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Working Paper

Backwardation and Normal Backwardation in Energy Futures Markets: With an Application to Metallgesellschaft's Short-Dated Rollover Hedging of Long-Term Contracts

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Non-Technical Summary

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Backwardation and Normal Backwardation in Energy Futures Markets

With an Application to *Metallgesellschaft's* Short-Dated Rollover Hedging of Long-Term Contracts

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September 2002

Abstract

We show that, since the inception of energy futures markets, prices have on average exhibited backwardation. Normal backwardation has also been the norm, but, because of the low power of the standard tests, most researchers have concluded that the unbiased expectations model cannot be rejected. The fact that backwardation has been and (though somewhat more weakly) continues to be prevalent makes *MGRM's* strategy of hedging long-term supply commitments with short-dated futures contracts look somewhat better than previous observers have argued. That said, it should be re-stressed that their strategy was a highly speculative one and its unraveling should have come as no great surprise.

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[*] This paper was finished during the stay of Richard Deaves as a guest professor at the ZEW. The author is grateful for helpful discussions and appreciates the hospitality of the ZEW.

1 Introduction

Headline debacles in derivatives markets during the last decade have attracted the attention of many observers. One of the most egregious was the billion dollar plus loss incurred by the German company *Metallgesellschaft* in the early 1990s. This arose as a result of a series of long-term contracts that its U.S. subsidiary, *Metallgesellschaft Refining and Marketing (MGRM)*, negotiated to sell energy products, which was hedged with a program based on short-dated derivatives, and the subsequent liquidation of these positions by the parent company. The wisdom of these actions has been extensively debated (Culp and Miller (1995), Edwards and Canter (1995a, 1995b), Mello and Parsons (1995) and Pirrong (1997)).

Most contentious is the debate over the soundness of, first, the original contractual program; second, the manner in which it was hedged; and third, the rapid unwinding of all positions. Culp and Miller (1995) are the main defenders, believing that the parent company should have weathered the storm, and were unwise to terminate the hedging program because of short-term liquidity problems. Pirrong (1997) has shown that *MGRM's* barrel-for-barrel short-dated hedging program implied significant overhedging. While protection was afforded from *parallel* shifts in the term structure of futures prices, significant exposure still existed to shifts in the *slope* of the term structure. In fact, this researcher shows that a hedge ratio of less than 50% would have been optimal, and that it would have been less risky to remain unhedged than hedge barrel-for-barrel. Neuberger (1999) has recently modeled the problem of an agent hedging a long-term supply commitment with short-dated futures. He suggests that medium-term maturity contracts would likely prove best.

Perhaps *MGRM,* despite claims to the contrary, was speculating rather than hedging (Mello and Parsons 1995). Their hedging program was heavily influenced by a belief that energy markets are typically in backwardation, that is, spot prices exceed futures prices (and short-dated futures exceed longer-dated futures). Backwardation will certainly occur at times for seasonal commodities because of a convenience yield which arises when a commodity is in short supply. Still, their overhedging seems to have been predicated on the view that backwardation would on average hold over long periods of time.

There is a related but somewhat different concept, namely normal backwardation, which exists when *future expected* spot prices exceed futures prices.[1] The extant empirical evidence (Kolb (1992) and Deaves and Krinsky (1995)) indicates that energy futures markets have historically been subject to neither normal backwardation nor normal contango. That is to say, futures prices are unbiased predictors of future spot prices, implying a pure expectations model is appropriate.

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[1] Though usage is not consistent here, I will use *contango* to signify the opposite of backwardation, and *normal contango* the opposite of normal backwardation.

The problem with this finding is that, as we discuss below, *persistent backwardation usually requires the existence of normal backwardation.* Therefore, if normal backwardation does not hold, *MGRM's speculative* hedging program seems to have been on shaky ground.

The purpose of this paper is two-fold. Our first intention is to revisit the *MGRM* debate. While we do not intend to delve into many of the issues ably dealt with by previous commentators, our contribution is to clarify the implication for energy price processes of *MGRM's* view that energy markets are typically in backwardation, using both data that management had at its disposal at the time of the hedge program, as well as data that have subsequently become available. Our second intention is to provide the latest evidence on the potential existence of normal backwardation in energy futures markets. To preview, we conclude that the preponderance of the evidence indicates that backwardation – both in the period up to the *MGRM* crisis, as well during the recent past – was present often enough and in sufficient degree to lead *MGRM* to believe that their strategy might have been a judicious one. On the other hand, we find that a pure expectations model of energy futures prices cannot be rejected (that is, neither normal backwardation nor normal contango holds). We suggest a simple explanation as to why it is possible to reject normal backwardation while at the same time concluding backwardation.

The paper is organized as follows. In Section 2, we consider the contractual position of *MGRM* and how they chose to hedge it. At the same time we address the relationship between backwardation and normal backwardation, and the role played by seasonality. In the next section, we examine the behavior of energy futures prices both prior to and subsequent to the liquidation of *MGRM's* positions, in order to see what the data tell us about the potential existence of backwardation and normal backwardation. In Section 4, we interpret our findings. The final section concludes.

2 The strategy of hedging long-term contracts by rolling over short-dated futures, and its relationship to backwardation and normal backwardation

2.1 The essential nature of *MGRM's c*ontracts

Consider a distributor which has locked itself into a long-term delivery contract but which only acquires the commodity shortly before it must make delivery. The profit (per unit) based on a contract to sell a commodity T periods in the future, hedged by initially going long in a matching number of nearby (single-period) futures contracts that are subsequently rolled over each time a contract reaches delivery, is:[2]

$$\pi_T = c_0 + \sum_{t=1}^{T}[f_t(0) - f_{t-1}(1)] - s_T \qquad (1)$$

where π_T is the distributor's profit as of time-T; c_0 is the long-term contract price negotiated at time-0; s_t is the spot price at t; and $f_t(i)$ is the futures price at t for delivery i periods ahead. This expression says that the firm's profit is the long-term contract price less the final spot price plus the sum of all profits made on the futures contracts, that is, the *cumulative futures returns*. We ignore daily marking-to-market and the compounding of intervening cash flows for simplicity. If energy futures are subject to normal backwardation, the terms in the summation are on average positive. Thus the greater is the extent of normal backwardation, the greater is the likely profit. On the other hand, normal contango tends to reduce profitability.

The above expression can also be written as:

$$\pi_T = c_0 + \sum_{t=1}^{T-1}[f_t(0) - f_t(1)] - f_0(1) \qquad (2)$$

where we have used the fact that the basis converges to zero. This expression says that the firm's profit equals the long-term contract price less the initial short futures price plus the sum of all profits made on the futures contract rollovers, that is the *cumulative futures rollovers*. If crude oil futures are subject to backwardation, the terms in the summation are on average positive, leading to an increase in the profitability of the strategy. On the other hand, if contango is the norm, rollovers would be negative thus reducing the profitability of the strategy.

2.2 Backwardation vs. normal backwardation

It is straightforward to decompose a rollover as follows:

$$f_t(0) - f_t(1) = s_t - E_t s_{t+1} - p_t(1) \qquad (3)$$

where $p_t(1)$ is the risk premium attached to a nearby futures contract. A negative premium indicates normal backwardation, while a positive premium indicates normal contango.

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[2] A rollover is the simultaneous sale of the expiring and purchase of the one-month contracts. While this is a gross simplification of the nature of *MGRM's* delivery obligations and the manner in which they were hedged, the essential idea of hedging a long-term obligation by rolling over short-dated futures is stressed.

To clarify the relationship between backwardation and normal backwardation, it is helpful to use equation (3) and consult Figure 1. Referring to the latter where the axes constitute a decomposition of the (negative of the) right hand side of (3), note that the anticipated price change is the *y*-axis and the risk premium is the *x*-axis. Normal backwardation corresponds to quadrants B and C. The line with a slope of negative unity intersecting the origin equally divides quadrants B and D. All points below this line are consistent with backwardation. Much of the time (areas C and B2) backwardation and normal backwardation go hand in hand.

Of greater interest though are areas wherein one condition holds without the other. Area D1 corresponds to backwardation without normal backwardation, while area B1 represents normal backwardation without backwardation. Of the two, B1 is a much more likely *long-term* scenario. Over the long term (both consumer and commodity) prices tend to rise. The implication is that under normal circumstances, especially over the long term, it is fair to say that backwardation *requires* normal backwardation.

The problem is that, as noted earlier, evidence exists that for most commodity futures most of the time futures prices are extremely close to expected future spot prices. That is, we have a world of pure expectations, not normal backwardation or normal contango (Kolb (1992) and Deaves and Krinsky (1995)). This finding is consistent with the idea that the risk inherent in futures positions is essentially diversifiable and thus should not be rewarded.[3]

Consider the case of pure expectations. If futures prices are unbiased predictors of future spot prices, we can rewrite each rollover as:

$$f_t(0) - f_t(1) = s_t - E_t s_{t+1} \qquad (4)$$

Here the rollover gain is the negative of the expected change in the spot price over the relevant period. If we are in a normal inflationary environment where prices usually creep up, rollovers would be expected to be negative and hence *detract from* profitability. In fact in a competitive market, one would expect delivery contract prices to be set at levels which, given current futures prices, would exactly offset expected losses (because of price increases) on rollovers. That is to say, contracts such as *MGRM's* should be normal-profit arrangements, and the sort of over-hedging that the company utilized was questionable.[4]

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[3] See Dusak (1973), Bodie and Rosansky (1980), Carter, Rausser and Schmitz (1983) and Baxter, Conine and Tamarkin (1985).

[4] In large part it was injudicious because of uncertainty about the future slope of the term structure of futures prices. As was previously stated, *MGRM's* hedging strategy protected it from parallel shifts in the term structure of price expectations but not against changes in the

2.3 Seasonality

Before moving to the empirics, an additional issue pertaining to backwardation and rollovers, namely seasonality, needs to be addressed. It is because of seasonality that backwardation will *sometimes* be expected even if there is a zero risk premium and the *general* price level is expected to rise. To see this, for simplicity suppose we are in a (two-season) environment where the commodity is in short supply during the year's first season *(w)* and is in plentiful supply during the second season *(s)*. Perfect foresight is sufficient to bring out the essentials. We characterize the situation as:

$$\begin{aligned} \ln s_{tw} &= k_1 + k_2 + \ln s_{t-1,s} \\ \ln s_{ts} &= k_1 - k_2 + \ln s_{t,w} \end{aligned} \qquad (5)$$

where $s_{t,x}$ is the spot price at time t and season x; k_1 is the (percentage) trend in the price of the commodity abstracting from seasonality; and k_2 is the percentage by which the real price at w is above the real price at s.[5]

Given a zero risk premium, the s-rollover is $-k_1 - k_2$ while the w-rollover is $-k_1 + k_2$. Provided $k_2 > k_1$ the w-rollover is positive (i.e., backwardation). Such a condition should not be surprising given the seasonal spikes that are observed in energy futures markets. Nevertheless it should be stressed that the average rollover during year t is $-k_1$.

Thus, while backwardation may be expected some of the time, seasonality has no impact on *average* rollovers *over multi-year time spans* (as corresponds to the case of *MGRM*). Moreover it now becomes quite clear that average rollovers are dominated by price level expectations. Over a long sample trends in the price of a commodity will likely not be too far from trends in the general price level. This implies the higher is the average inflation rate, the lower (i.e., the more negative) will be the average typical rollover (and the less likely we are to see backwardation).

3 Evidence on backwardation and normal backwardation

3.1 Results on backwardation

With a dataset consisting of daily closing energy futures price data for the period from January 1984 (January 1985 for gasoline) to December 2000, we begin by

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slope. Stated differently, protection existed for once-and-for-all shifts in commodity prices but not for changes in expected trends.

[5] Of course '*s*' stands for summer and 'w' for winter, and we have assumed – with no impact on the demonstration -- summer is the second season in the year.

generating gains/losses from rolling over futures contracts.[6] Recall that a rollover is calculated under the assumption that a trader, who is long the nearby futures contract, reverses his position on the last trading day of the contract while simultaneously purchasing a second-to-nearby (one-month) contract.[7] The rollover gain or loss (in dollar terms) from this strategy is the difference between the futures price of the expiring contract on its last trading day (which should be very close to the spot price) and the futures price of the one-month contract. That is,

$$\text{Dollar Rollover Gain/Loss } (t) = Roll_t = f_t(0) - f_t(1), \qquad (6)$$

where t is the last trading day of the old contract. In percentage terms, gains and losses are defined as:

$$\text{Percentage Rollover Gain/Loss } (t) = roll_t = \ln f_t(0) - \ln f_t(1). \qquad (7)$$

If backwardation is the norm in these contracts, then gains should occur more often than losses, and on average rollovers should be profitable.

We calculate in Table 1 rollover gains/losses during 1984-2000 (or 1985-2000 for gas), as well as during two roughly equal subperiods. The first is from 1984 to 1992 (or 1985-92 for gas). It is chosen because it runs from close to futures contract inception to just before *MGRM* implemented its hedging strategy, and so it should provide us with some insight into the futures price pattern that the company observed. The second period is from 1993 to 2000. This period is examined in order to ascertain whether the price pattern observed in the first period continued to hold.

Beginning with crude oil in Panel A, for all three periods, the overall averages, in dollar terms, are positive and significant at the 5% level. In percentage terms, the overall averages are significant in the first period and for the full sample, but only marginally so in the second subperiod. This appears to suggest that backwardation existed in the crude oil futures market in these periods. Two other points are salient. First, in all periods, rollover gains occurred only slightly above 50% of the time. Second, the averages of all rollover gains were much higher than the averages of all rollover losses, which explains why the overall averages are significantly positive even if occurrences of backwardation were only slightly more numerous than occurrences of contango.

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[6] Gasoline contracts began trading in January 1985. The data were obtained from the *Futures Industry Association.*

[7] Edwards and Canter (1995) use a rollover rule that is slightly different. Specifically, they use what they term the "three-day rollover rule," where the sale of the old contract and the purchase of the new contract occur three trading days prior to the last trading day of the old contract.

In Panels B and C we report rollover gains/losses for the heating oil and unleaded gasoline futures contracts respectively. As was the case with crude oil futures, both the overall and subperiod averages in these panels are positive and significant (or marginally so) in all three periods. Again, this means that average gains could be obtained from rolling over energy contracts. Nevertheless the rather low frequency of rollover gains (especially for heating oil) suggests that backwardation was far from bankable. Clearly, once again, average positive gains were due to the fact that rollover gains were generally of a higher magnitude than that of rollover losses.

One noteworthy result is that average rollovers for all three commodities, in both dollar and percentage terms, are lower in the second period than in the first period. Moreover, the frequency of rollover gains was also lower in the second period. This implies that rolling over energy contracts may not have been as profitable in the second period as in the first. Performing Chow tests for the differences in averages between the two periods, we note, however, that the null hypothesis of no differences cannot be rejected in any of the three cases.

With Table 2 we investigate seasonality. As mentioned earlier, it is well known that gas prices tend to be higher in the summer because of the greater demand induced by summer driving, while heating oil prices tend to be higher in the winter as the weather necessitates greater usage for home heating purposes. The table provides the frequency of rollover gains by month for our three energy commodities. As we expect, heating oil rollovers tend to positive in the winter and negative in the late summer and fall, while the opposite relationship emerges for gasoline.[8] Given crack arbitrage relationships (Girma and Paulson 1998), not surprisingly there is no strong seasonality for crude oil.

To formally test for seasonality in rollovers, we run the following regression for all three commodities in all three periods:

$$roll_t = c + \sum_{i=2}^{12} S_i + \varepsilon_t, \qquad (8)$$

where $roll_t$ is, as defined earlier, the *percentage* gain/loss from a rollover at time t, c is a constant and S_i, $i = 2$ to 12, are dummy variables for the months of February to December. S_i takes on the value of 1 if $roll_t$ comes from month i and zero otherwise.[9] The null hypothesis is that futures prices do not exhibit seasonal patterns, in which case the coefficients of S_i, $i = 2$ to 12, should be jointly equal to zero. Panel A of

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[8] It is noteworthy that these seasonal patterns were much weaker in the second period than in the first.

[9] For example, if the last trading day of the old contract (i.e., the rollover day) falls in the month of February, S_2 is equal to 1 while S_3 to S_{12} are equal to zero.

Table 3 reports the *p*-values from chi-squared tests of the null hypothesis of no seasonality for all three commodities in all three periods. As expected, the evidence strongly supports seasonality for heating oil and unleaded gasoline, while it fails to reject no seasonality for crude oil.

For the former two commodities then, proper estimation should account for a seasonal effect. There is an additional effect that needs potentially to be accounted for. Any calculations of means and *t*-statistics previously done are based on the assumption of constant variance. It is now well recognized that this is invalid in the presence of the volatility clustering that has been observed for energy futures (Deaves and Krinsky 1992, 1995). Panel B of Table 3 reports *p*-values for Lagrange multiplier ARCH(1) tests against the null hypothesis that lagged squared residuals have no power to explain current squared residuals (i.e., there is no first-order autoregressive conditional heteroscedasticity).[10] The null hypothesis is rejected in three cases – crude oil in the second period and in the combined period, and gasoline in the first period.[11] For these three cases, we re-estimate the mean rollovers (with seasonality where appropriate) using ARCH(1) processes.[12]

The results are presented in Table 4. Of particular note is that the mean rollover goes from being marginally positive to significantly positive (at the 5% level) in the case of crude oil during the second subperiod. Though not shown in this table since the point estimates are unchanged, for cases where seasonality is a factor but homoscedasticity cannot be rejected, the mean rollover also goes from being marginally positive to significantly positive in the case of heating oil during the second subperiod.[13]

To summarize, our results show that for all three commodities in all three periods, backwardation, as measured by the frequency of rollover gains, was not a frequent occurrence. Nevertheless, because rollover gains were generally of a higher magnitude than that of rollover losses, rolling over these three energy contracts was, on average, a profitable strategy, especially in the period prior to 1993. This conclusion is robust to consideration of seasonality and autoregressive conditional heteroscedasticity.

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[10] Where seasonality was previously concluded, these ARCH tests are based on equation (8).

[11] ARCH tests with lags up to six also failed to reject homoscedasticity for cases other than these three.

[12] ARCH(1) successfully accounted for the error structure since further ARCH testing was not able to reject homoscedasticity. The exception was crude oil in the second period, where the test could not reject ARCH in the residuals at lag six.

[13] When we perform a regression (as in (8)) of rollovers on a constant and the seasonal dummies, the overall average rollover is equal to the intercept plus the sum of the 11 dummies divided by 12.

3.2 Normal backwardation

To test for normal backwardation, we calculate returns from holding one-month futures contracts. That is, each month, a one-month futures contract is purchased and then held until maturity. The return (in dollar terms) from this strategy is:

$$\text{Dollar Return }(t) = RET_t = f_t(0) - f_{t-1}(1), \tag{9}$$

whereas the return in percentage form is:

$$\text{Percentage Return }(t) = ret_t = \ln f_t(0) - \ln f_{t-1}(1). \tag{10}$$

If normal backwardation is the norm in energy futures markets, then returns in either form should be positive more often than negative.

Our treatment of normal backwardation follows closely what was done for rollovers so it will be kept brief. Similar to our tests in the previous subsection, we calculate returns over the first, second and combined periods. Tables 5-8 for the most part correspond to Tables 1-4. In Table 5, we see that, in all three periods, the average percentage returns from the three commodities were positive but not significantly different from zero (except marginally so in one case), while the frequency of positive returns was close to 50%.[14] These results do not indicate that normal backwardation was typical in energy markets.

The frequencies of positive returns by month are reported in Table 6. Unlike the case of rollovers in the previous subsection, there does not appear to be any seasonal pattern in the frequencies of positive returns of any commodity. This is corroborated by the *p*-values from chi-squared tests on the null hypothesis of no seasonality in returns as reported in the upper panel of Table 7. In the lower panel of Table 7 we investigate the possibility that the volatility of returns changes through time and is serially correlated. The results of ARCH(1) tests suggest volatility clustering in four cases – crude oil in the first and combined periods, and heating oil in the first and combined periods.

For these four cases, we re-estimate mean returns using ARCH(1) processes. The re-estimated results are reported in Table 8. Mean returns remain positive but insignificantly so in all cases. Nevertheless, somewhat suggestively, crude oil for the first subperiod and the full sample becomes marginally significant.[15]

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[14] Returns are positive at marginal significance for heating oil during the full sample.

[15] We investigate (in the same manner as before) whether first-order ARCH is sufficient to capture the form of the autoregressive conditional heteroscedasticity, and we conclude that this

In summary, our results show that for all three commodities in all three periods, normal backwardation, as measured both by the frequency of positive returns and by their average magnitude, was not typical. In addition, we cannot detect any seasonal pattern in the returns.

3.3 Bivariate-ARCH estimation for crude oil

In this subsection, we re-estimate mean rollovers and returns for crude oil in a systems setting. Such a strategy is called for because simultaneity can cause single equation estimation to be inconsistent.[16] Since earlier we found that crude oil was the only energy commodity where we concluded both rollovers and returns were subject to an ARCH effect, we use a bivariate-ARCH approach, whereby the two means are simultaneously estimated. The two mean equations are:

$$\begin{aligned} ret_t &= c_1 + \varepsilon_{1,t} \\ roll_t &= c_2 + \varepsilon_{2,t} \end{aligned} , \qquad (11)$$

while the variance-covariance equations are assumed to follow:

$$\begin{aligned} \sigma_1^2 &= \omega_1 + \alpha_1 \varepsilon_{1,t-1}^2 \\ \sigma_2^2 &= \omega_2 + \alpha_2 \varepsilon_{2,t-1}^2 \\ \sigma_{12} &= \omega_3 + \alpha_3 \varepsilon_{1,t-1} \varepsilon_{2,t-1} \end{aligned} \qquad (12)$$

This is the diagonal representation of the BEKK model (Engle and Kroner 1995). In this parameterization, variances are determined only by past own squared residuals and covariances are determined only by cross-products of past residuals.

The results of our estimations are reported in Table 9. Noteworthy is the fact that rollovers continue to be significantly positive, while returns though positive, and in fact of greater magnitude than rollovers, continue to be insignificant.

4 Interpretation

How is that we can conclude that backwardation was common enough such that average rollovers were significantly positive while normal backwardation is rejected by the evidence – this despite the fact that we argued above that under normal circumstances backwardation requires normal backwardation?

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is so. For crude oil in the first and combined periods, the ARCH LM-test shows that lag nine is significant.

[16] A systems approach is justified by the fact that the error terms (resulting from univariate ARCH estimation) are highly correlated.

The answer turns out to be quite simple. Consulting the full sample results shown in Table 9, we see that, *logically enough,* on average returns (in percentage terms) exceeded rollovers (in percentage terms). *Less logically,* rollovers are significantly positive while the same cannot be said for returns. In fact it all comes down to variance. The standard error of the coefficient estimate for returns is over three times that of rollovers.[17] Rollovers exhibit less variability because both components of a rollover are contemporaneous, while, for returns, one component is contemporaneous and the other one lagged. Price shocks will have less of an impact on rollovers because both elements of the difference can adjust.

There are a couple of implications to this insight. First, standard tests of futures pricing models typically rely on the calculation of mean returns and their significance (e.g., Kolb 1992). Our evidence suggests that such approaches may have low power. Perhaps they should be supplemented by investigating evidence on mean rollovers. Second, since we have now demonstrated that positive rollovers were no sample-specific artifact only present in the first part of the sample, on this basis it now appears that *MGRM's* strategy is somewhat more defensible. Nevertheless it must still be acknowledged that this is not because they were pursuing a variance-minimization approach, but rather because they were endeavoring to capitalize on a tendency for energy futures markets to display backwardation. Moreover it remains clear that the company was overhedging, and was thus exposing itself to the risk of adverse shifts in the term structure.

5 Conclusion

Since the inception of energy futures markets, prices have on average exhibited backwardation. This finding is robust to considerations of seasonality and volatility clustering. Normal backwardation has also been the norm, but, because of the low power of the standard tests, most researchers have concluded that the unbiased expectations model cannot be rejected. The fact that backwardation has been and (though somewhat more weakly) continues to be prevalent makes *MGRM's* strategy look somewhat better than previous observers have argued. That said, it should be re-stressed that their strategy was a highly speculative one and its unraveling should have come as no great surprise.

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[17] For returns it is 0.0078 while for rollovers it is 0.0027.

Figure 1: Backwardation vs. normal backwardation

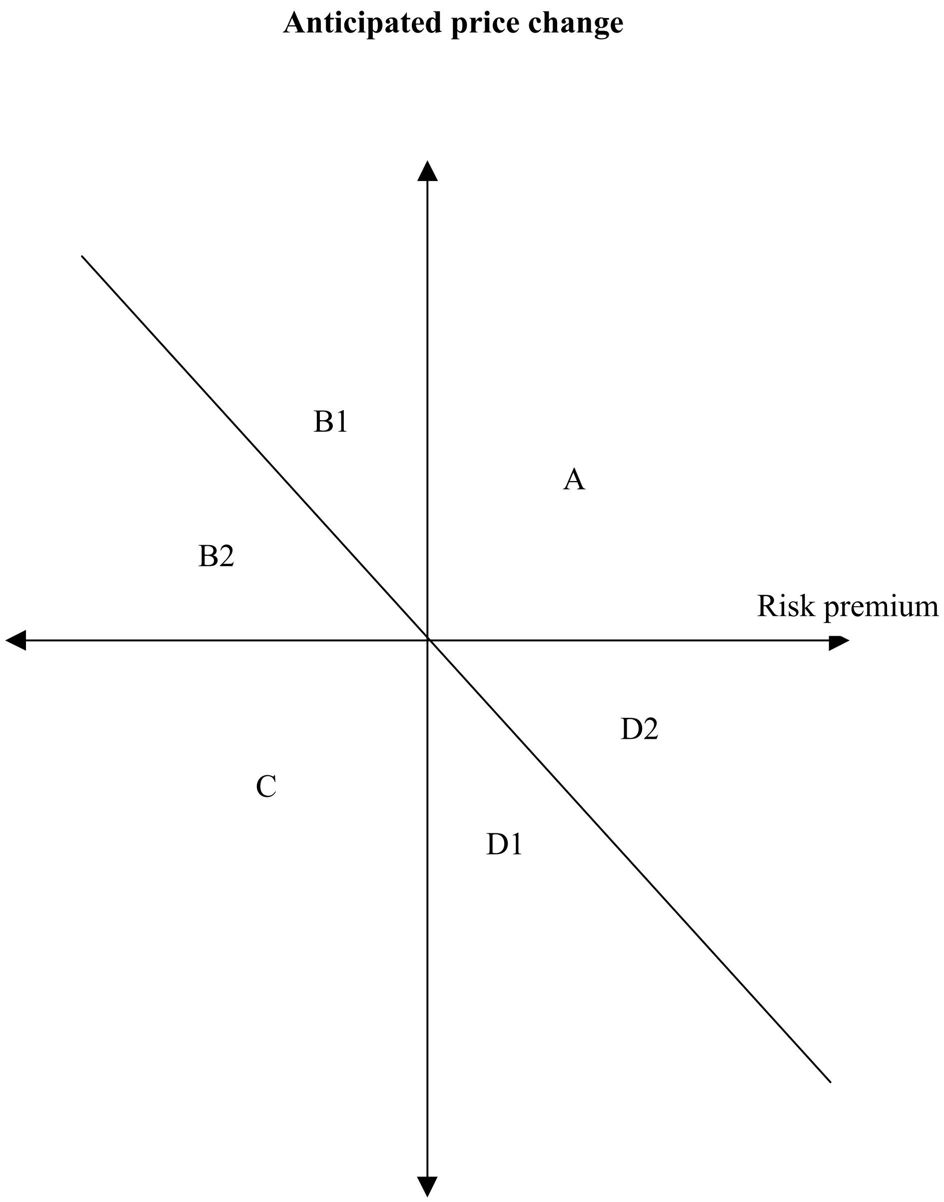

Table 1: Summary of Gains/Losses from Rollovers

Panel A: Crude Oil

	1984 – 1992		1993 – 2000		1984 – 2000	
	$	%	$	%	$	%
Average of All Rollovers	0.22*	0.93%*	0.21*	0.64%$^{\#}$	0.21*	0.79%*
Average of All Rollover Gains	0.65	3.00%	0.71	3.00%	0.68	3.00%
Average of All Rollover Losses	-0.32	-1.69%	-0.27	-1.65%	-0.30	-1.67%
Frequency of Rollover Gains	56%		49%		52%	

Panel B: Heating Oil

	1984 – 1992		1993 – 2000		1984 – 2000	
	$	%	$	%	$	%
Average of All Rollovers	0.43*	1.59%*	0.29*	0.84%$^{\#}$	0.36*	1.24%*
Average of All Rollover Gains	1.28	4.92%	1.12	4.02%	1.21	4.53%
Average of All Rollover Losses	-0.32	-1.30%	-0.25	-2.40%	-0.28	-1.27%
Frequency of Rollover Gains	46%		40%		43%	

Panel C: Gasoline

	1985 – 1992		1993 – 2000		1985 – 2000	
	$	%	$	%	$	%
Average of All Rollovers	0.50*	1.83%*	0.35*	0.90%*	0.43*	1.36%*
Average of All Rollover Gains	0.98	3.74%	1.04	3.55%	1.01	3.66%
Average of All Rollover Losses	-0.47	-2.00%	-0.45	-2.20%	-0.46	-2.12%
Frequency of Rollover Gains	67%		53%		60%	

Notes: 1) * and # denote significance at the 5% and 10% (two-tailed) levels respectively.

2) All dollar rollover gains and losses are reported in $/barrel. Since heating oil and gasoline futures are traded on a $/gallon basis, their dollar rollover gains and losses are multiplied by 42.

3) Data for gasoline futures begin in January 1985.

Table 2: Frequency of Rollover Gains

Month	1984 – 1992			1993 – 2000			1984 – 2000		
	Crude Oil	Heating Oil	Gas	Crude Oil	Heating Oil	Gas	Crude Oil	Heating Oil	Gas
Jan	44%	78%*	38%	63%	50%	38%	53%	65%**	38%
Feb	78%	78%**	25%	50%	50%	0%**	65%*	65%**	13%**
Mar	56%	100%**	38%	63%	63%	63%	59%	82%**	50%
Apr	67%	89%**	75%	75%	50%	50%	71%	71%**	63%
May	56%	78%**	88%**	25%	50%	50%	41%	65%	69%**
Jun	44%	22%**	88%**	50%	38%	25%	47%	29%	56%**
Jul	44%	11%**	75%*	38%	38%	75%	41%	24%*	75%**
Aug	44%	0%**	100%**	25%	13%**	88%**	35%	6%**	94%**
Sep	56%	0%**	88%*	63%	13%**	75%	59%**	6%**	81%**
Oct	44%	11%**	75%**	38%	13%**	63%	41%	12%**	69%**
Nov	78%	33%	63%	50%	38%	75%	65%	35%	69%*
Dec	56%	56%	50%	50%	63%	38%	53%*	59%	44%

Notes: 1) * denotes the case where *percentage* rollover gains/losses are significantly different from zero at the 5% (two-tailed) level.
2) ** denotes the case where both *dollar and percentage* rollover gains/losses are significantly different from zero at the 5% (two-tailed) level.

Table 3: Tests of Seasonality and ARCH in Rollovers

Panel A: *p*-values from Chi-Squared Tests of the Null Hypothesis of No Seasonality in Rollover Gains

Period	Crude Oil	Heating Oil	Gasoline
From 1984 to 1992	0.8604	0.0001	0.0082
From 1993 to 2000	0.8803	0.0055	0.0007
From 1984 to 2000	0.6057	0.0001	0.0001

Panel B: *p*-values from LM tests of the Null Hypothesis of No ARCH (1) Effect in the Rollover Regression Residuals

Period	Crude Oil	Heating Oil	Gasoline
From 1984 to 1992	0.0903	0.7253	0.0279
From 1993 to 2000	0.0171	0.7283	0.5443
From 1985 to 2000	0.0041	0.6452	0.1067

Table 4: Mean Rollover Estimation Using ARCH(1) and Seasonality

Commodity: Period	Effects included in the Adjustments	Mean Rollover Gains/Losses (%)
Crude Oil: From 1993 to 2000	No Seasonality/ ARCH (1)	0.75%*
Crude Oil: From 1984 to 2000	No Seasonality/ ARCH (1)	0.56%*
Gasoline: From 1985 to 1992	Seasonality/ ARCH (1)	1.65%*

Note: * denotes significance at the 5% (two-tailed) level.

Table 5: Summary of Futures Returns

Panel A: Crude Oil

	1984 – 1992		1993 – 2000		1984 – 2000	
	$	%	$	%	$	%
Average of All Returns	0.14	0.60%	0.30	1.00%	0.21	0.79%
Average of All Pos. Returns	1.52	7.35%	1.63	7.67%	1.57	7.50%
Average of All Neg. Returns	-1.58	-7.83%	-1.41	-7.58%	-1.50	-7.71%
Frequency of Positive Returns	56%		56%		56%	

Panel B: Heating Oil

	1984 – 1992		1993 – 2000		1984 – 2000	
	$	%	$	%	$	%
Average of All Returns	0.33	1.25%	0.43[#]	1.30%	0.38[#]	1.27%[#]
Average of All Pos. Returns	2.23	8.55%	2.13	8.43%	2.18	8.49%
Average of All Neg. Returns	-1.72	-6.62%	-1.49	-6.78%	1.61	6.69%
Frequency of Positive Returns	52%		53%		52%	

Panel C: Gasoline

	1985 – 1992		1993 – 2000		1985 – 2000	
	$	%	$	%	$	%
Average of All Returns	0.44	1.60%	0.46$^{\#}$	1.28%	0.45*	1.44%
Average of All Pos. Returns	2.21	8.86%	2.11	7.90%	2.16	8.38%
Average of All Neg. Returns	-1.64	-6.98%	-1.58	-6.88%	1.61	6.93%
Frequency of Positive Returns	54%		55%		55%	

Notes: 1) * and # denote significance at the 5% and 10% (two-tailed) levels respectively.
2) All dollar returns are reported in $/barrel. Since heating oil and gasoline futures are traded on a $/gallon basis, their dollar returns are multiplied by 42.
3) Data for gasoline futures begin in January 1985.

Table 6: Frequency of Positive Returns

Month	1984 – 1992			1993 – 2000			1984 – 2000		
	Crude Oil	Heating Oil	Gas	Crude Oil	Heating Oil	Gas	Crude Oil	Heating Oil	Gas
Jan	56%	44%	63%	50%	25%	63%	53%	35%	63%
Feb	44%	33%	38%	63%	50%	50%	53%	41%	44%
Mar	67%	89%**	75%	50%	63%	75%	59%	76%**	75%**
Apr	89%	67%	75%	75%	75%	75%	82%**	71%**	75%
May	44%	56%	63%	50%	38%	38%	47%	47%	50%
Jun	44%	22%	50%	50%	50%	38%	47%	35%	44%
Jul	56%	67%	38%	63%	63%	50%	59%	65%	44%
Aug	56%	67%	63%	75%	63%**	63%	65%	65%**	63%
Sep	56%	67%	63%	75%*	75%**	63%	65%	71%	63%
Oct	78%	44%	63%	50%	25%**	38%	65%	35%	50%
Nov	44%	33%	13%	38%	50%	50%	41%	41%	31%
Dec	33%	33%	50%	38%	63%	63%	35%	47%	56%

Notes: 1) * denotes the case where *percentage* returns are significantly different from zero at the 5% (two-tailed) level.
2) ** denotes the case where both *dollar and percentage* returns are significantly different from zero at the 5% (two-tailed) level.

Table 7: Tests of Seasonality and ARCH in Returns

Panel A: *p*-values from Chi-Squared Tests of the Null Hypothesis of No Seasonality in Returns

Period	Crude Oil	Heating Oil	Gasoline
From 1984 to 1992	0.6149	0.3045	0.1935
From 1993 to 2000	0.4499	0.4780	0.9521
From 1984 to 2000	0.1689	0.0694	0.1127

Panel B: *p*-values from LM tests of the Null Hypothesis of No ARCH(1) Effect in the Return Regression Residuals

Period	Crude Oil	Heating Oil	Gasoline
From 1984 to 1992	0.0064	0.0268	0.0574
From 1993 to 2000	0.9779	0.7362	0.4472
From 1984 to 2000	0.0010	0.0271	0.0881

Table 8: Mean Return Estimation Using ARCH(1)

Commodity: Period	Mean Returns (%)
Crude Oil: From 1984 to 1992	1.49%$^{\#}$
Crude Oil: From 1984 to 2000	1.04%$^{\#}$
Heating Oil: From 1984 to 1992	1.21%
Heating Oil: From 1984 to 2000	1.40%$^{\#}$

Note: # denotes significance at the 10% (two-tailed) level.

Table 9: Estimations of Mean Rollovers and Returns of Crude Oil Under Bivariate-ARCH

Coefficient	1984 – 1992	1993 – 2000	1984 – 2000
Mean Return	1.47%$^{\#}$	1.39%	1.12%
Mean Rollover	1.04*	0.64%$^{\#}$	0.65%*
ω_1	0.0061*	0.0083*	0.0077*
ω_2	0.0012*	0.0007*	0.0009*
ω_3	0.0016*	0.0014*	0.0013*
α_1	0.6709*	0.0246	0.2465*
α_3	0.0008	0.3707*	0.2183*
α_3	-0.0234	0.0956	0.2319*

Note: * and # denote significance at the 5% and 10% (two-tailed) levels respectively.

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