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Inventory and Transformation Hedging Effectiveness in Corn Crushing

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Recently developed ethanol futures contracts now allow direct-hedging by ethanol producers. This study examines the effectiveness of one- through eight-week hedges between 2005 and 2008. Our findings show (*a*) ethanol inventory hedging effectiveness is significant for two-week and longer hedges, and increases with the hedging horizon; (*b*) ethanol futures are significantly superior to gasoline futures for hedging ethanol price risk for two-week and longer hedges; (*c*) the corn crushing hedge, utilizing corn and ethanol futures, is effective and provides price risk management capabilities comparable to those provided by the soybean crush hedge.

Key words: corn crushing, cross-hedging, ethanol futures, hedging, processing hedge

Introduction

Corn-based ethanol has received considerable recent popular press attention for three reasons. First, the gasoline additive methyl tertiary-butyl ether (MTBE), which served as an octane enhancer and reduced the emission of urban smog precursors, was banned in California and New York beginning January 1, 2004 (Raffensperger, 2001). This ban occurred because of MTBE's water solubility, its resultant migration into groundwater supplies, and the absence of liability protection afforded to petroleum companies for groundwater contamination (U.S. Department of Energy, 2006). More recently, MTBE has been banned or its use discontinued in most other states as well (McKay, 2006). A 10% blend of ethanol with gasoline is now the standard auto fuel formulation.

Second, the U.S. retail gasoline price peak of $4.11 per gallon, reached in July 2008, created a renewed and urgent focus on energy policy. Renewable energy is viewed as part of the solution to high energy prices, and corn-based ethanol is a potential source of renewable energy. Third, ethanol production has become economically viable due to higher gasoline prices, combined with a 51¢ per gallon tax credit for blending ethanol (regardless of production source) with gasoline (Barrionuevo, 2007), and a 54¢ per gallon import tariff (Prater, 2006).

Corn-based ethanol is no panacea. It is frequently criticized for its 1.3 to 1.0 energy balance (Shapouri, Duffield, and Wang, 2002; Shapouri, Duffield, and Graboski, 1995). In contrast, soy biodiesel has an energy balance of 3.2 (Sheehan et al., 1998) and sugar cane-based ethanol has an energy balance of 8.3 (*The Economist* staff, 2007). Also, growth of the corn-based ethanol sector causes significant income transfers within agriculture,

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between urban and agricultural states, and between less developed nations and those with automobiles (Carey and Carter, 2007). Finally, the environmental impacts of ethanol fuels are not entirely beneficial. As noted by Raffensperger (2001), "Ethanol produces less carbon monoxide and carbon dioxide but more nitrous oxide and methane. Ethanol also produces aldehydes and alcohol which are carcinogens." Adverse effects also include pollution from increased intensity of agricultural production, deforestation in less developed countries as land is cleared for biofuels production, and carbon dioxide emissions from ethanol refineries. These adverse effects are magnified by ethanol's lower energy content—i.e., more than a gallon of ethanol is required to replace a gallon of gasoline.

Whether ethanol is a boon, a boondoggle, or something in between, the fact remains that the industry has grown dramatically (Renewable Fuels Association, 2008). Recognizing the increasing economic importance of ethanol, the Chicago Board of Trade (CBOT) developed an ethanol futures contract in collaboration with ethanol producers, ethanol marketers, oil companies, gasoline refiners, and independent gasoline retailers. This collaboration sought to ensure the new futures contract met the needs of cash market participants (CBOT, 2008). The contract began trading March 23, 2005. Meanwhile, the New York Mercantile Exchange developed a Reformulated Gasoline Blendstock for Oxygen Blending (RBOB) futures contract which has replaced the unleaded gasoline contract.[1]

In its infancy, the ethanol industry was dominated by Archer Daniels Midland Company (ADM) and six-month-forward contracts negotiated twice per year.[2] ADM's market share has fallen over time as other ethanol marketing firms have developed and grown. Veteran energy (mostly unleaded gasoline) traders, who were accustomed to more sophisticated risk management tools, have moved into ethanol marketing channels, and variable-length contracts, traded in an active over-the-counter (OTC) market, have replaced the six-month contracts. However, widespread forward contracting does not replace the need for hedging. Risk management practices are analogous to those of a local grain elevator that offsets its price risk of forward contracting with growers by either using the corn futures market or contracting with an agent who does. Likewise in ethanol markets, futures contracts are used to transfer forward-contracting price risk. While OTC swap prices are not publicly reported, they are tied to ethanol and RBOB futures prices so that the futures markets play a pivotal role in the price discovery and risk management processes.

Prior to the availability of ethanol futures contracts, ethanol price risk could be cross-hedged with unleaded gasoline futures (Franken and Parcell, 2003). Now ethanol futures provide opportunities for direct-hedging the price risks of holding ethanol inventories as well as processing corn into ethanol. The CBOT (2007) promotes the "corn crush" hedge as analogous to the soybean crush hedge. While soybean product and soybean prices are more highly correlated than are ethanol and corn prices, our findings show that this does not limit the corn crush hedge's potential as a risk management tool.

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[1] Trading in RBOB contracts began May 1, 2005, and trading in unleaded gasoline contracts ceased November 30, 2006. The difference between these two contracts is that the RBOB contract is for gasoline to be blended with ethanol; the unleaded gasoline contract specified MTBE content. Other contract specifications were largely unchanged (New York Mercantile Exchange, 2007).

[2] The factual detail in this paragraph was generously provided by Fred Seamon, Associate Director of Commodity Research for the CME Group. The Commodity Research group was instrumental in the development of the ethanol futures contract.

This study focuses on the risk management performance of the ethanol futures contract. Specific objectives are to examine the effectiveness of ethanol direct-hedging, to compare ethanol direct-hedging with cross-hedging in gasoline futures, to assess the hedging performance of the ethanol contract over time, and to evaluate the effectiveness of the corn crush hedge. The paper proceeds as follows. First, a review of previous process hedging studies is presented. Ethanol hedging strategies are then analyzed by using ethanol cash and futures prices to estimate hedge ratios and hedging effectiveness for various inventory holding horizons. For comparison, the same observational periods are used to estimate the effectiveness of cross-hedging using gasoline futures. We then estimate corn crush hedge ratios and effectiveness under various assumptions. A summary of our conclusions is provided in the final section.

Literature Review

Johnson (1960) and Stein (1961) provide the theoretical foundation for hedging. Profit (π_h) from a required spot position (x_s) and an attendant futures position (x_f) is represented as:

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

where p_0 and f_0 are initial spot and futures prices, and the unknown ending spot and futures prices, p_1 and f_1, are treated as random variables. Minimizing the variance of π_h gives the risk-minimizing futures position (x_f^*) and hedge ratio (x_f^*/x_s), which is estimated by regressing spot price changes on futures price changes. Ederington (1979) defined hedging effectiveness as the proportionate price risk reduction achieved by hedging. It is estimated as the squared correlation between spot and futures price changes.

Anderson and Danthine (1980, 1981) generalized the Johnson and Stein approach by allowing positions in multiple futures contracts and assuming a mean-variance utility maximization objective. Under these conditions the agent's problem is written as:

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

where $\pi_h = x_s(p_1 - p_0) + \mathbf{x}_\mathbf{f}'(\mathbf{f}_1 - \mathbf{f}_0)$, $\mathbf{x_f}$ 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 given by:

(2b) $$\mathbf{x}_\mathbf{f}^* = \lambda^{-1}\boldsymbol{\Sigma}_{\Delta\mathbf{f},\Delta\mathbf{f}}^{-1}\left[\mathbf{E}(\mathbf{f}_1) - \mathbf{f}_0\right] - \boldsymbol{\Sigma}_{\Delta\mathbf{f},\Delta\mathbf{f}}^{-1}\boldsymbol{\Sigma}_{\Delta\mathbf{f},\Delta\mathbf{p}}x_s,$$

where $\boldsymbol{\Sigma}_{x,y}$ represents the covariance matrix for variables x and y. Empirical applications proceed by assuming that either $\lambda = \infty$ (the agent is extremely risk averse) or $\mathbf{E}(\mathbf{f}_1) = \mathbf{f}_0$ (futures markets are efficient), so hedge ratios are estimated by the regression parameters in $\Delta\mathbf{p} = \Delta\mathbf{f}\boldsymbol{\beta} + \boldsymbol{\varepsilon}$. The multiple-regression R^2 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, p. 1127). Consequently, the Johnson, Stein, and Anderson and Danthine methods are typically employed.

Table 1. Anatomy of a Corn Crush Hedge

	Cash Market		Futures Market	
Time	Events	Positions	Transactions	Positions
t_0	Anticipate processing	Short corn (implicit) Long ethanol (implicit)	Buy corn Sell ethanol	Long corn Short ethanol
t_1	Buy corn Begin transformation	Long corn (actual) Long ethanol (implicit)	Sell corn	No corn Short ethanol
t_2	Sell ethanol	No corn No ethanol	Buy ethanol	No corn No ethanol

In commodity processing, input costs and output revenues can be hedged jointly. Tzang and Leuthold (1990) describe a soybean-processing hedging strategy which can be applied to processing other commodities. They argue that during an anticipatory period, when production is planned but inputs and outputs are not yet priced, price risk is hedged by a long futures position for the input and a short futures position for the output(s). When the input is purchased, the long input futures position is closed, and when the output is sold, the short output futures position is closed.

Table 1 applies this sequence to corn crushing. It shows that corn crush hedging can be treated either as long-hedging corn purchases from time t_0 to t_1 and short-hedging ethanol sales from time t_0 to t_2, or as hedging the crushing margin from time t_0 to t_1 (the anticipatory period) and short-hedging ethanol sales from time t_1 to t_2 (the transformation period). The latter approach assumes independence between the anticipatory and transformation periods but accounts for input-output price correlations during the anticipatory period. These correlations may be significant for some commodities (within the soybean complex, for example). The latter approach also explicitly identifies and hedges product transformation price risk in the anticipatory period and product inventory price risk in the transformation period. For these reasons, the latter treatment is used.

Dahlgran (2005) summarizes various approaches used by others to independently hedge inputs and outputs. The possibilities 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. This study examines risk-minimizing direct-hedging in the corn and ethanol futures markets.

Product transformation hedging strategies originated in soybean crushing studies. Tzang and Leuthold (1990) use weekly prices from January 1983 through June 1988 to investigate multi- and single-contract soybean-processing hedges over 1- through 15-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) examines the relationship between transaction frequency and hedging effectiveness in soybean processing.

The multi-contract, cross-hedging approach has been extended to cottonseed processing (Dahlgran, 2000; Rahman, Turner, and Costa, 2001), and Franken and Parcell (2003) found that ethanol cross-hedging with unleaded gasoline futures contracts is effective.

Empirical Model

A general commodity processing model assumes that input x is transformed into output y with fixed coefficient γ, so $y = \gamma x$. The hedge horizon is composed of an anticipatory period (period a) between times 0 and 1, and a transformation period (period b) between times 1 and 2 (table 1). During the anticipatory period (period a), gains or losses accrue as the processing margin (Π_a) widens or narrows. Thus the hedge target is expressed as:

(3a)
$$\begin{aligned}\Pi_a &= (yp_{y1} - xp_{x1}) - (yp_{y0} - xp_{x0}) \\ &= \left[(\gamma p_{y1} - p_{x1}) - (\gamma p_{y0} - p_{x0})\right]x = \Delta_a Mx,\end{aligned}$$

where M is the gross processing margin per unit of input x, p_{xt} and p_{yt} are input and output prices at time t, and Δ_a represents differencing over period a. After inputs are purchased, gains or losses in period b (Π_b) accrue as the output's cash price increases or decreases, so the hedge target is:

(3b)
$$\Pi_b = y(p_{y2} - p_{y1}) = \Delta_b p_y y,$$

where Δ_b represents differencing over period b.

With hedging, the processor takes futures positions in periods a and b to minimize price risk. Hedged gains or losses during the anticipatory and transformation periods, respectively, are denoted by:

(4a)
$$\Pi_a^h = \left[\gamma(p_{y1} - p_{y0}) - (p_{x1} - p_{x0})\right]x + \mathbf{x}'_{\mathbf{fa}}(\mathbf{f}_1 - \mathbf{f}_0) = \Delta_a Mx + \mathbf{x}'_{\mathbf{fa}}(\mathbf{f}_1 - \mathbf{f}_0)$$

and

(4b)
$$\Pi_b^h = y(p_{y2} - p_{y1}) + \mathbf{y}'_{\mathbf{fb}}(\mathbf{f}_2 - \mathbf{f}_1) = \Delta_b p_y y + \mathbf{y}'_{\mathbf{fb}}(\mathbf{f}_2 - \mathbf{f}_1).$$

The Anderson and Danthine (1981) solution in (2b) indicates the utility-maximizing futures positions during the anticipatory and transformation periods are:

(5a)
$$\mathbf{x}^*_{\mathbf{fa}} = \lambda^{-1}\mathbf{\Sigma}^{-1}_{\Delta_a\mathbf{f},\Delta_a\mathbf{f}}\left[\mathbf{E}(\mathbf{f}_1) - \mathbf{f}_0\right] - \mathbf{\Sigma}^{-1}_{\Delta_a\mathbf{f},\Delta_a\mathbf{f}}\mathbf{\Sigma}_{\Delta_a\mathbf{f},\Delta_a M}x$$

and

(5b)
$$\mathbf{y}^*_{\mathbf{fb}} = \lambda^{-1}\mathbf{\Sigma}^{-1}_{\Delta_b\mathbf{f},\Delta_b\mathbf{f}}\left[\mathbf{E}(\mathbf{f}_2) - \mathbf{f}_1\right] - \mathbf{\Sigma}^{-1}_{\Delta_b\mathbf{f},\Delta_b\mathbf{f}}\mathbf{\Sigma}_{\Delta_b\mathbf{f},\Delta_b p_y}y.$$

The respective hedge ratios are estimated by the parameters in the regression models:

(6a)
$$\Delta_a M_t = \Delta_a \mathbf{f}_t \boldsymbol{\beta} + \varepsilon_t$$

and

(6b)
$$\Delta_b p_{y,t} = \Delta_b \mathbf{f}_t \boldsymbol{\beta} + \varepsilon_t.$$

By (6a), the risk-minimizing, anticipatory period hedge ratios are found by regressing the processing margin's change in period a on the corresponding changes in the corn and ethanol futures prices. Assuming that each bushel of corn yields 2.6 gallons of ethanol[3] and 17 pounds of distillers dried grains, the corn-crushing margin (M_t) is calculated as:

[3] The CBOT *Ethanol Futures—Corn Crush Reference Guide* (2007, p. 2) uses 2.6 as the ethanol yield per bushel of corn. Shapouri, Duffield, and Wang (2002) report values ranging from 2.50 to 2.69, and Eidman (2007) reports yields of 2.8 gal./bu. Our analysis examined alternative ethanol yields of 2.6, 2.7, and 2.8 gal./bu.

(7) $$M_t = 2.6P_{e,t} + 17P_{d,t} - P_{c,t},$$

where $P_{e,t}$ represents ethanol's cash price ($/gal.), $P_{d,t}$ represents the distillers dried grains cash price ($/lb.), and $P_{c,t}$ represents corn's cash price ($/bu.). By (6b), risk-minimizing, transformation period hedge ratios are found by regressing the change over the transformation period in ethanol's cash price on the change in ethanol's futures price. This is the procedure used for estimating inventory hedge ratios.

Data

Cash ethanol prices can be purchased from DTN, Oil Price Information Service (OPIS), Platts, Jim Jordan & Associates, Kingsman, Axxis Petroleum, and Bloomberg. The Business Development Unit of the CBOT recommended the Bloomberg data, so the Bloomberg daily average U.S. ethanol rack price is used here to represent the cash price of ethanol.[4] Figure 1 shows two major spikes in these data: one due to Hurricane Katrina (August 29, 2005) and another in early summer of 2006 corresponding to the phase-out of the federal MTBE oxygenate requirement and the phase-in of the requirement that refiners use 4 billion gallons of ethanol in 2006 (McKay, 2006). Figure 1 also shows the reaction of ethanol cash prices to the rise and subsequent decline in crude oil and gasoline prices in 2008.

On March 23, 2005, ethanol futures contracts began trading on the CBOT open auction platform. These prices through December 31, 2008, were obtained from Barchart.com. The CBOT ethanol futures contract calls for delivery of 29,000 gallons of "Renewable Denatured Fuel Ethanol as specified in the latest version of The American Society for Testing and Materials (ASTM) Standard D4806 for 'Denatured Fuel Ethanol for Blending with Gasolines for Use as Automotive Spark-Ignition Engine Fuel.' In addition, delivery grade ethanol shall meet all California specifications" (CBOT, 2008). The contract is not cash settled. Settlement occurs by physical delivery, exchange for physicals, or exchange for risk. Delivery specifications call for "physical delivery by tank car, on track, at shipping origin with seller responsible for transporting product to buyer's destination.... As with the CBOT's corn contract, the delivery instrument for the Ethanol contract is a shipping certificate which gives the buyer the right, but not the obligation to demand load-out of physical ethanol from the firm that issued the certificate" (CBOT, 2008).

Contracts are traded for delivery in each month. Through August of 2006, corn and ethanol futures contracts shared the same last trading day, but commencing with the September 2006 contract, ethanol's last trading day was moved to the third business day of the month. Open interest in ethanol futures is small compared to corn and other major contracts, but market liquidity is enhanced through the use of market makers who are obligated to provide tight bid-offer spreads for various quantities (CBOT, 2008).

Weekly distillers dried grains (DDG) cash prices were obtained from the Internet archive of weekly USDA feedstuffs market news reports (USDA, 2009). Because the Illinois and southern Minnesota price series were the most complete of the available

[4] The Bloomberg Des Moines rack price was preferred, but it had several spans of missing values. The U.S. average rack price did not have these missing values. The Des Moines and U.S. rack prices were highly correlated (correlation of 0.993) as were their weekly changes (correlation of 0.951). Hedging outcomes for specific producers will vary to the extent that local prices differ from the aggregated reported prices used.

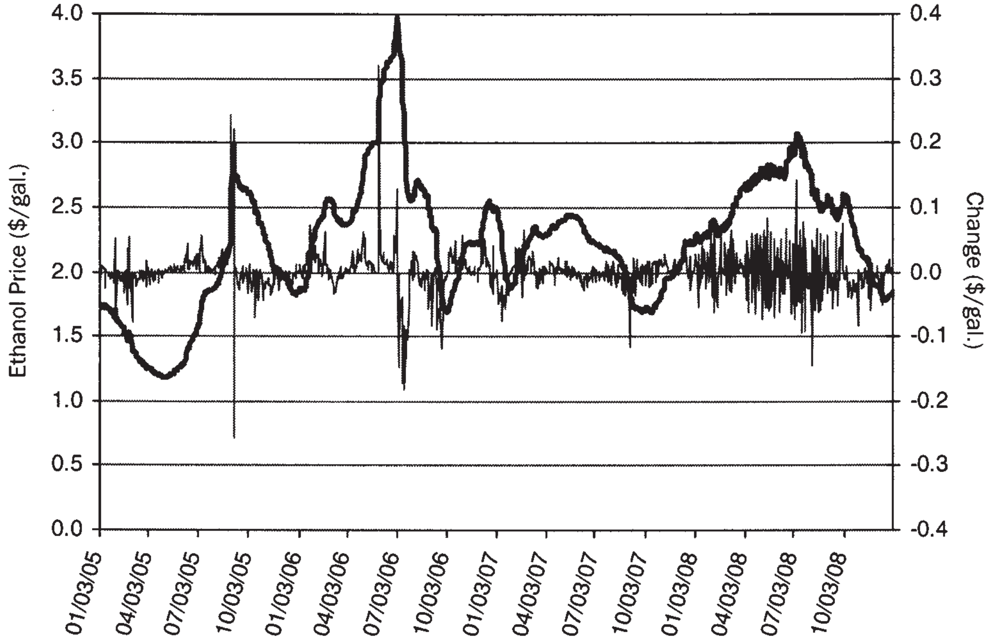

Figure 1. Ethanol cash prices, daily 2005 through 2008

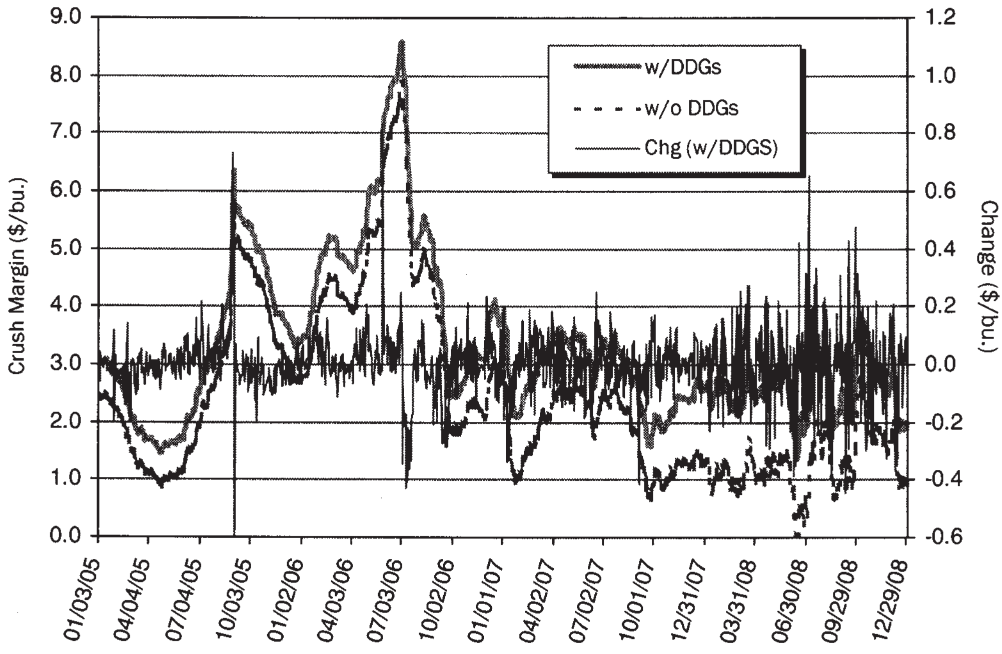

Figure 2. Corn crushing margin, daily 2005 through 2008

DDG price series, their average was used as the DDG cash price.[5] All other price data were obtained from Barchart.com.

Figure 2 shows the daily corn crushing margin computed by equation (7). The Hurricane Katrina and the MTBE phase-out events that influenced ethanol prices are reflected in the crushing margin. However, the 2008 petroleum price surge and decline which influenced ethanol prices is not reflected in the corn crushing margin because of high corn costs.

The data were subjected to several selection criteria. First, weekly time series were formed from Wednesday prices. When Wednesday's price was unavailable due to holidays or market closures, Tuesday's price was used. Second, contracts were selected so that settlement price changes over the hedge horizon were derived from a given contract maturity. Third, the corn and ethanol futures maturities were matched so that the transformation hedges did not have mixed maturities.[6] Corn futures maturities dictated the match because corn contracts mature only in December, March, May, July, and September, while ethanol contracts mature each month.

Hedge horizons were selected based on product inventory turnover at the average plant. Collectively, the current 170 ethanol refineries in the United States have a production capacity of 10.1 billion gallons per year, giving an average plant capacity of 59.6 million gallons per year (Renewable Fuels Association, 2008). This capacity requires the load-out of roughly 20 100-car-unit trains (29,000 gallons per tank car) per year or a unit train load-out every 2.6 weeks. Hedge horizons of one, two, four, and eight weeks were analyzed because they bracket this average load-out. Beyond eight weeks, the number of available nonoverlapping observations becomes small.

Results

The cash prices serving as dependent variables were examined for unit roots in order to rule out spurious correlation between co-integrated series. While the hypothesis that daily (or weekly) ethanol cash prices, weekly DDG prices, and daily (or weekly) crushing margins display a unit root was not rejected, this hypothesis was rejected for the first differences in each of these series. Because the regression models are formulated in first differences, the rejection of the unit root hypothesis for these series is of primary importance.

Preliminary analysis also sought to determine whether Hurricane Katrina or the MTBE phase-out [the major price-influencing events of our sample period (figure 1)] dictate the inferred characteristics of the data. To accomplish this, 104 observations (two years) were drawn from the weekly data beginning January 2, 2003, and the model, $\Delta P_{e,t} = \mu + \varepsilon_t$, $\varepsilon_t = \rho\varepsilon_{t-1} + v_t$, was fit to the data. Then a new two-year sample, starting one week later, was drawn. This process continued until the last observation in the two-year sample was the last observation available. Regardless of the sample period, serial correlation was always significant and the estimated mean never was. GARCH(p, q) specifications for q = 1, 2, and p = 0, 1, 2 were also fit to the samples, but no single

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[5] DDGs account for 13% of the product value from a bushel of corn and 21.5% of the crushing margin.

[6] The ethanol contract matures on the third business day of the month while the corn contract matures on the business day prior to the 15th calendar day of the contract month; thus, even with matching maturities, a slight temporal mismatch remains.

specification consistently fit the data well. Based on these results, the differenced data were treated as mean and variance stationary with potential serial correlation.

Hedge-ratio estimates for direct- and cross-hedging ethanol inventories are reported in table 2. Panel A reports direct-hedge ratios for one-, two-, four-, and eight-week hedges, obtained by fitting $\Delta P_{e,t} = \beta_1 \Delta F_{e,t} + \varepsilon_t$, $\varepsilon_t = \rho\varepsilon_{t-1} + \nu_t$ to all available data. The estimated hedge ratios all have the expected positive sign and are significant for all but the one-week hedge, while serial correlation is significant for only the one-week hedge. For the one-week horizon, effectiveness is low because the hedge ratio is so close to zero. Ethanol's cash price changes are explained mostly by serial correlation rather than by futures price changes.[7] For longer hedge horizons, serial correlation is insignificant (hence, excluded from the model), while futures price changes explain a significant amount of the variation in ethanol's cash price changes. Inventory hedging effectiveness ranges from 0.0053 for a one-week hedge to 0.7949 for an eight-week hedge. This result is consistent with Geppert's (1995) findings for currency and stock index futures where hedge ratios and effectiveness both increase with the hedge horizon. The hedge ratio is significantly different from unity for one- and two-week hedges. Thus, while one-to-one hedging does not expose processors to significantly more price risk for four- and eight-week hedges, it does so for one- and two-week hedges. This difference is due to less complete cash market adjustment to external shocks for the shorter horizons.

Estimated direct-hedging effectiveness is generally lower than cross-hedging effectiveness using unleaded gasoline futures as reported by Franken and Parcell (2003).[8] To compare the effectiveness of direct-hedging with that of cross-hedging using gasoline futures, gasoline futures prices were substituted for ethanol futures prices. Because the RBOB contract recently replaced unleaded gasoline futures, comparisons are conducted using the unleaded gasoline futures contract (panels B versus C) and the RBOB gasoline futures contract (panels D versus E) as separate hedge vehicles. The comparisons use identical time periods governed by the initiation of ethanol futures trading (March 23, 2005), the discontinuation of unleaded gasoline futures trading (November 30, 2006), the initiation of RBOB gasoline futures trading (May 1, 2006), and the last observation (December 31, 2008).

The gasoline cross-hedge ratios (panels B and D) display the same properties as the risk-minimizing, direct-hedge ratios (panels A, C, and E). Specifically, as the hedge horizon increases, so does the hedge ratio, and the serial correlation in cash ethanol prices, while highly significant for the one-week horizon, becomes insignificant for longer horizons.

The direct- versus cross-hedging comparison can be based on either the RMSE or the hedging effectiveness. A smaller RMSE or larger hedging effectiveness indicates less residual price risk and is identified with italic typeface for each comparison. Table 2 also shows the F-statistic for the test of residual error variance equality for each comparison. As revealed by these comparisons, other than for a one-week hedge, hedging with ethanol futures is more effective than cross-hedging with gasoline futures. The difference in

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[7] Serial correlation implies some of a price change can be anticipated based on the previous period. Because hedging is for protection from unanticipated price changes, hedging effectiveness should indicate only the portion of the unanticipated price change that has been removed through hedging. Thus, the appropriate measure of hedging effectiveness is the regression R^2, not the total R^2. This is equivalent to the Myers and Thompson (1989) argument that conditioning information is relevant to evaluating a hedge.

[8] Franken and Parcell (2003) used weekly average prices rather than daily prices. They found significant serial correlation, and reported hedging effectiveness of 0.338, 0.786, and 0.884 for one-, four-, and eight-week hedges, respectively.

Table 2. Ethanol Inventory Hedging, Direct- and Cross-Hedging Comparisons

	Hedge Horizon			
Description	1 Week	2 Weeks	4 Weeks	8 Weeks
A. Direct-Hedging Ethanol with Ethanol Futures (entire sample)				
Observations	197	98	49	24
First	Mar. 30, 2005	Apr. 6, 2005	Apr. 20, 2005	May 18, 2005
Last	Dec. 31, 2008	Dec. 24, 2008	Dec. 24, 2008	Nov. 26, 2008
Hedge Ratio	0.047 (0.047)	0.613** (0.091)	0.972** (0.101)	1.114** (0.118)
Serial Correlation [a]	0.565** (0.059)			
RMSE	0.0873	0.1576	0.1856	0.2469
Regression R^2	0.0053	0.3186**	0.6580**	0.7949**
B. Cross-Hedging Ethanol with Unleaded Gasoline Futures				
Observations	87	43	21	10
First	Mar. 30, 2005	Apr. 6, 2005	Apr. 20, 2005	May 18, 2005
Last	Nov. 22, 2006	Nov. 15, 2006	Nov. 1, 2006	Oct. 4, 2006
Hedge Ratio	0.113 (0.089)	0.236 (0.285)	0.517 (0.385)	0.709 (0.649)
Serial Correlation [a]	0.610** (0.086)	0.338* (0.147)		
RMSE [b]	*0.1077*	0.2311	0.3950	0.7148
Regression R^2	*0.0187*	0.0165	0.0826	0.1172
C. Direct-Hedging Ethanol with Ethanol Futures (same period as panel B)				
Hedge Ratio	0.011 (0.077)	0.755** (0.138)	1.016** (0.170)	1.186** (0.198)
Serial Correlation [a]	0.608** (0.087)			
RMSE [b]	0.1087	*0.1892*	*0.2474*	*0.3406*
Regression R^2	0.0003	*0.4166***	*0.6402***	*0.7998***
H_1: Equal error variances, panel B versus panel C:				
F-Statistic	1.019	1.492	2.549*	4.410*
D. Cross-Hedging Ethanol with RBOB [c] Gasoline Futures				
Observations	139	69	34	16
First	May 10, 2006	May 17, 2006	Jun. 14, 2006	Aug. 9, 2006
Last	Dec. 31, 2008	Dec. 24, 2008	Dec. 24, 2008	Nov. 26, 2008
Hedge Ratio	0.042 (0.060)	0.160 (0.149)	0.481** (0.172)	0.634* (0.218)
Serial Correlation [a]	0.542** (0.072)	0.262* (0.118)		
RMSE [b]	*0.0941*	0.1856	0.2798	0.3840
Regression R^2	*0.0035*	0.0171	0.1908**	0.3601*
E. Direct-Hedging Ethanol with Ethanol Futures (same period as panel D)				
Hedge Ratio	0.025 (0.055)	0.585** (0.112)	0.980** (0.121)	1.182** (0.130)
Serial Correlation [a]	0.539** (0.072)			
RMSE [b]	0.0942	*0.1647*	*0.1800*	*0.1883*
Regression R^2	0.0015	*0.2863***	*0.6651***	*0.8461***
H_2: Equal error variances, panel D versus panel E:				
F-Statistic	1.002	1.334	2.416**	4.159**

(continued . . .)

Table 2. Continued

Description	Hedge Horizon							
	1 Week		2 Weeks		4 Weeks		8 Weeks	
F. Composite Hedging Ethanol with Ethanol Futures and Gasoline Futures (same period as panel D)								
Hedge Ratios								
Gasoline Futures	0.037	(0.065)	−0.018	(0.138)	0.023	(0.131)	−0.021	(0.148)
Ethanol Futures	0.012	(0.060)	0.592**	(0.125)	0.967**	(0.144)	1.198**	(0.180)
Serial Correlation [a]	0.538**	(0.073)						
RMSE	0.0944		0.1659		0.1827		0.1948	
Regression R^2	0.0039		0.2865		0.6655		0.8463	
H_3: Gasoline hedge ratio not equal to zero								
t-Statistic	0.56		−0.13		0.18		−0.14	

Notes: * denotes statistical significance between 1% and 5%; ** denotes statistical significance beyond 1%. Values in parentheses are standard errors.

[a] When serial correlation is significant, generalized least squares results are reported; otherwise, ordinary least squares estimates are reported.

[b] Italic typeface indicates the smaller RMSE when direct- and cross-hedging are compared.

[c] The New York Mercantile Exchange contract is for delivery of reformulated gasoline blend stock for oxygen blending (abbreviated RBOB). This contract has replaced the unleaded gasoline futures contract.

effectiveness is significant at beyond the 5% level for four- and eight-week hedges (F-statistics of 2.549 and 2.416 for four-week horizons, and 4.410 and 4.159 for eight-week horizons). The superiority of the ethanol direct-hedge over the gasoline cross-hedge also holds for the two-week horizon, although the difference is not significant. For the one-week horizon, neither hedge results in significant price risk reduction, although the cross-hedge is slightly more effective.

Panel F of table 2 addresses the Sanders and Manfredo (2004) hedging effectiveness encompassing principle. Here a composite hedge consisting of a direct-hedge in ethanol futures and a cross-hedge in gasoline futures is examined. These results are consistent with those in the preceding panels—serial correlation is significant for a one-week hedge and the ethanol hedge ratio is significant and increases for longer hedges. Most importantly, the reported t-ratios indicate that the gasoline futures contract, when paired with the ethanol futures contract to form a risk-minimizing ethanol inventory hedge, offers virtually no further risk reduction. Hence, we conclude that ethanol futures perform better than gasoline futures in hedging ethanol price risk.

The newness of ethanol futures invites testing whether the contract's hedging performance has improved over time. Hedging performance is evaluated by simulating hedges that use only information available at time t to hedge in time $t + 1$. Beginning with the first period after the ethanol futures contract's launch, the risk-minimizing hedge ratio is computed. The estimated hedge ratio is used to compute anticipated (i.e., conditional expectations of) profits or losses from a one-period-ahead hedge [by (6b), $\Delta \hat{p}_{y,t+1} = \mathbf{\Delta f}_{t+1}\hat{\boldsymbol{\beta}}_t$]. The process is repeated by adding a period at the end of the sample, updating the hedge ratio, and computing anticipated profits or losses for the next one-period-ahead hedge. This simulation gives two series—anticipated hedged outcomes and anticipated unhedged outcomes.[9] Risk arises from unanticipated outcomes, which when hedged and unhedged are $e_{h,t+1} = \Delta p_{y,t+1} - \mathbf{\Delta f}_{t+1}\hat{\boldsymbol{\beta}}_t$, and $e_{u,t+1} = \Delta p_{y,t+1}$, respectively. Squaring each term estimates risk for each observation.

Table 3 summarizes our results. It begins with the mean squared forecast error, which is an aggregate estimate of risk if unhedged. This measure is also reported for the first and second halves of the simulated outcomes. The table shows (H_1) that unhedged risk is significantly larger in the simulation's first half than in the second. This is due in part to the market disruptions caused by the MTBE-to-ethanol switchover (June 2006), and by Hurricane Katrina (August 2005).

The goodness-of-fit test (Snedecor and Cochran, 1967, p. 21) is used to test for risk reduction, since out-of-sample effectiveness measures do not follow a well-known probability distribution. The logic follows. If hedging is effective, then the hedged-outcome squared error ($e^2_{h,t}$) should, more often than not, be smaller than the unhedged squared error ($e^2_{u,t}$). Accordingly, we tally outcomes where $e^2_{h,t} < e^2_{u,t}$, and compute $\chi^2 = \Sigma_i (Obs_i - Exp_i)^2/Exp_i$, where Obs_i is the observed frequency for class *i*, Exp_i is the expected frequency for class *i*, and *i* represents the classes where hedging is superior and where not hedging is superior. The hypothesis is rejected for large χ^2 values.

Panel A of table 3 reports risk-reduction frequencies resulting from risk-minimizing hedge ratios. To illustrate, the data provide 195 outcomes for the one-week horizon, and $e^2_{h,t} < e^2_{u,t}$ (i.e., risk reduction) occurs 111 times or in 56.9% of our observations. If hedging offers no risk reduction, then we would expect this to occur only half of the time. The observed 111 outcomes are better than the expected 97.5 outcomes under the hypothesis of no risk reduction through hedging. The computed χ^2 statistic of 3.738 has 1 degree of freedom and a probability of a larger value of 0.107; thus, we cannot reject the hypothesis that hedging is ineffective. This result is consistent with our previous finding (table 2) that the in-sample one-week hedge ratio is not significantly different from zero.

Table 3 also permits testing out-of-sample hedging effectiveness for the first and second halves of the sample. Continuing with the one-week hedge illustration, the first half of the sample has 97 observations, of which 47 (48.5%) have $e^2_{h,t} < e^2_{u,t}$. While the observed outcome is worse than the expected 50% (48.5 outcomes) if hedging effectiveness is zero, it is not significantly so; the computed χ^2 statistic (0.093) has a probability of a larger value of 0.760.

While out-of-sample risk-reduction frequencies are generally greater than 50%, they are significantly different from 50% only for the four-week hedge and for the one-week hedge in the second half of the sample. We generally observe that the longer the hedge horizon, the greater the likelihood that $e^2_{h,t} < e^2_{u,t}$.

The goodness-of-fit test is also applied to risk-reduction frequencies to test the notion that hedging in the ethanol futures contract has become more effective as the futures market has developed (H_2). Contrary to a priori expectations, the test results for H_2 indicate hedging effectiveness does not differ between the first and second halves of the simulation at beyond the 5% significance level, despite the significant (H_1) change in the risk of not hedging.

Out-of-sample hedging effectiveness is estimated as:

$$e = [MSFE_u - MSFE_h]/MSFE_u,$$

[9] An unhedged strategy assumes $\beta = 0$ so that absent serial correlation, the anticipated gain or loss is zero. When serial correlation is present, it determines the anticipated unhedged outcome.

Table 3. Out-of-Sample Hedging Effectiveness

	HEDGE HORIZON											
	1 Week by Subperiod			2 Weeks by Subperiod			4 Weeks by Subperiod			8 Weeks by Subperiod		
Description	All	1st Half	2nd Half	All	1st Half	2nd Half	All	1st Half	2nd Half	All	1st Half	2nd Half
Simulation Outcomes	195	97	98	96	48	48	47	23	24	22	11	11
Risk – Unhedged ($MSFE_u$)[a,c]	0.008	0.012	0.004	0.037	0.061	0.013	0.103	0.172	0.036	0.295	0.492	0.098
H_1: Hedgeable risk 1st half = hedgeable risk 2nd half												
F-Statistic		3.198**			4.651**			4.743**			5.041**	
Prob > *F*		0.000			0.000			0.000			0.000	
A. Using Risk-Minimizing Hedge Ratios												
Risk-Reduction Frequency[a,b]	0.569	0.485	0.653**	*0.573*	0.604	*0.542*	0.745**	0.739*	0.750*	0.682	0.727	0.636
H_2: Risk-reduction frequency 1st half = risk-reduction frequency 2nd half												
Prob > χ^2		0.107			0.686			0.866			0.796	
Effectiveness – Out-of-Sample[b,c]	−0.001	−0.016	0.043	0.192	0.256	*−0.105*	0.587	0.585	0.598	0.764	0.786	0.651
B. Using Unit Hedge Ratios												
Risk-Reduction Frequency[a,b]				0.552	*0.625*	0.479	*0.766***	*0.783***	0.750*	0.682	0.727	0.636
H_3: Risk-reduction frequency 1st half = risk-reduction frequency 2nd half												
Prob > χ^2					0.336			1.000			0.796	
Effectiveness – Out-of-Sample[b,c]				0.192	*0.367*	−0.624	*0.658*	*0.667*	*0.615*	*0.777*	*0.789*	*0.721*

Note: * Indicates difference from 0.5 between 1% and 5% significance levels; ** indicates difference from 0.5 beyond the 1% significance level.

[a] Risk-reduction frequency is the count of hedged forecast error squared less than unhedged forecast error squared relative to total outcomes.

[b] Italic typeface indicates the more effective hedging strategy based on the effectiveness indicator when choosing between risk-minimizing and unit hedge ratios.

[c] MSFE represents the mean squared forecast error based on a one-period-ahead forecast, and subscripts *u* and *h* indicate unhedged and hedged outcomes, respectively. Out-of-sample effectiveness is computed as $(MSFE_u - MSFE_h)/MSFE_u$.

where the u and h subscripts indicate unhedged and hedged outcomes, and *MSFE* is the average squared one-step-ahead forecast error. The negative value for a one-week horizon (–0.001) indicates that hedging increases risk by 0.1%, though the test above reveals this increase is not statistically significant. The out-of-sample effectiveness measures computed in this fashion are not greatly different from the in-sample measures reported in table 2 and increase as the hedge horizon increases.

De Jong, De Roon, and Veld (1997) demonstrate that for currencies the risk-minimizing hedge ratios do not perform better out-of-sample than naïve one-to-one hedging. Panel B of table 3 investigates this proposition for ethanol hedging. One-week hedge results are not reported because these hedge ratios were not significantly different from zero, so a comparison with one-to-one hedging is not meaningful.

The risk-reduction frequency indicators in panel B are similar to those in panel A. These frequencies are significantly different from 50% for only the four-week horizon. Likewise, the risk-reduction frequencies for the first and second halves are not significantly different (H_3) despite the significant difference in the overall level of risk if hedging is not practiced (H_1).

For the two-week hedge, the subsample specific out-of-sample effectiveness measures for unit hedge ratios differ substantially (first half higher, second half lower) from those reported for risk-minimizing hedge ratios (panel A). This occurs because the risk-minimizing hedge ratio is significantly different from one. Out-of-sample effectiveness for one-to-one hedging is higher for four- and eight-week hedges than for the two-week hedge because the four- and eight-week risk-minimizing hedge ratios are not significantly different from one.

In summary, the out-of-sample results in table 3 generally indicate that (*a*) hedging effectiveness increases with the hedge horizon whether effectiveness is computed in-sample (table 2) or out-of-sample (table 3); (*b*) market events create more price risk in the first half of the simulation period than in the second half; (*c*) more often than not, hedging is less effective in the second half of the simulation period (when there is less price risk) than in the first half; (*d*) the decrease in hedging effectiveness from the first half to the second half of the simulation period is not significant; and (*e*) naïve one-to-one hedging seems to be more effective than risk-minimizing hedging provided the hedge ratio is not significantly different from one.

In addition to having ethanol at the end of the production cycle, ethanol refiners also have inventories of distillers dried grains. Panel A of table 4 explores cross-hedging these inventories with corn futures. This panel shows that the corn futures hedge ratios are significant regardless of the horizon, and increase with the hedge's length. The out-of-sample effectiveness measures are considerably below the in-sample measures.

Having explored the direct-hedging potential of the ethanol futures contract, and cross-hedging strategies for distillers dried grains, we now turn our attention to hedging the corn crush. The results of fitting (6a) and (7) are reported in panel B of table 4. As expected, the estimated coefficient on the ethanol futures price is positive, corresponding to a short position in ethanol futures, and the estimated coefficient on the corn futures price is negative, indicating a long position in corn futures. As the hedge horizon increases, the ethanol futures coefficient increases in magnitude and significance while the corn futures coefficient is never significantly different from –1. Other features of the corn crush hedge are similar to those of the ethanol hedge. The hedge effectiveness, whether measured by the regression R^2 or the mean squared forecast error, is larger for

Table 4. Corn Crush Hedging with Ethanol and Corn Futures, Hedge Ratios and Effectiveness

Description	Hedge Horizon: 1 Week	2 Weeks	4 Weeks	8 Weeks
Observations	197	98	49	24
First	Mar. 30, 2005	Apr. 6, 2005	Apr. 20, 2005	May 18, 2005
Last	Dec. 31, 2008	Dec. 24, 2008	Dec. 24, 2008	Nov. 26, 2008
A. Cross-Hedge: Distillers Dried Grains with Corn Futures				
HR Corn	0.195** (0.063)	0.281** (0.097)	0.452** (0.145)	0.704** (0.172)
Serial Correlation [a]	0.181* (0.071)			
RMSE	0.1856	0.3002	0.4511	0.5468
Regression R^2	0.0479	0.0803**	0.1678**	0.4201**
Out-of-Sample Effectiveness	0.0082	0.0281	0.0535	0.0722
B. Ethanol Crushing Hedge: Ethanol Futures and Corn Futures				
HR Ethanol	0.144 (0.142)	1.898** (0.302)	2.675** (0.309)	3.054** (0.347)
HR Corn	−0.979** (0.080)	−1.222** (0.155)	−1.005** (0.177)	−1.042** (0.226)
Serial Correlation [a]	0.550** (0.060)			
RMSE	0.2370	0.4269	0.5078	0.6659
Regression R^2	0.4690**	0.4262**	0.6355**	0.7835**
Out-of-Sample Effectiveness	0.3782	0.3047	0.5662	0.7840
H_1: One-one crush ($\beta_{ethanol} = 2.6$, $\beta_{corn} = -1$)				
F-Value	181.89**	6.67**	0.04	0.90
H_2: Proportional crush ($\beta_{ethanol} = -2.6\,\beta_{corn}$)				
F-Value	151.67**	11.58**	0.02	0.38

Notes: * denotes statistical significance between 1% and 5%; ** denotes statistical significance beyond 1%. Values in parentheses are standard errors.

[a] When serial correlation is significant, generalized least squares results are reported; otherwise, ordinary least squares estimates are reported.

the longer hedge horizons, and serial correlation is significant for a one-week horizon but not for longer horizons.

Other test results are also shown in table 4. H_1 (panel B) tests a one-to-one crush hedging strategy, assuming a yield of 2.6 gallons of ethanol per bushel of corn.[10] This hypothesis is rejected for the one- and two-week horizons, but not for the four- and eight-week horizons. The same conclusions apply for a proportional crush hedging strategy, suggesting that following these simpler hedging strategies does not expose a processor to significantly more price risk for the longer hedge horizons.

Finally, the in-sample corn crush effectiveness estimates (panel B, table 4) are similar to soybean crush effectiveness estimates for the same hedge horizon, as reported by Garcia, Roh, and Leuthold (1995); Fackler and McNew (1993); and Dahlgran (2005). Thus, as a price risk management tool, the corn crush hedge is on par with the soybean crush hedge.

[10] Ethanol yields of 2.7 and 2.8 gallons of ethanol per bushel of corn were also investigated. The results obtained did not differ much from those reported in panel B of table 4.

Conclusions

This study was motivated by recent popular press attention received by the ethanol sector, the recent development of the CBOT ethanol futures contract, and the similarities between corn crushing and soybean crushing. Our overall objective was to determine the usefulness of the ethanol futures contract as a hedging vehicle. More specifically, this empirical analysis sought to determine (*a*) the effectiveness of direct-hedging ethanol price risk, (*b*) the comparable effectiveness of cross-hedging ethanol price risk with gasoline futures contracts, and (*c*) the effectiveness of hedging the price risk of transforming corn into ethanol using the corn and ethanol futures contracts.

Our major conclusions are that ethanol producers face considerable price risk, as recent data clearly show the impacts of Hurricane Katrina and the phase-out of MTBE. For short hedge horizons (one week), the serial correlation of ethanol prices makes hedging ineffective. For longer horizons (two to eight weeks), the serial correlation disappears and hedging is effective and is more effective the longer the horizon. This finding suggests ethanol producers and brokers can use the ethanol futures contract to manage price risk.

The comparison of direct-hedging in ethanol futures with cross-hedging in gasoline futures reveals that for one-week hedge horizons neither is very effective. As the hedge horizon lengthens, the advantage goes to direct-hedging with ethanol futures. For four- and eight-week hedge horizons, direct-hedging in ethanol shows a statistically significant advantage over cross-hedging in gasoline futures. Even adding gasoline futures as a cross-hedge to an ethanol inventory direct-hedge offers no significant risk reduction. This finding indicates that contrary to anecdotal evidence, ethanol producers and brokers should hedge price risk with ethanol futures contracts rather than with gasoline futures contracts.

Contrary to our a priori expectations, over time the hedging effectiveness of ethanol futures generally decreased, although not significantly so. More specifically, in the second half of our observational period, hedging with ethanol futures contracts allowed the elimination of a slightly smaller proportion of significantly less price risk when compared to the first half. Results of our comparison show that the explanatory power of the analysis holds over a broad range of changes in processing margins and in gasoline, ethanol, and corn prices.

Effectiveness patterns for transformation hedging mirror those for direct-hedging, as effectiveness increases with the hedge horizon. Using a one-to-one crush spread to hedge corn crushing exposes ethanol producers to superfluous price risk over short hedge horizons (one to two weeks) but not for longer hedge horizons. The same findings apply to a proportional crush spread. These results confirm that the corn crush promoted by the Chicago Board of Trade is an effective technique for locking in current processing margins, but the effort devoted to finding the risk-minimizing positions in the ethanol and corn futures markets pays off in risk reduction only for short hedge horizons.

Finally, the hedging effectiveness of the corn crush hedge and the soybean crush hedge are comparable. This means that as a risk management tool, the corn crush hedge offers ethanol producers as much price risk protection as the soybean crush hedge offers soybean processors. Hence, the corn crush hedge should find widespread use.

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