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Practitioner's Abstract

Interviews with ethanol refinery risk managers reveal that, at least for the firms represented, (a) working capital to fund margin accounts is limited so the optimal deployment of this capital is a major concern, and (b) these firms hedge with smaller positions than those indicated by the traditional price risk minimization theory. In response to those observations, this study examines the relationship between hedge outcome price risk and price risk induced intra hedge cash flow risk. A simulation analysis of a simple long hedge indicates that the sum of hedge outcome risk and intra hedge cash flow risk is minimized at hedging levels well below the levels that minimize only the hedge outcome risk. The model is generalized to apply to a commodity processor using ethanol refining as a specific example. While the preliminary results are promising, data deficiencies prevent pursuing the analysis to its logical completion. Steps for extending this study using higher quality data are proposed.

Keywords: hedging, liquidity, margin accounts, margin calls, cash flow risk, corn crushing, ethanol refining.

Introduction

Ethanol refinery risk managers were interviewed during the past year in an attempt to better understand hedging motivations and risk management practices in the ethanol industry. Specific questions addressed hedge horizons, hedge ratio determination, accountability and reporting of hedging outcomes, and the availability of capital to fund margin accounts. These interviews revealed (a) the managers use a six to nine month hedge horizon, (b) direct (*i.e.*, one-to-one) hedging was used and risk minimizing hedge ratios were not considered, (c) the risk managers typically report quarterly to upper management on hedging results, (d) some input purchases / output sales are deliberately left unhedged to allow participation in possible beneficial spot price alignments, and (e) working capital to fund margin accounts is limited and the optimal deployment of this capital in dynamic context is a major concern. These insights may be applicable to other processing sectors as well.

These stylized "facts" are at odds with the typical hedging formulation that assumes unconstrained capital availability which implies that the margin requirements of ongoing hedges can be ignored. This leaves the minimization of price risk in the hedge's final outcome as the sole hedging objective in the typical hedging formulation.

Consideration of capital requirements for hedge maintenance is of particular interest in light of the liquidity crisis of late 2008 and its lingering effects. Credit markets were referred to as "frozen" during the early stages of this crisis. Frozen credit markets implies that credit was unobtainable and while conditions have eased somewhat, credit availability continues to be a major concern for U.S. policy makers. Funds to cover losses from ongoing hedging may be difficult to obtain in such an environment. In extremely tight credit scenarios, hedging positions may have to be abandoned due to inadequate capitalization. Even without a liquidity crisis, the attainment of adequate working capital by a firm in a growing industry such as ethanol refining is typically a concern. When constrained, working capital must be allocated among many uses including the funding of margin accounts versus plant expansion and improvement, and within the hedging program, among the margin accounts for different types of futures contracts (i.e., corn versus ethanol). Finally, the ethanol blending tax credit may be a casualty in the debate over federal government expenditures. The potential elimination of this program will make credit more difficult to obtain as banks become hesitant to lend in the ethanol processing sector. Should the blending tax credit be eliminated, the reduction in ethanol refining profitability will result in reduced capital for all uses in the sector.

This study seeks to determine the relationship between hedge outcomes and intrahedge cash flows. Our starting point is that hedging studies typically seek to minimize the risk of the hedge's net result (i.e., the hedge outcome). In contrast, this study will also consider the potential margin calls required to maintain the hedge. When futures positions are taken to initiate a hedge, the timing and size of the resulting potential margin calls is unknown. Precautionary balances of cash or near cash assets must be maintained to meet these potential margin calls. The existence of the unknown amount and timing of potential margin calls constitutes risk while the maintenance of marginable asset balances to meet potential margin calls incurs a cost. The firm's pursuit of ethanol refining indicates a higher long run return on investment in ethanol refining than in investment in financial assets that can be used to satisfy margin calls.

The problem can be stated alternatively. Hedging allows a producer to reduce the risk of a transaction's final outcome but increases the risk of cash needs required to arrive at the final outcome. Just as hedging swaps basis risk for price risk, it also swaps intermediate liquidity risk for outcome risk. This paper examines these tradeoffs.

We proceed as follows. First we establish notation to allow consideration of the related literature. Second, we construct an empirical model that allows an examination of the tradeoff between outcome and liquidity risk for a long hedge. Next we generalize this model so that it can represent a processing hedge. The model's parameters are estimated and the implications of the estimates are discussed. Finally, extensions of this work are discussed.

Literature Review

Johnson (1960) and Stein (1961) use a portfolio approach to provide hedging's theoretical foundation. Their approach assumes an agent has a spot position of x_s units ($x_s > 0$ if long, $x_s < 0$ if short) and can take a futures position of x_f units to hedge the spot position. s_t represents a commodity's spot price and f_{Mt} represents a commodity's M-maturity futures price. A hedge placed at time 0 and removed at time 1 will generate a profit of

(1a) $$\Pi = x_s (s_1 - s_0) + x_f (f_{M1} - f_{M0})$$

The agent is assumed to either minimize $V(\Pi)$ or maximize utility where $U[E(\Pi), V(\Pi)]$. Optimization results in the risk minimizing hedge ratio, η^*, where $\eta^* = Cov(\Delta s, \Delta f)/Var(\Delta f)$ and the risk minimizing hedge $x_f^* = - \eta^* x_s$. η^* is estimated as the regression parameter η_1 in

(1b) $\Delta s_t = \eta_0 + \eta_1 \Delta f_{Tt} + \varepsilon_t$

Anderson and Danthine (1980, 1981) generalized this approach to accommodate multi-contract hedging (1980) and cross hedging (1981). The optimal hedging strategy depends on the hedging horizon (length of Δ), and the deliverable commodities and maturities (M) as defined by the futures contracts considered as hedging vehicles.

The hedge's outcome is judged by its effectiveness, defined as the proportionate reduction in the $V(\Pi)$ due to hedging (Ederington, 1979). Effectiveness is estimated empirically by the R^2 of the regression in (1b).

Recent work has focused on time varying (as opposed to constant) hedge ratios. Several studies suggest that the simplest hedging models such as the constant-hedge ratio models proposed by Johnson, Stein, and Anderson and Danthine work best. Garcia, Roh and Leuthold (1995) find that time-varying hedge ratios "provide minimal gain to hedging in terms of mean return and reduction in variance over a constant conditional procedure." Collins (2000) reports that multivariate hedging models offer no statistically significant improvement over "naive equal and opposite hedges."

In the processing sector both the time and product-form price dimensions are potentially hedgeable. Processing hedges have been studied in the context of the soybean sector because of the sector's importance, the existence of futures contracts for both inputs and outputs, and the availability of long price histories (Tzang and Leuthold 1990; Fackler and McNew 1993). Cottonseed crushing hedges have also been studied in a cross hedging framework (Dahlgran, 2000; Rahman, Turner, and Costa, 2001). More recently, processing hedges have been applied and analyzed in the corn-based ethanol refining (a.k.a. corn crushing) sector (Dahlgran, 2009; Franken and Parcell, 2003). These studies generally find that the ethanol futures contract provides acceptable levels of hedging effectiveness despite the limited ethanol futures trading volume compared to that in the soybean sector. None of these studies have considered the variation margin risk associated with hedging.

Empirical Model

We start by defining the end of day t margin account balance (M_t) as

(2) $M_t = M_{t-1} + x_f \Delta f_{Mt} + D_t - W_t$

where D_t represents the margin deposit required on day t and W_t represents permissible margin account withdrawals on day t.[1] The required deposits and permissible withdrawals are determined by the account's level at the completion of trading session relative to initial and maintenance margin thresholds established by the exchange clearing house.

For our purposes, we define the initial and maintenance margin thresholds in terms standard deviations of futures prices changes. This definition reflects the assumption that these thresholds

[1] x_f and Δf_{Mt} are as defined earlier.

are set so that the probability that the session's price change depletes the margin account is acceptably low. For example, suppose that daily futures price changes follow a unit normal process [i.e., N(0,1)] and we want to ensure that the probability that the margin account will be depleted by a day's price changes is less than 0.001. Thus, we set k such that
$\Pr\{ Z < -k \} = 0.001$, so k = 3.09 standard deviations.

The hedger's initial (M_0) and maintenance (M_m) margin requirements are

(3a) $M_0 = | x_f | k_0 \sigma_{\Delta f}$

(3b) $M_m = | x_f | k_m \sigma_{\Delta f}$

where $k_m \leq k_0$. and these values are set by the exchange clearinghouse in accordance with the probabilities of margin account depletion. More precisely, $k_0 - k_m$ determines the probability that a margin account funded at the initial level will experience a margin call at the end of the trading session, and k_m determines the probability that a margin account funded at the maintenance level will be depleted at the end of a trading session.

Margin deposits and withdrawals are determined by margin account balances in relation to initial and maintenance levels. Required margin deposits are defined as

(4a) $D_t = M_0 - (M_{t-1} + x_f \Delta f_{Tt})$ if $M_{t-1} + x_f \Delta f_{Tt} < M_m$, 0 otherwise,

while permissible margin account withdrawals are

(4b) $W_t = M_{t-1} + x_f \Delta f_{Tt} - M_0$ if $M_{t-1} + x_f \Delta f_{Tt} > M_0$, 0 otherwise.

M_0 is known so the hedge's uncertain cash flows are

(4c) $W_t - D_t = (M_{t-1} + x_f \Delta f_{Tt} - M_0) [\delta(M_{t-1} + x_f \Delta f_{Tt} > M_0) + \delta(M_{t-1} + x_f \Delta f_{Tt} < M_m)]$

where δ indicates logic conditions returning 1 if true and 0 if false.

Figure 1a demonstrates the features of a long hedge's random cash flow ($W_t - D_t$). Δf_{Mt} is the random variable that determines the daily variation margin requirements so its distribution is shown. If the daily price change is negative and large enough to cause the margin account to fall below the maintenance level (i.e., $\Delta f_{Tt} < [M_m - M_{t-1}] / x_f$), then variation margin is required to bring the margin account back up to its initial level ($M_{t-1} + x_f \Delta f_{Tt} - M_0$). If the daily price change is positive and large enough to cause the margin account balance to exceed its initial margin balance, (i.e., $\Delta f_{Tt} > [M_0 - M_{t-1}] / x_f$), then the hedger can remove margin from the account, taking it back down to its initial level. If the daily price change is such that that the margin account balance remains between the initial and the maintenance levels, then the hedge neither faces a margin call nor can funds be removed from the margin account. These rules result in the discontinuous function indicated by thick lines in figure 1a.

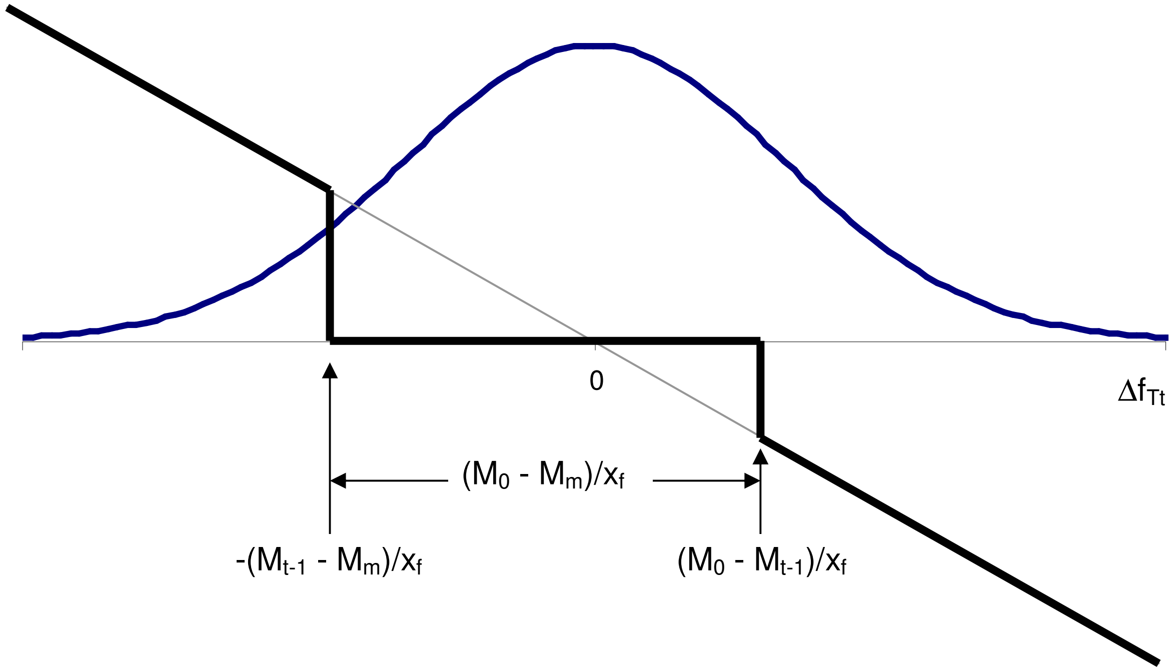

Figure 1a. Variation Margin Requirements under Long Hedging, $M_0 > M_m$..

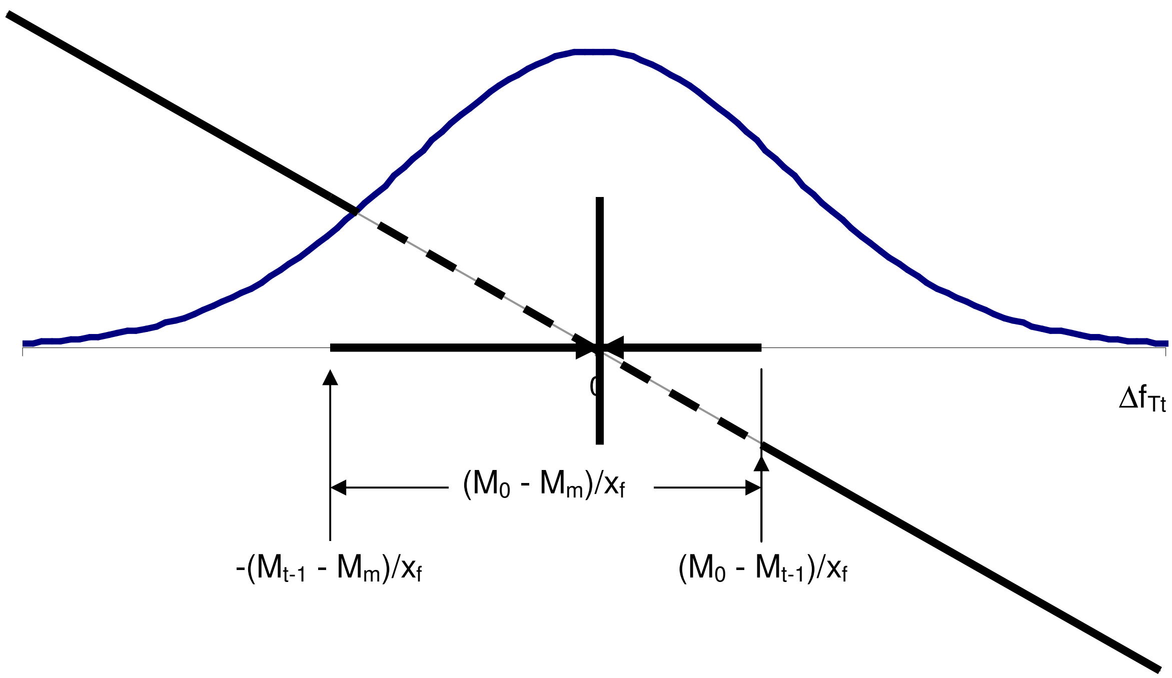

Figure 1b. Variation Margin Requirements under Long Hedging, $M_0 = M_m$..

Figure 1b demonstrates that when the initial and maintenance margin requirements are identical, the discontinuity in figure 1a vanishes and the hedge's daily cash flows are equivalent to the daily futures price changes time the hedge position size. The variance of cash flows under the assumptions of figure 1b is x_f^2 Var(Δf_{MT}). The variance of cash flow subject to the discontinuity depicted in figure 1a is more complex because of the discontinuity. We will use simulation to estimate cash flow risk in the presence of the discontinuity created by margin account rules.

Continual back substitution for M_{t-1} in (2) gives

(5a) $$M_T = M_0 - \sum_{t=1}^{T}(W_t - D_t) + \sum_{t=1}^{T} x_f \Delta f_{Tt}\text{ , or}$$

(5b) $$\sum_{t=1}^{T}(W_t - D_t) + M_T - M_0 = x_f \sum_{t=1}^{T} \Delta f_{Tt}$$

Hedging studies typically focus on aggregate hedging gains and losses (the sum on the right-hand side of 5b) and how well they offset gains and losses on the spot market position. Our interest lies in the incremental generation of those gains and losses and the flow of investible funds over the life of the hedge (i.e., the hedge's cash flows) as well as the final outcome for hedged and unhedged positions. The hedge's outcome depends on two points on the paths taken by spot and futures prices over the life of the hedge while the hedges cash flows depends on the entire path taken by the futures price.

The commodity's spot and futures price paths are represented with a vector error correction (VEC) process (Enders, 1995). This model was selected because futures prices generally display a unit root processes while the forces of arbitrage create a long run equilibrium relationship between spot and futures prices. Our model selection also offers the benefit of integrating models used to study market efficiency with hedging analysis.

A p-order n-variable VEC model derives from the vector autoregressive model

(6) $$x_t = A_0 + A_1 x_{t-1} + A_2 x_{t-2} + \ldots + A_p x_{t-p} + \varepsilon_t$$

where x_t is the $(n \times 1)$ vector $(x_{1t}, x_{2t}, \ldots, x_{nt})'$, and ε_t is an independently and identically distributed $(n \times 1)$ vector of random variables with zero mean and variance matrix Σ_ε. If x_t contains unit roots, then the model is more appropriately expressed as

(6b) $$\Delta x_t = \pi_0 + \sum_{i=1}^{p-1} \pi_i \Delta x_{t-i} + \pi x_{t-p} + \varepsilon_t$$

where $\pi_0 = A_0$, $\pi_i = -(I - \sum_{j=1}^{i} A_j)$, and $\pi = -(I - \sum_{j=1}^{p} A_j)$. An equivalent expression is

(6c) $$\Delta x_t = \pi_0^* + \pi^* x_{t-1} + \sum_{i=1}^{p-1} \pi_i^* \Delta x_{t-i} + +\varepsilon_t$$

where $\pi_0^* = \pi_0 = A_0$, $\pi^* = \pi = -(I - \sum_{j=1}^{p} A_j)$, and $\pi_i^* = -\sum_{j=i+1}^{p} A_j = \pi_i - \pi$.

Analysis

We perform two analyses with this model. First, to determine the order of magnitude of liquidity risk, we simulate a simple long hedge. This simulation will indicate the key parameters that influence liquidity risk levels. Our second analysis generalizes the model to a commodity processor with a specific application to an ethanol refiner. In this second analysis, we will estimate the applicable ethanol processing parameters.

Long Hedging Simulation

To understand the model's implications, we use a first order (p = 1) vector error correction model, $\Delta x_t = \pi\, x_{t-1} + \varepsilon_t$, where x_t contains a commodity's spot price (s_t) and a M-maturity futures contract price (f_{Mt}). The long run equilibrium (cointegrating) relationship between the spot and futures prices is simply $s_t = f_{Mt}$. We further assume that the spot price adjustment coefficient in response to equilibrium error is 0.5, while the futures market is efficient so that today's equilibrium error is of no value in predicting tomorrow's futures price change. Finally, we assume that each of the errors ($\varepsilon_{i,t}$) has a unit variance and that the correlation between the errors is 0.3. These assumptions result in the VEC specification

$$\begin{bmatrix}\Delta s_t \\ \Delta f_{M,t}\end{bmatrix} = \begin{bmatrix}\alpha_s \\ \alpha_f\end{bmatrix}\begin{bmatrix}1 & -1\end{bmatrix}\begin{bmatrix}s_{t-1} \\ f_{M,t-1}\end{bmatrix} + \begin{bmatrix}\varepsilon_{s,t} \\ \varepsilon_{f,t}\end{bmatrix}, \text{ or}$$

(7)

$$\begin{bmatrix}\Delta s_t \\ \Delta f_{M,t}\end{bmatrix} = \begin{bmatrix}-0.5 & 0.5 \\ 0 & 0\end{bmatrix}\begin{bmatrix}s_{t-1} \\ f_{M,t-1}\end{bmatrix} + \begin{bmatrix}\varepsilon_{s,t} \\ \varepsilon_{f,t}\end{bmatrix}, \quad V(\varepsilon_t) = \begin{bmatrix}1 & 0.3 \\ 0.3 & 1\end{bmatrix}$$

We use random draws for ε_t for t = 1,2, … 40 to simulate Δs_t and Δf_{Mt} in (7) over the life of a 40 day long hedge. The series of price changes is then used to simulate the daily margin account balance in (2) and the daily variation margin requirements and withdrawals in (4c) over the life of the hedge assuming a given hedge ratio. Each hedge is replicated 10,000 times for a given hedge ratio. Hedge ratios from 0 to 1.2 by 0.1 are evaluated.

We first assume identical initial and maintenance margin requirements as depicted in figure 1b. We do this because when $M_0 = M_m$, the discontinuity in $D_t - W_t$ disappears (figure 1a becomes figure1b) and $V(D_t - W_t) = V(\Delta f_{Mt})$ is easily derived from Σ_ε.[2] These results are

(8a) $E(x_t \mid x_{t-1}) = A_0 + A_1\, x_{t-1}$ $\qquad V(x_t \mid x_{t-1}) = \Sigma_e$

(8b) $E(x_t \mid x_0) = (\sum_{j=0}^{t-1}\mathbf{A}_1^j)\mathbf{A}_0 + \mathbf{A}_1^t\mathbf{x}_0$ $\qquad V(x_t \mid x_0) = \sum_{j=0}^{t}\mathbf{A}_1^j\Sigma_{\boldsymbol{\varepsilon}}(\mathbf{A}_1^j)'$

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2 Expectations of x_t given x_0 require the following. Starting with a first order vector autoregressive model, $x_t = A_0 + A_1\, x_{t-1} + \varepsilon_t$ and substituting iteratively, (i.e., $x_{t-1} = A_0 + A_1\, x_{t-2} + \varepsilon_{t-1}$, $x_{t-2} = A_0 + A_1\, x_{t-3} + \varepsilon_{t-2}$, …) we find $x_t = (\sum_{j=0}^{t-1}\mathbf{A}_1^j)\mathbf{A}_0 + \mathbf{A}_1^t\mathbf{x}_0 + \sum_{j=0}^{t}\mathbf{A}_1^j\boldsymbol{\varepsilon}_{t-j}$.

(8c) $E(\Delta x_t \mid x_{t-1}) = (A_1 - I)\, x_{t-1}$ $V(\Delta x_t \mid x_{t-1}) = \Sigma_e$

(8d) $E(x_t - x_0 \mid x_0) = (\sum_{j=0}^{t-1} \mathbf{A}_1^j)\mathbf{A}_0 + (\mathbf{A}_1^t - \mathrm{I})\mathbf{x}_0$ $V(x_t - x_0 \mid x_0) = \sum_{j=0}^{t} \mathbf{A}_1^j \Sigma_{\boldsymbol{\varepsilon}} (\mathbf{A}_1^j)'$

The simulation outcomes are compared to these results to verify each method.

The results of our simulations are show in figures 2a and 2b. A visual comparison of the simulated results (indicated by symbols) with the theoretical values (indicated by lines) is shown in figure 2a. This figure indicates that a simulation of 10,000 repetitions for each hedge ratio value accurately portrays the value of the underlying parameters expressed in (8a) through (8d). Furthermore, this figure indicates that a hedge ratio near 1 minimizes the variance of the hedge outcome but the futures positions associated with the unit hedge ratio create substantial cash flow risk. The minimum of the combined cash flow risk and hedge outcome risk occurs at a hedge ratio of about 0.5.

The simulations depicted in figure 2a assumed identical initial and maintenance margins. In practice, maintenance margin levels are well below initial margin levels. Figure 2b depicts this. Figure 2b shows the theoretical values of the hedge outcome variance and cash flow variance (solid lines) as derived and shown in figure 2a. The variance of hedge outcomes does not depend on margin requirements so it is invariant to assumed margin requirements. Cash flow risk however does depend on the size of the gap between the initial and maintenance margin levels (figures 1a versus 1b). Figure 2b shows cash flow variance when the maintenance margin level is two standard deviations below the initial margin level (indicated by X) and five standard deviations below the initial margin level (indicated by dots). This figure demonstrates that even when the gap between initial margin and maintenance margin is a sizeable five standard deviations of price, the cash flow risk is substantial relative to hedge outcome risk. Figure 2b also shows (square markers) combined outcome and cash flow risk when $k_0 - k_m = 5$. While the combined risk is minimized at a higher hedge ratio than when initial and maintenance margin levels are identical, this minimum is still substantially below the risk minimizing hedge ratio that considers only the hedge outcome. These findings lead us to the conclusion that the sole focus in traditional hedging analysis on the hedge outcome provides only a partial explanation of hedger's behavior.

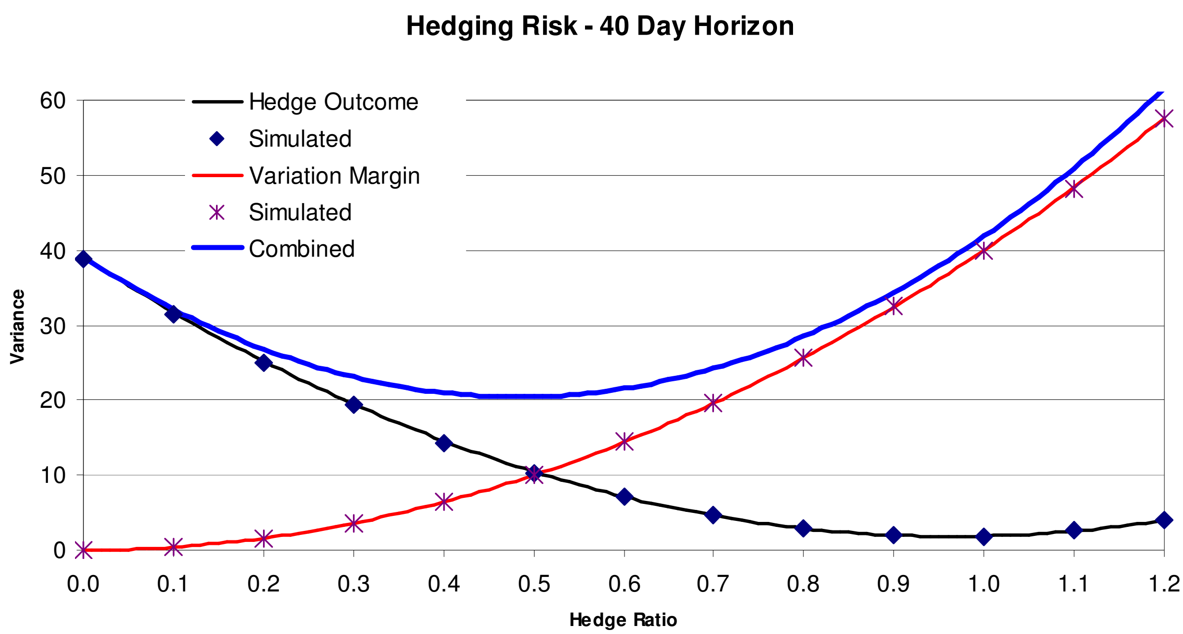

Figure 2a. Simulation results: identical initial and maintenance margin requirements.

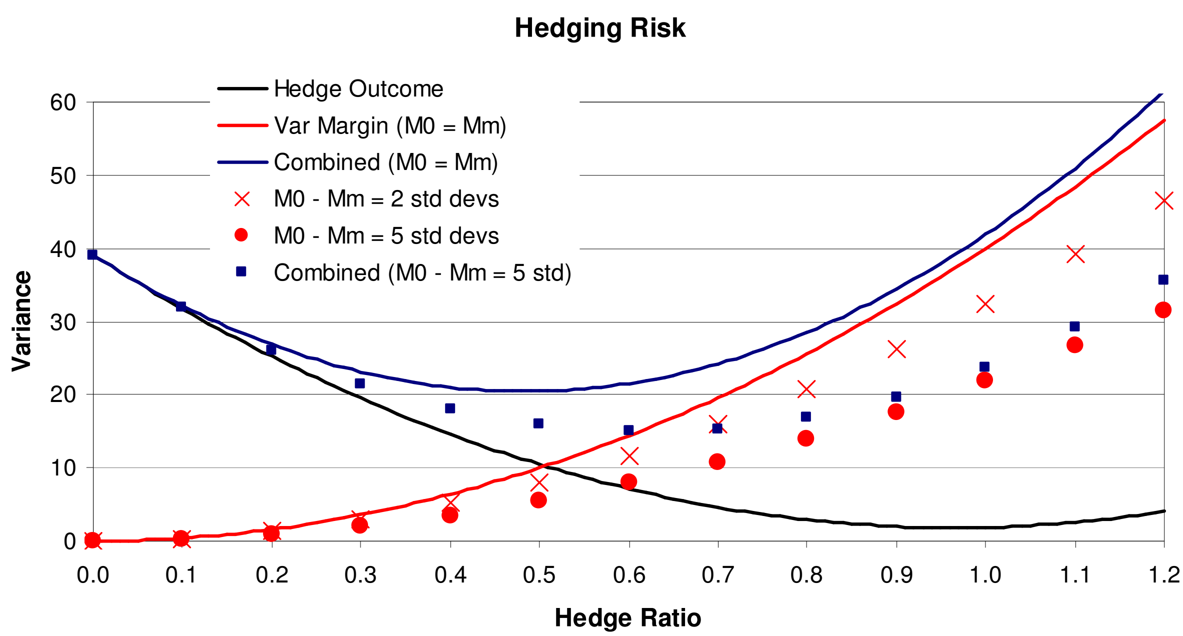

Figure 2b. Simulation results: initial margin greater than maintenance margin.

Processing Hedges

The previous simulation was useful for understanding the relative magnitude of cash flow risk and it provided an analytical framework for a simple long (or short) hedge. We now generalize that framework to apply to a commodity processor. An ethanol refiner will be used as an example.

We continue using the vector error correction model to represent prices behavior. However, the price behavior model must be expanded as a processor faces price risk in the cash markets for inputs as well as outputs and so uses futures markets in an attempt to hedge those price risks. We assume that the futures and cash markets for the inputs as well as the outputs are integrated because of temporal arbitrage forces. This temporal arbitrage is reflected by the basis relationship in the input market and by the basis relationship in the output market. In ethanol refining these basis relationships are for corn and ethanol, respectively,

(9a) Corn basis: $s_{xt} - f_{xT,t} = a_x + b_x [T(M_x) - t]$, or

(9b) Ethanol basis: $s_{yt} - f_{yT,t} = a_y + b_y [T(M_y) - t]$.

Spot and futures price are assumed to adjust to the basis errors, which are defined as

(10a) Corn basis error: $e_{xt} = s_{xt} - f_{xT,t} - a_x - b_x [T(M_x) - t]$

(10b) Ethanol basis error: $e_{yt} = s_{yt} - f_{yT,t} - a_y - b_y [T(M_y) - t]$.

Inputs and outputs are also integrated by product form arbitrage. Inputs are transformed into outputs as represented by the production function

(11) $y_t=2.7 x_t$

where y_t is gallons of ethanol produced and x_t is bushels of corn processed. This crushing relationship is implicit in the crushing margin offered by the spot and futures markets where

(12a) Spot crush margin ($/bu): $m_{st} = y_t s_{yt} - x_t s_{xt} = 2.7 s_{yt} - s_{xt}$

(12b) Futures crush margin ($/bu) $m_{ft} = 2.7 f_{yTt} - f_{xTt}$.

The errors in these relationships entr our pricing model so they are defined as

(12c) Spot crush margin error $w_{st} = 2.7 s_{yt} - s_{xt} - \overline{m}_{st}$.

(12d) Futures crush margin $w_{ft} = 2.7 f_{yTt} - f_{xTt} - \overline{m}_{ft}$.

where $\overline{m}_{st}$ and $\overline{m}_{ft}$ represent the average crushing margin.

These relationships are combined to form the vector error correction model

(13a) Corn cash: $\Delta s_{xt} = \beta_{sx}\, e_{x,t-1} + \gamma_{sx}\, w_{s,t-1} + \zeta_{sxt}$

(13b) Corn futures: $\Delta f_{xT,t} = \beta_{fx}\, e_{x,t-1} + \gamma_{fx}\, w_{f,t-1} + \zeta_{fxt}$

(13c) Ethanol cash: $\Delta s_{yt} = \beta_{sy}\, e_{y,t-1} + \gamma_{sy}\, w_{s,t-1} + \zeta_{syt}$

(13d) Ethanol futures: $\Delta f_{yT,t} = \beta_{fy}\, e_{y,t-1} + \gamma_{fy}\, w_{f,t-1} + \zeta_{fyt}$

This model was estimated using daily cash and futures market data from March 25, 2005 through December 31, 2010. Futures contracts were restricted to include only those maturing within 270 days of the date of observation in accordance with the interviews with the ethanol refinery risk managers.

The model was estimated in two steps. First, regressions were estimated and the equilibrium errors were estimated from these regressions. In a general form, the regressions estimated in this first step were

(14a) Corn basis: $s_{xt} - f_{xM,t} = a_x\, [D(M), D(t)\,] + b_x\, (T(M) - t\,) + \varepsilon_{xt}$.

(14b) Ethanol basis: $s_{yt} - f_{yM,t} = a_y\, [D(M), D(t)\,] + b_y\, (T(M) - t\,) + \varepsilon_{yt}$..

(14c) Spot crush margin: $2.7\, s_{yt} - s_{xt} = a_s\, [\, D(t)\,] + \varpi_{st}$..

(14d) Futures crush margin: $2.7\, f_{yMt} - f_{xMt} = a_f\, [\, D(M), D(t)\,] + \varpi_{ft}$

where D(M) represents a set of dummy variables for contract maturities. These dummy variables are constructed with individual dummies for the year of M, the month of M, and the interaction between year and month. Similarly, D(t) represents a set of dummy variable for the observation's time with individual effects for the year of t, the month of t, and the interaction between year and month. T(M) - t represents days to maturity as T(M) converts the contract's maturity year and month to the indexing sequence that represents t.

The results of fitting (14a) through (14d) are shown in table 1. These results indicate that the models provide a statistically significant fit of the data with R^2s ranging from 0.778 to 0.975. Each set of individual dummy variables is also statistically significant as is the days to maturity in the basis relationships.

We use the fitted values of the regressions reported in table 1 to derive the fitted errors for each regression. These errors are then used to estimate the vector error correction model.

On each day (t) several futures contract prices are quoted so several bases and futures processing margins are available. The vector error correction structure assumes only one futures price change and only one set of equilibrium errors can influences this price change. The contract maturity selected (M) was the nearest contract with 182 days or more to maturity. Futures price

Table 1. Regression results for corn - ethanol integrating relationships.

		Corn basis cts/bu	Ethanol basis $/gal	Cash Crush $/gal	Futures Crush $/gal
N		7,755	13,226	1,017	6,978
R-sq		0.804	0.778	0.864	0.975
MSE		144.40	0.006972	0.061255	0.03943
DFE		7,636	13,094	968	6,867
Regression Effects		Pr > F (df)	Pr > F (df)	Pr > F (df)	Pr > F (df)
Time(t)	Yr(t)	<0.0001 (5)	<0.0001 (4)	<0.0001 (4)	<0.0001 (5)
	Mo(t)	<0.0001(11)	<0.0001(11)	<0.0001(11)	<0.0001(11)
	Mo(t)*Yr(t)	<0.0001(55)	<0.0001(33)	<0.0001(33)	<0.0001(53)
Mat(M)	Yr(M)	<0.0001 (9)	<0.0001 (6)		<0.0001 (8)
	Mo(M)	<0.0001 (4)	<0.0001(11)		<0.0001 (4)
	Mo(M)*Yr(M)	<0.0001(33)	<0.0001(65)		<0.0001(29)
Days to maturity		<0.0001 (1)	<0.0001 (1)		

changes were for that maturity (M).[3] Likewise all lagged basis errors are for that maturity corresponding to the maturity selected for the futures price change. This selection procedure resulted in 764 usable observations.

In the second step of the model estimation procedure, the selected price changes and selected estimated equilibrium errors were combined to estimate the vector error correction model in (13a) through (13d). The results, reported in table 2, indicate the following: First, none of the intercepts are significantly different from zero meaning that none of the series displays a significant drift. Second, neither the basis error nor the spot market processing margin error significantly influences the corn futures market. This result is consistent with corn futures market efficiency because neither the basis error nor the cash processing margin error is useful in predicting changes in corn futures prices. Third, the cash corn price adjusts to errors in the cash market processing margin. Likewise, the cash price of ethanol responds to ethanol basis errors. Both of these effects are significant indicating that long run price adjustment occurs only in the cash markets and extends beyond the current market period. The result of this long run adjustment is that short run hedge ratios will differ from long run hedge ratios as reported by Dahlgran (2009). Finally, while the lack of significance in the corn futures price equation suggests corn futures market efficiency, the presence of significant effects in the ethanol futures price equation indicates inefficiency in the ethanol futures market as errors in the previous period's futures market processing margin can be used to predict changes in the price of the ethanol futures contract.

[3] In other words, futures price changes were always computed across time but never across contract maturities.

Table 2. Vector error correction regression results for corn crush hedging.

Model		Estimated equation			Equation MSE
Corn cash (cts/bu):	Δs_{xt} =	0.121 (0.320)	- 0.029 $e_{x,t-1}$ (0.028)	+ 1.696 ** $w_{s,t-1}$ (0.536)	73.98
Corn futures (cts/bu):	$\Delta f_{xM,t}$ =	-0.141 (0.310)	+ 0.026 $e_{x,t-1}$ (0.026)	+ 1.723 $w_{f,t-1}$, (1.068)	69.77
Eth cash ($/gal):	Δs_{yt} =	-0.001 (0.001)	- 0.102 *** $e_{y,t-1}$ (0.024)	- 0.005 $v_{s,t-1}$ (0.008)	0.000746
Eth futures ($/gal):	$\Delta f_{yM,t}$ =	-0.000 (0.001)	+ 0.003 $e_{y,t-1}$ (0.009)	- 0.043 *** $w_{f,t-1}$ (0.007)	0.000783

Contemporaneous correlation matrix

	Δs_x Spot corn	Δf_x Fut corn	Δs_y Spot ethanol	Δf_y Fut ethanol
Δs_x Spot Corn (cts/bu)	1.000	0.931	0.051	0.161
Δf_x Futures Corn (cts/bu)		1.000	0.050	0.706
Δs_y Spot Ethanol ($/gal)			1.000	0.120
Δf_y Futures Ethanol ($/gal)				1.000

System weighted R^2: 0.053

Table 2 also reports the contemporaneous correlation matrix. The largest correlation, is as expected, between the random shocks to the corn cash price equation and the random shocks to the corn futures price equation (0.931). The correlation between the ethanol cash and futures price equations is much lower (0.120). The correlation between the random shock to the corn futures price and the ethanol futures price is surprisingly large (0.706).

Closer inspection of the data reveals that the ethanol spot prices display no intra week variation. Further analysis based on these weak data will not be meaningful as data deficiencies will generate suspect results. Further work will incorporate improved data. The analysis will then proceed as follows. Spot and futures processing margins will be recomputed using the revised ethanol spot price series. Distillers dried grains will be included as an additional output from ethanol refining. The integrating relationships in (9a), (9b), (12a) and (12b) will be re-estimated along with the model in (14a) though (14d). Our current results indicate the likely usefulness of this price behavior model and better data will only add to this. The parameter estimates will be used to simulate the cash flow and hedge outcome risks for ethanol refiners. These results will be summarized in a manner similar to that shown in figure 1b. Finally, the methodology for finding the overall risk minimizing hedge ratio will be derived.

Summary and Conclusions

The testable null hypothesis of this study was that the cash flow risk implicit in hedging can be disregarded because its magnitude is negligible or its cost is immaterial. This notion is refuted based on interviews with ethanol refinery risk managers and based on the behavior of cash flow variance under typical assumptions in a simple long hedge. We found that even when the maintenance margin level is well below the initial margin level, the variation in the cash flows attributable to a simple hedge were considerable and comparable in magnitude to the variance of the unhedged outcome.

The approach used for simulating the long hedge was generalized to represent a processing hedge. Despite problems with the data used, we found that the vector error correction specification was a useful representation of the price generating process for hedging analysis. This finding is important in several respects. First, this model bridges the gap between market efficiency studies where the cointegration model is frequently employed and hedging studies which typically rely ordinary least squares (equation 1b) or seemingly unrelated regression analyses. Second, this model incorporates the multiple basis and crushing relationships which a commodity processor considers in implementing a hedging plan. Third, it allows the ratio to depend on the hedge horizon even when futures markets are efficient. Lags in spot price adjustment account for this hedge ratio elasticity. Finally, this model generalizes the analytical solution for hedge ratios in the traditional portfolio approach to hedging. This solution still depends on the covariance between cash and futures price changes but the simultaneous determination of both in the market is explicitly recognized.

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