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by

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In response to the development of the U.S. ethanol industry, the Chicago Board of Trade (CBOT) launched the ethanol futures contract in March 2005. This contract is promoted by the CBOT as allowing ethanol producers to hedge corn crushing using strategies similar to those used in soybean crushing. The similarities end, however, when the lack of short-term correlation between corn and ethanol prices is compared to the strong correlation between soybean and soy product prices. This contrast motivates the examination of the price risk management capabilities of the CBOT's ethanol futures contract.

Standard hedging methodology is applied to weekly cash and futures price data from March 23, 2005 through March 7, 2007. Findings include (1) for two- to eight-week hedging horizons, the ethanol futures contract effectively hedges ethanol inventory price risk. The effectiveness of the hedge increases with the hedging horizon. Thus, ethanol producers and brokers can use the ethanol futures market to reduce the price risk of holding ethanol inventories. (2) Contrary to anecdotal evidence, ethanol futures are not significantly inferior to gasoline futures for hedging ethanol price risk and for a four-week hedge they are significantly superior to gasoline futures. Thus, ethanol producers and brokers get greater price risk protection from hedging with ethanol futures than with gasoline futures. (3) The corn crushing hedge, utilizing corn and ethanol futures contracts, is an effective means to "lock in" a processing margin. The effectiveness of this hedge increases as the hedging horizon increases. Finally, to understand the processing hedge, the corn crush hedge and the soybean crush hedge were compared. I found that (4) the price risk of corn crushing is greater than that of soybean crushing and the effectiveness of corn crush hedging exceeds that of soybean crush hedging. This difference is explained by the high correlations in the soybean complex.

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

Introduction

U.S. ethanol production from corn has received much recent attention in the popular press. There are three reasons for this. First, the gasoline additive MTBE (methyl tertiary-butyl ether) was banned in California and New York beginning January 1, 2004 because of its water solubility, its resultant ready migration into groundwater supplies, and the absence of liability protection afforded to petroleum companies for groundwater contamination (U.S. Dept. of Energy 2006). More recently, MTBE has been banned or its use discontinued in most other states as well (McKay 2006). MTBE served as an octane enhancer and reduced the emission of urban-smog precursors (Raffensperger 2001). A 10% blend of ethanol with gasoline is an economical alternative to MTBE.

Second, the "Twenty in Ten" policy initiative outlined in the president's 2007 State of the Union Address seeks to reduce U.S. gasoline usage by 20% over the next ten years. This goal is to be achieved by "increasing the supply of renewable and alternative fuels by setting a mandatory fuels standard to require 35 billion gallons of renewable and alternative fuels in 2017 – nearly five times the 2012 target now in law. In 2017, this will displace 15% of projected annual gasoline use" (The White House Jan 23, 2007). Corn-based ethanol is a renewable fuel, and hence a potential substitute for gasoline.

Third, ethanol production appears to have become economically viable due to recent record high crude oil and gasoline prices, combined with a 51 cent per gallon tax credit for blending ethanol (regardless of production source) with gasoline,[1] and a 54 cent per gallon tariff on imports.[2]

Corn-based ethanol is no panacea. It is frequently criticized for its 1.3 to 1 energy balance meaning that corn-based ethanol generates 30% more energy than is required to produce it (Shapouri, Duffield, and Wang 1995, 2002). In contrast, soy biodiesel has an energy balance of 3.24 (Sheehan et al. 1998) and sugar cane-based ethanol has an energy balance of 8.3 (The Economist March 8, 2007). Second, the development of the corn-based ethanol sector is causing substantial adjustments in corn, agricultural land, and food prices (Carey and Carter 2007). Within the agricultural sector, these price adjustments cause income transfers from livestock feeders to crop farmers. Other transfers occur from urban states to agricultural states, and "between [the world's] 800 million people with automobiles and the 2 billion poorest people" (Carey and Carter 2007 p82 quoting Lester Brown, president of the Earth Policy Institute). Finally, the environmental impacts of ethanol fuels are not entirely beneficial as "ethanol produces less carbon monoxide and carbon dioxide but more nitrous oxide and methane. Ethanol also produces aldehydes and alcohol which are carcinogens" (Raffensperger 2001). Adverse environmental impacts also include pollution from the production and application of fertilizers and pesticides used in growing corn, the environmental impacts of deforestation in less developed countries to bring land into use for biofuels production, and carbon dioxide emissions from ethanol refineries. These adverse impacts are magnified by ethanol's lower energy content which requires more than a gallon of ethanol to replace a gallon of gasoline.

Whether ethanol is a boon, a boondoggle, or something in between, the fact is that there are currently 115 ethanol plants in the United States with production capacity of 5.75 billion gallons per year. Another 79 new plants and 7 expansions are planned or under construction with production capacity of 6.34 billion gallons per year (Renewable Fuels Association 2007). Figure 1 indicates the locations of these plants.

In recognition of the significant ethanol production from these refineries, the Chicago Board of Trade developed an ethanol futures contract which began trading on March 23, 2005. In addition, the New York Mercantile Exchange developed a "Reformulated Gasoline Blendstock for Oxygen Blending (RBOB)" futures contract which has replaced the unleaded gasoline futures

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[1] "With the influence of Dwayne O. Andreas, A.D.M.'s longtime chief executive and now chairman emeritus, Congress passed the federal excise tax in 1978 that gave ethanol its primary subsidy, a credit worth 51 cents per gallon of ethanol. Mr. Andreas had powerful friends in Congress, including Senator Robert J. Dole, a Republican from Kansas who rose to majority leader and who pushed consistently over the years to retain the ethanol subsidy." (Barrionuevo 2007).

[2] Congress established this tariff in 1980 as part of a plan to reduce America's dependence on foreign sources of energy (Prater 2006). The tariff expires in 2009 but farm state legislators favor extending it indefinitely.

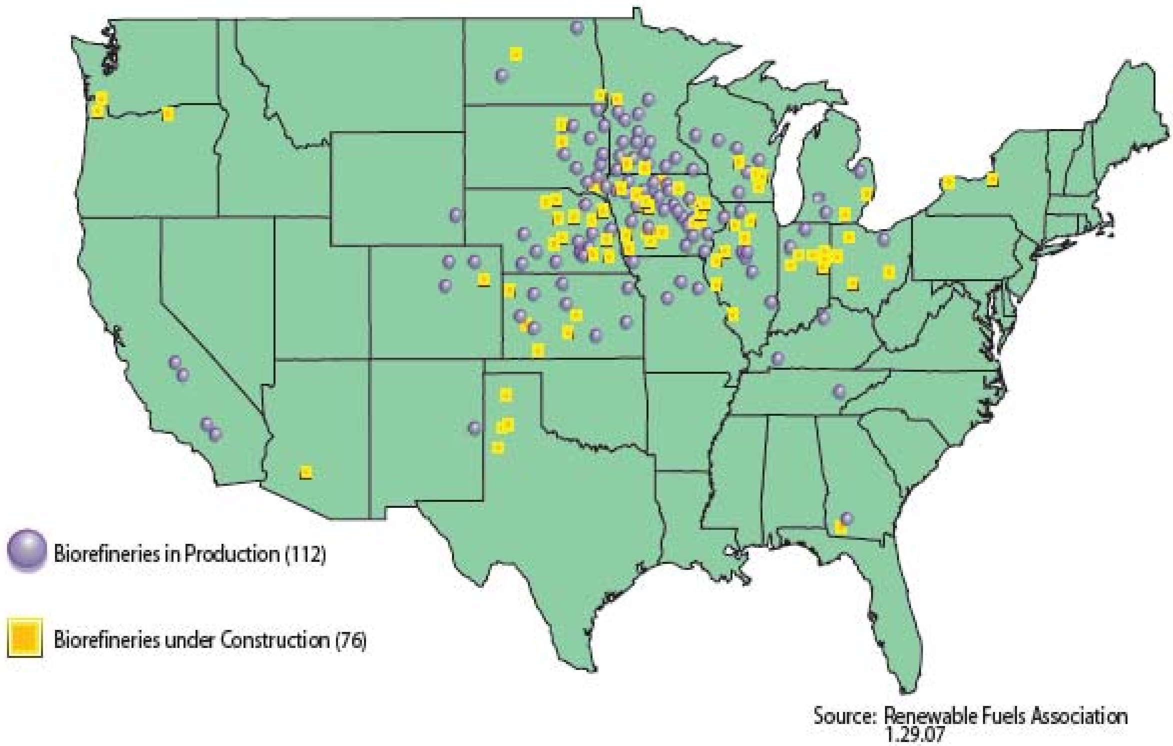

Figure 1. Biorefineries in the United States.

contract.[3] Trading in RBOB contracts began on May 1, 2005 and trading in unleaded gasoline ceased on Nov 30, 2006.

Prior to the availability of ethanol futures contracts, ethanol price risk could be cross hedged with unleaded gasoline futures (Franken and Parcell 2003) and anecdotal evidence indicates that this frequently is the hedging venue. However, ethanol futures contracts provides direct hedging of ethanol inventory price risk as well the price risk of processing corn into ethanol. The Chicago Board of Trade promotes this "corn crush" as a processing hedge that is analogous to the soybean crush hedge (CBOT 2007a). This comparison suffers, however, in that soybean product prices are highly correlated with soybean prices while correlations between corn and ethanol prices are much lower. Thus, the corn-crushing margin is more variable than the soybean-crushing margin.

The risk management potential of this "corn-crushing hedge" is the focus of this paper. Specific objectives are (1) to estimate corn crush-hedging effectiveness, (2) to compare ethanol direct

3 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 contracts specifications were largely unchanged. (New York Mercantile Exchange 2007).

hedging with cross hedging in the gasoline futures market, and (3) by comparing corn crushing to soybean crushing, to examine the role of the input-output price correlations in processing hedges.

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 and ethanol to estimate hedge ratios and hedging effectiveness for various inventory and transformation hedging horizons. For comparison, the same observational period will be used to examine the effectiveness of cross hedging using gasoline futures contracts. Finally, to better understand the role of the input-output price correlation in determining hedging effectiveness, the hedging effectiveness for corn crushing will be compared to that of soybean crushing.

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

(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 spot and futures prices. The unknown spot and futures prices are treated as random variables so,

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

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

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

and the hedge ratio (x_f^* / x_s), which is estimated by the 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 $V(\pi_u) = x_s^2\,V(p_1\text{-}p_0)$. Ederington (1979) defined hedging effectiveness (e) as 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.

Anderson and Danthine (1980, 1981) generalized this approach by allowing positions in multiple futures contracts and 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 $\pi_h = x_s\ (p_1\text{-}p_0) + \mathbf{x'_f}\ (\mathbf{f_1}\text{-}\mathbf{f_0})$, $\mathbf{x_f}$ 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

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

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

In commodity processing, input costs and output revenues can both be hedged. Tzang and Leuthold (1990) analyzed soybean processing and argue that during an anticipatory period, when production is planned but inputs and outputs are not yet priced, price risk is hedged with 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 eliminated but the short output futures position is retained. Finally, the output is sold and the short output futures position is closed. Table 1 applies this sequence to corn crushing.

Table 1 reveals 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 transformation periods but accounts for input-output price correlations

Table 1. Anatomy of a corn-crushing 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

during the anticipatory period. These correlations may be significant for some commodities (within the soybean complex, for example). This 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) 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*. Because futures markets now exist for both corn and ethanol, risk-minimizing direct hedging will be used.

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 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.

Empirical Model

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

(3a) $$\Pi_a = (y\, p_{y1} - x\, p_{x1}) - (y\, p_{y0} - x\, p_{x0}) = [(\gamma\, p_{y1} - p_{x1}) - (\gamma\, p_{y0} - p_{x0})]\, x = \Delta_a M\, x.$$

where M is the gross processing margin per unit of input and p_{xt} and p_{yt} represent input and output prices at time t. After inputs are purchased, gains or losses (Π_b) accrue as the cash price of the output increases or decreases. Thus, the hedge target is

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

Through hedging, the processor attempts at different times to minimize risk by adding futures positions to the portfolio. Hedged gains or losses during the anticipatory and transformation periods, respectively, are

(4a) $\Pi_a^h = [\gamma\,(p_{y1} - p_{y0}) - (p_{x1} - p_{x0})]\, x + \mathbf{x_{fa}}'\,(\mathbf{f_1}\text{-}\mathbf{f_0}) = \Delta_a M\, x + \mathbf{x_{fa}}'\,(\mathbf{f_1}\text{-}\mathbf{f_0})$, and

(4b) $\Pi_b^h = y\,(p_{y2} - p_{y1}) + \mathbf{y_{fb}}'\,(\mathbf{f_2}\text{-}\mathbf{f_1}) = \Delta_b\, p_y\, y + \mathbf{y_{fb}}'\,(\mathbf{f_2}\text{-}\mathbf{f_1})$.

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

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

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

The hedge ratios in these equations are estimated by the parameters in the regression models

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

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

By (6a), risk-minimizing hedge ratios during the anticipatory period are found by regressing the change in the processing margin over the hedge period against the changes in the corn and ethanol futures contract prices. As each bushel of corn yields 2.6 gallons of ethanol, the corn-crushing margin (M_t) is

$$M_t = 2.6\, P_{e,t} - P_{c,t},$$

where $P_{c,t}$ is the cash price of corn ($/bu) and $P_{e,t}$ is the cash price of ethanol ($/gal). By (6b), risk-minimizing hedge ratios for the transformation 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.

Data

Cash ethanol prices are available for a fee from DTN, Oil Price Information Service (OPIS), Platts, Jim Jordan & Associates, Kingsman, Axxis Petroleum, and Bloomberg. The Business Development Unit of the Chicago Board of Trade considers the Bloomberg average U.S. rack price series to best represent the cash price of ethanol so these data are used in this study.[4] These data are shown in figure 2. Figure 2 shows a spike in ethanol prices at the time of Hurricane Katrina (August 29, 2005) and a price bubble in the early summer of 2006, which corresponds to the phase-out of the federal MTBE oxygenate requirement and the phase-in of the requirement

[4] The Des Moines rack price series was also considered but it had several missing values and was highly correlated (correlation of 0.9932) with the average U.S. rack price which didn't have missing values. Therefore, the average U.S. rack price was used.

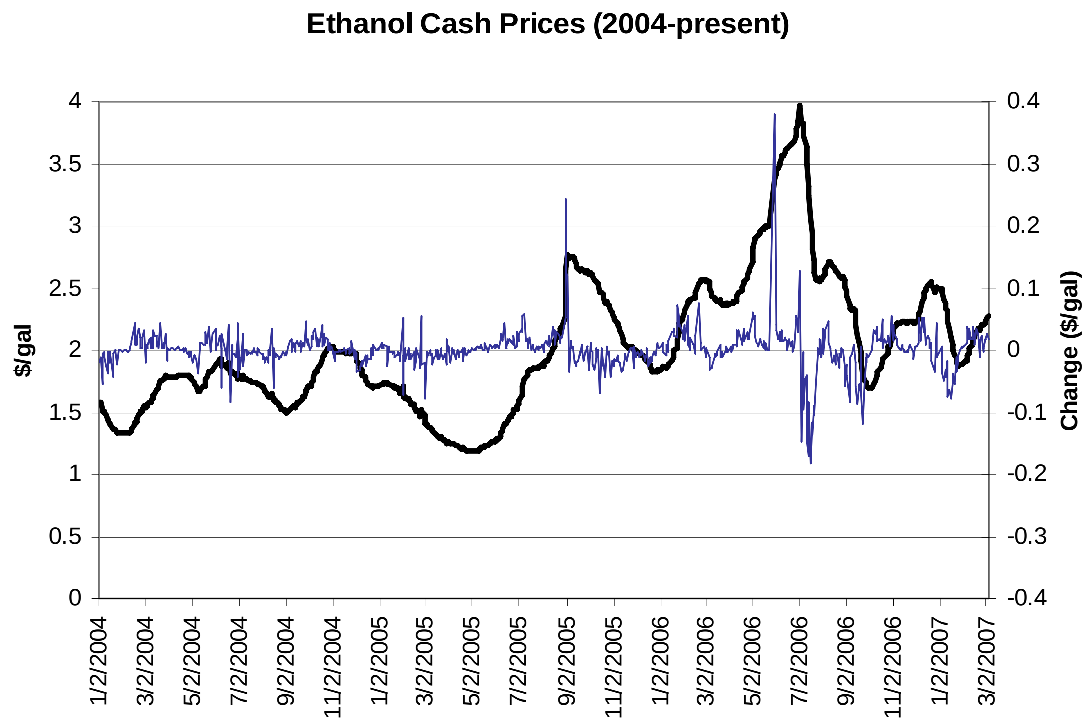

Figure 2. Ethanol cash prices, daily January 2004 through March 2007.

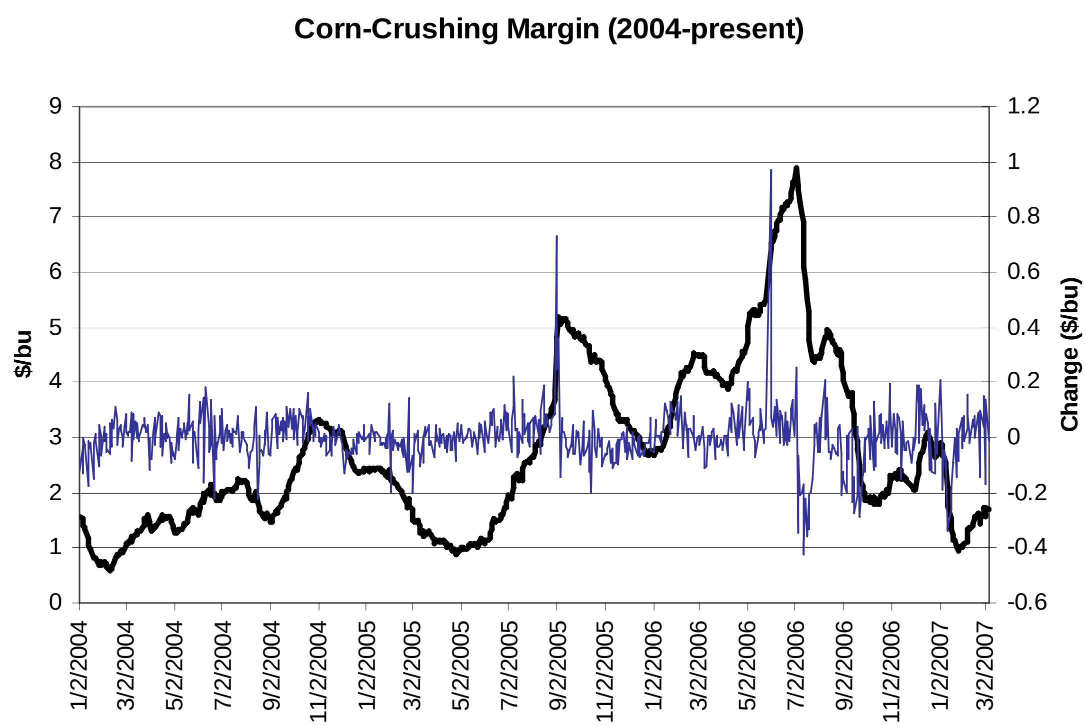

Figure 3. Corn-crushing margin, daily January 2004 through March 2007.

that refiners use 4 billion gallons of ethanol in 2006 (McKay 2006). Close inspection of the daily price changes in figure 2 reveals that they are serially correlated.[5]

The daily corn-crushing margin and its changes are shown in figure 3. The events that influenced the ethanol market are also evident in figure 3. The change in the daily crushing-margin change displays serial correlation.[6]

On March 23, 2005 ethanol futures contracts began trading on the Chicago Board of Trade open auction platform. These prices through March 7, 2007 were obtained from Barchart.com. The CBOT ethanol 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 (A.S.T.M.) 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 2007b). The contract is settled by physical delivery (i.e., not cash settled) or exchange for physicals and trades in a section of the corn pit. 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, 2007b). 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.

Cash and futures prices for corn were obtained from Barchart.com. The pertinent details for corn futures are the maturity months (December, March, May, July, and September), and the last trading day (the business day prior to the 15th calendar day of the contract month). Cash and futures prices for the soybean complex and for gasoline were also obtained from this source. These data were used for hedging-effectiveness comparisons.

The data analyzed were governed by several selection considerations. First, weekly time series were formed by selecting Wednesday prices from the daily series. When Wednesday prices were not available because of holidays or market closures, Tuesday's prices were used. Second, futures prices were represented by the nearby contract settlement price, 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. Third, the maturity months of the corn and ethanol futures contracts were matched for transformation hedging, so that the transformation price risk was free of temporal dimensions. This means that the nearby corn futures maturity controlled the selection of the ethanol contract with a corresponding maturity because ethanol contracts mature in each month but corn contracts mature only in selected months. Rollovers into the next

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5 Fitting the model $\Delta P_{et} = \mu + \varepsilon_t$ where P_{et} represents the cash price of ethanol, μ represents the overall mean price change, and $\varepsilon_t = \rho\, \varepsilon_{t-1} + \nu_t$ to the 493 observations shown in figure 2 results in an estimate of ρ of 0.4296 with a t value of 10.54.

6 Fitting the model $\Delta M_t = \mu + \varepsilon_t$ where M_t represents the cash corn-crushing margin, μ represents the average crushing-margin change, and $\varepsilon_t = \rho\, \varepsilon_{t-1} + \nu_t$ to the 471 observations shown in figure 3 results in an estimate of ρ of 0.4978 with a t value of 12.43.

nearby month are triggered by the last trading day (less one week) which occurs first in ethanol.[7] Contract matching is not an issue for inventory price risk hedging where the nearby ethanol contact is used. Finally, because of contract rollovers, the change in the futures price is defined as the change in the price of the nearby contract at the end of the hedge, not simply the change in the price of the nearby contract as the maturity of the nearby contract may differ between the hedge's beginning and end.

One-, two-, four-, and eight-week hedge horizons were analyzed by differencing the data accordingly. The maximum horizon was selected in light of average plant production of 1,724 29,000-gallon railroad tank cars per year.[8] This average exceeds one 100-car unit train of ethanol per month. If a transaction cycle is used as the hedge horizon, then the average transaction cycle (load out) is less than a month. Eight weeks roughly doubles the average hedge horizon. Beyond eight weeks, the number of non-overlapping observations becomes small.

Results

In light of the two price bubbles during the March 2005 through March 2007 period (figure 2), I sought to determine whether the sample period dictates the inferred characteristics of the data. As a preliminary analysis, recursive two-year samples of one-week differenced ethanol cash prices were analyzed. Specifically 104 observations (two years) were drawn from the weekly data beginning January 2, 2003. The model $\Delta P_{e,t} = \mu + \varepsilon_t$, $\varepsilon_t = \rho\ \varepsilon_{t-1} + \nu_t$ for t = 1,2, … 104 was fit to the data. Then a new two-year sample, which started one week later, was drawn. This process continued until the last observation in the two-year sample was the last observation in the available data. Estimation results revealed that serial correlation was always significant and the estimated mean was never significant. GARCH(p,q) specifications for q = 1, 2 and p = 0, 1, 2 were also fit to the data but no specification consistently fit the data well. Based on these results, the differenced data used in the estimation of inventory and transformation hedge ratios were treated as stationary in the mean and variance though potentially serially correlated.

Direct hedge ratio estimation results are reported in table 2. The top half reports inventory hedge ratios. These results were obtained by fitting $\Delta P_{e,t} = \beta_1\ \Delta F_{e,t} + \varepsilon_t$, $\varepsilon_t = \rho\ \varepsilon_{t-1} + \nu_t$ to the available data (Wednesday to Wednesday changes from the March 23, 2005 through March 7, 2007 time period). We observe the following. First, hedge ratios have the expected sign for all hedge horizons and are significant for all but the one-week hedge while serial correlation is significant for only the one-week hedge. The effectiveness for the one-week hedge is low because serial correlation explains most of the period-to-period change in the cash price of ethanol and little is explained by the change in the futures price of ethanol.[9] For longer hedge horizons, serial

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7 The ethanol contract matures earlier in the month than the corn contract so that, even with matching maturities, a slight temporal mismatch remains.

8 Current plant capacity divided by the number of plants divided by 29,000 gallons per tank car. Current plant capacity and number of plants are provided by Renewable Fuels Association (2007).

9 Serial correlation of prices implies that some portion of a price change can be anticipated due to the serial correlation. As hedging is for protection from unanticipated price changes, the hedging effectiveness should indicate only the portion of the unanticipated price changes that has been removed. Thus, the appropriate measure of hedging effectiveness is the regression R^2, not the total R^2.

Table 2. Direct-hedging estimation results.[a]

Hedge horizon:	1 wk		2 wks		4 wks		8 wks	
Observations	101		50		25		12	
Ethanol inventory hedge model: $\Delta P_{e,t} = \beta\ \Delta F_{e,t} + \varepsilon_t,\ \varepsilon_t = \rho\ \varepsilon_{t-1} + \nu_t$								
$\hat{\beta}$ (std err)	0.031	(0.072)	0.322*	(0.128)	0.913**	(0.139)	0.756**	(0.179)
$\hat{\rho}$ (std err)	0.612**	(0.080)						
RMSE	0.1059		0.2348		0.2265		0.2638	
Regr R^2	0.0020		0.1134*		0.6537**		0.6182**	
Transformation hedge model: $\Delta M_t = \beta_1\ \Delta F_{e,t} + \beta_2\ \Delta F_{c,t} + \varepsilon_t,\ \varepsilon_t = \rho\ \varepsilon_{t-1} + \nu_t$								
$\hat{\beta}_1$ (std err)	0.017	(0.194)	0.633	(0.382)	2.380**	(0.419)	2.263**	(0.550)
$\hat{\beta}_2$ (std err)	-0.590*	(0.225)	-0.830	(0.668)	-1.417*	(0.604)	-1.635*	(0.528)
$\hat{\rho}$ (std err)	0.608**	(0.080)						
RMSE	0.2810		0.6368		0.6605		0.7150	
Regr R^2	0.0658		0.0911		0.6160**		0.6730**	
Other tests:								
One-to-one crush (H_0: β_1=2.6, β_2=-1)								
F value	89.03**		13.62**		0.39		1.27	
Proportional crush (H_0: β_2=-2.6 β_1)								
F value	6.20*		0.70		0.66		2.31	

a/ * indicates significance beyond 5%, ** indicates significance beyond 1%.

correlation is not significant (hence, is not included in the model) and futures price changes are more significant. The hedge ratio and effectiveness generally increase with the hedge horizon. The hedge ratio is significantly different from unity for one- and two-week hedges, indicating that direct (one-to-one) hedging of ethanol for short time horizons exposes refiners to superfluous price risk. The effectiveness of the inventory hedge ranges from 0.02 for a one-week hedge to 0.64 for an eight-week hedge.

The estimated effectiveness statistics are generally lower than those reported by Franken and Parcell (2003) for cross hedges using unleaded gasoline futures.[10] Because anecdotes suggest that gasoline futures are an effective cross-hedging vehicle, and because Parcell and Franken present evidence that this is so, I substituted gasoline futures prices for ethanol futures prices to compare the effectiveness of directly hedging ethanol inventories with the effectiveness of cross hedging ethanol inventories with gasoline futures. The comparison uses identical time periods. Because the unleaded gasoline futures contract has been phased out and the RBOB contract has been phased in, these comparisons are conducted for both the unleaded gasoline and RBOB futures contracts.

Table 3 shows the comparisons. The gasoline cross-hedge ratios (table 3) display the same properties as the risk-minimizing hedge ratios (table 2). Specifically, as the hedge horizon becomes longer, the hedge ratios tend to become larger, and serial correlation in ethanol prices is significant for the one-week horizon. Direct hedging can be compared with cross hedging by comparing the MSE of hedging with ethanol futures with the MSE of hedging with gasoline futures. This comparison indicates that ethanol futures do not perform significantly worse than the corresponding gasoline futures and for a four-week hedge, ethanol futures perform significantly better. Hence, a general conclusion is that the ethanol futures contract outperforms the gasoline futures contract in hedging ethanol inventories.

The recent introduction of the ethanol futures contract invites the question of whether its hedging effectiveness has increased over time. This question is addressed by testing the null hypothesis that ethanol's hedging effectiveness has remained constant over time. The effectiveness measure should incorporate only the information available at time t into the hedging outcome for time t+1. A recursive procedure is used to represent this process. Beginning with the first period after the launch of the ethanol futures contract, the ethanol inventory hedge ratio is computed. The estimated ratio is used to compute profits or losses from a one-period-ahead hedge. The process is repeated by adding a period at the end of the sample, updating the hedge ratio, and computing the profits or losses for the next one-period-ahead hedge. Upon completion of this simulation, two series are available: hedged and unhedged outcomes. A Goldfeld-Quandt-like comparison (1965) of the mean square errors over the first and the last third of the observations in each series will indicate the relative amounts of risk and the reduction due to hedging. The MSE of both the hedged ($MSE(\pi_h)$) and unhedged ($MSE(\pi_u)$) outcomes increased in the last third of the sample (table 4). This increase was significant for the one- and two-week hedges, but not for the four-week hedge. The result is that over time, hedging went from somewhat effective to ineffective for the one-week hedge, went from effective to somewhat effective for the two-week hedge, and was effective for both periods for the four-week hedge. This result is contrary to the notion that generated the hypothesis. The market disruption caused by the switchover from MTBE to ethanol that occurred in June of 2006 greatly influences these results. It is also worth noting that the effectiveness results in table 4 are out-of-sample as opposed to the in-sample effectiveness estimates reported in table 2.

Transformation hedging attempts to “lock in” the current processing margin for future operations. Transformation hedge ratios estimated by regression analysis are reported in the

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

Table 3. Comparisons of direct hedging with cross hedging.[a]

Hedge horizon:	1 wk	2 wks	4 wks	8 wks
Cross hedging in unleaded gasoline: $\Delta P_{e,t} = \beta \Delta F_{hu,t} + \varepsilon_t, \varepsilon_t = \rho \varepsilon_{t-1} + \nu_t$				
$\hat{\beta}$ (std err)	0.113 (0.089)	0.328 (0.138)	0.528 (0.451)	1.395** (0.427)
$\hat{\rho}$ (std err)	0.610** (0.086)			
Observations	87	43	21	10
RMSE[b]	**0.1077**	0.2469	0.3773	0.3063
Regr R^2	0.0187	0.0609	0.0642	0.5427**
Direct hedging in ethanol (same period): $\Delta P_{e,t} = \beta \Delta F_{e,t} + \varepsilon_t, \varepsilon_t = \rho \varepsilon_{t-1} + \nu_t$				
RMSE	0.1087	**0.2427**	**0.2302**	**0.2674**
Regr R^2	0.0003	0.0832	0.6522**	0.6516**
Test for equal variances				
F stat	1.019	1.035	2.686*	1.312
RBOB gasoline cross hedge: $\Delta P_{e,t} = \beta \Delta F_{rb,t} + \varepsilon_t, \varepsilon_t = \rho \varepsilon_{t-1} + \nu_t$				
$\hat{\beta}$ (std err)	0.191 (0.197)	0.641 (0.444)	0.989 (1.826)	0.552 (0.524)
$\hat{\rho}$ (std err)	0.581** (0.126)			
Observations	43	21	10	5
RMSE	**0.1416**	**0.3170**	0.4593	0.3144
Regr R^2	0.0224	0.0944	0.1376	0.2167
Direct hedging in ethanol (same period): $\Delta P_{e,t} = \beta \Delta F_{e,t} + \varepsilon_t, \varepsilon_t = \rho \varepsilon_{t-1} + \nu_t$				
RMSE	0.1431	0.3192	**0.2540**	**0.2380**
Regr R^2	0.0004	0.0817	0.7363	0.5517
Test for equal variances				
F statistic	1.021	1.014	3.270*	1.745

a/ * indicates significance beyond 5%, ** indicates significance beyond 1%.
b/ Bold face indicates the smaller RMSE when direct and cross hedging are compared.

Table 4. Out-of-sample hedging effectiveness.[a]

Hedge horizon	1 wk	2 wks	4 wks
Number of subsample periods	33	17	8
First third of available observations			
Begin	Apr 6, 2005	Apr 13,2005	Apr 27, 2005
End	Nov16, 2005	Nov 23, 2005	Nov 9, 2005
MSE(π_u)	0.00531	0.0281	0.0991
MSE(π_h)	0.00400	0.00953	0.0396
Effectiveness	0.247	0.662	0.600
Last third of available observations			
Begin	Jul 19, 2006	Jul 19, 2006	Aug 16, 2006
End	Feb 28, 2007	Feb 28, 2007	Feb 28, 2007
MSE(π_u)	0.0180	0.112	0.132
MSE(π_h)	0.0182	0.0996	0.0495
Effectiveness	-0.011	0.109	0.620
Equal variance tests			
F statistic - unhedged	3.90**	3.99**	1.33
F statistic - hedged	4.55**	10.45**	1.25

a/ * indicates significance beyond 5%, ** indicates significance beyond 1%.

lower half of table 2. As expected, the estimated coefficients on the futures prices of ethanol and corn are respectively positive and negative indicating respective short and long positions in ethanol and corn futures. As the hedge length increases, the hedge ratios take larger (absolute) values and the hedge's effectiveness increases. Three of the four hedge ratios are insignificant for one- and two-week hedges, while all four are significant for four- and eight-week hedges.

Other test results in table 2 indicate whether the hedge ratios are significantly different from those dictated by a one-to-one crushing hedge or a proportional crushing hedge. As the corn crush margin is 2.6 $P_{e,t}$ - $P_{c,t}$, a test of one-to-one crush hedging is H_0: $\beta_1 = 2.6$, $\beta_2 = -1$. This hypothesis is rejected for one- and two-week horizons, but not for four- and eight-week horizons. This means that direct hedging the processing margin for short time horizons significantly decreases the hedge's effectiveness. This conclusion does not hold for longer horizons.

The notion of a proportional direct hedge is that the hedge ratios are proportional to those of a one-to-one hedge so the null hypothesis is H_0: $\beta_1 = -2.6\ \beta_2$. This hypothesis was rejected for only the one-week horizon.

The similarities between corn and soybean crushing invite comparison as a means to better understand processing hedges. Table 5 facilitates this comparison by showing the hedging effectiveness reported in three different soybean crushing studies. The effectiveness estimates are similar given the hedge horizon and the hedging strategy. Of particular interest is the explicit distinction between inventory hedging and transformation hedging. While no study specifically reports transformation hedging effectiveness, the Dahlgran (2005) study reports effectiveness in a manner such that the increment from adding transformation hedging to inventory hedging can be imputed. This small increment leads to the conclusion that transformation hedging is relatively ineffective in soybean crushing where input and output prices are correlated, while, at least for longer hedges, it is effective in corn crushing where input and output prices are seemingly unrelated. What explains this apparent paradox?

Table 5. Hedging effectiveness from soybean-processing studies.

Author(s)	Hedge horizon	Obs	Study period and hedging effectiveness: In sample	Out of sample
Garcia, Roh, and Leuthold	3-wk	daily (Wed)	1983-1990	1991
Crush spread			0.129	0.432
Multiproduct			0.439-0.468	0.328-0.508
				Recursive
Fackler and McNew	1-mon	monthly avg	1980-92	1985-92
Crush spread			0.702	0.497
Single commodity			0.689	0.508
Proportional crush spread			0.732	0.544
Multiproduct			0.780	0.575
Dahlgran		daily (Wed)	1990-2003	2004
Inv hedge (multiproduct)	1-wk		0.342	0.228
	2-wk		0.550	0.578
	4-wk		0.738	0.824
	13-wk		0.872	0.898
Inv and transform hedge (multiproduct)	1-wk		0.303	0.408
	2-wk		0.487	0.667
	4-wk		0.696	0.861
	13-wk		0.850	0.871

Equation (6a) represents a general method for estimating transformation hedge ratios for commodity processing. If $\mathbf{f}_t$ contains only $f_{x,t}$, the futures price of the input x at time t, and $f_{y,t}$, the futures price of the output y at time t, then hedging effectiveness is

$$(7)\qquad R^2 = \frac{\rho^2_{\Delta M,\Delta f_x} + \rho^2_{\Delta M,\Delta f_y} - 2\rho_{\Delta M,\Delta f_x}\rho_{\Delta M,\Delta f_y}\rho_{\Delta f_x,\Delta f_y}}{1-\rho^2_{\Delta f_x,\Delta f_y}},$$

where $\rho_{x,y}$ is the correlation between x and y, $\rho_{\Delta M,\Delta f_x} = (\gamma\rho_{\Delta p_y,\Delta f_x}\sigma_{\Delta p_y} - \rho_{\Delta p_x,\Delta f_x}\sigma_{\Delta p_x})/\sigma_{\Delta M}$, $\rho_{\Delta M,\Delta f_y} = (\gamma\rho_{\Delta p_y,\Delta f_y}\sigma_{\Delta p_y} - \rho_{\Delta p_x,\Delta f_y}\sigma_{\Delta p_x})/\sigma_{\Delta M}$, and $\sigma_{\Delta M} = \sqrt{\gamma^2\sigma^2_{\Delta p_y} + \sigma^2_{\Delta p_x} - 2\gamma\sigma_{\Delta p_y}\sigma_{\Delta p_x}\rho_{\Delta p_x,\Delta p_x}}$.

Corn crushing transforms one input into one output. To make soybean crushing comparable, let y represent the product from a bushel of soybeans, and let p_y and f_y represent the revenues at the respective cash and futures prices for this product.[11]

Table 6 aids the comparison of transformation hedging effectiveness for corn crushing (0.64) with soybean crushing (0.16) by showing the components of (7). The standard deviation of the

Table 6. Corn- versus soybean-crushing effectiveness, 28-day hedge horizon.

	Soybean crush correlations (std dev \$/bu)				Corn crush correlations (std dev \$/bu)			
	$\Delta p_{soybeans}$	$\Delta p_{soyprods}$	$\Delta f_{soybeans}$	$\Delta f_{soyprods}$	Δp_{corn}	$\Delta p_{ethanol}$	Δf_{corn}	$\Delta f_{ethanol}$
Δp_x	***(0.4457)***				***(0.2122)***			
Δp_y	0.9414	***(0.5069)***			-0.1231	***(0.3830)***		
Δf_x	0.9711	0.9554	***(0.4602)***		0.9546	-0.0965	***(0.2197)***	
Δf_y	0.9632	0.9607	0.9887	***(0.4921)***	-0.0353	0.7844	-0.0239	***(0.3060)***
	Partial derivative of R^2 with respect to each simple correlation							
Δp_y	2.3468				0.2553			
Δf_x	7.3873	-8.4015			0.1091	-0.5118		
Δf_y	-9.0072	10.2441	5.058		-0.3087	1.4486	0.4070	
	Second order partial correlations							
Δp_y	0.1763				-0.1156			
Δf_x	0.4532	0.0147			0.9541	0.0729		
Δf_y	0.0352	0.3571	0.7639		0.0650	0.7866	-0.0370	

[11] A 60-pound bushel of soybeans yields 48 pounds of soymeal and eleven pounds of soybean oil. Define the product as the yield from one bushel so $p_y = 48\ p_m + 11\ p_o$ and $f_y = 48\ f_m + 11\ f_o$ where p_m and f_m represent the per pound cash and futures prices of soymeal and p_o and f_o represent the per pound cash and futures prices of soybean oil. γ in this case is implicitly 1.

corn-crushing margin ($1.04/bu) is six times that of soybean crushing (standard deviation of $0.17/bu), so corn crushing has more room for variance reduction through hedging. However, effectiveness expresses proportional reduction, so we must look further. Inspection of the simple correlations reveals that the hedging vehicles for soybean crushing are more highly correlated than the hedge vehicles for corn crushing. Hence, we might be tempted to focus on the correlation between the futures contracts and conclude hedging vehicles that are highly correlated (for example, soybean futures and soybean product futures have a correlation of 0.99) offer less hedging advantage than hedging vehicles with little apparent price correlation (corn and ethanol futures have a correlation of -0.02). Alternatively, equation (7) offers the chance to examine the partial derivative of R^2 with respect to each of the correlations ($\rho_{\Delta p_x,\Delta p_y}$, $\rho_{\Delta p_x,\Delta f_x}$, $\rho_{\Delta p_x,\Delta f_y}$, $\rho_{\Delta p_y,\Delta f_x}$, $\rho_{\Delta p_y,\Delta f_y}$, and $\rho_{\Delta f_x,\Delta f_y}$) for both soybean and corn crushing. These partial derivatives are shown in the middle of table 6. Note that for both soybean and corn crushing the partial derivative of R^2 with respect to the correlation between the input's cash price and the output's futures price ($\rho_{\Delta p_x,\Delta f_y}$) and with respect to the correlation between the output's cash price and the input's futures price ($\rho_{\Delta p_y,\Delta f_x}$) are both negative. As a result, the transformation hedge is less effective for soybean crushing than for corn crushing as the respective correlations for soybean crushing are both close to 0.96 while for corn crushing they are respectively -0.03 and -0.10. From this we conclude that processing hedges with high correlation between the futures price of the output and the cash price of the input, and vice versa, will be less effective than processes where these correlations are small.

A second insight into process-hedging effectiveness is provided by the second-order partial correlations shown at the bottom of table 6. These partial correlations are the correlation between two variables holding all else constant. The partial correlations between cash and futures prices for the inputs as well as the outputs are higher for corn crushing than for soybean crushing (table 6). From this we conclude that the partial, rather than the simple, correlations are the critical components for determining the effectiveness of processing hedges.

Summary and Conclusions

This study was motivated by the notion that, by its name, corn crushing is comparable to soybean crushing. The *ex ante* expectation was that the input-output price correlations for cash and futures are higher for soybean crushing than for corn crushing so that hedging the soybean crush would be more effective than hedging the corn crush. Analysis of the data confirms the differences in the correlations, yet the corn-crushing hedge is more effective than the soybean-crushing hedge. These apparent contradictions add intrigue to this study.

In this study I analyzed data to determine (1) the effectiveness of direct hedging of ethanol inventories, (2) the effectiveness of cross hedging ethanol inventories with gasoline futures contracts, and (3) the effectiveness of hedging the transformation of corn into ethanol using the corn and ethanol futures contracts. Finally, by comparing the price correlations for soybean crush hedging to those for corn crush hedging, I sought to explain why corn crush hedging is more effective than soybean crush hedging.

The major conclusions reached are that ethanol producers face considerable price risks as recent data clearly show the impacts of Hurricane Katrina and the phase-out of MTBE. The serial correlation of ethanol prices makes hedging for short hedge horizons (one week) ineffective. For longer hedge horizons, (two to eight weeks) the serial correlation disappears and hedging is effective and is more effective the longer the hedge horizon. This finding indicates that ethanol producers and brokers can use the ethanol futures markets to reduce the price risk inherent in holding ethanol inventories.

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 tends to go to direct hedging with ethanol futures. Cross hedging in gasoline futures never showed a significant advantage over direct hedging in ethanol futures and for a four-week hedge horizon, direct hedging in ethanol showed a statistically significant advantage over cross hedging in gasoline futures. This finding indicates that contrary to the anecdotal evidence, ethanol producers and brokers should hedge price risk by using ethanol futures contracts rather than gasoline futures contracts.

Effectiveness patterns for transformation hedging tend to mirror those for direct hedging of ethanol in that crush hedging is ineffective with a one-week hedge horizon. For longer hedge horizons, the effectiveness increases and is significant for four- and eight-week hedges. Using a 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 applied for a proportional crush spread. These findings indicate that the corn crush promoted by the Chicago Board of Trade is an effective technique for locking in current processing margins and that effort devoted to finding the risk-minimizing positions in the ethanol and corn futures markets pays off in risk reduction.

Finally, the corn crush hedge and the soybean crush hedge were compared. Corn-crushing price risk is greater than soybean-crushing price risk. Nonetheless, the corn crush hedge was found to be the more effective of the two indicating that simple correlations are inadequate for predicting the effectiveness of a processing hedge and partial correlations should be used instead. Our analysis also indicates that higher correlations between the input's cash price and the output's futures price and between the input's futures price and the output's cash price lower the effectiveness of a processing hedge. Conversely, when input and output prices are not highly correlated (as in corn to ethanol), then processing price risk can be reduced with carefully selected hedge ratios. Thus, the returns to risk management in corn crushing are greater than in soybean crushing.

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