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Transaction Frequency and Hedging in Commodity Processing

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This study examines the effect of transaction frequency on profit and cash flow risk for firms that periodically purchase inputs, continuously transform inputs into outputs, and periodically sell output. Soybean-processing profit and cash flows are computed for unhedged, direct-hedged, and risk-minimizing-hedged processing with up to 52 transactions per year. Findings include: (*a*) higher transaction frequencies result in lower unhedged profit and cash flow risk and lower hedging effectiveness, (*b*) anticipatory hedging provides less risk protection than product-transformation hedging, (*c*) stabilizing cash flow stabilizes annual profits but the converse does not hold, and (*d*) hedging profits makes cash flow more variable.

Key words: process hedging, risk management, soybean crushing

Introduction

One sage bit of agricultural marketing advice is "if you want to get the annual average price for your crop, sell one-twelfth each month." While the logic of this advice is unassailable, business strategies are typically not so simple. More specifically, agricultural producers might face substantial transaction and marketing costs, which can make this strategy uneconomical. However, the strategy is more practical for processing firms because they frequently purchase inputs, continuously transform inputs into outputs, frequently sell outputs, and deal in quantities where transaction cost economies are less significant.

To envision the transaction frequency effect, suppose that a firm's annual output of y units is produced uniformly over T sub-annual periods and that this output is sold in n uniform transactions ($n \le T$). The number of transactions per year (n) is the transaction frequency, y/n is the size of each transaction, and T/n is the length of the transaction cycle measured in sub-annual periods.[1] Our purpose is to show how n, one of the firm's decision variables, can be manipulated to manage risk.

Suppose further that for each transaction the firm receives p_t, the prevailing price when the sale occurs, and that p_t follows a random walk with $p_t = p_{t-1} + \varepsilon_t$, where ε_t is stochastic with mean zero and variance σ^2. If annual production is sold in a single transaction at year's end ($n = 1$), the variance of revenue is $V(yp_T) = y^2 T\sigma^2$. More generally, if annual production is sold through n uniform transactions at intervals of T/n, the

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[1] For example, four transactions ($n = 4$) per 52-week year ($T = 52$) gives a transaction cycle of 13 weeks with product sales in weeks 13, 26, 39, and 52. The mismatch between continuous production and periodic sales is accommodated by inventory fluctuations.

revenue variance is given by $y^2T\sigma^2(n+1)(2n+1)/6n^2$.[2] This variance decreases as the transaction frequency increases ($n \to T$) and approaches one-third that of a single year-end transaction when transactions occur in every subperiod and the number of subperiods is large ($n = T$, $T \to \infty$).

Rather than following a random walk, cash commodity prices have generally been found to display serial correlation so that $p_t = \mu(1-\rho) + \rho p_{t-1} + \varepsilon_t$. Figure 1 shows revenue variances for selected values of ρ between -1 and $+1$ and for integer-valued transaction frequencies with 12 sub-annual market periods. As observed from figure 1, higher sales frequencies have lower revenue variances, and the variance drops dramatically as the first few transactions are added. If ρ is negative, then revenue variance can be further reduced if transactions alternate between even and odd periods, such as when transactions occur either in every period ($n = 12$) or in every third period ($n = 4$).

The optimal inventory model (Ravindran, Phillips, and Solberg, 1987) further illustrates the nature of this problem. In addition to our previous assumptions, assume that the firm's annual average inventory of $y/2n$ is carried at a constant marginal cost of c per unit, and that each transaction of size y/n costs $a + b(y/n)$. Total transaction costs are therefore $a \cdot n + b \cdot y$. Finally, suppose the firm values price risk exposure at a constant marginal cost of χ per unit, and the random walk revenue variance, $y^2T\sigma^2(n+1)(2n+1)/6n^2$, measures this risk. The firm's total inventory cost is thus

$$C = cy/(2n) + (a \cdot n + b \cdot y) + \chi y^2 T\sigma^2(n+1)(2n+1)/6n^2.$$

Applying the implicit function theorem of calculus reveals that the optimal number of transactions is positively related to χ and σ^2 for any $n \geq 1$.

The overall objective of this paper is to examine the effect of transaction frequency on hedging outcomes for agricultural processing firms that periodically purchase inputs, continuously transform these inputs into outputs, and then periodically sell the outputs. This study addresses the following questions:

- Is the transaction frequency effect significant for these firms?
- Is the transaction frequency effect mitigated or enhanced by hedging?
- Is the transaction frequency effect important enough to be part of a risk management strategy?

To answer these questions, we examine the impact of input procurement and product sales frequency on profit variability both with and without hedging.

The soybean-processing sector provides an opportune setting in which to study these issues because production occurs with known, fixed coefficients, the sector is economically important, and the abundant cash and futures prices allow hedging over a wide range of transaction cycles. While our attention focuses on soybean processing, the findings can be generalized to other agribusinesses that engage in continuous production such as cottonseed processors, meat packers, fertilizer manufacturers, and cereal manufacturers. Likewise, some traditional agricultural enterprises, such as hog and broiler production, have also adopted continuous production modes.

[2] If p_t follows a random walk, then $\mathbf{Cov(p, p')} = \sigma^2\mathbf{M}_T$, where $\mathbf{M}_T = \{m_{ij} \mid m_{ij} = \min(i,j), i = 1, 2, ..., T; j = 1, 2, ..., T\}$. If observations are drawn at intervals of T/n, then the covariance matrix of the periodic prices is $\sigma^2\mathbf{(T/n)M}_n$. $\mathrm{Var(Rev)} = \mathrm{Var}((y/n)\sum_{\tau=1}^{n} p_{(T/n)\tau}) = (y/n)^2\sigma^2(T/n)\sum_{\tau=1}^{n}\tau^2 = (y/n)^2(T/n)\sigma^2 n(n+1)(2n+1)/6$.

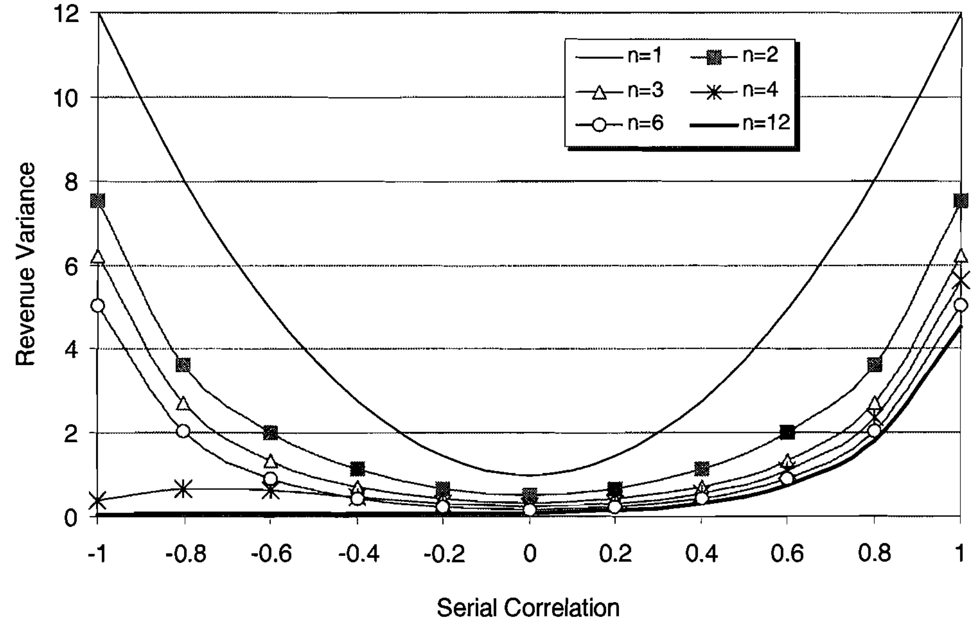

Figure 1. Revenue variance (times $\sigma^2 y^2$) for 12 market periods by serial correlation of prices and number of transactions (n)

Soybean processing involves crushing and flaking soybeans, then removing the oil with hexane (Chicago Board of Trade, 1985). The hexane is evaporated from the oil, and then reused. This process yields 11 pounds of oil per 60-pound bushel of soybeans. After extracting the oil and solvent, the remaining material is toasted and ground into 47 pounds of soybean meal (44% protein if hulls are not removed prior to processing, 48% if the hulls are removed). Thus, the production coefficients describe the yield of 11 pounds of oil and 47 pounds of meal from each bushel of soybeans. The crushing margin is the difference between the revenue from the soybean meal and oil obtained and the cost of a bushel of soybeans.

Tzang and Leuthold (1990) describe a three-step soybean-crushing hedge: (*a*) at the beginning of the planning horizon, buy soybean futures and sell soybean meal and soybean oil futures; (*b*) when processing is initiated, buy soybeans and sell the soybean futures contracts; and (*c*) when processing is complete, sell soybean oil and meal and buy soybean oil and meal futures. These steps are respectively denoted as anticipatory hedging, transformation hedging, and hedge closure. Table 1 illustrates the futures transactions that hedge quarterly cash market transactions required for continuous processing. This table assumes quarterly anticipatory hedging and futures maturities that match the timing of cash market transactions.[3]

Under scenario A (table 1), the processor anticipates in September purchasing soybeans in December, crushing them, and selling the resulting meal and oil in March. This batch is identified with the output-sale time in parentheses (March). The Tzang and

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[3] Table 1 serves only for illustration. Actual soybean futures maturities are Jan, Mar, May, Jul, Aug, Sep, and Nov, and soybean meal and oil futures maturities are Jan, Mar, May, Jul, Aug, Sep, Oct, and Dec. This analysis uses the nearby contract at the time of the cash market transaction.

Table 1. Cash and Futures Transactions for Continuous Processing with a Quarterly Transaction Cycle

	Cash Market (Batch)		Futures Market (Batch)			
			Soybeans		Meal and Oil	
Time	Soybeans	Meal and Oil	Buy	Sell	Buy	Sell
A. Continuous hedging in nearby contract for cash transaction, quarterly anticipatory period:						
Sep	Buy (Dec)	Sell	Dec (Mar)	Sep (Dec)	Sep (Sep)	Mar (Mar)
Dec	Buy (Mar)	Sell	Mar (Jun)	Dec (Mar)	Dec (Dec)	Jun (Jun)
Mar	Buy (Jun)	Sell	Jun (Sep)	Mar (Jun)	Mar (Mar)	Sep (Sep)
Jun	Buy (Sep)	Sell	Sep (Dec)	Jun (Sep)	Jun (Jun)	Dec (Dec)
Sep	Buy (Dec)	Sell	Dec (Mar)	Sep (Dec)	Sep (Sep)	Mar (Mar)
Dec	Buy (Mar)	Sell	Mar (Jun)	Dec (Mar)	Dec (Dec)	Jun (Jun)
B. Continuous hedging in nearby contract for cash transaction, no anticipatory period:						
Sep	Buy (Dec)	Sell			Sep (Sep)	Dec (Dec)
Dec	Buy (Mar)	Sell			Dec (Dec)	Mar (Mar)
Mar	Buy (Jun)	Sell			Mar (Mar)	Jun (Jun)
Jun	Buy (Sep)	Sell			Jun (Jun)	Sep (Sep)
Sep	Buy (Dec)	Sell			Sep (Sep)	Dec (Dec)
Dec	Buy (Mar)	Sell			Dec (Dec)	Mar (Mar)
C. Cumulative hedging, one quarter anticipatory period:						
Sep	Buy (Dec)	Sell	Dec, Mar, Jun, Sep	Sep	Sep	Mar, Jun, Sep, Dec
Dec	Buy (Mar)	Sell		Dec	Dec	
Mar	Buy (Jun)	Sell		Mar	Mar	
Jun	Buy (Sep)	Sell		Jun	Jun	
Sep	Buy (Dec)	Sell	Dec, Mar, Jun, Sep	Sep	Sep	Mar, Jun, Sep, Dec
Dec	Buy (Mar)	Sell		Dec	Dec	

Leuthold hedge for this batch consists of (*a*) in September, hedge the December purchase of soybeans with the purchase of December soybean futures contracts and sell March soybean meal and soybean oil futures contracts to hedge the March sale of the resulting output; (*b*) in December, when the soybeans are purchased, sell the soybean futures contracts; and (*c*) in March, sell the soybean oil and soybean meal and close the respective futures positions. Similar transactions are shown for other quarters. Hedging for scenario A consists of establishing an intertemporal crush spread (in September, buy December soybeans, sell March meal and oil) and executing a reverse crush spread at the time of each cash transaction (in September, sell September soybeans and buy September meal and oil). In the intertemporal crush spread, the soybean futures contract maturity is dictated by the length of the anticipatory period, and the intertemporal aspect of the crush spread is governed by the length of the cash transaction cycle (one quarter).

Panels B and C in table 1 show other hedging configurations. The anticipatory period is eliminated in panel B. As a result, the crush spread is eliminated from the hedging strategy. Panel C assumes variable anticipatory periods as all hedge positions for the coming year are established in September and then removed with a reverse crush spread at the time of the cash market transactions. Other scenarios involving non-simultaneous soybean meal and oil sales, and meal and oil sales that are not simultaneous with the purchase of soybeans, are conceivable. Table 1 gives a structure for considering these variations. At issue is how well traditional hedging methods work when applied to continuous processing.

Literature Review

Hedging theory treats a commodity market position as part of a portfolio that may also contain a futures market position (Johnson, 1960; Stein, 1961). With hedging, the portfolio's profits are

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

where x_s is the predetermined commodity market position, x_f is the attendant futures market position, and p_0 and p_1, and f_0 and f_1 are spot and futures prices at the beginning and end of the hedge period. Initial spot and futures prices are assumed given, while the ending period prices are assumed to be random variables. Risk is defined as the variance of the portfolio's profits,

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

and hedging involves setting x_f so as to minimize risk. The solution,

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

indicates the hedge ratio (x_f^*/x_s) can be estimated as the slope in the regression of futures price changes against spot price changes. Unhedged profits are simply $\pi_u = x_s(p_1 - p_0)$, as $x_f = 0$. Hedging effectiveness, defined as the proportionate price risk reduction due to hedging, is

(2) $$\begin{aligned} e &= [V(\pi_u) - V(\pi_h)]/V(\pi_u) \\ &= [\operatorname{Cov}(p_1 - p_0, f_1 - f_0)]^2/[V(f_1 - f_0)V(p_1 - p_0)] = (r_{\Delta p,\Delta f})^2, \end{aligned}$$

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

Anderson and Danthine (1980, 1981) generalized this approach by including multiple futures contracts in the portfolio. Their profit function (1980) is

$$\pi = x_s(p_1 - p_0) + \mathbf{x_f}(\mathbf{f_1} - \mathbf{f_0}),$$

where the terms are as defined under (1) except that $\mathbf{x_f}$ represents positions in multiple futures contracts, and $\mathbf{f_0}$ and $\mathbf{f_1}$ are initial and terminal futures price vectors. The agent chooses a futures position to

$$\max U(\pi) = E(\pi) - (\lambda/2)\operatorname{Var}(\pi) \quad \text{w.r.t. } \mathbf{x_f}.$$

Let $\Sigma_{\Delta f,\Delta f}$ and $\Sigma_{\Delta f,\Delta p}$ represent covariance matrices for the indicated price changes. The solution,

$$\mathbf{x}_f^* = \lambda^{-1}\Sigma_{\Delta f,\Delta f}^{-1}\left[\mathbf{E}(\mathbf{f}_1) - \mathbf{f}_0\right] - \Sigma_{\Delta f,\Delta f}^{-1}\Sigma_{\Delta f,\Delta p}\mathbf{x}_s,$$

provides for multi-contract hedging (Anderson and Danthine, 1980) and cross-hedging (Anderson and Danthine, 1981). Risk-minimizing hedge ratios are obtained by assuming that $\lambda = \infty$ or $\mathbf{E}(\mathbf{f}_1) = \mathbf{f}_0$. These hedge ratios can be estimated by the regression parameters in $\Delta\mathbf{p} = \Delta\mathbf{f}\beta + \varepsilon$. Hedging effectiveness is estimated by the regression multiple correlation statistic.

Myers and Thompson (1989) examined whether hedge ratios are best estimated from price levels, changes, or returns. They derive a generalized hedge ratio estimator based on deviations from the conditional mean at hedge placement. Ederington (1979) found that for many commodities, Johnson's (1960) portfolio-risk minimization approach is more effective than the one-unit futures to one-unit cash hedge. Other studies suggest that the simplest hedging models work best. Garcia, Roh, and Leuthold (1995, p. 1133) report that time-varying hedge ratios "provide little gain to the hedger in terms of mean return and reduction of the variance of returns over constant optimal hedges." Collins (2000) concludes multivariate-hedging models offer no statistically significant improvement over naive equal and opposite hedges.

Nonetheless, the Johnson (1960) and Anderson and Danthine (1980, 1981) methods are frequently employed in agricultural production and storage hedging. Production hedges that resemble processing hedges include the cattle feeding hedge using corn, feeder cattle, and live cattle futures (Leuthold and Mokler, 1979; Shafer, Griffin, and Johnson, 1978), and the hog feeding hedge using live hog, soybean meal, and corn futures (Kenyon and Clay, 1987).

The soybean-processing hedge is similar to the multi-commodity production hedge. Several methods for determining futures positions in soybean processing have been examined (Tzang and Leuthold, 1990; Fackler and McNew, 1993). In a *one-to-one hedge* (a.k.a. *equal and opposite*), each unit of cash market commitment is matched with a corresponding unit of futures market commitment. In a more general *risk-minimizing direct hedge*, each unit of cash market commitment is hedged with a risk-minimizing futures commitment in the same commodity. More general still is a *commodity-by-commodity cross-hedge*, where each unit of cash market commitment is hedged with a risk-minimizing futures commitment in a different but related commodity. In a *multi-contract hedge*, each unit of cash market commitment is hedged with risk-minimizing commitments in several futures contracts.[4] These contracts may differ by maturity, may specify the delivery of a different commodity (i.e., a cross-hedge), or may specify non-commodity financial instruments (currencies, securities, indices, or weather).

Other hedging strategies are defined in terms of the speculative soybean futures crush spread.[5] In a *one-to-one crush hedge*, the processor is long one bushel in a soybean

[4] Fackler and McNew (1993) refer to this as a multi-commodity hedge. Because the unhedged processor already has a multi-commodity cash market position, we define this as a multi-contract hedge with the "multi" explicitly referring to the futures markets. An additional advantage of this definition is that it allows consideration of multiple maturities in the same futures contract.

[5] The crush spread involves a long soybean futures position and short soybean meal and soybean oil futures positions in the ratios of 47 pounds of meal and 11 pounds of oil for each bushel of soybean futures.

crush spread for each anticipated bushel to be processed. This strategy is identical to a one-to-one hedge if the soybean oil and soybean meal are sold simultaneously. The *proportional crush hedge* generalizes the one-to-one crush hedge. Here the soybean processor employs a risk-minimizing crush spread that is proportional to the soybean cash market position.

Various studies have examined these hedging approaches. Using weekly prices from January 1983 through June 1988, Tzang and Leuthold (1990) investigate multi- and single-contract soybean-processing hedges over 1 through 15-week hedging horizons. Fackler and McNew (1993) use monthly prices to examine three soybean-processing hedging strategies: multi-contract hedges, single-contract hedges, and proportional crush-spread hedges. The multi-contract approach has recently been extended to cross-hedging in the cottonseed-processing sector (Dahlgran, 2000; Rahman, Turner, and Costa, 2001).

These process-hedging studies typically follow Johnson (1960), Stein (1961), and Anderson and Danthine (1980) in formulating a two-period model where the hedger's assumed objective is minimum profit variance. This formulation surreptitiously incorporates the notion of batch processing, as profits are defined as the terminal-period value of the batch's output(s) less the initial-period value of the batch's input(s). Profit computed in this manner is henceforth referred to as batch or accounting profit. With the consideration of continuous processing, periodic profit, defined as outputs valued at current-period prices less inputs also valued at current-period prices, ascends in importance. Periodic profit corresponds to cash flow if commodity purchases and sales are conducted on a cash basis, or to changes in working capital if payables and receivables are involved.[6] We will see that periodic profit behaves differently than batch profits in the face of price variability.

Cash-flow or working-capital stability is a concern for several reasons. First, discounted cash flow is the criterion used in buy-or-build decisions for processing plants, so cash flow as a hedging target is consistent with its use in the capital investment decision. Second, costs are associated with managing working capital. Cash flow variations affect working capital availability, so the stabilization of cash flow reduces working capital management costs. Finally, it will be shown that, even though annual aggregations of batch profits and cash flows converge, the sub-annual components behave differently. Further, cash flow stabilization will be observed to stabilize annual accounting profit, but the converse does not hold.

Empirical Analysis

We begin by defining profit for a batch of output sold in period t and cash flow for period t, and then examine the relationship between these concepts. Accordingly, let $\mathbf{y}_t$ represent a row vector of outputs (soybean meal and oil) produced and sold at time t for price $\mathbf{p}_t$, and let x_{t-L} represent the inputs (soybeans) embodied in $\mathbf{y}_t$ and purchased L periods earlier at a price of r_{t-L}. Assume further that production occurs with fixed coefficients so $\mathbf{y}_t = \gamma x_{t-L}$, that processing is uniform over time giving uniform transaction and inventory cycles, and that inputs are purchased for the next batch of output when the current

[6] Periodic profits are henceforth referred to as cash flow, though we recognize that the term may represent the slightly broader concept of changes in working capital.

batch is sold. The firm selects n, the number of transactions executed during the year, which consists of T market periods. By selecting n the firm also selects L, the time lag separating input purchases and output sales, as L is T/n. Input purchases for each cycle are X/n, where X represents annual processing volume. Accounting profit for the batch of product sold at time t is:

(3) $$\Pi(n)_t = \begin{bmatrix} \mathbf{p}_t & -r_{t-L} \end{bmatrix} \begin{bmatrix} \mathbf{y}_t \\ x_{t-L} \end{bmatrix} = (X/n) \begin{bmatrix} \mathbf{p}_t & r_{t-(T/n)} \end{bmatrix} \begin{bmatrix} \gamma \\ -1 \end{bmatrix}.$$

Cash flow in period t is the difference between revenues and expenditures, and is represented as

$$\Phi(n)_t = \begin{bmatrix} \mathbf{p}_t & -r_t \end{bmatrix} \begin{bmatrix} \mathbf{y}_t \\ x_t \end{bmatrix} = (X/n) \begin{bmatrix} \mathbf{p}_t & r_t \end{bmatrix} \begin{bmatrix} \gamma \\ -1 \end{bmatrix}.$$

The difference between accounting profit and cash flow in period t is:

$$\Pi(n)_t - \Phi(n)_t = (X/n)(r_t - r_{t-(T/n)}) = (X/n)\Delta^L r_t,$$

where $\Delta^L r_t$ represents the L-period difference in r_t (i.e., $r_t - r_{t-L} = r_t - r_{t-(T/n)}$). The difference between annual accounting profit and cash flow is the sum over the n transactions in the year, so

(4) $$\sum_{\tau=1}^{n} \left[\Pi(n)_{(T/n)\tau} - \Phi(n)_{(T/n)\tau} \right] = (X/n) \sum_{\tau=1}^{n} \Delta^L r_{L\tau} = (X/n)(r_T - r_0),$$

where τ indexes the transactions, and $(T/n)\tau$ designates the market periods in which transactions occur.[7] These equations demonstrate the inverse relationship between transaction frequency (n) and the respective left-hand-side variables. Equation (3) also shows that as transactions become more frequent, the temporal separation between input and output prices decreases, while (4) shows that as n increases, annual accounting profit and annual cash flow converge.

We now apply these general relationships to soybean processing. Letting $\pi(n)_t$ represent accounting profit in cents per bushel for the batch of soybean products sold in period t gives:

(5) $$\pi(n)_t = 47S_{M,t} + 11S_{O,t} - S_{B,t-T/n},$$

where $S_{M,t}$, $S_{O,t}$, and $S_{B,t}$, respectively, represent spot or cash prices of soybean meal (cents per pound), soybean oil (cents per pound), and soybeans (cents per bushel) in period t. Hedging product transformation during the T/n interval separating input and output cash pricing is one aspect of a hedging strategy. To include anticipatory hedging, suppose that at one point in time a processor decides on the amount of input to be purchased and processed at a future time with the product to be sold later still. We designate the time between the decision point and the input purchase as the anticipatory period of length A. When $A = 0$, anticipatory hedging is not practiced, but this does not preclude transformation hedging.

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[7] For example, suppose transactions are executed four times in a 52-week year. Inputs must be purchased at $t = 0, 13, 26,$ and 39, and the resulting output is sold at $t = 13, 26, 39,$ and 52. L, the time lag between input purchase and output sale, is $T/n = 13$, and $L\tau$ points to the proper time index on the prices, in essence transforming the transaction frequency domain to the price frequency domain.

Suppose, as Collins (2000) found, there is no significant advantage to hedging methods that use risk-minimizing hedge ratios. Profit in cents per bushel for product sold in period t, when hedged by one-to-one Tzang and Leuthold hedges, is designated as $\pi^*(n, A)_t$, where

(6) $$\pi^*(n,A)_t = \left[47S_{M,t} + 11S_{O,t} - S_{B,t-(T/n)}\right] - \left[47(F_{M,t} - F_{M,t-(T/n)}) + 11(F_{O,t} - F_{O,t-(T/n)})\right] - \left[47(F_{M,t-(T/n)} - F_{M,t-(T/n)-A}) + 11(F_{O,t-(T/n)} - F_{O,t-(T/n)-A}) - (F_{B,t-(T/n)} - F_{B,t-(T/n)-A})\right],$$

and $F_{M,t}$, $F_{O,t}$, and $F_{B,t}$, respectively, represent futures prices of soybean meal (cents per pound), soybean oil (cents per pound), and soybeans (cents per bushel) in period t. The bracketed terms respectively represent unhedged accounting profit [per equation (5)], profit from hedging over the transformation period of length T/n, and profit from hedging over the anticipatory period of length A. More compactly, let

(7) $$\pi^*(n,A)_t = \pi(n)_t + \theta(n)_t + \eta(n,A)_t,$$

where the respective bracketed terms in (6) are represented by $\pi(n)_t$, $\theta(n)_t$, and $\eta(n,A)_t$.

Let ϕ_t represent cash flow from unhedged processing in period t in cents per bushel, so

(8) $$\phi_t = 47S_{M,t} + 11S_{O,t} - S_{B,t}.$$

Finally, combine (7) and (8) to show the effect of a one-to-one Tzang and Leuthold hedging regimen on cash flow:

(9) $$\phi^*(n,A)_t = \phi_t + \theta(n)_t + \eta(n,A)_t,$$

where $\phi^*(n,A)_t$ represents cash flow with hedging over a transformation period of length T/n and an anticipatory period of length A.[8]

The data used for this analysis were obtained from online archives maintained by BarChart.com, an online brokerage service. The archive contains daily central Illinois cash prices for soybeans (#1 yellow), soybean oil, and soybean meal beginning with January 2, 1990. These prices and crushing margins through December 2003 are shown in figure 2. Figure 2 reveals considerable variation in the crushing margin, indicating substantial potential for hedging. Hedging outcomes are computed using Chicago Board of Trade soybean, soybean oil, and soybean meal futures prices, which are also contained in the archive.

Transaction frequencies (n) of 1, 2, 4, 13, 26, and 52 transactions per year were selected for study. Because these frequencies correspond to integer multiples of weekly observations, the archive's daily data were sampled weekly, resulting in $T = 52$ market periods per year. Wednesday's prices were used to represent each week. If Wednesday was a holiday, then Thursday's prices were used.

Settlement prices were used for futures transactions. The nearby maturing contract at the time of the cash market transaction was used as the hedge vehicle, provided the

[8] Margin requirements have no effect on cash flow except at startup because initial margin deposit is assumed to remain on deposit at hedge closure to support the next hedge.

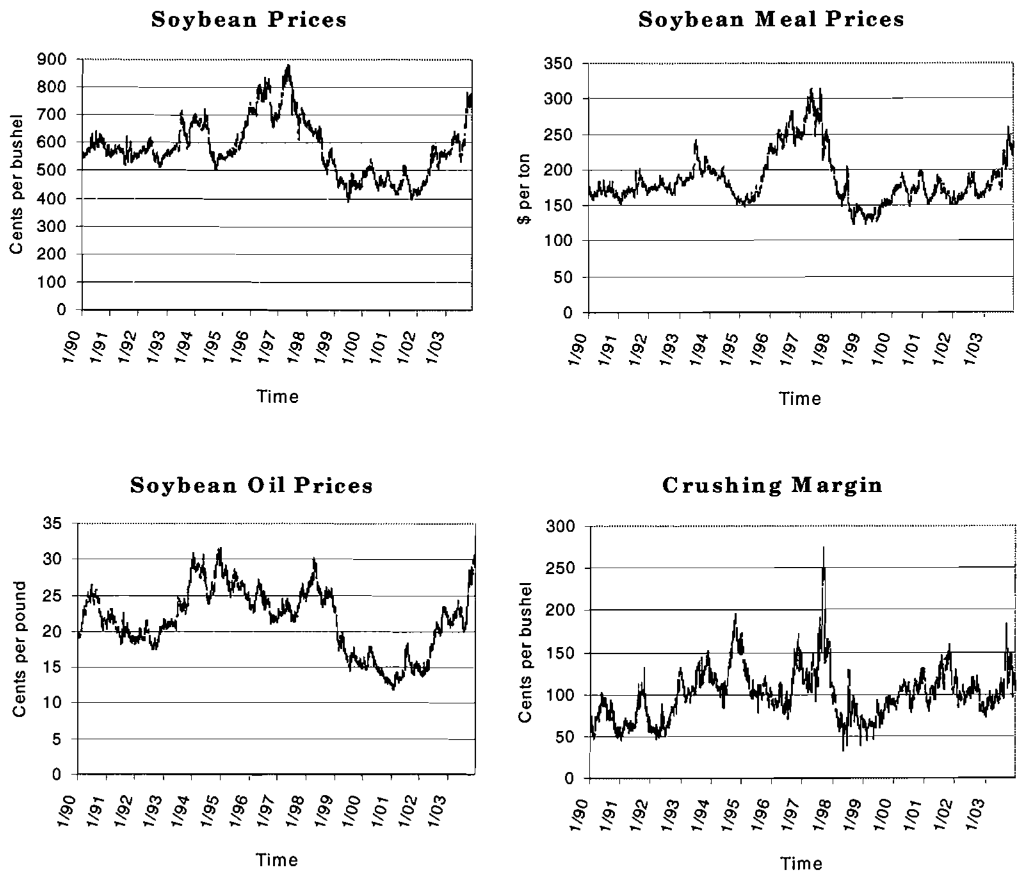

Figure 2. Historical data: Cash prices for soybeans, soybean meal, and soybean oil, and the gross crushing margin

contract was at least one week from maturity. Three hedging strategies were examined: (*a*) no hedging, (*b*) hedging only product transformation (i.e., $L = 52/n$ and $A = 0$), and (*c*) hedging both anticipated and actual product transformation (i.e., $L = 52/n$ and $A \neq 0$). For the third strategy, the length of the anticipatory period was set to the length of the transaction cycle ($A = L$).

Rollovers were used when a single contract did not trade over a hedge's entire life. The rollover's initial contract was the most distant contract available at hedge initiation. The initial position was closed one week prior to contract maturity and a new position was established in the contract that would be the nearby maturity at the time of the cash market transaction. Occasionally, with one-year and half-year transaction cycles, two contracts failed to cover the entire span of the hedge. Hedge rollovers through three futures contracts were not priced because of ambiguities in the selection and timing of transactions in the middle contract.

The price data reflect anomalies that affect our analysis. Early soybean meal futures contracts specified delivery of 44% protein meal, but this specification changed to 48% protein beginning with the September 1992 maturity. The cash-priced commodity also changed during the sample period. Comparison of soybean meal cash prices in the data set to those published in the *Wall Street Journal* reveals that the data-set prices were for 44% meal prior to November 17, 1992, and for 48% meal thereafter. Rather than throw out part of the data, or mix prices representing different grades of soybean meal, or conduct the analysis for two grades of soybean meal, the 44% meal prices were converted to a 48% equivalent and the analysis was conducted for the current standard, 48% soybean meal. This was done by collecting Wednesday's 44% and 48% soybean meal prices from the *Wall Street Journal* from November 18, 1992 through December 26, 2001, the period when both prices were reported. OLS regression estimation of the relationship between these prices gives:

$$S_{M48,t} = \underset{(0.476)}{5.96} + \underset{(0.00257)}{1.0221} S_{M44,t}$$

$$\text{Observations} = 476,\ R^2 = 0.997,\ \text{MSE} = 5.186,$$

where $S_{M48,t}$ is the 48% soybean meal cash price in period t, $S_{M44,t}$ is the 44% soybean meal cash price in period t, and standard errors are in parentheses. This relationship was used to generate fitted values for 48% cash prices prior to November 17, 1992, and for 48% futures prices for contracts maturing prior to September of 1992. The high regression R^2 assures these fitted values are good proxies for the unavailable 48% meal prices.

After incorporating the proxy 48% protein meal prices, and after differencing the weekly prices to account for the transaction cycle lengths, and after including hedge rollovers, the profit and cash flow series in (5), (6), (8), and (9) were computed. Unhedged-hedged comparisons can be based on profits [(5) versus (6)] or cash flows [(8) versus (9)] and involve means and variances. Table 2 facilitates these comparisons for various transaction frequencies (the columns) by reporting averages and standard deviations (cents per bushel) for profits and cash flows, without hedging, with transformation hedging, and with transformation and anticipatory hedging, for the transaction cycle and then for annual aggregates of the transactions.[9]

Preliminary analysis indicated that the weekly observations displayed significant serial correlation but not unit roots. Thus, the $\pi(n)_t$ series, for example, is represented as $\pi(n)_t = (1 - \rho)\mu + \rho\pi(n)_{t-1} + \varepsilon_t$, where μ is the mean, ρ is the serial correlation, and $\varepsilon_t \sim \text{IID}(0, \sigma^2)$. The other series can be represented similarly. The variance of profit is $\text{Var}[\pi(n)_t] = \sigma^2/(1 - \rho)$. Hence, the unconditional means and variances (standard deviations) represent the returns and risks from soybean crushing. These estimates are reported in table 2.

Observations are weekly. Eighty-seven and four observations, respectively, were lost under 1-year and 26-week transaction cycles because the longer hedge horizons require rollovers, and rollovers are increasingly subject to the unavailability of two overlapping contracts that span to the hedge horizon as the horizon becomes more distant. A hedge that could not be accomplished with a single rollover was treated as a missing observation. For comparability, the same observations were used for all strategies within a transaction frequency even though the rollover limitation may not be binding on a particular strategy (e.g., not hedging).

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[9] The row groupings in table 2 represent $\pi(n)_t$; $\pi(n)_t + \theta(n)_t$; $\pi(n)_t + \theta(n)_t + \eta(n,A)_t$; ϕ_t; $\phi_t + \theta(n)_t$; and $\phi_t + \theta(n)_t + \eta(n,A)_t$ in equations (5)–(9), presented first without and then with annual aggregation. Anticipatory periods (A) are assumed equal in length to the transformation periods (T/n).

Table 2. One-to-One Hedging Outcomes (in cents per bushel) by Transaction Frequency

Outcome	Hedge Type [a]		Transactions per Year: 1	2	4	13	26	52
PERIODIC RETURNS:		Observations	641	724	728	728	728	728
Batch Profit	Unhedged	Average	94.68	93.23	94.09	92.35	91.84	91.57
		Std. Dev.	109.23	76.49	61.98	43.76	36.69	33.17
	Transformation	Average	100.99	91.43	90.18	90.24	90.64	90.90
		Std. Dev.	37.08	31.53	24.39	24.58	26.53	27.83
		Effectiveness	0.885	0.830	0.845	0.684	0.477	0.296
	Anticipatory &	Average	95.46	90.83	89.60	89.64	90.06	90.69
	Transformation	Std. Dev.	37.92	26.72	24.66	23.09	25.26	27.23
		Effectiveness	0.879	0.878	0.842	0.722	0.526	0.296
Cash Flow	Unhedged	Average	93.53	91.36	91.27	91.27	91.27	91.27
		Std. Dev.	29.60	29.55	29.50	29.50	29.50	29.50
	Transformation	Average	99.84	89.56	87.36	89.17	90.07	90.60
		Std. Dev.	85.07	66.25	58.31	38.07	34.05	32.17
		Effect [b]	-7.260	-4.026	-2.907	-0.665	-0.322	-0.189
	Anticipatory &	Average	94.31	88.96	86.78	88.56	89.49	90.40
	Transformation	Std. Dev.	94.15	70.12	60.83	37.17	33.25	31.78
		Effect [b]	-9.117	-4.631	-3.252	-0.588	-0.270	-0.161
ANNUAL AGGREGATE:								
Profit	Unhedged	Std. Dev.	93.25	53.74	35.75	25.46	23.65	22.91
	Transformation	Std. Dev.	26.86	18.24	14.49	18.61	20.47	21.46
		Effectiveness	0.917	0.885	0.836	0.466	0.251	0.123
	Anticipatory &	Std. Dev.	26.37	19.91	14.84	17.70	19.72	21.11
	Transformation	Effectiveness	0.920	0.863	0.828	0.517	0.305	0.151
Cash Flow	Unhedged	Std. Dev.	23.75	22.52	22.46	22.46	22.46	22.46
	Transformation	Std. Dev.	64.49	36.47	23.77	18.46	20.04	21.20
		Effect [b]	-6.373	-1.623	-0.120	0.324	0.204	0.109
	Anticipatory &	Std. Dev.	72.58	41.29	25.10	17.81	19.34	20.87
	Transformation	Effect [b]	-8.339	-2.362	-0.249	0.371	0.259	0.137

[a] An anticipatory hedge, constructed in anticipation of buying and crushing soybeans, consists of a long position in soybean futures and short positions in soybean oil and soybean meal futures. A transformation hedge is constructed after soybeans are purchased. The long cash soybean position is hedged with short soybean oil and soybean meal futures positions.

[b] Cash flow effect is the proportional reduction (negative signifies increase) in cash flow variance due to hedging.

Table 2 reveals several relationships. First, the average unhedged crushing margin is about 92 cents per bushel. Except under one transaction per year, the average crushing margin declines when product transformation is hedged, and it declines further still when anticipatory hedging is included. To test whether these differences are significant, the following models were fit to the data for n = 1, 2, 4, 13, 26, and 52:

$$\theta(n)_t = (1 - \rho_\theta)\mu_\theta + \rho_\theta \theta(n)_{t-1} + \varepsilon_t \tag{10}$$

and

$$\eta(n,A)_t = (1 - \rho_\eta)\mu_\eta + \rho_\eta \eta(n,A)_{t-1} + \nu_t . \tag{11}$$

In (10), θ_t represents transformation hedging profit in period t; μ_θ and ρ_θ, respectively, represent the mean and serial correlation of transformation hedging profit; and $\varepsilon_t \sim \text{IID}(0, \sigma_\theta^2)$. Similar definitions apply for anticipatory hedging profits in (11), with the added assumption that $A = T/n$. The Dickey-Fuller unit-root test and the test of H_0: $\mu = 0$ were both performed. The unit-root hypothesis was rejected for all frequencies except one transaction per year, and the significance of the test statistic increased with transaction frequency.[10] The mean, while consistently negative, is not significantly different from zero.[11]

A second result apparent in table 2 is that batch profit variability declines as transaction frequency increases. This occurs because increased transaction frequency reduces the temporal separation of input purchases and output sales, and market integration is inversely related to this temporal pricing separation. The cash flow series represents simultaneous pricing of inputs and outputs, so it is less variable (standard deviation of 29.5 cents per bushel) than any of the batch profit series. Transaction frequency does not affect cash flow per bushel processed because (8) shows that cash flow per bushel does not depend on price lags.[12]

The standard deviation of profit (or cash flow) for a period is the product of volume processed times the per bushel crush margin's standard deviation. Thus, at higher transaction frequencies, the lower per bushel crush margin variability reinforces the smaller quantity per transaction [X/n in equations (3) and (4)] to further reduce periodic profit (or cash flow) variability. The standard deviation of batch profits and cash flows for each transformation period cannot be determined directly from table 2 because annual processing volume (X) is unspecified. However, relative comparisons are possible under the assumption that the annual processing volume is evenly divided among the transactions. For example, the standard deviation of unhedged profit with weekly transactions is 0.6% of the standard deviation of unhedged profit with one annual transaction ($0.6 = 100\% \times [33.17 \times (X/52)/109.23 \times (X/1)]$).

[10] The Dickey-Fuller test statistics for (10) were -2.17, -4.13, -5.10, -9.58, -14.84, and -27.49 for values of n of 1, 2, 4, 13, 26, and 52. Similar results were found for (11), where Dickey-Fuller test statistics of -2.33, -4.44, -5.07, -9.28, -14.36, and -25.37 were obtained for the respective transaction frequencies. The Dickey-Fuller 5% critical value for testing $\rho = 1$ is -2.86.

[11] Fitting the autoregressive model in (10) gives t-statistics for the intercept of -0.10, -0.26, -0.64, -0.60, -0.79, and -1.10 for n = 1, 2, 4, 13, 26, and 52. The respective t-statistics for the intercept in (11) are -0.28, -0.30, -0.69, -0.74, -1.07, and -1.26.

[12] The average return and standard deviation is 91.27 and 29.50 cents per bushel, respectively, for frequencies using all 728 observations. The mean and standard deviation take values at low transaction frequencies that differ from their high-frequency values because of the missing observations created by rollovers.

As reported in table 2, transformation-hedging effectiveness declines as transaction frequency increases, falling from 0.885 with one transaction per year to 0.296 with one transaction per week. Table 2 also shows that the incremental effectiveness of anticipatory hedging is relatively small, in the 3%–4% range.

To test the incremental effectiveness of transformation and anticipatory hedging, let e_θ represent the effectiveness of adding transformation hedging to unhedged processing, and let e_η represent the effectiveness of further adding anticipatory hedging. Then,

$$e_\theta = \left[V(\pi_t) - V(\pi_t + \theta_t)\right]/V(\pi_t) = -\left[V(\theta_t) + 2\,\mathrm{Cov}(\theta_t, \pi_t)\right]/V(\pi_t)$$

and

$$\begin{aligned} e_\eta &= \left[V(\pi_t + \theta_t) - V(\pi_t + \theta_t + \eta_t)\right]/V(\pi_t + \theta_t) \\ &= -\left\{V(\eta_t) + 2\,\mathrm{Cov}[\eta_t(\pi_t + \theta_t)]\right\}/V(\pi_t + \theta_t), \end{aligned}$$

where π_t, θ_t, and η_t are defined under (6) and (7), and effectiveness is defined by (2). Note that $e_\theta > 0$ requires $\mathrm{Cov}(\theta_t, \pi_t)/V(\theta_t) < -0.5$. $\mathrm{Cov}(\theta_t, \pi_t)/V(\theta_t)$ can be estimated by $\hat{\beta}_1$ in the model $\pi_t = \beta_0 + \beta_1\theta_t + \varepsilon_t$. Therefore, testing $e_\theta \le 0$ is equivalent to the one-tailed test of H_0: $\beta_1 \ge -0.5$, and rejecting H_0 is equivalent to rejecting the notion that the hedge is ineffective. Similarly, testing $e_\eta \le 0$ is equivalent to the one-tailed test of H_0: $\delta_1 \ge -0.5$ in the model $\pi_t + \theta_t = \delta_0 + \delta_1\eta_t + \varepsilon_t$. We conclude that transformation hedging significantly reduces batch profit risk, as the $\hat{\beta}_1$ t-ratios are −20.6, −24.2, −27.2, −27.4, −25.6, and −30.1 for 1, 2, 4, 13, 26, and 52 transactions per year.[13] Moreover, the incremental effectiveness of adding anticipatory hedging to transformation-hedged processing is not statistically significant, as the respective $\hat{\delta}$ t-ratios are 27.2, 26.3, 34.2, 31.3, 33.3, and 36.7.

The effect of profit hedging on cash flow variability is evaluated in a manner that parallels effectiveness, by examining the proportionate reduction in cash flow variation attributed to hedging.[14] Table 2 reports this effect. These results are interpreted as follows. Suppose a processor has a four-week transaction cycle (13 transactions per year) and hedges profits with a transformation hedge. While this strategy reduces profit variability by 68.4%, it increases cash flow variability by 66.5%. Regardless of frequency, the cash flow risk associated with either transformation hedging or anticipatory and transformation hedging exceeds the cash flow risk of unhedged processing. Alternatively stated, direct hedging reduces profit variability and increases cash flow variability.[15]

Finally, table 2 shows the standard deviations of annual aggregations of batch profits and cash flows. Because all hedging strategies and frequencies have the same annual processing volume, these standard deviations are directly comparable. The results indicate that the standard deviations of profits and cash flows converge as transaction

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[13] These t-ratios all assume the ε_t is generated by a first-order autoregressive process. This assumption does not affect the conclusions. The same applies for the testing of the effectiveness of anticipatory hedging.

[14] More precisely, the effect of hedging on cash flow is defined as $[\mathrm{Var}[\phi_t] - \mathrm{Var}[\phi^*(n,A)_t]]/\mathrm{Var}[\phi_t]$. A negative value indicates that hedging increases cash flow variation.

[15] A direct hedge reduces the variance from an unhedged position so long as the correlation between spot and futures price changes exceeds $0.5[V(f_1 - f_0)/V(p_1 - p_0)]^{0.5}$. To see this, use the notation surrounding (1)–(2) and let π_u represent unhedged profit so $\pi_u = x_s(p_1 - p_0)$. Hedged profit is $\pi_h = x_s(p_1 - p_0) + x_f(f_1 - f_0)$. When applied to soybean crushing, spot and futures prices are interpreted as spot and futures crushing margins. The result follows from the comparison $V(\pi_h) < V(\pi_u)$ subject to the one-to-one hedge assumption that $x_s = -x_f$.

frequency increases, and hedging destabilizes annual aggregate cash flows when there are few transactions per year.

To investigate how the direct hedging assumption affects the results reported in table 2, the "equal and opposite" assumption of (6) was dropped and risk-minimizing hedge ratios were estimated. As shown by the results in table 3, batch-profit hedging is highly effective—the R^2 varies from 0.924 to 0.342, with greater effectiveness at lower frequencies. The R^2s are statistically significant, with all having a probability of a larger value of less than 0.0001. If anticipatory hedging is eliminated [regression (2)], the effectiveness declines by 1.5% to 7.2%, depending on the transaction frequency, but the effectiveness remains statistically significant. These effectiveness estimates are not much different from the direct-hedging estimates in table 2. Table 3 also indicates that the estimated hedge ratios can be used to attain these risk-reduction levels outside the sample, as the effectiveness for out-of-sample simulations (year 2004) is similar in magnitude and behavior to the in-sample (1990–2003) effectiveness.

Hypothesis 1 (H_1) tests whether anticipatory hedging with risk-minimizing hedge ratios significantly reduces profit risk. Table 3 shows that the risk reduction, though small, is statistically significant. This contrasts with the direct hedging results (table 2). H_2 tests whether transformation hedging with risk-minimizing hedge ratios significantly reduces profit risk. H_2's F-statistics are highly significant. By comparison, the risk reduction attributable to transformation hedging greatly exceeds the risk reduction attributable to anticipatory hedging. Further, even though anticipatory hedging's risk reduction is statistically significant, it may not be large enough to justify the transactions costs, especially at higher transaction frequencies.

H_3 and H_4 in table 3 correspond to the Collins (2000) hypothesis that "equal and opposite" hedging performs as well as risk-minimizing hedging. Hypothesis H_3 (equal and opposite hedging during the anticipatory period) is rejected for all transaction frequencies, while the results for H_4 (equal and opposite during the transformation period) are mixed. Taken together, the tests of H_3 and H_4 suggest that direct hedging is significantly less effective than the risk-minimizing hedge. H_5 (table 3) tests whether anticipatory-period hedge ratios are equal to transformation-period hedge ratios. This hypothesis is rejected for all transaction frequencies.

Hedge ratio equality across transaction frequencies was also tested. The resulting F-statistics, with 5 and 4,241 degrees of freedom, were 13.21, 21.99, and 13.83 for soybeans, meal, and oil for the anticipatory period, and 33.04 and 13.27 for meal and oil for the transformation period. The probability of a larger value for each F-statistic was less than 0.0001, so the null hypothesis was rejected. Table 3 reveals that hedge ratios are the largest in absolute terms for 13 transactions per year. This means the impact of futures price changes on the crush margin is greatest for a four-week time difference, possibly indicating that crushing plants and physical product flows take four weeks to fully adjust to input-output price realignments.

Table 4 shows the proportionate change in cash flow variation caused by profit-risk-minimizing hedges. A comparison of the variance reductions given in table 4 to the effect of one-to-one hedging in both the anticipation and transformation periods given in table 2 reveals that risk-minimizing hedges destabilize cash flow to a slightly greater degree than direct hedges.

Table 3. Effectiveness, Hedge Ratios, and Hypothesis Test *F*-Statistics for Risk-Minimizing Hedges, by Transaction Frequency

	Transactions per Year					
Description	1	2	4	13	26	52
Observations[a]	641	724	728	728	728	728
1. Hedge ratios with anticipatory hedging:						
$\pi_t = \beta_0 + \beta_1\Delta^A F_{S,t\text{-}L} + \beta_2\Delta^A F_{M,t\text{-}L} + \beta_3\Delta^A F_{O,t\text{-}L} + \beta_4\Delta^L F_{M,t} + \beta_5\Delta^L F_{O,t} + \varepsilon_t$, where $\varepsilon_t = \rho\varepsilon_{t-1} + \nu_t$						
Effectiveness,[b] in-sample	0.924*	0.902*	0.872*	0.738*	0.550*	0.342*
Effectiveness, out-of-sample	0.907	0.933	0.898	0.824	0.578	0.228
Estimated hedge ratios (standard errors):						
β_1 soybeans, anticipatory per	-0.284	-0.511	-0.532	-0.617	-0.451	-0.475
	(0.0402)	(0.0416)	(0.0456)	(0.0561)	(0.0568)	(0.0459)
β_2 soymeal, anticipatory per	-0.101	-0.517	-0.528	-0.655	-0.448	-0.423
	(0.0393)	(0.0491)	(0.0515)	(0.0570)	(0.0574)	(0.0471)
β_3 soyoil, anticipatory per	-0.211	-0.512	-0.567	-0.646	-0.529	-0.457
	(0.0645)	(0.0720)	(0.0643)	(0.0701)	(0.0731)	(0.0615)
β_4 soymeal, transformation per	-0.909	-0.978	-0.928	-0.969	-0.918	-0.915
	(0.0270)	(0.0242)	(0.0217)	(0.0215)	(0.0239)	(0.0213)
β_5 soyoil, transformation per	-0.931	-0.957	-0.953	-1.013	-0.975	-0.943
	(0.0535)	(0.0486)	(0.0438)	(0.0434)	(0.0481)	(0.0426)
ρ serial correlation	0.881	0.878	0.906	0.912	0.890	0.919
	(0.1880)	(0.0179)	(0.0158)	(0.0152)	(0.0170)	(0.0147)
RMSE	12.241	10.483	9.009	8.607	9.259	8.368
Hypothesis tests–F-statistics:[c]						
H_1: $\beta_1 = \beta_2 = \beta_3 = 0$	22.95*	50.93*	46.14*	46.37*	23.76*	35.91*
H_2: $\beta_4 = \beta_5 = 0$	990.05*	1,404.78*	1,615.60*	1,777.20*	1,292.98*	1,612.42*
H_3: $\beta_1 = \beta_2 = \beta_3 = -1$	196.12*	46.36*	35.27*	15.71*	32.70*	52.43*
H_4: $\beta_4 = \beta_5 = -1$	8.60	1.19	7.98	1.08	7.23	11.57*
	(0.0002)	(0.3048)	(0.0004)	(0.3415)	(0.0008)	
H_5: $\beta_2 = \beta_4$, $\beta_3 = \beta_5$	189.05*	49.50*	34.95*	18.36*	33.32*	57.82*
2. Without anticipatory hedging:						
$\pi_t = \beta_0 + \beta_4\Delta^L F_{M,t} + \beta_5\Delta^L F_{O,t} + \varepsilon_t$, where $\varepsilon_t = \rho\varepsilon_{t-1} + \nu_t$						
Effectiveness, in-sample	0.909*	0.830*	0.850*	0.696*	0.487*	0.303*
Effectiveness, out-of-sample	0.822	0.906	0.871	0.861	0.667	0.408

[a] The in-sample period is 1990–2003; the out-of-sample period is 2004.

[b] All reported effectiveness statistics are R^2s for the unconditional errors.

[c] An asterisk (*) indicates that the probability of a larger F-statistic is less than 0.0001. If the probability of a larger F-value exceeds 0.0001, then the probability is shown in parentheses.

Table 4. Effect on Cash Flow of Risk-Minimizing Hedges, by Transaction Cycle

	Transactions per Year					
Description	1	2	4	13	26	52
Unhedged Cash Flow:						
N	641	724	728	728	728	728
Mean	93.53	91.36	91.27	91.27	91.27	91.27
Standard Deviation	29.60	29.55	29.50	29.50	29.50	29.50
Cash Flow Under Risk-Minimizing Hedging:						
N	641	724	728	728	728	728
Mean	-1.15	-1.87	-2.82	-1.08	-0.57	-0.30
Standard Deviation	101.36	71.65	57.00	39.14	33.71	32.02
Variance Reduction:	-10.726	-4.897	-2.733	-0.760	-0.306	-0.178

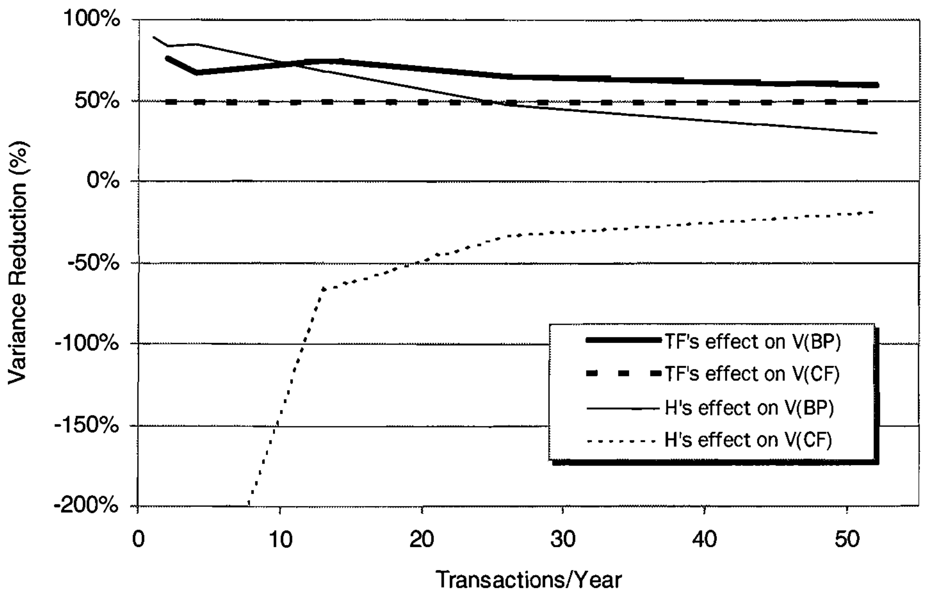
Summary and Conclusions

Figure 3 summarizes our findings by showing the impact of hedging and transaction frequency on batch profit and cash flow variability (figure 3a) and on the variability of annual batch profit and cash flow aggregates (figure 3b). The batch profit variance reduction associated with doubling the transaction frequency [TF's effect on V(BP) in figure 3a] is computed from the standard deviations reported in table 2. Figure 3a shows, for example, that doubling the transaction frequency from one to two transactions per year decreases the output's profit variance by 75% [one transaction with variance of X^2 109.23^2 versus two transactions each with variance of $(X/2)^2$ 76.49^2]. Doubling the transaction frequency reduces unhedged profit variance by 50% when the initial volume is divided between two transactions, plus the per unit processing margin variance declines when market integration increases.

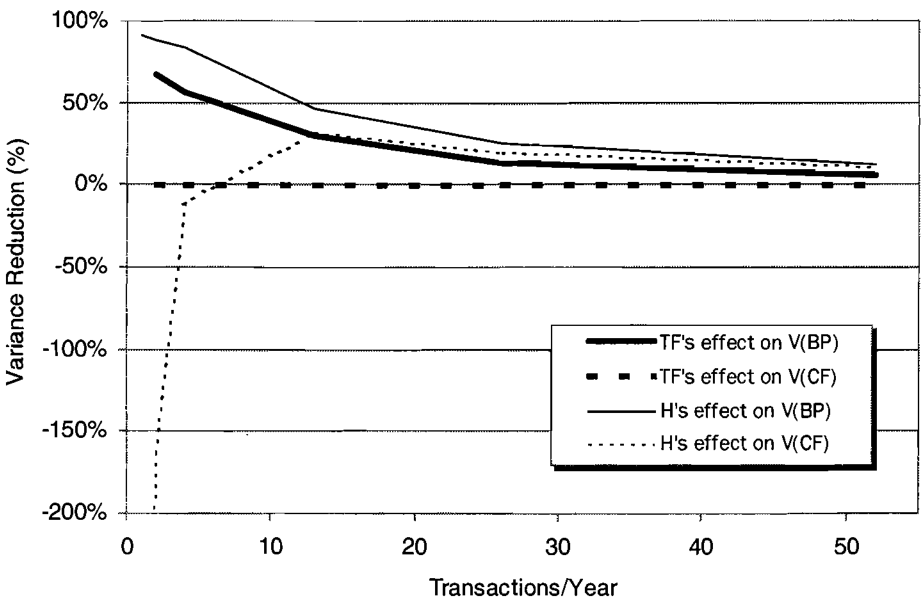
As illustrated in figure 3a, doubling the transaction frequency reduces the output's cash flow variance by 50% [TF's effect on V(CF)] because the output is split between two transactions while the per bushel crush margin variance is unchanged. Figure 3a also shows the transformation hedging effectiveness [H's effect on V(BP)], which declines as transaction frequency increases. This hedging effectiveness decline accompanies a decline in hedgable risk. Finally, figure 3a demonstrates that hedging destabilizes cash flow regardless of transaction frequency, but the destabilization is less severe at higher frequencies [H's effect on V(CF)].

Figure 3b presents annual aggregates of the periodic effects reported in figure 3a. The proportional reduction in annual profit variance attributable to transformation hedging [H's effect on V(BP)] exceeds that attributable to doubling the transaction frequency [TF's effect on V(BP)]. Moreover, doubling the transaction frequency has no effect on the annual cash flow variance [TF's effect on V(CF)] because both the annual processing volume and the standard deviation of the crushing margin per bushel are unaffected by transaction frequency. Finally, figure 3b shows that the destabilizing effect of hedging on periodic cash flows dissipates upon annual aggregation [H's effect on V(CF)].

The three questions raised in the introduction can be addressed in light of the findings summarized in figure 3. First, is the transaction frequency effect significant for agricultural commodities? We have determined that the transaction effect arises from



3a. Periodic batch profit and cash flow variance reduction



3b. Annual profit and cash flow variance reduction

Figure 3. Effectiveness of hedging versus doubling the transaction frequency

two sources. More transactions mean that each transaction is smaller with increased integration between input and output prices. The volume effect is primary, but the price integration effect also plays a significant role in variance reduction. The traditional profit-hedging approach ignores existing price integration that is the inherent source of cash flow stability.

Second, is the transaction frequency effect mitigated or enhanced by hedging? We have shown that hedging reinforces the transaction frequency effect by reducing the variance of batch and annual profit while it increases the variance of periodic cash flow. Stockholders would apparently favor hedging as a profit-assurance mechanism, while managers might favor not hedging as a cash flow management strategy. However, stockholders receive profit reports annually, and the income-stabilizing effect of hedging on annual profits is limited.

Third, is the transaction frequency effect important enough to be part of a risk management strategy? The answer here is that frequent transactions represent a major source of risk reduction. Hedging strategies that fail to recognize the risk protection afforded by multiple transactions vastly overstate the amount of risk protection achieved. Furthermore, given the findings of this paper, the pertinent question is why would a processor hedge? The stabilization of periodic profits would be unrecognized by stockholders, profit enhancement is insignificant, and more variable cash flows would have to be dealt with by managers. It seems that managerial effort to increase transactional efficiency, whereby transaction frequency can be increased, would have a risk management payoff exceeding that of hedging.

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