1} \Sigma_{\Delta_p F, \pi_p}$.

where x_p^{f*} is the utility maximizing position in futures contract i per bushel of corn processed. The hedge ratios are estimated by the parameters $\boldsymbol{\beta}$ in the regression model

(7) $\boldsymbol{\pi_p} = \boldsymbol{\Delta_p} \boldsymbol{F} \boldsymbol{\beta} + \boldsymbol{\varepsilon}$ where p = or s.

Thus, risk-minimizing hedge ratios for the anticipatory period are found by regressing the change in the processing margin over the anticipatory period against the changes over the anticipatory period in the corn, natural gas, ethanol and other futures contract prices. Risk-minimizing hedge ratios for the storage period are found by regressing the change over the transformation period in the cash price of ethanol against the change in the futures price of ethanol and other commodities that form useful cross-hedges.

Data

To address "Does location matter?" we selected a large ethanol refining firm with thirteen refineries spread across a wide geographic area. We selected six plants from among the thirteen for inclusion in our analysis. The selection was based on geographic dispersion and above-average plant capacity.

The selected plants are designated by location as

- SW IA (Southwest Iowa), capacity: 75 mill. gal/yr,
- S MN (Southern Minnesota), capacity: 119 mill. gal/yr,
- NC NE (Northcentral Nebraska), capacity 55 mill. gal/yr,
- SC NE (Southcentral Nebraska), capacity: 121 mill. gal/yr,
- NW TN (Northwest Tennessee), capacity: 120 mill. gal/yr, and
- N TX (North Texas), capacity: 105 mill. gal/yr.

We scanned multiple data sources to find location specific prices pertinent to ethanol refining. The Bloomberg system includes prices from the USDA, U.S. Department of Energy as well from non-government agencies.

Daily local corn prices were available in the Bloomberg system. For many locations these prices were collected by DTN and CGB (Continental Grain and Barge). Natural gas prices were reliably available only at pipeline terminals like Gage, NE, Ventura IA, and Amarillo TX. The ideal "city gate" natural gas prices were not available so we used the nearest available terminal price.

State level daily ethanol prices were available for the major ethanol producing states. No daily state level ethanol prices were available the Tennessee and Texas plants so we used state level ethanol prices for the nearest state.

Distiller grain varieties differ by moisture content. Dried distiller grain is the most storable and transportable and hence has the broadest market at each location. The USDA publishes daily data on distiller grain prices by state. These prices typically hold for an entire week so the data might more accurately be described as compiled weekly, published daily.

Finally, daily local data for distiller corn oil are not available. The USDA publishes a daily IA, IL, IN average and a central IL series. Here again, we selected the series that best matched each location.

The data collected are summarized in table 3. This table indicates the proxies used when the ideal daily local data were not available.

The data summarized in table 3 are used to compute the processing margin by location over time (figure 1). The most obvious feature of crush margin is its price spike in early 2014 due to transportation bottlenecks caused by severe weather (Saefong). Close inspection of this figure reveals gaps in the computed crushing margins for various plants at various times due to missing values in the underlying data.

Figure 2 contrasts by location the revenues from ethanol, distiller dried grain and distiller corn oil with corn and natural gas costs, and the crush margin. Ethanol, DDG and distiller corn oil respectively generate roughly eighty, fifteen and five percent of revenues. Roughly 67 percent of revenue is expended on corn, and the crushing margin is about thirty percent of revenue (figure 2). Locational variations are due to differences in corn and ethanol prices as well as differences the times for which complete data are available.

Table 3. Data series summary statistics.

Id	Commod	Source[a]	Location	Units	Data Span	Obs	Avg	Range
SW IA								
s62	Corn	B	Local	$/bu	10/07-02/19	2524	4.53	2.77-8.36
s66	NG	B	IA	$/MMBtu	09/08-02/19	2448	3.70	1.39-68.6
s65	ETH	B	IA plant	$/gal	09/07-02/19	2796	1.84	1.12-3.15
s64	DDG	USDA	West IA	$/tn	10/06-02/19	3002	151.9	71.0-305.8
s63	DCO	B	IA,IL, IN	cts/lb	10/92-02/19	6586	33.53	9.50-88.50
S MN								
s68	Corn	B	Local	$/bu	03/06-02/19	2757	4.20	1.72-8.21
s90	NG	B	Amerillo	$/MMBtu	11/03-02/19	3651	4.37	1.37-23.51
s70	ETH	B	MN plant	$/gal	02/15-02/19	983	1.41	1.10-1.79
s69	DDG	USDA	MN	$/ton	11/08-04/19	2503	152.0	71.5-302.5
s63	DCO	B	IA,IL, IN	cts/lb	Same as SW IA DCO			
NC NE								
s73	Corn	B	Local	$/bu	10/04-02/19	3025	3.77	1.19-8.32
s76	NG	B	Gage, NE	$/MMBtu	04/01-02/19	4466	4.22	0.61-22.39
s75	ETH	B	NE plant	$/gal	09/07-02/19	2792	1.83	0.96-3.15
s74	DDG	USDA	NE	$/ton	11/07-04/19	2764	162.1	78.0-333.0
s63	DCO	B	IA,IL, IN	cts/lb	Same as SW IA DCO			
SC NE								
s77	Corn	B	Local	$/bu	01/14-02/19	1231	3.54	2.86-4.87
s76	NG	B	Gage, NE	$/MMBtu	Same as NG NE NE			
s75	ETH	B	NE plant	$/gal	Same as ETH NE NE			
s78	DDG	USDA	NE	$/ton	Same as DDG NE NE			
s63	DCO	B	IA,IL, IN	cts/lb	Same as DCO SW IA			
NW TN								
s81	Corn	USDA	Local	$/bu	01/07-02/19	2888	4.53	2.76-8.04
s90	NG	B	Amerillo	$/MMBtu	Same as NG S MN			
s89	ETH	B	IL plant	$/gal	11/08-03/19	2926	1.92	1.17-3.85
s83	DDG	B	Cent IL	$/ton	01/08-02/19	2896	165.7	91.0-307.5
s82	DCO	B	Cent IL	cts/lb	01/96-02/19	5703	33.99	9.75-88.50
N TX								
s86	Corn	B	Local	$/bu	11/06-12/18	1266	4.25	3.71-9.24
s90	NG	B	Amerillo	$/MMBtu	Same as NG S MN			
s89	ETH	B	IL plant	$/gal	Same as ETN NW TN			
s83	DDG	USDA	Cent IL	$/ton	Same as DDG NW TN			
s63	DCO	B	IA,IL, IN	cts/lb	Same as DCO SW IA			

a/ B denotes Bloomberg, USDA denotes USDA Daily Ethanol Report.

Futures prices were obtained from Barchart.com. This source contains daily futures prices for all maturities of all major futures contracts.

The data analyzed were governed by several selection considerations. First, horizons of 84 and 7 days were selected for the anticipatory and storage hedging periods. These values were consistent with planning and production horizons mentioned by plant managers and conveniently amounted 8-week and one-week price differences and an annual quarter (91 days) as the total hedge horizon. Second, Wednesday prices were selected as the prices within the week. When Wednesday prices were not available because of holidays or market closures, Tuesday's prices were used. Third, futures prices were represented by the nearby contract settlement price at hedge termination, provided that the contract was at least one week from maturity. If the nearby contract was within one week of its maturity, then the next nearby contract was used. Finally, we modeled our hedges as a batch rather than a continuous process. This approach meant that each quarter's hedges were completed, then hedging for the next quarter began.[4] The advantages of this approach were (1) it is consistent with the methodology of previous process-hedging studies, (2) the hedges were serially independent as the differenced data did not overlap, (3) the regression R^2 measures hedge effectiveness as regression data are differenced according to the hedge horizon. The disadvantages of this approach are (1) plant operations are continuous so that the quarterly planning horizon shifts continuously over time rather than coming into focus at the completion of a quarter, and (2) data are lost as only successive quarterly differences are observed.

Results

Two of the methods for estimating hedge ratios outlined by Fackler and McNew will be attempted. These methods will be referred to as "hedging the crush" and "crushing the hedges."

In "hedging the crush" we define the crushing margin as $\lambda\ \mathbf{S}_t$ where λ is a vector of input (<0) and output (> 0) coefficients and $\mathbf{S}_t$ is a vector of input and output prices. We attempt to hedge or cross-hedge $\lambda\ \mathbf{S}_t$ with various futures contracts. A simplified example of this approach is to hedge the ethanol processing margin with corn and ethanol futures contracts. The resulting hedge ratios reflect the corn-to-ethanol conversion coefficient, the relationships between corn prices and corn futures prices, the relationship between ethanol prices and ethanol futures prices, and the cross market effects between corn prices and ethanol futures prices and between ethanol prices and corn futures prices.

In "crushing the hedges" we attempt to cross or direct hedge each component of $\mathbf{S}_t$ and then use λ to aggregate the individual hedges in order to hedge the processing margin target. A simplified example of this approach dictates that we determine hedge ratios for corn using the corn futures contract and determine the hedge ratio for ethanol using the ethanol futures contract. We then combine 2.9 ethanol hedges with each 1 bushel corn hedge.

4 This assumption will be relaxed in subsequent revisions of this paper.

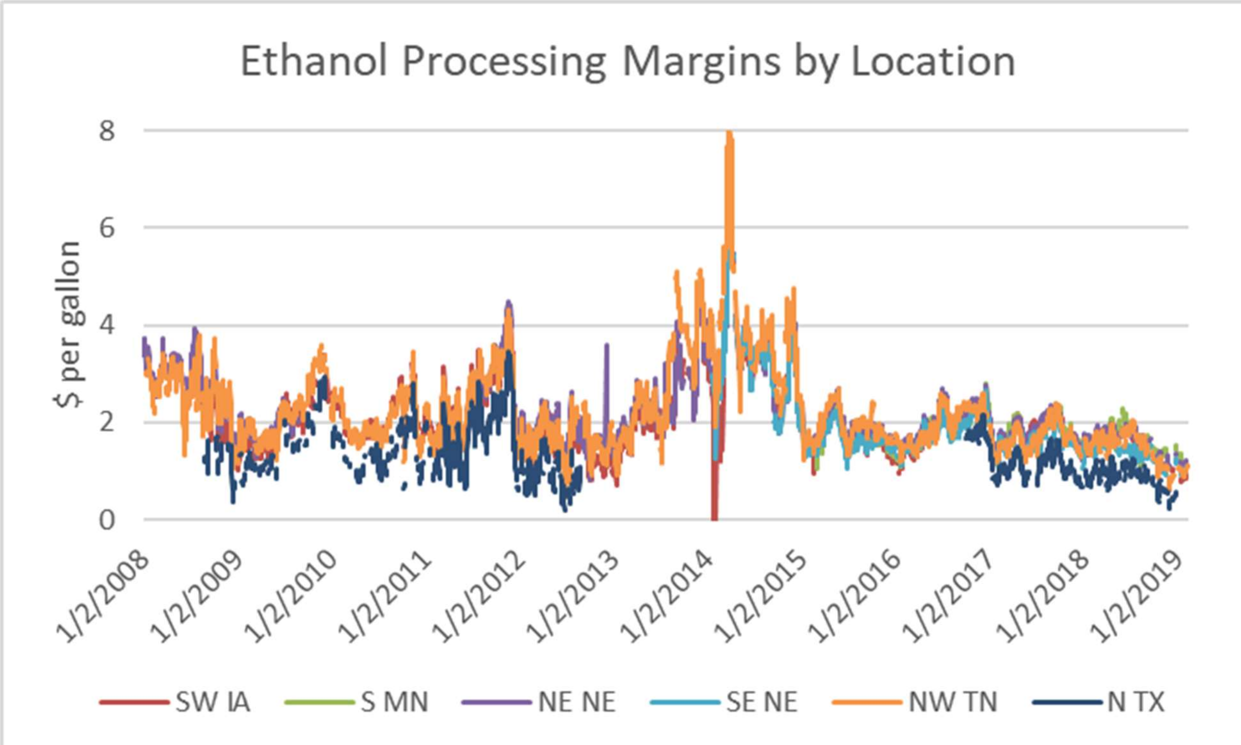

Figure 1. Corn-crushing margin by location, daily January 2008 through March 2019.

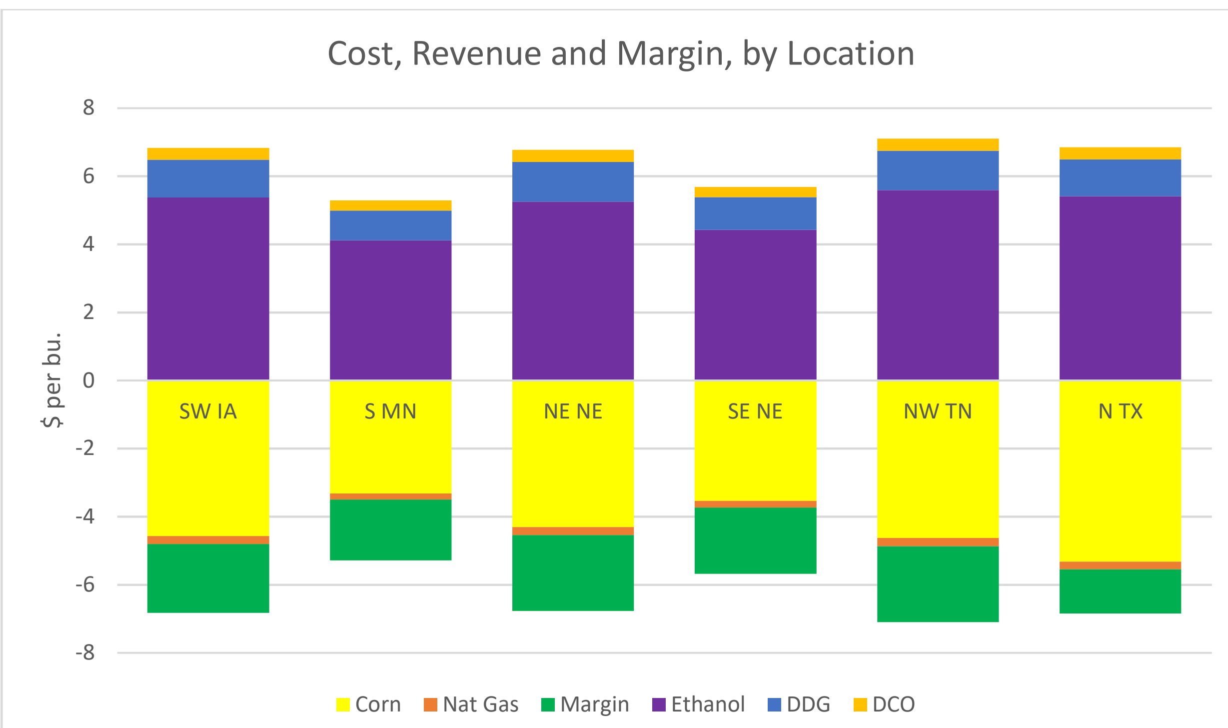

Figure 2. Corn-crushing margin components by location.

Some general preliminary findings are

1. Serial correlation is not significant. This result is intuitive in that the anticipatory period dependent variable is $\lambda\ \Delta\ \mathbf{S}_t$ where Δ represents 84 day differences within each 91-day quarter, $\lambda(\mathbf{S}_t - \mathbf{S}_{t\text{-}84})$). The elapsed time in the differences and the explanation of processing margin change by changes in futures prices leaves no serial correlation in the residuals.
2. Using natural gas futures to hedge natural gas costs in the processing margin and using soybean oil futures to cross hedge distiller corn oil revenues in the processing margin during the anticipatory period is ineffective. This finding is intuitive based on figure 3. Natural gas costs and corn oil revenues both play a minor role in determining the magnitude and fluctuations in the processing margin.
3. Likewise, in the storage period, using soybean oil futures to hedge distiller corn oil is ineffective because ethanol price fluctuations overwhelm the relatively miniscule effects of distiller corn price fluctuations in the value of the refiner's products.

Table 3 reports results that incorporate these three general findings. The SW IA plant serves to illustrate the interpretation of the hedge ratios. The crusher is short corn in the anticipatory period so for the SW IA plant, the crusher should be long 0.086 bushels of corn futures and short 1.657 gallons of ethanol futures per bushel of anticipated corn crush. These hedge ratios are smaller in magnitude than hedge ratios suggested by a one-to-one crush (i.e., long 1 bushel of corn futures, short 2.9 gallons of ethanol futures) because of the long term correlation between corn and ethanol price changes, and because of long term correlations between corn and DDG price changes. The effectiveness of 0.216 indicates that this hedge eliminates 21.6% of the crush margin risk over the twelve-week anticipatory period. The anticipatory period hedge ratio estimates are all of the correct sign except for SC NE corn. The lack of significance of the hedge ratios and hedge effectiveness for other the SW MN and SC NE plants is attributable to the small sample sizes due to missing data in the observational period.

During the one-week storage period we use corn futures to cross-hedge DDG and ethanol futures to hedge ethanol. The results (table 3) indicate that during the storage period, hedging for the SW IA plant should consist of a long corn futures position of 0.439 bushels per anticipated bushel crushed and a short ethanol position of 2.288 gallons per anticipated bushel crushed. The effectiveness of this hedge indicates it removes 8.6% of the price risk over the one week horizon.

Table 3. "Hedging the crush" estimation results.[a]

		Anticipatory Period			Storage Period		
Location	Obs	Corn	Ethanol	Eff	Corn	Ethanol	Eff
SW IA	41	-0.086	1.657 *	0.216 **	-0.439	2.288 +	0.086
SW MN	15	-0.317	2.077 +	0.230	0.957	-2.562	0.238
NC NE	44	-0.167	1.674 *	0.155 *	-0.341	2.022 +	0.075
SC NE	19	0.232	1.829	0.206	-0.083	-0.495	0.008
NW TN	43	-0.287	2.204 *	0.201 *	-1.144 **	4.347 ***	0.258 **
N TX	41	-0.037	3.425 **	0.348 ***	-1.115 *	4.474 ***	0.272 ***

a/ Significance indicators: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < + < 0.10 < " " < 1

The storage period results are generally weaker than the anticipatory period results because in addition to the data difficulties encountered in constructing the anticipatory period hedges, the correlations between price changes are smaller due to the briefer time interval inherent in the storage period.

The alternative approach to corn crush hedging is "crush" individual commodity hedges. This approach first requires a hedging strategy for each input and output. These individual hedges are then combined according to the fixed coefficients in λ.

In our analysis we hedge corn with corn futures, natural gas with natural gas futures, ethanol with ethanol futures and cross hedge distiller dried grain with corn and soybean meal futures and, distiller corn oil the soybean oil futures. Table 4 shows these results where the columns represent the commodities hedged and the rows are ordered by location, hedge period within location, and hedge ratios (HR) and effectiveness (Eff) within each hedge type. The DDG cross-hedge involves both corn and soymeal futures contracts. Consequently, two hedge ratios are reported with a single hedge effectiveness statistic. The ===> symbol points to the effectiveness for these cross-hedges. There is no need to hedge corn and natural gas purchases in the storage period so hedge ratios and effectiveness statistics are not reported for these transactions.

The individual commodity direct hedge ratios are generally significant with hedge ratios near 1.0. The cross-hedge ratios are also generally significant. The pattern of less effective hedging in the storage period than in the anticipatory period continues to hold.

Table 5 reports the location-specific corn-crush hedging strategies. This table results from applying the production coefficients to the estimated hedge ratios (table 4) and reports optimal hedging per bushel crushed for each location. The table is arranged with futures positions (negative values are short, positive values long) corresponding to the columns. The rows are locations and hedging period within locations. One subtlety of table 5 is that corn futures are used to long hedge corn purchases and to short cross-hedge DDG sales. Hence, the net corn position (table 5, last column) accounts for both of these hedges. In the anticipatory period, this correction reduces the hedge ratio from the expected unit value of the of the anticipatory corn purchase hedge ratio.

The signs of the hedge ratios reported in table 5 are as expected with the exception of the soy meal futures positions in the storage period for NC NE and the net corn futures position in the storage period in SC NE. These results merely reflect the weakness of soymeal as a cross-hedging vehicle for DDG. Table 5 does not report the effectiveness of the "crushing the hedges" approach. These statistics can be derived from simulations and will be added to the analysis. Because hedging the major commodities was effectiveness, we expect that "crushing the hedges" will also be effective.

Table 4. Hedging/cross hedging results for the corn crushing commodities.

Loc	Target:		Corn	Nat gas	Ethanol	DDG		DCO
	Vehicle:		Corn(F)	Nat gas(F)	Eth(F)	Corn(F)	Soyml(F)	Soyoil(F)
	HR units:		bu_F/bu_S	Btu_F/Btu_S	gal_F/gal_S	$bu_F/0.01tn$	tn_F/tn_S	lb_F/lb_S
	Period							
SW IA	anticip	HR	0.948 ***	0.933 ***	0.850 ***	0.324 ***	0.134 +	0.099 ***
		Eff	*0.783*	*0.575*	*0.499=====>*		*0.594*	*0.448*
	storage	HR			0.478	0.119 +	0.095	0.164 **
		Eff			*0.059=====>*		*0.162*	*0.161*
SW MN	anticip	HR	0.894 ***	0.969 ***	1.020 **	0.431 +	0.134	0.271
		Eff	*0.908*	*0.842*	*4.760=====>*		*0.642*	*0.120*
	storage	HR			0.292	0.078	0.239	0.117
		Eff			*0.061=====>*		*0.176*	*0.040*
NC NE	anticip	HR	0.901 ***	0.893 ***	0.925 ***	0.262 ***	0.039	1.254 ***
		Eff	*0.664*	*0.723*	*0.585=====>*		*0.443*	*0.589*
	storage	HR			0.378	0.141 **	-0.112	2.680 **
		Eff			*0.042=====>*		*0.163*	*0.196*
SC NE	anticip	HR	0.830 ***	1.357 ***	1.251 ***	0.642 *	-0.128	0.348 +
		Eff	*0.894*	*0.786*	*0.463=====>*		*0.458*	*0.154*
	storage	HR			-0.177	-0.093	0.285	0.151
		Eff			*0.004=====>*		*0.090*	*0.062*
NW TN	anticip	HR	1.008 ***	0.897 ***	1.103 ***	0.244 ***	0.217 *	1.132 ***
		Eff	*0.715*	*0.732*	*0.596=====>*		*0.607*	*0.634*
	storage	HR			0.627 *	0.010	0.001	0.410 ***
		Eff			*0.109=====>*		*0.001*	*0.269*
N TX	anticip	HR	0.573 *	0.631 ***	1.098 ***	0.316 ***	0.236 **	0.966 ***
		Eff	*0.113*	*0.295*	*0.537=====>*		*0.638*	*0.448*
	storage	HR			0.804 *	0.017	0.020	0.164 **
		Eff			*0.157=====>*		*0.104*	*0.161*

Table 5. Hedging per bushel, by location and period.

Loc	Period	Futures Contracts Corn[a] (bu)	Nat gas (MMBtu)	Ethanol (gal)	Corn[b] (bu)	Soymeal (tn)	Soyoil (lb)	Net Corn[c] (bu)
SW IA	anticip	0.948	0.0622	-2.465	-0.2268	-0.0131	-0.079	0.721
	storage			-1.386	-0.0833	-0.0093	-0.131	-0.083
SW MN	anticip	0.894	0.0646	-2.958	-0.3017	-0.0131	-0.217	0.592
	storage			-0.847	-0.0546	-0.0234	-0.094	-0.055
NC NE	anticip	0.901	0.0596	-2.682	-0.1834	-0.0038	-1.003	0.718
	storage			-1.096	-0.0987	0.0110	-2.144	-0.099
SC NE	anticip	0.830	0.0905	-3.628	-0.4494	0.0125	-0.278	0.381
	storage			0.513	0.0651	-0.0279	-0.121	0.065
NW TN	anticip	1.008	0.0598	-3.120	-0.1708	-0.0213	-0.906	0.837
	storage			-1.818	-0.0070	-9.8E-05	-0.328	-0.007
N TX	anticip	0.573	0.0421	-3.184	-0.2212	-0.0231	-0.773	0.352
	storage			-2.332	-0.0119	-0.0020	-0.131	-0.012

Summary and Conclusions

This study was motivated by the notion that hedge ratios vary by location and the findings might be useful to an ethanol firm with multiple processing locations as it constructs more effective hedging strategies. We found that publicly available data were insufficient to fully test this hypothesis. In particular, we found readily-available local corn prices, but local prices for ethanol, dried distiller grain, and distiller corn oil eluded us. We used state or multi-state aggregates as proxies for local prices for ethanol, dried distiller grain, and distiller corn oil. Natural gas prices were readily available for pipeline terminal locations but “city gate” prices were not. We again used closest available as a proxy for the desired local prices. The unavailability of public data does not invalidate the hypothesis because an ethanol firm could apply our methodology using private firm-level data.

The use of state-level aggregate data to estimate local hedge ratios suggests one instance where location matters. In particular, suppose we represent the local price as $S_t + e_t$ where St is the state average and e_t is random variation about the state average. Suppose we then run a hedge ratio regression, $\Delta S_t = \alpha + \beta\ \Delta F_t + \varepsilon_t$, using state level data and report the R^2 from that regression as the hedge effectiveness. It would seem that the reported effectiveness is higher than what would be expected from hedging locally. This notion is warrants further investigation.

This study was informed by visits to ethanol plants and discussions with plant managers. These visits provided useful insights regarding inventory (corn and ethanol) holding times and hence hedge horizons, variations in input output ratios across plants, and the role natural gas plays in ethanol refining. Variation in input-output coefficients among plants affirms that location does indeed matter for ethanol refiners.

Undaunted by the unavailability of ideal data, we examined two corn crush hedging strategies looking for variation in optimal hedge ratios that are independent from plants' input-output technology. We called these strategies "hedging the crush" and "and crushing the hedges". The empirical results from "crushing the hedges" performed better in terms of hedge effectiveness than the aggregated "hedging the crush". The "hedging the crush" hedge ratios were affected by multicollinearity among corn, ethanol and DDG.

Further research is warranted. In particular, the search continues for local prices for ethanol, dried distiller grain, distiller corn oil, and natural gas. Additional tests are called for. In particular we want to test whether optimal corn-crush hedge ratios vary by location. While testing for differences using state aggregate prices is not definitive, the data do support testing for differences for in local optimal corn hedge ratios. Third, additional analysis of alternative hedge horizons and simulations to determine the effectiveness of crushing the hedges would both be useful.

So, to answer the question posed by this paper's title, "Corn-Crush Hedging – Does Location Matter?" we conclude the answer is yes, if for no other reason than plant managers' focus on corn-ethanol conversion coefficients. These coefficients are accurately measured and tracked and are the primary determinant of the corn crush spread and they vary by plant. Location also matters when considering hedging effectiveness estimated from aggregated spot prices.

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