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Hedging Break-Even Biodiesel Production Costs Using Soybean Oil Futures

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The effectiveness of hedging volatile input prices for biodiesel producers is examined over one- to eight-week time horizons. Results reveal that hedging break-even soybean costs with soybean oil futures offers significant reductions in input price risk. The degree of risk reduction is dependent upon type of hedge, naïve or risk-minimizing, and upon time horizon. In contrast, cross-hedging break-even poultry fat costs with soybean oil futures failed to reduce input price risk.

Key Words: biodiesel, hedging, poultry fat, soybean oil

High crude oil prices and political instability in some oil-exporting countries have made the production of alternative energy from agricultural resources a growing enterprise across America. To date, ethanol and biodiesel, touted as fuels from renewable resources, are two of the main alternative sources to liquid transport fuel. Production of ethanol has increased dramatically over the last few years, and has become a substantial and well-developed industry sector (Renewable Fuels Association, 2007). However, this growth has also led to an increase in the price of corn, with more than 20% of U.S. production of this commodity tied to energy production. By contrast, the biodiesel sector is not as large and established as the ethanol sector, but has also experienced tremendous growth over the last few years. In 2006, 105 biodiesel production plants were on line, and over 80 additional plants were expected to start production of biodiesel sometime in 2007 (National Biodiesel Board, 2006).

Analogous to the dramatic increase in corn prices induced by ethanol demand, a similar rise in soybean price may in part be attributed to increased demand for biodiesel. Moreover, higher corn prices have driven up soybean prices, as higher corn acreage demands have come at the cost of soybean acres, thereby contributing to increased supply pressure on soybean prices. By adding energy demand to the original food and feed demand for soybeans and corn, producers and processors may also be faced with additional price volatility driven by expected volatility in energy markets. Price volatility could therefore become a

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heightened issue for biodiesel producers; hence, risk management in terms of hedging and/or diversification of raw material inputs could be of interest to them.

Biodiesel producers can choose between various sources of inputs such as vegetable oils or animal fats (Mattingly, 2005) to diversify their raw material input use. To a degree, switching between input sources does not require adjustments to the production equipment performing the transesterification process if a producer is willing to live with some yield losses due to changes in the free fatty acid profile in the initial raw material. Adding a pretreatment facility to remove free fatty acid or using a two-stage process of esterification followed by transesterification allows producers to switch relatively easily among an array of alternative feedstocks (Popp et al., 2006). However, due to limited availability of some feedstocks and logistics, plants typically do not switch from one feedstock to the next in the short run. Essentially, this eliminates input diversification for price risk reduction in the short term.

Accordingly, the objectives of this study are to examine the possibility of hedging to minimize input price risk for biodiesel producers using soybean oil and poultry fat. Hedging strategies are analyzed only from an input perspective because recorded biodiesel prices have not been found prior to 2005, thus making an output hedging analysis difficult. Specifically, the paper analyzes hedges between soybean oil futures (F) and a partial biodiesel break-even cost (P_{Soy}^{BE}) calculated using soybean oil as feedstock (table 1), as well as cross-hedges between F and a partial biodiesel break-even cost (P_{Fat}^{BE}) using poultry fat as feedstock over 1- to 8-week hedge horizons in one-week increments.

Results from this study compare and contrast average and standard deviations of P_{Soy}^{BE} and P_{Fat}^{BE} using (naïve) fully hedged, unhedged, or a futures hedge position determined by a risk-minimizing hedge ratio. Break-even costs are analyzed rather than raw input prices, as this measure provides a better description of the true production costs faced by biodiesel producers. In addition, these hedging strategies are evaluated out of sample to analyze hedge ratio consistency and hedging performance over time.

Methods

Hedging can be an effective tool to reduce input price risk for biodiesel producers attempting to manage their exposure from the time biodiesel production is planned (presumably to meet demand at a certain price) until the feedstock is purchased to fill this demand. This is usually a very simple procedure for direct hedges, where typically a naïve hedge or fully hedged position (size of cash position is exactly matched by an equal but opposite futures position) is employed. Yet, a naïve hedge may not necessarily minimize input price risk. Therefore, in this study, risk-minimizing (minimum-variance) hedge ratios are determined by estimating the optimal size of a futures position to minimize standard deviations of expected P_{Soy}^{BE} and P_{Fat}^{BE}.

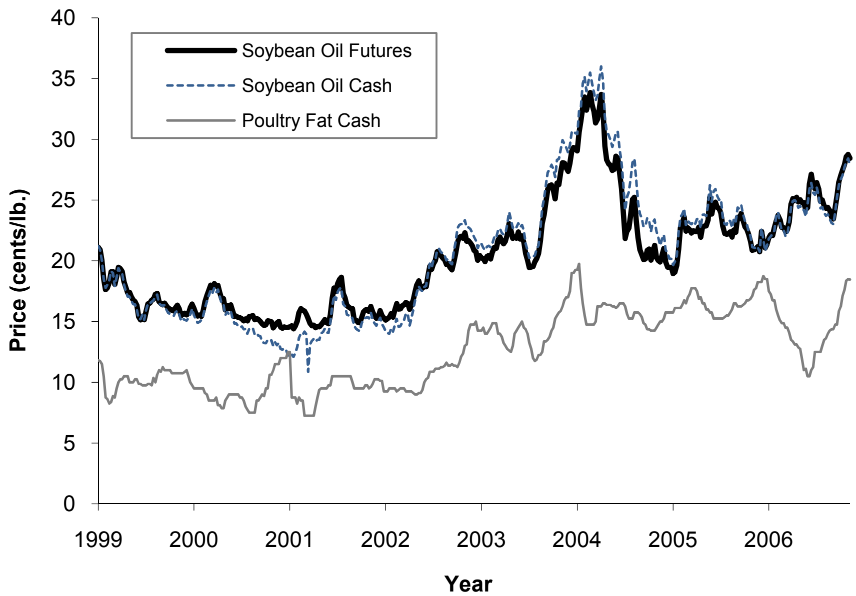
Table 1. Input Quantities and Costs Associated with Using One Pound of Poultry Fat or Soybean Oil for the Production of Biodiesel Using 1999–2006 Average Prices

Poultry Fat			Soybean Oil		
Inputs			**Inputs**		
Quantity (lbs.)	**Input**	**Average Price ($/lb.)**	**Quantity (lbs.)**	**Input**	**Average Price ($/lb.)**
2.20	Poultry Fat	0.13	2.20	Soybean Oil	0.21
0.25	Methanol	0.10	0.24	Methanol	0.10
0.01	NaOH	0.09	0.01	NaOH	0.09
0.004	H_2SO_4	0.03			
Outputs			**Outputs**		
Quantity (lbs.)		**Output**	**Quantity (lbs.)**		**Output**
2.21		Biodiesel	2.21		Biodiesel
0.23		Glycerine	0.23		Glycerine
Partial Biodiesel Break-Even Costs			**Partial Biodiesel Break-Even Costs**		
0.134 $/lb. of input 1.044 $/gal. of output			0.246 $/lb. of input 1.760 $/gal. of output		

Source: Popp et al. (2006).

Further, biodiesel producers using poultry fat as an input cannot use a simple hedge because there is no poultry fat futures contract traded on an exchange. A cross-hedge with another commodity could solve this problem for producers. However, hedging becomes more complicated when considering a cross-hedge, and again a naïve hedge is not likely to optimally reduce input price risk. A cross-hedge uses information in one market to predict the price of a different commodity (Franken and Parcell, 2003).

In order for cross-hedging to work, the prices of the commodities being cross-hedged must be correlated by reacting to price shocks in the same direction (Graff et al., 1997). This could be the case for poultry fat and soybean oil. Although typically used for different purposes, fats and oils are somewhat substitutable primarily for the purpose of dust reduction and improved palatability in livestock and pet feed rations. Consequently, fat and oil prices tend to react to changes in market conditions in a similar fashion (i.e., partial correlation = 0.788 for cash poultry fat and soybean oil prices over the sample period; see also figure 1). An effective cross-hedge could give producers protection from poultry fat price volatility, even though poultry fat is not traded on futures exchanges. If the cross-hedge is effective, it would offer producers a viable option to reduce price risk when considering using raw material inputs other than soybean oil.



Notes: Price series for poultry fat were received from Tyson Foods (1999–2004) and purchased from the Jacobsen Publishing Company (2005–2006). Price series for soybean oil were purchased from the Commodity Research Bureau.

Figure 1. Co-movement of poultry fat prices (Mid-South), soybean oil cash prices (Decatur, Illinois), and nearby soybean oil futures prices (CBOT), February 1, 1999–November 25, 2006

Discussions with industry participants (Mattingly, 2005) indicated that storage capacity at typical biodiesel plants would not exceed six weeks due to storage and cost considerations. Because of the short reaction times of the transesterification and cleaning processes (less than one day), inputs are purchased from one to six weeks in advance to maintain a steady supply of biodiesel to meet expected demand. Given this timeframe—when inputs are purchased until biodiesel output is sold—the following theoretical model was developed to determine the optimal risk-minimizing hedge ratio in terms of the statistical relationships among biodiesel output price, implied break-even price (cost), and soybean oil futures price.

First consider the profit $\tilde{\pi}_t$ for a biodiesel producer in period t:

$$\tilde{\pi}_t = \tilde{P}_t \bar{Q}_t - \tilde{\mathbf{c}}_t \bar{\mathbf{x}}_t, \tag{1}$$

where $\tilde{P}_t$ is the stochastic output price for biodiesel in period t, $\bar{Q}_t$ is the known and fixed amount of biodiesel output, $\tilde{\mathbf{c}}_t$ represents a vector of stochastic input costs realized in period t, and $\bar{\mathbf{x}}_t$ represents the known and fixed amount of inputs required to produce $\bar{Q}_t$ of biodiesel (refer to table 1 for a list of inputs associated with using soybean oil and poultry fat in the production of biodiesel).

This paper focuses on implied partial break-even price per unit of known and aggregated inputs, $\overline{\mathbf{x}}_t$. This break-even cost (or implied break-even cash price) is calculated by adding the required cost of inputs needed to convert one pound of soybean oil or poultry fat to biodiesel (table 1). Only operating inputs of sodium hydroxide and methanol are added with zero charges or credits for glycerin.[1] Further, plant operating and capital costs are excluded as they (*a*) typically make up less than 25% of cost of production, (*b*) exhibit plant size economies, and (*c*) are not expected to fluctuate over the intended hedging horizon (Tiffany, 2001; Ginder and Paulson, 2006). Thus, feedstock costs (soybean oil or poultry fat) make up over 80% of P_{Soy}^{BE} and P_{Fat}^{BE}, and are the primary source of input price risk to be hedged.

Now $\tilde{P}_{Soy/Fat_t}^{BE}$, representing either ($P_{Soy_t}^{BE}$ or P_{Fat}^{BE}) multiplied by required input quantities, $\overline{\mathbf{x}}_t$, to produce $\overline{Q}_t$ make up production cost, $\tilde{P}_{Soy/Fat_t}^{BE}\overline{\mathbf{x}}_t = \tilde{\mathbf{c}}_t\overline{\mathbf{x}}_t$, and so the firm's net hedged profit when it uses a long hedge in soybean oil futures established (bought) in period $t - n$ and offset (sold) in period t may be rewritten as:

$$\tilde{\pi}_t = \tilde{P}_t\overline{Q}_t - \tilde{P}_{Soy/Fat_t}^{BE}\overline{\mathbf{x}}_t + (\tilde{F}_t - \overline{F}_{t-n})z_{t-n}, \tag{2}$$

where $(\tilde{F}_t - \overline{F}_{t-n})$ is the futures gain (or loss) from the long hedge, and z_{t-n} represents the size (quantity) of futures position chosen by the firm in period $t - n$.

If we assume stochastic prices have the following multivariate normal distribution:

$$\begin{pmatrix} \tilde{p}_t \\ \tilde{p}_{Soy/Fat_t}^{BE} \\ \tilde{F}_t \end{pmatrix} \sim N\left[\begin{pmatrix} \mu_p \\ \mu_{p^{BE}} \\ \mu_F \end{pmatrix}\begin{pmatrix} \sigma_p^2 & 0 & 0 \\ & \sigma_{p^{BE}}^2 & \sigma_{p^{BE},F} \\ & & \sigma_F^2 \end{pmatrix}\right],$$

where μ terms represent averages, σ^2 terms represent variances, and $\sigma_{p^{BE},F}$ is the covariance between break-even price and soybean oil futures price, then the variance of net hedged profits is given by:

$$\sigma_{\pi_t}^2 = \sigma_p^2\overline{Q}_t^2 - \sigma_{p^{BE}}^2\overline{\mathbf{x}}_t^2 + \sigma_F^2 z_{t-n}^2 - 2\overline{\mathbf{x}}_t z_{t-n}\sigma_{p^{BE},F}. \tag{3}$$

The optimal risk-minimizing hedge position[2] (z_{t-n}^*) can be derived by differentiating equation (3) with respect to z_{t-n}, and is expressed as:

$$z_{t-n}^* = \overline{\mathbf{x}}_t \frac{\sigma_{p^{BE},F}}{\sigma_F^2}. \tag{4}$$

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[1] Crude glycerin prices have moved to very low price levels, as biodiesel production has created excess supply in the market. Therefore, the impact of crude glycerin production was ignored in this study.

[2] It should be noted that the optimal mean-variance utility-maximizing hedge position is equivalent to the optimal risk-minimizing hedge position assuming the futures market is unbiased.

Dividing the left- and right-hand sides of equation (4) by $\overline{\mathbf{x}}_t$ yields the optimal risk-minimizing hedger ratio (optimal futures position/quantity of inputs),

$$HR = \frac{\sigma_{p^{BE},F}}{\sigma_F^2}.$$

The more highly correlated are the break-even price and soybean oil futures, the closer the hedge ratio is to unity (a naïve or full hedge). Note in this case it is assumed that biodiesel output price is uncorrelated with either break-even price or soybean oil futures price (i.e., covariance terms in multivariate normal distribution are zero). In essence, the hedging problem is concerned only with input price risk.

If we relax the assumption that biodiesel output price is uncorrelated with break-even price and soybean oil futures price, and assume stochastic prices have the following multivariate normal distribution:

$$\begin{pmatrix} \tilde{p}_t \\ \tilde{p}^{BE}_{Soy/Fat_t} \\ \tilde{F}_t \end{pmatrix} \sim N\left[\begin{pmatrix} \mu_p \\ \mu_{p^{BE}} \\ \mu_F \end{pmatrix} \begin{pmatrix} \sigma_p^2 & \sigma_{p,p^{BE}} & \sigma_{p,F} \\ & \sigma_{p^{BE}}^2 & \sigma_{p^{BE},F} \\ & & \sigma_F^2 \end{pmatrix}\right],$$

then the variance of net hedged profits is represented by

$$(5) \qquad \sigma_{\pi_t}^2 = \sigma_p^2 \bar{Q}_t^2 - \sigma_{p^{BE}}^2 \overline{\mathbf{x}}_t^2 + \sigma_F^2 z_{t-n}^2 - 2\bar{Q}_t \overline{\mathbf{x}}_t \sigma_{p,p^{BE}} + 2\bar{Q}_t z_{t-n} \sigma_{p,F} - 2\overline{\mathbf{x}}_t z_{t-n} \sigma_{p^{BE},F}.$$

The optimal risk-minimizing hedge position (z_{t-n}^*) can now be derived by differentiating equation (5) with respect to z_{t-n}, and is computed as:

$$(6) \qquad z_{t-n}^* = \overline{\mathbf{x}}_t \frac{\sigma_{p^{BE},F}}{\sigma_F^2} - \bar{Q}_t \frac{\sigma_{p,F}}{\sigma_F^2}.$$

In this case, the optimal size of the futures position is comprised of two terms:

$$\overline{\mathbf{x}}_t \frac{\sigma_{p^{BE},F}}{\sigma_F^2} \quad \text{and} \quad \bar{Q}_t \frac{\sigma_{p,F}}{\sigma_F^2}.$$

The first term is identical to the optimal hedge position in equation (4) and reflects the size of the long futures position needed to hedge break-even price (input costs). The second term represents the size of the futures position needed to hedge biodiesel output price (or revenue). Hence, the net use of soybean oil futures, z_{t-n}^*, is the difference in the number of contracts needed to hedge break-even price and biodiesel output price. Importantly, as long as $\sigma_{p,F}$ and $\sigma_{p^{BE},F} > 0$, the size of the optimal net hedged position in equation (6) will be smaller than the optimal hedged position in equation (4), or equivalently, the hedge ratio (*HR*) will be less than unity because the biodiesel output price itself provides an implicit long position in break-even price that is a partial hedge. In other words, if input costs and break-even price increase (decrease), biodiesel output price increases (decreases) and profit margins remain stable, the need to hedge is negated. A similar theoretical result is derived in McDonald (2006, pp. 114–116) with respect to gold prices and a hypothetical output denoted "widgets."

As previously mentioned, hedging strategies in this paper are analyzed only from an input perspective due to a lack of recorded biodiesel prices prior to 2005. Thus, we proceed in the next section to derive optimal risk-minimizing hedging positions under the implicit assumption that biodiesel price is uncorrelated with either break-even price or soybean oil futures price—a condition that would be consistent with a situation where biodiesel producers can lock in (forward contract) with biodiesel buyers for long periods in advance. In such a situation, biodiesel price would essentially be a fixed predetermined value. However, it is important to recognize that if biodiesel producers face a stochastic price (output price risk), our results will overstate the case for hedging.

Regression Techniques Used for Estimating Hedge Ratios

If it is assumed that hedging is used to minimize price risk, then hedge or cross-hedge ratios may be obtained by estimating a simple regression between cash and futures prices either in price changes or price levels over periods of time. The coefficient estimate of the futures price variable is then interpreted as the minimum-variance (or risk-minimizing) hedge or cross-hedge ratio,

$$HR = \frac{\sigma_{P^{BE},F}}{\sigma_F^2},$$

from equation (4) (Lence, Hayenga, and Patterson, 1996). In this analysis, price changes were used rather than price levels, as price series usually exhibit unit roots and first differencing time series generally leads to stationary series. Augmented Dickey-Fuller tests indicated that prices contained unit roots at the 10% critical level. However, after taking first differences, prices were found to be stationary at the 1% critical level. Therefore, all results presented here pertain to the first-differenced price series.

The conditional regression model, using price differences similar to Brorsen, Buck, and Koontz (1998), and Franken and Parcell (2003), is described as follows:

$$\text{(7)} \quad \Delta P^{BE}_{Soy/Fat_t} = \tilde{\beta}_0 + \tilde{\beta}_1(\Delta F_t) + \tilde{\rho}_1\left[\Delta P^{BE}_{Soy/Fat_{t-1}} - \tilde{\beta}_0 - \tilde{\beta}_1(\Delta F_{t-1})\right] + \tilde{\rho}_k\left[\Delta P^{BE}_{Soy/Fat_{t-1}} - \tilde{\beta}_0 - \tilde{\beta}_1(\Delta F_{t-1})\right],$$

where $\Delta P^{BE}_{Soy/Fat_t}$ is the difference of break-even cash price P^{BE}_{Soy/Fat_t} over the hedge period. Thus, for an *n*-week hedge horizon, the difference for a particular week *t* is calculated by subtracting $P^{BE}_{Soy/Fat_{t-n}}$ from P^{BE}_{Soy/Fat_t}. Similarly, ΔF_t is the soybean oil futures price difference over the hedge period; $\Delta P^{BE}_{Soy/Fat_{t-1}}$ and ΔF_{t-1} are break-even cash and futures price differences lagged one period, and terms that include these variables are used to account for first-order autocorrelation. Thus, $\tilde{\rho}_1$ is a first-order autocorrelation parameter, and $\Delta P^{BE}_{Soy/Fat_{t-k}}$ and ΔF_{t-k} are *k* lagged break-even cash and futures price differences, where *k* represents the hedge period. Terms that include these variables are used to account for a moving average process with order equal to the length of the hedge period. The presence of a *k*-order moving average process in the data is due to our use of overlapping time periods to estimate equation (7) (Brorsen, Buck, and Koontz, 1998; Franken and Parcell, 2003). Parameter $\tilde{\beta}_0$ is the intercept and parameter $\tilde{\beta}_1$ is interpreted as the risk-minimizing hedge ratio. Since two-stage acid-catalyzed esterification followed by base-catalyzed transesterification (Popp et al., 2006) was used, a sulfuric acid catalyst was needed in addition to the base catalyst when calculating P^{BE}_{Fat}.

Following Myers and Thompson (1989), alternative specifications of equation (7) were investigated to estimate conditional minimum-variance hedge ratios. Specifically, additional lags (ranging from two to eight lags) of break-even and futures price differences were included as explanatory variables in equation (7). However, results presented in this paper are robust with respect to other specifications.[3] The data used for in-sample regression models commenced on February 1, 1999 and ended on December 31, 2005. Out-of-sample hedging effectiveness was evaluated using data from January 1, 2006 to November 25, 2006. Once the hedge ratios were estimated, standard *t*-tests were used to determine if soybean oil (poultry fat) hedge ratios were statistically different from 1 (0).

Determining Hedging Effectiveness and Hedge Ratio Consistency

First, we define hedged portfolio cost or net hedged position as the break-even cash price purchases adjusted for the gain or loss in the futures market:

$$(8) \qquad \textit{Hedged Portfolio Cost} = P^{BE}_{Soy/Fat_t} - \beta_1(\tilde{F}_t - \overline{F}_{t-n}),$$

where β_1 is the estimated in-sample hedge ratio and $(\tilde{F}_t - \overline{F}_{t-n})$ is the gain or loss in the futures market [as in equation (2)]. The gain/loss in the futures market was calculated by taking the difference in futures price between the time the long position was established and then offset (long futures position). If the futures price rose (fell) over the hedge horizon, then a gain (loss) was made in the futures market.

[3] In order to conserve space, results pertaining to other specifications are not presented here, but are available from the authors upon request.

Next, hedging effectiveness was analyzed by comparing the ability of different hedging strategies to reduce the variance of the hedged portfolio cost or net hedged position compared to an unhedged position of simple cash break-even purchases, $P^{BE}_{Soy/Fat}$, over the out-of-sample period. The variance of the hedged portfolio cost over time (depending on the hedge horizon) was calculated as:

$$\text{(9)} \qquad \mathrm{Var}(\mathit{Hedged\ Portfolio\ Cost}) = \frac{\sum\left(\mathit{Hedged\ Portfolio}_i - \overline{\mathit{Hedged\ Portfolio}}\right)^2}{n-1},$$

where *Hedged Portfolio*$_i$ is hedged portfolio cost in week *i*, $\overline{\mathit{Hedged\ Portfolio}}$ is the mean hedged portfolio cost, and *n* denotes the number of out-of-sample observations.

Furthermore, to better compare the variances, the percentage reduction in variance of hedged portfolio cost relative to the cost of an unhedged position is calculated following Fackler and McNew (1993):

$$\text{(10)} \qquad 1 - \frac{\mathrm{Var}(\mathit{Hedged\ Portfolio\ Cost})}{\mathrm{Var}(\mathit{Unhedged\ Purchases\ Cost})}.$$

All of the calculations, described in the section above, should provide an accurate picture of the performance of hedging P^{BE}_{Soy} with *F*, as well as cross-hedging P^{BE}_{Fat} with *F*.

Data

Daily price series of soybean oil futures prices (*F*) and soybean oil cash prices were purchased from the Commodity Research Bureau. Soybean oil futures prices were recorded on the Chicago Board of Trade, and soybean oil cash prices were recorded in Decatur, Illinois. These price series were converted to weekly average prices by adding the daily closing prices of the week and dividing the sum by the number of trading days in that particular week. The price series ranged from the week of February 1, 1999 to the week of November 25, 2006, a total of 409 weeks. Soybean oil futures contracts are traded for the months of January, March, May, July, August, September, October, and December. A futures contract position was assumed to be established in the same contract month as the hedge is offset, thus avoiding the need to roll a contract over to the next available delivery month. Transaction costs were not accounted for in this study.

Poultry fat prices for the Mid-South for this time period were obtained from Tyson Foods up until the end of 2004, and from that point on they were obtained from the Jacobsen Publishing Company. Soybean oil cash, futures, and poultry fat prices are all reported in ¢/lb. Methanol prices (¢/gal.) were collected from the *Chemical Market Reporter*. Sodium hydroxide (NaOH) and sulfuric acid (H_2SO_4)

Table 2. Summary Statistics for Variables Used in the Hedging Analysis (weekly data from February 1, 1999 to November 25, 2006)

Variable	Average	Std. Dev.	Min.	Max.
		— Price (¢/lb.) —		
Soybean Oil [a] (cash)	20.53	5.40	10.87	36.00
Soybean Oil [b] (futures)	20.35	4.55	14.41	33.86
Poultry Fat [c]	12.58	3.12	7.25	19.75
Partial Biodiesel Break-Even Cost [d] (soybean oil)	24.62	5.60	15.17	40.21
Partial Biodiesel Break-Even Cost [e] (poultry fat)	13.40	3.13	8.52	20.98

[a] Price series (Decatur, Illinois) purchased from the Commodity Research Bureau.

[b] Price series (nearby futures contract, CBOT) purchased from the Commodity Research Bureau.

[c] Price series (Mid-South) received from Tyson Foods (1999–2004) and purchased from the Jacobsen Publishing Company (2005–2006).

[d] The partial biodiesel break-even cost is calculated by adding the cost of 1 lb. of soybean oil, sodium hydroxide, and methanol necessary to make biodiesel; zero charges or credits for glycerin are added; non-feedstock operating costs and capital costs are excluded.

[e] The partial biodiesel break-even cost is calculated by adding the cost of 1 lb. of poultry fat, sodium hydroxide, sulfuric acid, and methanol necessary to make biodiesel; zero charges or credits for glycerin are added; non-feedstock operating costs and capital costs are excluded.

catalyst prices were held fixed at \$0.17/lb. and \$0.03/lb., respectively. Conversion efficiency to biodiesel was assumed to be 98%. Table 2 shows summary statistics for F, soybean oil cash prices, and poultry fat cash prices, as well as P^{BE}_{Soy} and P^{BE}_{Fat} per lb. of oil or fat input used in the production of biodiesel using cash price information.

Results

Table 3 shows the in-sample regression results and statistics of the estimated hedge relationship involving P^{BE}_{Soy}. The null hypothesis that a naïve hedge is equivalent to an optimal risk-minimizing hedge, with respect to P^{BE}_{Soy}, could be rejected for longer hedge horizons of 6, 7, and 8 weeks (the risk-minimizing hedge ratio was significantly different from unity). In contrast, optimal hedges for shorter horizons of 1–5 weeks were not statistically significantly different from naïve or fully hedged positions. Once corrected for serial correlation, all models exhibited acceptable R^2 values that improved with the length of the hedging horizon. All coefficient estimates were statistically significant at the 0.05 level with the exception of intercept terms. Hedge ratios for the 6-, 7- and 8-week horizons ranged between 0.92 and 0.95, suggesting that a biodiesel producer should hedge approximately 92–95% of his or her soybean oil purchases using soybean oil futures contracts (excluding the impact of transactions costs).

Table 4 reports the statistical results for the in-sample regressions considering break-even poultry fat costs (P_{Fat}^{BE}). Somewhat surprisingly, it was not advisable to cross-hedge purchases of poultry fat using soybean oil futures contracts. All hedge ratios were close to zero and statistically insignificant. Similar to the soybean oil models, autocorrelation coefficient estimates and R^2 values were acceptable with the exception of the 1-week hedge horizon ($R^2 \sim 0.05$).

Out-of-sample hedging effectiveness for soybean oil purchases using risk-minimizing hedge ratios was also evaluated; however, out-of-sample tests for poultry fat were not performed because the risk-minimizing hedge ratios were not statistically significantly different from zero. Table 5 presents the out-of-sample estimates of average cost of optimally hedged, naïve (fully) hedged, and unhedged P_{Soy}^{BE} purchases; standard deviations of optimally hedged, naïve (fully) hedged, and unhedged P_{Soy}^{BE} purchases; and variance reduction of P_{Soy}^{BE} purchases using the different hedging strategies (compared to unhedged positions) for all hedging horizons. Average costs of P_{Soy}^{BE} purchases were similar irrespective of hedging strategy or hedging horizon. However, both optimal risk-minimizing hedges and naïve (or fully hedged) positions were effective at reducing input price risk across all hedge horizons, with the greatest variance reduction observed for the longer horizons.

Turning to a comparison of optimal risk-minimizing hedges versus naïve hedges, it can be seen that risk-minimizing hedges outperformed the simple naïve hedges for the longer hedge horizons (6, 7, and 8 weeks). For example, risk-minimizing hedges result in lower standard deviations (5¢/lb. on average) and greater variance reduction (ranging from 3% to 6%) compared to naïve hedges for these longer hedge horizons. This is consistent with our in-sample results where we found risk-minimizing hedge ratios for these horizons were significantly different from naïve hedge ratios. Again, consistent with our in-sample results, variance reductions for risk-minimizing hedges and naïve hedges were very similar for 1- through 5-week hedge horizons.

Conclusions and Recommendations

The purpose of this study was to estimate hedge relationships between P_{Soy}^{BE} and F, and cross-hedge relationships between P_{Fat}^{BE} and F. Results suggest that producers using poultry fat may wish to enter a contractual arrangement with their input supplier(s) rather than use a soybean oil cross-hedge for protection from input price volatility, as it was not beneficial to use the soybean oil futures market to reduce input price risk. Producers using soybean oil, on the other hand, would be advised to implement hedging strategies based on risk-minimizing (minimum-variance) hedge ratios for 6-, 7-, and 8-week hedge horizons. Furthermore, in-sample findings show that estimated optimal risk-minimizing hedge ratios for the 6-, 7-, and 8-week hedge horizons differed significantly from naïve hedge ratios. The 1-, 2-, 3-, 4-, and 5-week risk-minimizing hedge ratios were not significantly different from naïve (fully) hedged positions. This result implies that producers

Table 3. Estimated Hedge Relationships Between Soybean Oil Futures and the Partial Biodiesel Break-Even Cost Using Soybean Oil

	Hedge Horizon			
Description	**1-Week**	**2-Week**	**3-Week**	**4-Week**
Constant (β_0)	0.0078 (0.0023)	0.0246 (0.0144)	0.0414 (0.0208)	0.0593 (0.0287)
Hedge Ratio (β_1)	0.9809*** (0.0239)	1.0205*** (0.0171)	1.0215*** (0.0181)	1.0245*** (0.0186)
1st-Order Autocorrelation (ρ_1)	0.4091*** (0.0484)	0.3361*** (0.0500)	0.4718*** (0.0481)	0.5842*** (0.0464)
*k*th-Order Autocorrelation (ρ_k)	N/A	−0.3421*** (0.0500)	0.2258*** (0.0481)	−0.1563*** (0.0465)
R^2 Statistic	0.7761	0.9307	0.9501	0.9606
Durbin-Watson Statistic	2.1112	1.8340	1.9767	2.1185
H_0: $\beta_1 = 1$ (*p*-value)	0.4260	0.2321	0.2363	0.1893

Notes: Triple asterisks (***) denote statistical significance at the 0.01 level. Values in parentheses are standard errors.

(extended . . . →)

Table 4. Estimated Cross-Hedge Relationships Between Soybean Oil Futures and the Partial Biodiesel Break-Even Cost Using Poultry Fat

	Hedge Horizon			
Description	**1-Week**	**2-Week**	**3-Week**	**4-Week**
Constant (β_0)	0.0187 (0.0288)	0.0456 (0.0626)	0.0800 (0.0800)	0.0982 (0.0916)
Hedge Ratio (β_1)	0.0315 (0.0374)	0.0163 (0.0375)	0.0052 (0.0358)	−0.0138 (0.0350)
1st-Order Autocorrelation (ρ_1)	0.2233*** (0.0517)	0.8580*** (0.0509)	0.9367*** (0.0349)	0.9364*** (0.0278)
*k*th-Order Autocorrelation (ρ_k)	N/A	−0.2717*** (0.0509)	−0.2657*** (0.0342)	−0.2395*** (0.0269)
R^2 Statistic	0.0514	0.4988	0.6922	0.7671
Durbin-Watson Statistic	2.0521	1.8712	1.8885	1.8114
H_0: $\beta_1 = 1$ (*p*-value)	0.4011	0.6632	0.8855	0.6926

Notes: Triple asterisks (***) denote statistical significance at the 0.01 level. Values in parentheses are standard errors.

(extended . . . →)

Table 3. Extended

	Hedge Horizon			
Description	**5-Week**	**6-Week**	**7-Week**	**8-Week**
Constant (β_0)	0.0765 (0.0369)	0.0819 (0.0541)	0.1043 (0.0688)	0.1037 (0.0787)
Hedge Ratio (β_1)	1.0198*** (0.0197)	0.9529*** (0.0226)	0.9325*** (0.0252)	0.9202*** (0.0246)
1st-Order Autocorrelation (ρ_1)	0.6470*** (0.0446)	0.6310*** (0.0450)	0.6571*** (0.0436)	0.7241*** (0.0408)
*k*th-Order Autocorrelation (ρ_k)	−0.1245*** (0.0448)	−0.0323 (0.0445)	−0.0160 (0.0431)	−0.0196 (0.0406)
R^2 Statistic	0.9642	0.9546	0.9501	0.9615
Durbin-Watson Statistic	2.2442	2.2638	2.1484	2.3721
H_0: $\beta_1 = 1$ (*p*-value)	0.3159	0.0380	0.0077	0.0013

Table 4. Extended

	Hedge Horizon			
Description	**5-Week**	**6-Week**	**7-Week**	**8-Week**
Constant (β_0)	0.1039 (0.1035)	0.1192 (0.1198)	0.1322 (0.1317)	0.1507 (0.1396)
Hedge Ratio (β_1)	0.0000 (0.0349)	0.0187 (0.0354)	0.0273 (0.0344)	0.0364 (0.0357)
1st-Order Autocorrelation (ρ_1)	−0.9292*** (0.0236)	−0.9129*** (0.0222)	−0.9213*** (0.0194)	0.9138*** (0.0193)
*k*th-Order Autocorrelation (ρ_k)	−0.2060*** (0.0229)	−0.1700*** (0.0218)	−0.1440*** (0.0193)	−0.1373*** (0.0193)
R^2 Statistic	0.8170	0.8317	0.8705	0.8730
Durbin-Watson Statistic	1.5937	1.6536	1.4022	1.5063
H_0: $\beta_1 = 1$ (*p*-value)	0.9983	0.5976	0.4281	0.3095

Table 5. Partial Biodiesel Break-Even Cost Using Soybean Oil (P_{Soy}^{BE}) and Risk Reduction from Alternative Soybean Oil Hedging Strategies

Hedge Horizon	Model	Average Cost of Hedged and Unhedged (P_{Soy}^{BE}) Purchases (¢/lb.)	Standard Deviation of Hedged and Unhedged (P_{Soy}^{BE}) Purchases (¢/lb.)	Variance Reduction from Unhedged Position (%)
1-Week	Unhedged	28.48	1.69	—
	Fully Hedged	28.33	1.65	4.81
	Optimally Hedged	28.34	1.65	5.02
2-Week	Unhedged	28.48	1.69	—
	Fully Hedged	28.21	1.59	11.82
	Optimally Hedged	28.20	1.59	11.23
3-Week	Unhedged	28.48	1.69	—
	Fully Hedged	28.09	1.55	16.56
	Optimally Hedged	28.08	1.55	15.63
4-Week	Unhedged	28.48	1.69	—
	Fully Hedged	27.98	1.50	21.10
	Optimally Hedged	27.87	1.49	22.50
5-Week	Unhedged	28.48	1.69	—
	Fully Hedged	27.89	1.47	24.29
	Optimally Hedged	27.88	1.49	22.85
6-Week	Unhedged	28.48	1.69	—
	Fully Hedged	27.82	1.45	26.24
	Optimally Hedged	27.86	1.42	29.78
7-Week	Unhedged	28.48	1.69	—
	Fully Hedged	27.80	1.45	26.98
	Optimally Hedged	27.85	1.40	31.81
8-Week	Unhedged	28.48	1.69	—
	Fully Hedged	27.72	1.54	17.21
	Optimally Hedged	27.78	1.48	23.24

would be well advised to adjust the size of their hedge positions depending on the time horizon they are planning to hedge their input (break-even) cost risk. Moreover, out-of-sample results show that the 6-, 7-, and 8-week risk-minimizing hedge positions yielded a significant reduction in input price risk when compared to simple naïve hedged or unhedged positions. Most importantly, hedging break-even costs (P_{Soy}^{BE}), using either naïve or risk-minimizing hedges, appears to offer substantial rewards to biodiesel producers using soybean oil in the form of input price risk reduction.

Finally, we note two caveats to our general conclusions. First, this study analyzed only eight hedge horizons over a specific period of time, and did not include futures transactions costs. Should these costs be significant, the same results may not universally apply and are subject to further research. Second, if biodiesel output prices are correlated with break-even prices (input costs), then hedging effectiveness of soybean oil futures prices may be compromised and our hedging results would be overstated. To what extent such a correlation exists, and the associated impact on hedged positions, is a focus of our ongoing and future research.

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