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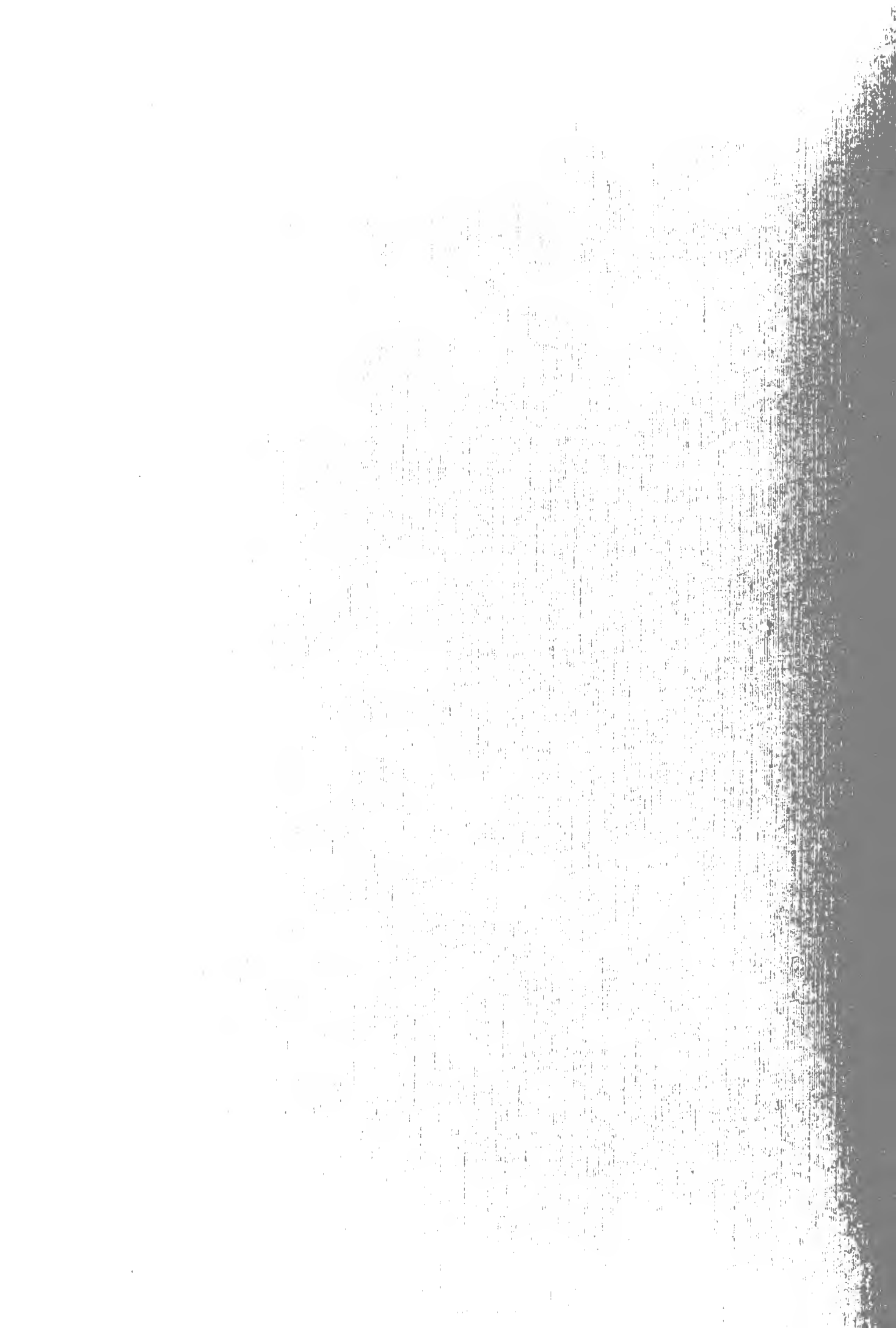
UNIVERSITY OF ILLINOIS  
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## Oil Prices and Energy Futures

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## Abstract

Oil price volatility has increased dramatically in the last few years. Energy futures can play a vital role in hedging the oil price volatility faced by producers, refiners and consumers. The empirical evidence in this research shows a strong correlation between futures price movements and spot prices in the crude oil, heating oil and leaded gasoline markets. The hedging results show that a substantial portion of the price risk can be removed through the use of energy futures while at the same time enhancing the hedger's portfolio return.



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## Oil Prices and Energy Futures

Prior to the 1970's, the oil industry was highly concentrated and vertically integrated. Many firms produced the crude oil, moved the crude to their refineries, and then distributed refined products such as heating oil and gasoline. During this time, prices were relatively low and stable.

The oil industry went through major structural changes in the 1970's. As a result of these changes and a variety of other factors, there was a dramatic increase in the price volatility in oil prices which, in turn, affected the financial risk exposure of oil producers and users.<sup>1</sup> Some of the possible measures which may aid in hedging this risk include:

- (1) a revision of the process by which oil prices are set;
- (2) long-term contracting between producers, refiners and consumers;
- (3) using the energy futures markets.

Among these solutions, the use of energy futures markets would appear to be very promising.

The purpose of this paper is to provide an ex post empirical analysis of the hedging potential of energy futures for three widely traded commodities: crude oil, heating oil and leaded gasoline. The analysis indicates the desirability of energy futures in reducing the price risk of energy products as well as in improving the risk-return performance of the hedger's position. The results also show that, in general, hedging effectiveness increases with the hedger's holding period and the nearer the contract's time to delivery.

Section I contains a brief summary of the theoretical basis for determining hedge ratios and hedging effectiveness. A description of

the data base and empirical results regarding the hedging effectiveness of energy futures is presented in Section II. Section III summarizes the findings.

I. Alternative Approaches to Hedging and Their Effectiveness

Several hedging approaches have been discussed in the academic literature. In this section, we review briefly two of these approaches that will be used in our analysis.

A. Minimum Risk Hedging

Following the early works of Johnson (1960) and Stein (1961), Ederington (1979), Makin (1978), and McEnally and Rice (1979) have shown that the optimal minimum risk hedge ratio (HR\*) and the hedging effectiveness of this ratio is related to the covariance between spot and futures price changes and the variance in futures price changes. Mathematically, the minimum risk hedge ratio is found as the solution to the following problem:

$$\min_{x_f} \sigma^2(\Delta p_t) = x_s^2 \sigma^2(\Delta s_t) + x_f^2 \sigma^2(\Delta f_t) + 2x_s x_f \text{cov}(\Delta s_t, \Delta f_t) \quad (1)$$

where:  $\Delta s_t, \Delta f_t, \Delta p_t$  = the price change during period t of the spot, futures, and a portfolio of spot and futures, respectively.

$x_f$  = the proportion of the portfolio held in futures contracts.

$x_s$  = the proportion of the portfolio held in the spot commodity and = 1, by assumption.

$\sigma^2$  = variance of price changes.

The solution yields the optimal minimum risk hedge ratio HR\*:

$$x_f^* = \text{HR}^* = -\text{cov}(\Delta s_t, \Delta f_t) / \sigma^2(\Delta f_t) \quad (2)$$

The value of  $HR^*$  is equivalent to the negative of the slope coefficient of a regression of  $\Delta s_t$  against  $\Delta f_t$ . When  $HR^* < 0$ , a short position in futures is indicated; when  $HR^* > 0$ , a long position in futures is required. For example, an  $HR^*$  of  $-1.5$  ( $1.5$ ) indicates that the hedger should sell (buy)  $\$1.50$  in futures for every  $\$1.00$  held in the spot commodity.

Many studies (e.g., Cicchetti, Dale and Vignola (1981), Franckle (1980), Grammatikos and Saunders (1983), Hill, Liro and Schneeweis (1983), Hill and Schneeweis (1982), Kuberek and Pefley (1983), Maness (1981), Marmer (1986), Overdahl and Starleaf (1986) and Senchack and Easterwood (1983)) have employed this "risk minimization" approach in the analysis of a variety of futures contracts. Determining hedge ratios in this manner assumes that the hedger's objective is to receive the maximum amount of price change reduction. Literature (Energy Futures: Trading Opportunities for the 1980's (1984)) describing the oil industry suggests that the objective of price change risk minimization is a reasonable assumption for many producers and refiners who are primarily in the business of production or delivery of oil and its refined products and must make commitments to buy and sell in an uncertain price environment.

The hedging effectiveness of a minimum risk hedged position is measured by the  $R^2$  of the regression of  $\Delta s_t$  against  $\Delta f_t$ . The higher the  $R^2$  value, the higher is the correlation between  $\Delta s_t$  and  $\Delta f_t$  and the greater is the reduction in price change variance as a proportion of total variance that results from maintaining a hedged ( $x_f \neq 0$ ) rather than an unhedged ( $x_f = 0$ ) position.

B. Risk-Return Hedging

The risk minimization approach does not consider the return dimension of hedging. Research by Anderson and Danthine (1980, 1981) Kopenhaver (1984), Nelson and Collins (1985) and Working (1953a, 1953b) have emphasized the need for a risk-return approach to hedging. Recent research by Howard and D'Antonio (1984, 1986) has extended these earlier efforts and developed an optimal risk-return hedge ratio and a risk-return measure of hedging effectiveness. The desirable feature of a risk-return approach is that it enables hedgers with different risk tolerances to hedge in an optimal fashion.

The principal differences between the Howard and D'Antonio (1984) analysis and the more traditional risk-minimization approach include:

- (1) the use of returns rather than price changes
- (2) the incorporation of a risk-free asset  $i$  (e.g., Treasury Bill) in the analysis.

The risk-return approach can be visualized in Figure 1. In Figure 1, the investor (hedger) has the choice of putting money into three assets: the risk-free asset ( $i$ ), the spot commodity ( $s$ ) and a futures contract on the spot commodity. The curved portion of Figure 1 represents the risk ( $\sigma$ ) and expected return ( $\bar{r}$ ) combinations for alternative spot-futures portfolios. Point  $i(s)$  represents the risk and return position of a portfolio containing only the risk-free asset (spot) commodity.<sup>2</sup> Assuming that the investor is seeking the greatest expected return for a given level of risk, all optimal portfolios lie on the straight line running from point  $i$  through the tangent portfolio point  $t$  and beyond. Portfolio  $t$  represents the optimal combination of spot and futures.

The investor would invest in this portfolio and borrow (at rate  $i$ ) or invest (at rate  $i$ ) to move to the desired point along the line. The exact position taken in the futures portion of portfolio  $t$  will depend upon the risk-free rate, the expected returns and standard deviations of returns for the spot and futures and the correlations between those returns. The optimal level of futures (hedge ratio) associated with portfolio  $t$  is found as the solution to the following problem:

$$\max_{x_f} (\bar{r}_p - i) / \sigma_p \quad (3)$$

where:  $\bar{r}_p$ ,  $i$  = expected return on a portfolio of spot and futures and the risk free asset  $i$ , respectively.

$\sigma_p$  = standard deviation of returns.

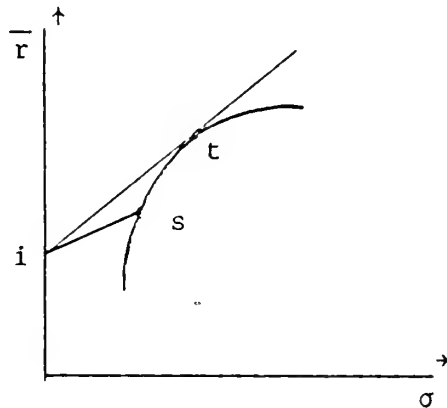


Figure 1

Risk-Return Hedging Analysis

The solution (see Howard and D'Antonio (1984)) yields the optimal risk-return hedge ratio  $b^*$ :

$$x_f^* = b^* = (\lambda - \rho) / \gamma \pi (1 - \lambda \rho) \quad (4)$$

where:

$$\lambda = (\bar{r}_f / \sigma_f) / ((\bar{r}_s - i) / \sigma_s)$$

$$\pi = \sigma_f / \sigma_s$$

$$\gamma = p_f / p_s$$

$\rho$  = correlation between spot and futures returns

$\bar{r}_s, \bar{r}_f$  = expected one-period returns for spot and futures, respectively.

$\sigma_s, \sigma_f$  = standard deviation of returns for spot and futures, respectively.

$p_s, p_f$  = current price per unit for spot and futures, respectively.

The risk-return hedging effectiveness of futures can be measured by comparing the increase in portfolio expected returns for a portfolio which contains futures to one without futures at the same risk level. Figure 1 illustrates how this can be done. In Figure 1 the optimal risk-return hedge ratio  $b^*$  measures the slope of line (i-t) and can be interpreted as the excess (in excess of risk-free return  $i$ ) return per unit of risk available with the use of futures. The slope of line (i-s) measures the excess return per unit of risk available by investing in the spot only. Dividing the slope of line (i-t) by the slope of line (i-s) gives the increase in excess return per unit of risk of using futures and measures the hedging effectiveness (HE( $b^*$ )) of the optimal risk-return hedge ratio:

$$HE(b^*) = \sqrt{(1 - 2\lambda\rho + \lambda^2) / (1 - \rho^2)} \quad (5)$$

For example, an HE( $b^*$ ) value of 1.20 means that the hedger can enhance the portfolio's excess return by twenty percent while maintaining the same risk level.

With regard to the risk-return approach and equations (4) and (5), several comments are in order. First, although the minimum risk hedge ratio (HR\*) and the risk-return hedge ratio (b\*) have the same interpretation, in general the numerical values of two ratios will be different, even for the same spot-futures analysis. Second, the hedging effectiveness measures for the two ratios are different. For HR\*, which is estimated using price changes, hedging effectiveness is measured by  $R^2$  (correlation between spot and futures price changes). For b\*, which is estimated using returns,  $\lambda$  (the risk-return parameter) and  $\rho$  (correlation between spot and futures returns) are both important. Third, although HR\* is usually derived using price changes, its hedging effectiveness can also be gauged on a risk-return basis by:

$$HE(HR^*) = \sqrt{1/(1-\rho^2)} \quad (6)$$

since HR\* is derived under the assumption that  $r_f = \lambda = 0$ . Thus, equations (5) and (6) enable a comparison of the "risk-return" effectiveness of b\* and HR\*, respectively. Finally, it is instructive to note that the risk-return approach is an ex ante method; b\* may not have the highest ex post risk-return effectiveness. Having discussed these methods, we now turn to the empirical analysis and the evidence regarding the hedging effectiveness of energy futures.

## II. Empirical Analysis

The purpose of the empirical analysis is to examine, ex post, the hedging effectiveness of energy futures. The analysis will begin with a description of the data base and sample period. Next, empirical results will be presented regarding hedge ratios determined using the risk

minimization and risk-return approaches. Finally, the ex post risk-return hedging effectiveness of these two approaches will be compared.

#### A. The Data

Currently, three commodity exchanges in the United States trade energy-related futures: New York Mercantile Exchange (NYMEX), New York Cotton Exchange (NYCE) and the Chicago Board of Trade (CBOT). Futures volume and open interest figures indicate particularly heavy trading in three commodities: NYMEX Heating Oil, No. 2 (introduced in 1978), NYMEX Gasoline, Leaded Regular (introduced in 1981) and NYMEX Crude Oil, Light Sweet (introduced in March, 1983).<sup>3</sup> Whereas producers are primarily concerned with fluctuations in crude oil prices, refiners and consumers are also concerned with the volatility in the prices of refined products such as heating oil and leaded gasoline. For this reason, all three commodities and their related futures contracts will be examined in the empirical analysis.

Futures contracts on each of the three commodities call for delivery of 1000 barrels (1 barrel = 42 gallons). Currently, futures contracts trade as far out as 15 consecutive months for heating oil and leaded gasoline and 18 consecutive months for crude oil. Futures prices are quoted by the gallon for heating oil and leaded gasoline and by the barrel for crude oil.

The sample period extends from July 20, 1983 - March 31, 1986. The July 20, 1983 date is chosen to provide for seasoning in the crude oil market and to provide for a common sample period for all three commodities. Figure 2 presents the weekly price series (per barrel) for these three commodities over the sample period. As Figure 2 indicates,



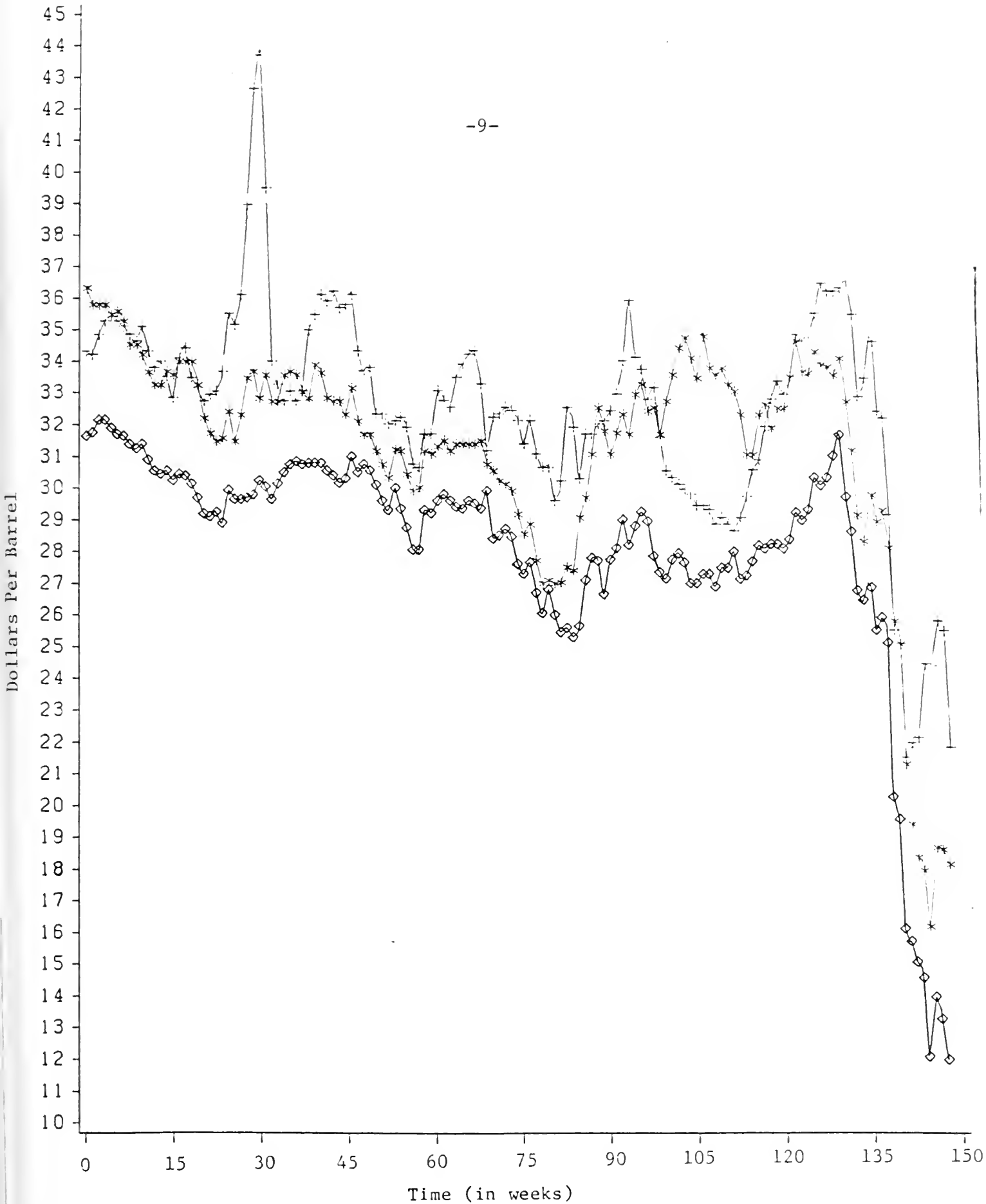


Figure 2

Weekly prices per barrel for Heating Oil (+), Leaded Gas (\*) and Crude Oil (◇) for the period July 20, 1983-March 31, 1986.

energy prices were quite volatile and on average were declining over the sample period.

Because many of the distant futures contracts have limited data, only the six nearby monthly contracts for each of the three commodities are used in the analysis. Futures prices for the six nearby monthly contracts as well as for each of the three commodities are gathered from the Wall Street Journal on a weekly basis using Wednesday closing prices. Although the sample includes 141 weekly spot prices for each commodity, some futures contracts do not have full data for all 141 weeks because on any given Wednesday a particular contract may not trade.

Previous analyses of futures hedging indicate that hedging results can be affected by both the length of the investment horizon as well as the time to delivery of the futures contract.<sup>4</sup> While the choice of any particular hedging horizon provides information about the correlation between spot and futures price changes, its choice necessarily involves an assumption about the period of time for which the hedger desires coverage for the risk of unexpected price changes.

Choosing an appropriate hedging horizon in energy futures is particularly interesting because, unlike many commodities, the energy market deals with a product (oil well) whose production may extend for 10-20 years (or longer). Because existing futures contracts go out only 15-18 months, producers and refiners cannot hedge (at one time) the full value of all future production. Thus, an important decision is at what point should the hedge be placed? Because much of the oil trade operates on monthly delivery cycles, one possibility is to "stack" hedges for the next few months' deliveries. That is, use

futures contracts to place hedges for several months at a time, then as deliveries are made, establish new hedges to cover new future deliveries. However, because the trading is very thin in contracts beyond six months, this strategy seems advisable only for nearby production.

Ideally, an empirical analysis of energy futures would examine hedging horizons ranging from one week to about six months. However, because the crude oil futures market is so new, data limitations restrict this study to hedges of just a few weeks. With this in mind, the data sets are partitioned so as to examine one and two week hedges across contracts separated into six monthly periods representing time to delivery (closest to delivery = one month; farthest to delivery = six months). Partitioning the sample in this manner produces twelve data sets for each of the three commodities.

#### B. Risk Minimization Hedging Results

As discussed in Section I(A), the risk minimization hedge ratio (HR\*) can be estimated via the following regression:

$$\Delta s_t = a_1 + a_2 \Delta f_t + e_t \quad (7)$$

where:  $\Delta s_t, \Delta f_t = s_t - s_{t-1} (s_t - s_{t-2})$  and  $f_t - f_{t-1} (f_t - f_{t-2})$  for one (two) week hedges.

$a_1, a_2$  = regression parameters where  $HR^* = -a_2$

$e_t$  = residual term

Table I presents the statistical results of this regression for the one week hedging horizon while Table II presents the results for the two week horizon.<sup>5</sup>

It is instructive to note several things regarding the results in Tables I and II. First, all hedge ratios are negative and significantly different from zero. Thus, over the period examined, the risk-minimization hedging strategy was a short position in energy futures for both one week and two week investment horizons. Second, the  $R^2$  values are highly significant, especially for the crude oil and leaded gas contracts, and indicate substantial risk reduction potential through hedging across all commodities, contracts and investment horizons. Interestingly, the  $R^2$  values for heating oil are considerably lower than the other two commodities. One factor that may account for this result is the greater seasonality present in heating oil.

Third, the  $R^2$  values indicate that, in general, hedging effectiveness declines with time to delivery for both the one week and two week investment horizons. Thus the closer to expiration a contract is, the more effective it is in hedging energy price risk. This result is consistent with the general findings of earlier studies of other commodities: Treasury Bills (Cicchetti, Dale and Vignola (1981) and Ederington (1979)), GNMA's (Ederington (1979) and Hill, Liro and Schneeweis (1983)), foreign currencies (Hill and Schneeweis (1982)), corporate debt (Kuberek and Pefley (1983)), certificates of deposit (Overdahl and Starleaf (1986)), and corn and wheat (Ederington (1979)). Marmer's (1986) study of Canadian dollars reports mixed results regarding  $R^2$  and time to delivery.

Fourth, in general, the  $R^2$  values are higher for the two week hedging horizon (Table II) which indicates the greater hedging effectiveness for the longer (two week) investment period. This relationship between  $R^2$  and the hedging period is similar to the findings of other

studies of futures: Treasury Bills (Cicchetti, Dale and Vignola (1981) and Ederington (1979)), Canadian dollars (Marmer (1986)), certificates of deposit (Overdahl and Starleaf (1986)), GNMA's (Ederington (1979) and Hill, Liro and Schneeweis (1983)) and corn and wheat (Ederington (1979)).

Fifth, many of the risk minimization hedge ratios are significantly different from one, and, in general, the magnitude of the hedge ratios increases as the hedging period increases from one week to two weeks. This indicates the desirability of the risk-minimization approach in these cases vis a vis a commonly used naive strategy of hedging the spot commodity dollar for dollar with the futures contract. Studies by Cicchetti, Dale and Vignola (1981), Ederington (1979), Franckle (1980), Hill and Schneeweis (1982) and Marmer (1986) generally found hedge ratios to be an increasing function of hedging horizon. On the other hand, Miller's (1982) study of live hog futures found an inverse relationship between the length of the hedging horizon and the magnitude of the hedge ratio. Maness (1981), Miller and Luke (1982) and Overdahl and Starleaf (1986) found no particular relationship between these two variables.

Finally, it is instructive to note that our objective is to present ex post evidence of the hedging potential of energy futures. The hedge ratios presented in Tables I and II are average relationships over the sample period and may vary from period to period.<sup>6</sup>

### C. Risk-Return Hedging Results

The calculation of the risk-return hedge ratios is accomplished by first converting each data set from prices into percentage return equivalents:

$$r_{s,t} = (s_t/s_{t-1})^{-1} \text{ and } r_{f,t} = (f_t/f_{t-1})^{-1} \text{ for one week returns} \quad (8)$$

$$r_{s,t} = (s_t/s_{t-2})^{-1} \text{ and } r_{f,t} = (f_t/f_{t-2})^{-1} \text{ for two week returns} \quad (9)$$

From the series of returns, ex-post average returns and the associated statistics required for Equation (4) can be computed. The risk-free rate  $i$  is calculated as the return on a one (two) week Treasury bill for the one (two) week investment horizon. Tables II and III present the results for  $b^*$ ,  $\rho$  and  $\lambda$  for the one and two week investment horizons.

Consistent with the risk-minimization (price changes) results, there is a strong correlation between spot and futures returns and the correlation declines, in general, with time to delivery for both the one week and two week investment horizon data sets. Furthermore, the correlation in returns increases, in general, with investment horizon.

However, unlike the risk minimization horizon results (but similar to the results presented in Howard and D'Antonio (1986)), not all of the risk-return hedge ratios are negative. If  $1 - \lambda\rho > 0$  (see Equation 4), then  $b^* > 0$  when  $\lambda > \rho$  and  $b^* < 0$  when  $\lambda < \rho$ . In general, we observe these results in Tables III and IV. However, the data in Tables III and IV indicate considerable variation in the value of  $\lambda$  (particularly for the heating oil results), the return/risk parameter. Because  $b^*$  is affected not only by  $\rho$ , but also return/risk ( $\lambda$ ), this can produce considerable changes in both the magnitude as well as the sign (when  $1 - \lambda\rho < 0$ ) of  $b^*$ .<sup>7</sup> Thus, the determination of  $b^*$  can be quite sensitive to the relative values of the parameters (particularly  $\lambda$ ) affecting its value.

D. Risk-Return Hedging Effectiveness--Risk-Minimization vs. Risk-Return

Using Equations (5) and (6), the risk-return effectiveness measures for the risk-return hedge ratios ( $b^*$ ) and the risk-minimization hedge ratios ( $HR^*$ ) are calculated for the one week and two week investment horizons data sets. These results are presented in Tables V and VI.

The results reveal some interesting aspects regarding the ex post hedging effectiveness of these two hedging approaches. First, all of the effectiveness numbers are greater than one, indicating a risk-return benefit to hedging with energy futures. Second, an examination of both tables reveals that, on the whole, the risk-return effectiveness of both  $HR^*$  and  $b^*$  decline with time to delivery. That is, the most effective hedge (whether risk-minimization or risk-return) from a risk-return perspective is the nearby (one month) contract. Exceptions to this (see Table V) are the crude and heating oil one week  $HE(b^*)$  results. The  $HE(HR^*)$  results are not particularly surprising since the risk-return effectiveness measure (equation (6)) increases directly when the correlation in returns increases.

The results also indicate that the risk-return effectiveness improves with the length of the hedging period. With the exception of leaded gas, the two week results (Table VI) are higher than the one week results (Table V). Finally, in most cases, the ex post risk-return effectiveness for the risk-minimization ratios is greater than the risk-return ratios. This result is comparable to the finding by Howard and D'Antonio (1986) that, ex post, the risk-return approach may not provide the highest performance. Thus, although the risk-return hedge approach

would have improved the risk-return performance of the hedger's portfolio, the performance would have been even better by following a risk minimization approach.

### III. Conclusion

Oil price volatility has increased dramatically in the last few years. Energy futures can play a vital role in hedging the oil price volatility faced by producers, refiners and consumers. The empirical evidence in this research shows a strong correlation between futures price movements and spot prices in the crude oil, heating oil and leaded gasoline markets. The hedging results show that a substantial portion of the price risk can be removed through the use of energy futures while at the same time enhancing the hedger's portfolio return.



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Footnotes

<sup>1</sup>Financial exposure to oil price volatility also extends to many governmental units as evidenced in the recent decline in crude oil prices in 1985-1986. For example, it has been estimated that for every \$1 drop in the price per barrel of crude oil, the states of Alaska and Texas will lose \$150 million and \$70 million, respectively, in current tax revenues (USA Today, March 14, 1986, p. 10a).

<sup>2</sup>As Howard and D'Antonio (1984) point out, their zero margin requirement assumption implies that a portfolio containing only futures cannot be represented in Figure 1 because both the expected return and standard deviation of such a portfolio would be infinite.

<sup>3</sup>Futures contracts on unleaded gasoline were recently introduced. Because of their limited data base, these contracts are not included in the analysis.

<sup>4</sup>Prior empirical studies of hedging in futures markets have used a variety of hedging period lengths. In general, studies of financial futures have used shorter investment horizons than studies of agriculturally-related products whose analyses employ storage and/or planting/harvest periods. The table below gives a partial bibliography of prior studies, the commodities examined and the hedging periods used.

<u>Study</u>	<u>Commodity</u>	<u>Hedging Period(s)</u>
Chang and Shanker (1986)	foreign currencies	1 week
Cicchetti, Dale and Vignola (1981)	Treasury Bills	2 and 4 weeks
Ederington (1979)	Treasury Bills, GNMA's, corn and wheat	2 and 4 weeks
Franckle (1980)	Treasury Bills	2 and 4 weeks
Grammatikos and Saunders (1983)	foreign currencies	2 weeks
Hill, Liro and Schneeweis (1983)	GNMA's	1 week
Hill and Schneeweis (1982)	foreign currencies	1, 2 and 4 weeks
Hayenga and Pietre (1982)	beef	2 months
Howard and D'Antonio (1986)	Treasury Bills	1 week
Kahl and Tomek (1982)	potatoes	4, 5 and 6 months
Kopenhaver (1984)	Treasury Bills	3 months
Kuberek and Pefley (1983)	Treasury Bonds and corporate debt	4 weeks
Maness (1981)	Treasury Bills	5 days to 60 days
Marmar (1986)	Canadian dollars	1, 2 and 4 weeks
McEnally and Rice (1979)	corporate debt	1 week
Miller (1982)	hogs	6 and 10 months
Miller and Luke (1982)	beef	3, 6 and 12 months
Overdahl and Starleaf (1986)	certificates of deposit	1, 2 and 13 weeks
Senchack and Easterwood (1983)	certificates of deposit	3 and 6 months

<sup>5</sup> Even though the regressions are expressed in difference form, some of the regressions required correction for first order autocorrelation of the residuals. While this correction preserves the desirable econometric properties of the coefficients, its correction implies that  $R^2$  values (a relative goodness of fit measure) are not strictly comparable, per se. This is because the dependent variable is no longer the same across the corrected regressions.

<sup>6</sup> Each regression was also estimated via the random coefficient approach (see Grammatikos and Saunders (1983) for discussion). While the random coefficient hedge ratios are very similar to those presented in Tables I and II, some regressions showed evidence of non-stationarity. These results are not presented here and are available upon request from the authors.

<sup>7</sup> Results for  $\gamma$  and  $\pi$  which also determine  $b^*$  are not presented here, but are available upon request from the authors. In general,  $\gamma (p_f/p_s)$  is close to 1.00 and the effects of  $\pi (\sigma_f/\sigma_s)$  are incorporated in  $\lambda$ .

Table I

Energy Futures Minimum Risk Hedge Ratio (HR\*) Results (July 20, 1983-March 31, 1986)  
Hedge Duration: One Week<sup>a</sup>

Number of Months Prior to Contract Month	Crude Oil			Heating Oil			Leaded Gas					
	HR*	R <sup>2</sup>	SEE <sup>b</sup>	OBS <sup>c</sup>	HR*	R <sup>2</sup>	SEE <sup>b</sup>	OBS <sup>c</sup>	HR*	R <sup>2</sup>	SEE <sup>b</sup>	OBS <sup>c</sup>
1	-.958 <sup>d,e</sup> (.038)	.821	.349	140	-.848 (.051)	.666	.017	140	-.816 (.043)	.719	.011	140
2	-.859 (.051)	.677	.449	140	-.908 <sup>d,e</sup> (.070)	.548	.019	140	-.843 (.052)	.657	.012	140
3	-.902 (.054)	.672	.453	140	-.829 <sup>d</sup> (.086)	.403	.022	140	-.846 (.055)	.629	.012	140
4	-.968 <sup>e</sup> (.054)	.698	.438	140	-.749 <sup>d</sup> (.087)	.349	.023	140	-.833 (.057)	.620	.012	132
5	-.954 <sup>e</sup> (.056)	.675	.454	140	-.833 <sup>d,e</sup> (.109)	.321	.024	127	-.853 (.067)	.596	.013	111
6	-.898 (.061)	.620	.496	136	-.898 <sup>d,e</sup> (.114)	.383	.024	102	-.836 (.079)	.550	.013	94

<sup>a</sup>Numbers in parentheses are standard errors. All HR\* values are significantly different from zero at the .05 level using a two-tailed test.

<sup>b</sup>Standard error of the estimate.

<sup>c</sup>Number of observations.

<sup>d</sup>The HR\* value reflects the adjustment for first-order autocorrelation of the residuals.

<sup>e</sup>Not significantly different from -1.0 at the .05 level using a two-tailed test.

Table II

Energy Futures Minimum Risk Hedge Ratio (HR\*) Results (July 20, 1983-March 31, 1986)  
Hedge Duration: Two Weeks<sup>a</sup>

Number of Months Prior to Contract Month	Crude Oil			Heating Oil			Leaded Gas					
	HR*	R <sup>2</sup>	SEE <sup>b</sup>	OBS <sup>c</sup>	HR*	R <sup>2</sup>	SEE <sup>b</sup>	OBS <sup>c</sup>	HR*	R <sup>2</sup>	SEE <sup>b</sup>	OBS <sup>c</sup>
1	-1.032 <sup>e</sup> (.049)	.878	.428	64	-1.081 <sup>e</sup> (.065)	.817	.021	64	-.927 <sup>e</sup> (.058)	.805	.013	64
2	-1.095 <sup>d</sup> (.040)	.924	.416	64	-1.103 <sup>e</sup> (.118)	.587	.031	64	-.917 <sup>e</sup> (.072)	.721	.016	64
3	-1.115 <sup>d</sup> (.050)	.892	.498	64	-1.024 <sup>e</sup> (.156)	.409	.037	64	-.900 <sup>e</sup> (.078)	.680	.017	64
4	-1.151 <sup>d</sup> (.055)	.876	.530	64	-.994 <sup>e</sup> (.173)	.348	.039	64	-.888 <sup>e</sup> (.091)	.624	.019	59
5	-1.163 <sup>d</sup> (.065)	.842	.583	64	-1.083 <sup>e</sup> (.207)	.332	.042	57	-.927 <sup>e</sup> (.101)	.633	.019	51
6	-1.119 <sup>d,e</sup> (.082)	.765	.687	60	-1.123 <sup>e</sup> (.252)	.315	.045	45	-.949 <sup>e</sup> (.095)	.708	.017	43

<sup>a</sup>Numbers in parentheses are standard errors. All HR\* values are significantly different from zero at the .05 level using a two-tailed test.

<sup>b</sup>Standard error of the estimate.

<sup>c</sup>Number of observations.

<sup>d</sup>The HR\* value reflects the adjustment for first-order autocorrelation of the residuals.

<sup>e</sup>Not significantly different from -1.0 at the .05 level using a two-tailed test.

Table III

Energy Futures Risk-Return Hedge Ratio (b\*) Results (July 20, 1983-March 31, 1986)  
Hedge Duration: One Week

Number of Months Prior to Contract Month	Crude Oil		Heating Oil		Leaded Gas	
	b <sup>*a</sup>	$\lambda$	b <sup>*a</sup>	$\lambda$	b <sup>*a</sup>	$\lambda$
1	-.810	.558	-.076	.818	-.716	.893
2	-.799	.452	-.203	.740	-.473	.854
3	-.742	.581	.592	.615	-.304	.842
4	-.600	.698	1.284	.588	-.235	.828
5	-.535	.714	1.883	.569	-.082	.830
6	-.290	.780	-10.704	.588	-.470	.789

<sup>a</sup> Calculated using Equation (4).

Table IV

Energy Futures Risk-Return Hedge Ratio (b\*) Results (July 20, 1983-March 31, 1986)  
Hedge Duration: Two Weeks

Number of Months Prior to Contract Month	Crude Oil		Heating Oil		Leaded Gas		
	b <sup>*a</sup>	$\rho$	b <sup>*a</sup>	$\rho$	b <sup>*a</sup>	$\rho$	$\lambda$
1	-.930	.961	-1.065	.921	-.802	.916	.484
2	-.942	.952	3.625	.807	-.267	.860	.780
3	-.866	.927	-13.915	.677	.082	.837	.857
4	-.811	.915	-8.637	.623	1.739	.805	1.044
5	-.735	.902	-7.508	.609	1.243	.808	1.004
6	-.700	.885	-5.416	.598	-.530	.877	.702

<sup>a</sup> Calculated using Equation (4).



Table V

A Comparison of the Ex Post Risk-Return Hedging Effectiveness (HE) of  
the Minimum Risk (HR\*) and Risk-Return (b\*) Hedge Ratios  
Hedge Duration: One Week

Number of Months Prior to Contract Month	Crude Oil		Heating Oil		Leaded Gas	
	HE(HR*) <sup>a</sup>	HE(b*) <sup>b</sup>	HE(HR*) <sup>a</sup>	HE(b*) <sup>b</sup>	HE(HR*) <sup>a</sup>	HE(b*) <sup>b</sup>
1	2.907	1.493	1.740	1.751	2.222	1.508
2	2.449	1.508	1.488	1.010	1.921	1.074
3	2.438	1.285	1.268	1.048	1.851	1.020
4	2.306	1.104	1.237	1.146	1.782	1.011
5	1.188	1.071	1.216	1.208	1.794	1.001
6	1.199	1.014	1.236	1.980	1.682	1.070

<sup>a</sup> Calculated using Equation (6).

<sup>b</sup> Calculated using Equation (5).

Table VI

A Comparison of the Ex Post Risk-Return Hedging Effectiveness (HE) of the Minimum Risk (HR\*) and Risk-Return (b\*) Hedge Ratios  
Hedge Duration: Two Weeks

Number of Months Prior to Contract Month	Crude Oil		Heating Oil		Leaded Gas	
	HE(HR*) <sup>a</sup>	HE(b*) <sup>b</sup>	HE(HR*) <sup>a</sup>	HE(b*) <sup>b</sup>	HE(HR*) <sup>a</sup>	HE(b*) <sup>b</sup>
1	3.600	2.001	2.562	2.983	2.493	1.471
2	3.256	1.834	1.693	1.123	1.963	1.012
3	2.665	1.466	1.358	1.617	1.825	1.001
4	2.484	1.278	1.278	1.961	1.684	1.078
5	2.314	1.172	1.261	2.172	1.696	1.054
6	2.145	1.142	1.248	2.723	2.081	1.064

<sup>a</sup>Calculated using Equation (6).

<sup>b</sup>Calculated using Equation (5).

Oil Prices and Energy Futures\*  
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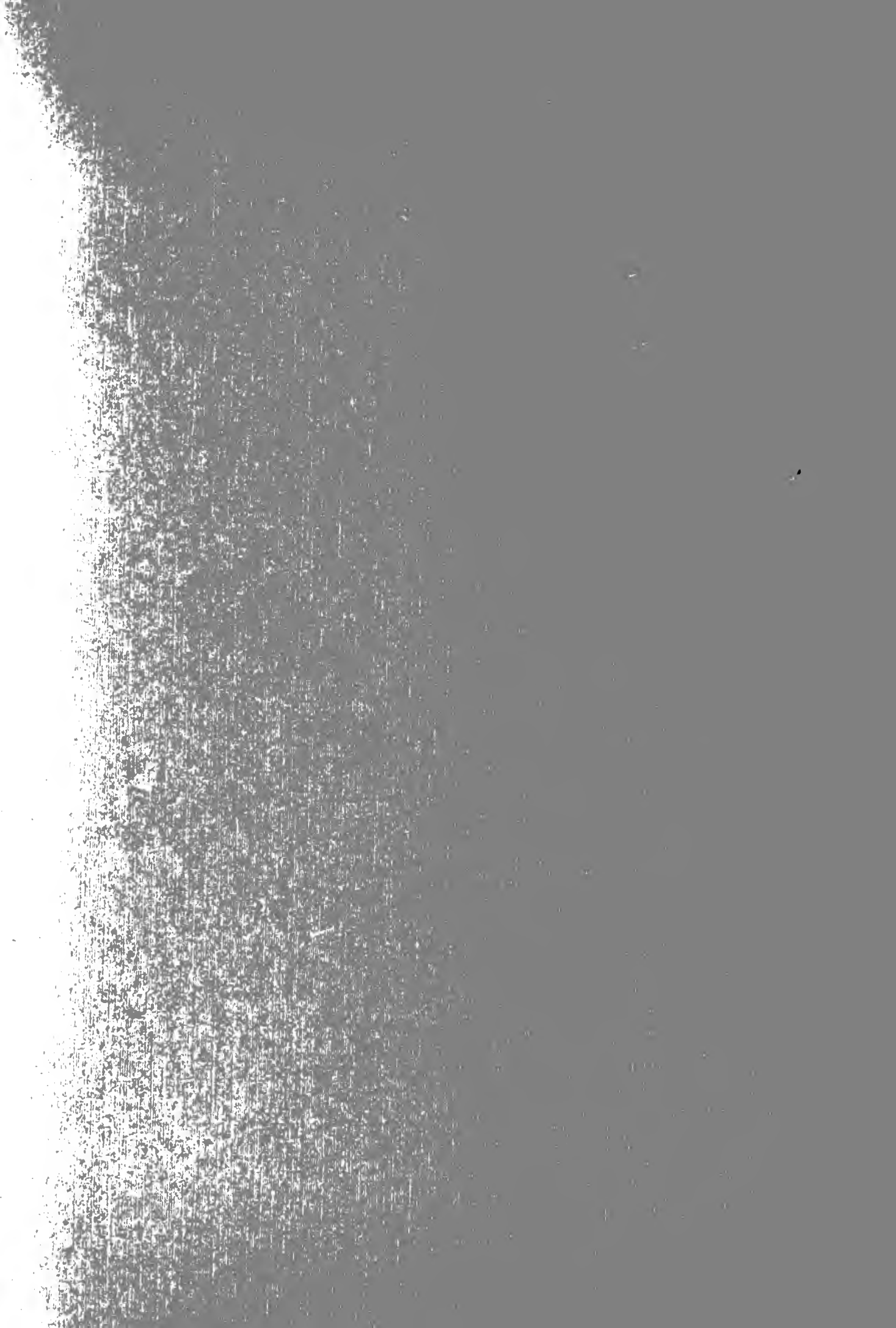
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