Hedging Oil Price Risk: Lessons from Metallgesellschaft

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Abstract

Metallgesellschaft Refining and Marketing (MGRM) hedged long term oil commitments on a one to one basis with short term futures. Two very different views on the effectiveness of this hedging strategy exist in the literature. On the one hand, Hanke, Culp and Miller argue that the strategy of Metallgesellschaft was basically sound and effectively reduced MGRM´s oil price risk. On the other hand, a number of authors like Ross, Edwards and Canter, Mello and Parsons argue that instead of reducing its oil price risk, MGRM actually increased risk by using a grossly oversized hedge position. This paper compares both arguments and their underlying assumptions. It shows that the main reason for the diverging views lies in the implicitely assumed time horizon over which risk is measured. The analysis reveals that hedgers with short time horizons will use a small hedge ratio of only about one third, while the 1:1 hedge strategy followed by Metallgesellschaft was very effective when risk is measured over the complete contract length.

We then test the effect of allowing cross hedges that were eligible under the MGRM hedging program on MGRM's short term risk. It is shown that even when risk is measured over a short time horizon, the 1:1 hedge strategy had the potential to significantly reduce MGRM's oil price risk once cross hedges are admitted. Finally, we investigate the adequacy of MG's equity cushion by comparing its equity capital to the minimum equity requirements for banks from the new BIS market risk proposals. It is shown that MG's equity capital of MG was probably not sufficient to cover its oil price risk under future BIS regulations for banks.

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1   Introduction

In December 1993, Metallgesellschaft (MG) was effectively bankrupt after huge losses in its oil business that was conducted in its New York based subsidiary MG Refining and Marketing (MGRM). According to officials at MG´s house bank, Deutsche Bank, the balance sheet losses from its oil business will total approximately 4 billion DM. Losses from MGRM´s derivatives activities in 1993 alone are reported to be 1.25 billion $ (2 billion DM at that time) of which more than 800 Million $ were realized in the fourth quarter alone.[1] Only a massive rescue operation of a large banking consortium kept MG from declaring bankruptcy. After the recent failure of Klöckner in the oil business, MG is already the second large German company that experienced immense losses from oil derivatives trading. Other spectacular losses from derivatives transactions at Proctor and Gamble, Orange County and Barings raise the question, whether corporations can and should use derivatives as a risk management tool. The answer to this question has become more ambiguous through recent academic research which shows wide disagreement as to the proper way to hedge oil price risk in the case of MGRM. On the one hand, authors like Culp, Hanke and Miller repeatedly argued that the 1:1 hedge strategy of MGRM was a basically sound strategy.[2] They claim that MGRM followed a textbook hedging strategy which was not properly understood by MG´s supervisory board and house banks.[3] On the other hand, Edwards and Canter, Mello and Parsons, and Ross argue that a 1:1 hedge strategy was significantly oversized given MGRM´s underlying oil business.[4] These authors claim that the variance minimizing hedge ratio for MGRM´s business was actually below 0.5:1. In this case, the 1:1 hedge strategy would increase MGRM´s oil price risk instead of reducing it.

The dispute is not only of academic interest but also constitutes a crucial point in the legal procedure of MGRM´s former chief trader W. Arthur Benson against Metallgesellschaft Corporation in which he demands compensatory as well as punitive damages. According to Benson, the new MG management team had untruthfully announced that speculative oil deals had led to the massive losses of MGRM. [5] In an interview, MG´s president of the supervisory board, Ronaldo Schmitz, had compared the situation of MGRM with that of someone who lost all his money in a casino and now demands new money in order to continue the game.[6] Among other things, the court thus has to decide whether MGRM´s trading strategy was indeed a speculation or was instead capable to effectively reduce MGRM´s oil price risk.

This paper explores the rationales for both views and argues that a different time horizon implicitly underlying both arguments may at least partly explain the different results. We run several tests which indicate that an investor who wants to hedge oil price risk over a long time horizon will use a considerably higher hedge ratio as a short term oriented investor. We then analyse the effect of allowing cross hedges as were used by MGRM on its short term risk. Surprisingly, the analysis shows that even when risk is measured over a short time horizon, a 1:1 hedge strategy had the potential to effectively reduce MGRM' oil price risk. Finally, we investigate whether MG's equity base was adequate to cover the short term risk of its oil operations.

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[1] Special Auditors Report (1995), p. 58
[2] Culp and Miller (1995a), Culp and Miller (1995b), Culp and Miller (1994), Culp and Hanke (1994).
[3] Culp and Hanke (1994), p. 14.
[4] Edwards and Canter (1995), Mello and Parsons (1995), Ross (1995). See also Falloon (1995) for a similar judgement of oil market professionals. Ross does not explicitly link his analysis to the MGRM case.
[5] Benson (1994).
[6] Schmitz (1995). See also Börsenzeitung (1994).

2 The Oil Business of MGRM

In 1991, MGRM started to market long term OTC oil contracts to its customers. These contracts obligated MGRM to sell a variety of refined oil products at a predetermined price every month for five or ten years.[7] The contract price was determined by the current future prices of the following 12 month plus a margin between 5 and 10 cent per gallon (equivalent to 2.1 - 4.2 $ per barrel). There were two programs that differed in their attached cancellation rights („blow out option") as well as delivery timing options.[8] Under the so called firm fixed program that accounted for 2/3 of the business, the customer had the right to cancel the contract when the front month future price exceeded the contract price. In that case he was entitled to a payment of 50% of the price difference times the amount of outstanding deliveries. During autumn 1993, 50% of the contracts were renegotiated such that exercise would be triggered automatically when the front month future price reached a certain level. The other program was the firm flexible contracts that allowed the customers to choose the time of delivery of the underlying product as long as deliveries did not exceed 20% of its yearly oil purchases. The firm flexible contracts also allowed early termination when the second month futures price exceeded the contract price. In this case the customer was entitled to a payment of the price difference times the outstanding amount. In order to compensate MGRM for the larger flexibility of the customer the contract price was determined by the maximum futures price of the following 12 month plus a higher margin.

The risk management strategy of MGRM specified that „the firm may not engage in speculative trading and therefore may not hold any outright long or short position".[9] Since long term hedge contracts were not available in the market to a sufficient extent, MGRM decided to use short term futures and OTC swaps to hedge its exposure. By rolling these transactions forward at maturity MGRM created a so called stacked hedge. The amount of outstanding futures in barrels was at any time equivalent to the amount of outstanding deliveries. A peculiarity of MGRM´s hedging program was that oil traders were free to choose either gasoline, heating oil or crude oil futures as the appropriate hedge contract.[10] According to the special auditors report, the actual hedge ratio even exceeded 1:1 during autumn 1993 because MGRM initiated its hedging program at the time the contract offer was made. However, contracts with a volume of 7.8 Million $ were not confirmed by the customers and therefore created an temporary hedge ratio exceeding 1:1.[11]

The volume of MGRM´s oil business increased tremendously in 1993. The long term delivery programs started from a volume of 43 Million at the beginning of the year, more than tripled until September 1993 and remained at that level until the end of the year when the liquidation of the portfolio started.

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[7] Special Auditors Report (1995), p 29 ff. A small number of contracts had o duration of only 2 years.
[8] See the Special Auditors Report (1995).
[9] MGRM Policy and Procedures Manual, Section 20.01.
[10] Special Auditors Report (1995), p. 39, Ma (1995), p. 19.
[11] Special Auditors Report (1995), p. 36.

Volume of Firm Fixed and Firm Flexible Contracts	
in Million barrels	
December 1992	43
July 1993	84
September 1993	154
December 1993	150
Source: Special Auditors Report	

In December 1993, MGRM was forced to decrease its derivatives positions after counterparties of OTC transactions refused to prolong swap transactions. Additionally, NYMEX had decreased MGRM´s positions limit by suspending its hedge exemption status. Still open is the question how the following liquidation was performed: According to MG, the delivery contracts with customers and the hedge deals were reduced simultaneously to a volume of 109 Million barrel until February 1994.[12] In contrast, Culp and Miller claim that MG liquidated the whole hedging program before it reduced its long term contract volume and thereby created an open position.[13] In the aftermath of the liquidation, MG also decided to change its hedge strategy and abandoned the 1:1 hedge.[14] In the following section, we want to investigate whether the 1:1 hedge had a sound economic foundation. In order to keep the analysis simple and comparable with the existing papers, we ignore the option components of MGRM´s delivery contracts.

3 Hedging Long Term Commitments with Short Term Futures: the Time Horizon Problem

The diverging views that emerged concerning the effectiveness of MGRM´s hedging program are based on very different analytics. Culp and Miller (1994) base their argument in favour of a 1:1 hedge ratio on a 3 period example with a numerical example in which a firms market value is fully protected against spot price risk by using a 1:1 hedge strategy. In order to make their argument somewhat more transparent, we develop the argument for arbitrary numbers. Consider a firm that commits to deliver 1 barrel of oil in three periods at a price of C. Since the firm has no oil in its storage, it buys it at the time of delivery at then prevailing spot prices. Let the spot price of oil at time t be S_t, the future price of oil in t for delivery in $t+i$ be $F_{t,i}$ and let dS_t and $dF_{t,i}$ denote the change of these values over one period. Note that due to the decreasing maturity of the future $F_{t,i} + dF_{t,i} = F_{t+1,i-1}$ and $F_{t,1} + dF_{t,1} = S_{t+1}$. Culp and Miller make the crucial assumption that the 1 period future price has a constant basis of B, i.e. $F_{t,i}=S_t+B$.[15] In every period, it can buy x_t short term futures in order to hedge its oil price exposure which will result in a cash flow of $x_t\left(S_{t+1} - F_{t,1}\right)$ one period later. Culp and Miller assume an interest rate of zero which makes the present value of the program identical to the sum of its cash flows:

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[12] Metallgesellschaft (1995), p. 15.

[13] See for example Culp and Miller (1995), p. 6.

[14] Special Auditors Report (1995), p. 44.

[15] In their 1995 paper, they use the slightly different assumption $F_{t,i}=S_t(1+b_t)$. Under this assumption, the 1:1 hedge strategy does not eliminate oil price risk in the above formula. Culp and Miller argue that the hedge was nonetheless perfect in the sense that it hedged the present value net of „implicit costs of storage". We do not want to follow this approach here.

$$V = \sum_{t=0}^{2} \left[\left(C - S_{t+1} \right) + x_t \left(S_{t+1} - S_t - B \right) \right] \tag{1}$$

When a 1:1 hedge is chosen such that x_t equals the remaining total delivery commitment ($x_{0=}3$, $x_1=2$, $x_2=1$), this formula reduces to

$$V = 3 \left(C - S_0 - 2B \right) \tag{2}$$

As can be seen, the sum of cash flows is independent of future oil prices. Under the assumption of a constant basis, the 1:1 hedge strategy is thus able to completely eliminate the risk from changing oil prices. The assumption of a constant basis is clearly unrealistic. However, note that the argument continues to hold if the basis is randomly fluctuating in the short run but at the same time its average value over long horizons is not random.

On the other hand, Edwards and Canter derive their risk minimizing hedge ratio by regressing price changes of long term futures on price changes of short term futures. This gives the variance minimizing hedge ratio, if the volatility of wealth is minimized over the next period of time. To see this, suppose that a firm commits to deliver 1 barrel of oil at t_3. The initial market value of this liability is $-F_{0,3}$. Given a position in one period futures of x_0 the market value of both positions one period later is $-F_{1,2} + x_0(S_1 - F_{0,1})$ and has a variance of

$$Var\left(V_1 \right) = Var(dF_{0,3}) + x_0^2 \, Var(dF_{0,1}) - 2x_0 \, Cov\left(dF_{0,3}, dF_{0,1} \right) \tag{3}$$

If the firm minimizes the variance of V_1, the resulting variance minimizing hedge position is

$$x_0^* = \frac{Cov\left(dF_{0,3}, dF_{0,1} \right)}{Var(dF_{0,1})} \, . \tag{4}$$

x_0 is of course identical to the regression as advocated by Edwards and Canter.

When comparing the two approaches, two main differences can be observed: first Culp and Miller make an explicit assumption about the futures price formation while Edwards and Canter do not. Secondly, Culp and Miller investigate the risk over the complete remaining life of the contract while the Edwards/Canter analysis is based on a short term analysis of risk over the next period of time only. In the following, we argue that the differing time horizons are an important reason for the diverging results. The fact that there may be a difference between a short term and a long term view on hedging is explicitly expressed in Benson (1994a, p.4f.) who reports that „it was understood by all involved that the profitability of the program to be embarked upon was never to be looked at as a snap-shot in time, but only on a long-term basis as the long-term commitments fully played out." To investigate the importance of the time horizon, we first develop an analytical framework that is able to encompass both approaches and to show the reasons for their different results.

Suppose as in Edwards and Canter that a firm enters into a delivery contract that specifies the delivery of one barrel of oil in t_3 at a price of C. Let the continuos interest rate used for discounting be r. The present value of the combined delivery and hedge program at different points of time is

$$V_0 = Ce^{-3r} - F_{0,3}$$

$$V_1 = Ce^{-2r} - F_{1,2} + x_0\left(S_1 - F_{0,1}\right)$$

$$V_2 = Ce^{-r} - F_{2,1} + x_0\left(S_1 - F_{0,1}\right)e^r + x_1\left(S_2 - F_{1,1}\right)$$

$$V_3 = C - S_3 + x_0\left(S_1 - F_{0,1}\right)e^{2r} + x_1\left(S_2 - F_{1,1}\right)e^r + x_2\left(S_3 - F_{2,1}\right)$$

(5)

Note that cash flows must be discounted according to the period in which they fall. When choosing its hedge policy in t_o the firm must choose a time horizon over which is wishes to minimize the risk. Suppose for the moment that the firm takes a long term view and wishes the minimize the variance of its value in t_3, i.e. it wishes to minimize the risk of the overall outcome of the delivery contract. When the firm chooses its initial hedge position x_0 it must anticipate its later choices of x_1 and x_2 because the variance of V_3 depends on x_1 and x_2 .The optimal hedge strategy at later points of time can be found by backward induction. Using the fact that $S_3 = F_{0,3} + dF_{0,3} + dF_{1,2} + dF_{2,1}$ and that $S_i - F_{i-1,1} = dF_{i-1,1}$ the only remaining source of uncertainty in t_2 is $dF_{2,1}$ and irrespective of earlier spot and futures price changes the variance of V_3 as seen in period 2 is

$$Var(V_3|t_2) = \left(x_2 - 1\right)^2 Var\left(dF_{2,1}\right)$$

(6)

Clearly the risk minimizing hedge is to set $x_2=1$ which completely eliminates all remaining oil price risk. Given this optimal choice in t_2 we can now solve for the risk minimizing hedge in t_1. Since the time horizon is t_3, the firm now has to choose its hedge ratio such that the variance of V_3 as evaluated in period 1 is minimized under the assumption that $x_2=1$. The resulting variance is

$$Var\left(V_3|t_1\right) = x_1^2 e^{2r} Var\left(dF_{1,1}\right) + Var\left(dF_{1,2}\right) - 2x_1 e^r Cov\left(dF_{1,1}, dF_{1,2}\right)$$

(7)

The variance minimizing x_1 turns out to be

$$x_1^* = \frac{Cov\left(dF_{1,1}, dF_{1,2}\right)}{Var\left(dF_{1,1}\right)} e^{-r}$$

(8)

Now we are in a position to determine the optimal hedge ration in t_0. At that point of time, the firm anticipates that it will choose the optimal values of x_1 and x_2 in the future and will again choose x_0 such that the risk of firm value changes over the remaining time periods is minimized. The risk minimizing value for x_0 turns out to be the following expression:

$$x_0^* = \left\{\frac{Cov\left(dF_{0,3}, dF_{0,1}\right)}{Var\left(dF_{0,1}\right)} + \frac{Cov\left(dF_{0,1}, dF_{1,2}\right)}{Var\left(dF_{0,1}\right)} - x_1^* e^r \frac{Cov\left(dF_{0,1}, dF_{1,1}\right)}{Var\left(dF_{0,1}\right)}\right\}e^{-2r}$$

(9)

The first term is similar to the expression for x_1^* and is identical to the minimum hedge ratio proposed by Edwards and Canter.[16] It is the usual hedge coefficient gained from a regression of the short term futures price change on the long term future price changes. However, the minimum variance hedge ratio formula consists of additional terms when risk is measured over a long time horizon. The additional terms arise from the fact that the current change of the short term future $dF_{0,1}$ may be stochastically linked with the expected hedge returns in periods 2 and 3. Consider for

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[16] The tailing factor e^{-2r} is not explicitly shown in Edwards and Canter but mentioned in the text.

example the second term: When there is a positive correlation between $dF_{0,1}$ and $dF_{1,2}$, a gain on the short term future ceteris paribus tends to increase the value of the delivery commitment which depends on $dF_{1,2}$. Thus the firm would have to buy more protection against rising spot rates and increase its hedge ratio. Equivalently, if the short term future is negatively autocorrelated $\left(Cov\left(dF_{0,1},dF_{1,1}\right)<0\right)$ a profit on the period 1 hedge will ceteris paribus decrease the expected period 2 hedge pay off. Again the firm needs more protection against rising spot rates and will choose a higher hedge ratio.

The results of Edwards/Canter and Culp/Miller can now be shown to be special cases in the above general framework. The hedge ratio of Edwards and Canter turns out to be the risk minimizing hedge ratio when risk is minimized over a short (one period) time horizon. Under this assumption, the firm chooses x_0 as to minimize the variance of its value in t_1. The value of the program in t_1 and its variance can be expressed as

$$V_1|t_0 = Ce^{-2r} - F_{0,3} - dF_{0,3} + x_0\,dF_{0,1}$$

(10)

$$Var(V_1|t_0) = Var\left(dF_{0,3}\right) + x_0^2 Var\left(dF_{0,1}\right) - 2x_0 Cov\left(dF_{0,1},dF_{0,3}\right)$$

Although derived in a different context, the resulting variance minimizing hedge ratio turns out to be the one advocated by Edwards and Canter:

$$x_0^* = \frac{Cov\left(dF_{0,1},dF_{0,3}\right)}{Var\left(dF_{0,1}\right)}$$

(11)

The hedge strategy advanced by Edwards and Canter is therefore the strategy that minimizes the risk of short term wealth changes in the above framework. Alternatively, the Edwards and Canter strategy is optimal for the long time horizon investor, when future price changes fulfil the OLS conditions $\left(Cov\left(dF_{0,1}dF_{1,2}\right) = Cov\left(dF_{0,1},dF_{1,1}\right) = 0\right)$. When these conditions are met, equations (11) and (9) collapse and the time horizon has no effect on the minimum variance hedge strategy.[17]

Also the 1:1 hedge strategy of Culp and Miller can also be derived as a special case of the general framework if we assume that future price changes satisfy the OLS conditions, that all futures have the same volatility, that future prices are perfectly correlated and finally that the interest rate is zero. In that case it is easy to verify that x_0 in equation (9) turns out to be *1*. However, this is of course only one among many combinations of variances and covariances that result in a 1:1 hedge strategy. Thus while the specific assumptions made by Culp and Miller are clearly unrealistic, their resulting hedge strategy may not necessarily be wrong for hedges over a long time horizon.

The difference between of the optimal hedge ratio implied by equation (9) and hedge ratios gained through regressions of high frequency data will to a large extent depend on the autocorrelation structure of future price changes. When prices follow random walks and thus satisfy the OLS conditions, it is well known that the minimum variance hedge ratio gained through a regression of the Edward and Canter type does not depend on the considered sampling interval.[18] However, it is

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[17] This assumes that the tailing factor is first applied to the Edwards Canter hedge ratio.
[18] See for example Duffie (1989).

well known that many commodity futures show long term seasonalities.[19] Moreover, it is a well established empirical fact that it is often difficult to reject the random walk hypothesis using high frequency data although long term changes show a high degree of predictability.[20] In order to assess whether oil price changes fulfil the OLS conditions, first order autocorrelations of future price changes over different time intervals were calculated. An approximate test of significance was carried out using large sample confidence intervals.[21] The results indicate that first order autocorrelation of daily changes is small and mostly insignificant. In contrast, first order autocorrelations of price changes over longer time periods such as several month are large and generally highly significant. As an example, first order autocorrelations of spot and future price changes over 125 days are given in the table:

First order autocorrelation of price changes over 125 days		
	Maturity	*Autocorrelation*
Heating Oil	0	-0.250 ***
	1	-0.262 ***
	6	-0.222 **
	12	-0.286
Gasoline	0	-0.278
	1	-0.291
	6	-0.281 **
	12	-0.268
Crude Oil	0	-0.326 **
	1	-0.325 **
	6	-0.244
	18	-0.210
*** (**) indicates significance at the 99% (95%) level		

Given this high degree of autocorrelation, it is obvious that the time horizon of a hedger will be affected by the chosen hedge ratio. The next section empirically investigates the risk minimizing hedge ratio when a long time horizon is assumed.

4 Estimation of Hedge Ratios for Long Time Horizons

The question whether the 1:1 hedge strategy proposed by Culp and Miller is valid for long horizon investors, can be answered only empirically. The fact that minimum variance hedge ratios may dependent on the considered time horizon is a well documented fact in the hedging literature.[22] Chen, Sears and Tzang provide evidence that minimum hedge ratios based on a one and two week time horizon differ, with hedge ratios being larger in the two week case. [23] Froot[24] considers a much larger range of time horizons for the problem of hedging foreign exchange rate risk from foreign

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[19] Fama and French (1987).

[20] Froot (1993), Cochrane (1988).

[21] Standard errors of autocorrelation coefficients of order τ for large samples are approximately given by

$$n^{-.5}\left[1+2\left(r_1^2+r_2^2+...+r_q^2\right)\right]^{.5}$$ for $q = \tau -1$, where n is the number of observations. See Granger and Newbold (1977), p. 76.

[22] See for example Stoll and Whaley (1993), p. 58.

[23] Chen, Sears and Tzang (1987). See also their references for similar results in other markets.

[24] Froot (1993).

investments. He shows that the minimum variance hedge ratio of foreign stock holdings change dramatically when the time horizon is changed: Over short time horizons, the risk minimizing hedge strategy is close to 1:1 hedge while over time horizons of many years, the optimal hedge ratio is close to zero. Given his results, a hedge strategy that is effective in the short run not only fails to reduce risk over long time horizons but actually significantly increases long term risk. Similar evidence is provided by Siegel[25] who calculates minimum variance portfolios of stocks and bonds over different time horizons. While the risk minimizing portfolio over 1 year has only 6.2% stocks, this amount increases to 72.1% when a 30 year time horizon is chosen.

The studies of Froot and Siegel are both based on extremely long time series reaching back to the last century. For the case of oil price hedging, a severe limitation in estimating long time horizon hedge ratios lies is the nonavailability of sufficient long term data series. Unfortunately oil futures were not traded until the early 80th and the empirical data of the early years of trading is notoriously incomplete due to market illiquidity. The existing data series therefore provide only limited evidence on oil market dynamics over long holding periods. Another problem with estimating hedge ratios over long time horizons is the fact that exchange traded futures cover only future contract maturities up to 12 (for heating oil and gasoline) and 18 month (for crude oil). However, MGRM traded delivery contracts with maturities up to 10 years. The estimation of the variance minimizing hedge ratio from equation (9) for the case of MGRM thus requires variance and covariance estimators of future price maturities up to 10 years which cannot be estimated from empirical data.

This paper applies several approaches in order to derive reasonable hedge ratios for long term hedge strategy in the case of MGRM: First we show that OLS conditions are violated in the Edwards and Canter regression and that the regression coefficients in the analysis of Edwards and Canter are highly sensitive to the sampling interval over which price changes are measured. Second, we perform a historical simulation where historical profits and losses of delivery contracts over the complete contract length for different hedge strategies are simulated. Third we test the robustness of our historical simulation results by performing similar simulations for contracts with shorter maturities.

4.1   The Impact of the Sampling Interval on Estimated Hedge Ratios

In our first test, we investigate whether hedge ratios gained from a regression analysis as in Edwards and Canter depend on the time lag between two observations. If the OLS conditions are met, regression coefficients should be independent of the sampling interval, i.e. the time distance between two observations should not affect the regression results. However, the long term autocorrelations reported above indicate that OLS conditions may not be satisfied. Canter and Edwards report that the Durbin Watson statistic of residuals did not show significant autocorrelation. But the Durbin Watson test tests only for first order autocorrelation and fails to identify autocorrelations of higher order. We used the Breusch-Godfrey test[26] in order to test for higher order autocorrelation in the estimated residuals of the regression. When daily price changes were used, there is indeed no first order autocorrelation as indicated by the Durbin Watson statistic. We find significant residual autocorrelation for lags higher than the second (for heating oil and crude oil) and the sixth order (for gasoline). To get a first impression of the importance of these effects, we repeat the regression of Edwards and Canter for different sampling intervals and report the resulting minimum variance hedge ratios:

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[25] Siegel (1994), p. 299.
[26] Greene(1993). p. 426.

Regression coefficient from $\mathbf{D}$(Lag x)F(t,T)=$\mathbf{a}$+$\mathbf{b}$ $\mathbf{D}$(Lag x)F(t,1)+$\mathbf{e}$ for different time lags			
Lag in days	Heating Oil 12 month	Gasoline 12 month future	Crude Oil 18 month future
1	0.42	0.47	0.37
5	0.48	0.46	0.43
20	0.59	0.61	0.44
60	0.63	0.71	0.49
120	0.77	0.72	0.62
240	0.77	0.72	0.62
Regression estimates of Relationship between front month and long term futures prices. Daily Futures price data rolled at expiration from Jan 1985- Feb. 1995 were used.			

The table shows a considerable increase in the regression coefficient when the sampling interval is increased, indicating that the sampling interval has a profound effect on hedge ratios. While the analysis shows the hedge ratio is not invariant to the time horizon considered, it cannot be used to directly derive hedge ratios for long term investors. The reason is that the short term future matures within the sampling period. The change of short term futures prices over long time periods therefore does not accurately specify the profit and loss of holding a short term future over long time intervals. An estimation of hedge ratios over long time horizons must therefore account for the fact that the final pay off is determined by the pay off of continuously rolling short term futures forward. Additionally, regression analysis cannot be used to deliver hedge ratios for the case of MGRM because no long term futures are traded.

4.2 Historical Simulation of Pay Offs from MGRM´s Oil Program

Fortunately, a historical simulation of contract pay offs prevents both problems of regression analysis and is easily conducted. While we cannot determine the market value of a 5 year commitment at any point of time, we can nonetheless simulate the exact pay offs from MGRM´s oil program by calculating its cash flows over the complete contract duration for different historical start dates. If a hedge strategy is effective in the long run, it should produce a low volatility of final outcomes when applied to actual historical data. To evaluate this volatility, we simulate the final outcome of a long term oil delivery program for different historical start dates and for different hedge strategies. We simulate the outcome of a 5 year delivery programs which obligates MGRM to deliver one barrel of oil every month for 5 years after the start date. One problem in the historical simulation is the large variety of potential hedge strategies since we can choose different hedge ratios for all 60 one month periods in the sample. In order to reduce the hedge strategy choice problem to one single number, we restrict attention to exponential hedge strategies. According to this strategy, one barrel of oil to be delivered in time T is hedged with an amount

$$x_t = e^{-dT} \tag{12}$$

of short term futures. The exponential hedge strategy is a generalized form of the familiar „tailing the hedge" strategy[27] with a tailing factor of δ. When the tailing factor is 0, the strategy implies the 1:1 hedge proposed by Culp and Miller. It can be easily shown that the exponential hedge strategy

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[27] See for example Duffie (1989), p. 239.

encompasses the variance minimizing hedge strategy if all returns are i.i.d., interest rates are constant and the correlation between futures and spot prices is one. In this case, the tailing factor δ of the minimum variance hedge turns out to be the interest rate. Additionally, Ross[28] has shown that this strategy is risk minimizing when the spot price follows a mean reverting process and the market price of basis risk is zero. He also shows that this strategy has desirable robustness properties when the stochastic process is not known.

In the historical simulation, the present value of all cash flows over 5 years is calculated as a function of the tailing factor δ. Monthly crude oil futures prices that are rolled at expiration is used to calculate the monthly pay offs. Oil price data from January 1984 until January 1995 is used. From this data, 73 overlapping observations of 5 year contracts starting between January 1984 and January 1990 are calculated. The one month federal funds rates were used to discount cash flows. In line with the MGRM practice for the firm fixed program, the contract price is set to be the average of the futures prices with maturities up to 9 month at the start date plus a margin of 2.1 \$. Then we calculate the volatility of the resulting present values and its mean for different values of δ. These results are summarized in the following chart which shows the risk return combinations for different values of δ:

Risk Return Trade Off from Historical Simulation
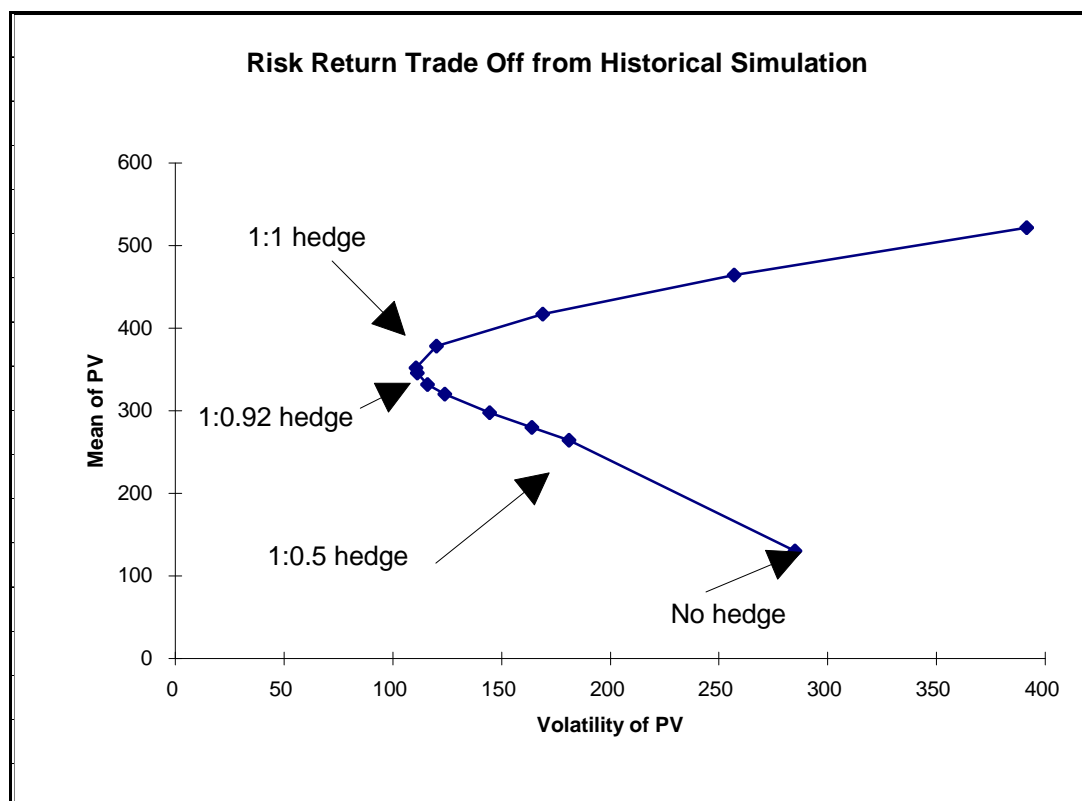
The hedge ratio displayed in the chart is the hedge ratio at the contract start date implied by the specific exponential strategy under consideration. As can be seen, the 1:1 hedge performs surprisingly well over long time horizons. Contrary to the conclusion of Edwards and Canter, it is far less risky than not hedging at all. It is also considerably less risky than the 1: 0.5 hedge strategy proposed by Edwards and Canter. The risk minimizing hedge strategy turns out to start with an initial hedge ratio of 1: 0.92. The diagram also shows that large hedge ratios are considerably more

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[28] Ross (1995).

profitable that small ones. This effect is due to the well known fact that oil future markets have been in backwardation much more often than in contango. The strategy of simply rolling forward one month oil futures therefore was on average profitable in the past. An investor who aims to optimize his risk reward trade off instead of simply minimizing his risk would therefore choose a hedge ratio which is higher than the variance minimizing hedge ratio.

It is interesting to compare our results with the simulation results of Ross (1995) which qualitatively confirm the Edwards and Canter result. Ross does not perform a historical simulation but generates random samples of possible oil price path over nine years using a bootstrap algorithm on daily price changes. In one simulation he generates random future and spot price paths by resampling independently historical returns of holding the front month future and the spot price return. By assuming independence between daily returns, his analysis clearly fails to account for possible long term seasonalities in oil price data.

4.3 The Issue of Precontractual Risk

One interesting difference between the hedge ratio estimation from a historical simulation and a traditional analysis should be noted: the issue of pre contractual risk. The usual regression analysis covers only postcontractual risk that arises after the delivery contract has been signed because it is only concerned with wealth changes after the contract is signed. In the historical simulation, the present value of all cash flows depends both on postcontractual price changes and the contract price fixed at the start date. If the contract price equals the market price of a forward with appropriate maturity, then the very act of signing a delivery contract does not create or destroy wealth on its own. However, the contract price in the case of MGRM was the average of short term futures prices, which will only by chance equal the (unknown) price of long term futures. The empirical evidence indicates that high spot prices tend to be associated with a decreasing future price curve (a backwardation situation) and vice versa.[29] If futures prices have predictive power for future spot prices and MGRM sells in a time of low spot prices, its contracts tend to have negative present value at the contract start day and vice versa. MGRM could offset this risk by buying more short term futures because these compensate the precontractual loss from increasing spot prices.

Due to the limited amount of historical data, the results of the historical simulation must be interpreted with caution. Nonetheless it provides clear evidence that hedge estimates based on the same empirical data may be very different when one changes the time horizon. In order to check both the importance of precontractual risk and the robustness of our simulation results, we repeat the simulation for a one year delivery contract of crude oil. Neglecting interest rate effects, the present value of cash flows is:

$$V_t = C_t - S_{t+12} + \sum_{s=t}^{t+11} e^{-d(t+12-s)/12}\left(S_{s+1} - F_{s,1}\right); \tag{13}$$

The variance of present values derived from all cash flows during the contract period was calculated for all monthly start dates between November 1983 and February 1994. Since 12 month futures prices are available for the considered time period, we can separately calculate present values with and without precontractual risk. 3 different hedge ratios are reported in the table below: First the slope from regressing monthly changes of 12 month futures on 1 month futures as calculated as in Edwards and Canter. Second the initial hedge position from an exponential hedge strategy that minimizes the variance of the outcome after one year is calculated when the contract delivery price C_t is the 12 month forward price at the contract start date, i.e. there is no precontractual risk. Third,

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[29] Ross (1995).

we introduce the maximum possible amount of precontractual risk into the contract by replacing the delivery price C_t by the current spot price S_t and again report the resulting initial risk minimizing hedge position.

Minimum Variance Hedge ratios from hedging 1 year delivery contracts with 1 month futures	
1 month time horizon	0.51
1 year time horizon without precontractual risk	0.64
1 year time horizon with precontractual risk	0.87
based on monthly crude oil futures prices 1983 - 1995	

The table shows that lengthening the time horizon increases the risk minimizing hedge ratio. However, the consideration precontractual risk leads to a further significant increase of the minimum variance hedge ratio. In the example, the effect introduced by precontractual risk is even larger than the time horizon effect. Whether this was also the case in the MGRM simulation cannot be determined definitely since the decomposition in pre- and postcontractual risk requires a valuation of the delivery commitment at any point of time. If precontractual risk is important, one may wonder whether the assumption in the historical simulation that MGRM sells one barrel of oil every month is indeed realistic. Since futures prices have predictive power in respect to future spot prices,[30] customers may realize that their expected pay off from the delivery program is higher when the futures market is in contango, i.e. long term futures prices exceed short term prices. In times of backwardation, the contract price exceeds the expected future oil price and customers may be reluctant to enter into the contract. This view is consistent with the observation that MGRM experienced a large expansion of its contract volume during summer 1993 when the market was in contango.

5   Cross Hedges and the Amount of Risk Assumed by MGRM

The preceding evidence shows that the 1:1 hedge strategy MGRM had taken made good sense when MG took a long term perspective on risk: Contrary to the short horizon analysis, the strategy was effectively reducing oil price risk and it produced positive expected hedging profits. In this section, we want to extend the analysis in two directions: First, we want to investigate the impact on hedge ratios of the fact that MGRM did also use cross hedges. Since MGRM´s oil traders had the freedom to choose between gasoline, heating oil and crude oil futures, the minimum variance hedge ratio may be different from the single product case considered so far. Second we want to examine whether MG had enough equity capital to bear the short term price risks of its oil program. Even when the 1:1 hedge strategy made sense in the long run, its success depended on the ability of MG to absorb temporary losses. The preceding analysis implies that a 1:1 hedge strategy comes at the cost of substantial short term risk. We want to investigate, whether the equity capitalization of MG was sufficient to cover this risk.[31]

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[30] See Ross (1995).

[31] Mello and Parsons[31] argue that the real risk of MG was not oil price risk bur liquidity risk. Since the cash losses from its hedge program were only compensated by unrealized gains from their delivery contracts, the program could be carried out only when enough liquidity was available. The argument of Mello and Parsons is certainly valid in a world of highly imperfect capital markets. However, MG had strong ties to its house banks and there is little reason to believe that these banks would not be willing to lend to MG as long as enough collateral in the form of unrealized gains from their delivery contracts was available. The much larger danger for MGRM was probably the fact that the 1:1 hedge strategy created a very high probability that temporary short term losses would wipe out the firms equity capital.

As a measure to quantify MG´s ability to absorb short term losses, we use the value at risk approach as defined by the BIS proposals[32] which will define the future minimum equity capitalization for banks engaging in securities and derivatives trading. Since the main competitors of MGRM were banks, it is interesting to know whether MGRM would have been able to carry out its program if it were a bank under future capital standards. The BIS defines value at risk as the maximum loss within a 99% confidence interval measured over a ten day holding period. The required bank equity base must exceed 3 times its value at risk of its trading book (plus the equity cushion needed to cover credit risk). Three methods are allowed to calculate value at risk: the variance covariance approach, historical simulation, and Monte Carlo simulation. Since MGRM traded only forward delivery contracts and futures which do not carry convexity risk, a Monte Carlo simulation in this case will coincide with the variance covariance approach.[33] Thus, we calculate value at risk for both the variance covariance approach and the historical simulation.

The variance covariance approach is an application of Markowitz portfolio theory to the risk of arbitrary trading positions. Two basic assumptions are needed to derive the maximum loss within a 99% confidence interval of a portfolio of positions: returns are assumed to follow a multivariate normal distribution and portfolio profit is approximated with a local first order Taylor series expansion of the pricing functions of every portfolio position. Under these assumptions, the portfolio profit is also normally distributed and the worst loss is the appropriate percentile of the resulting density function. The profit over the next 10 days is thus calculated as

$$\boldsymbol{p}_{t+10} = \sum_i \frac{\P PV}{\P S_i} S_{t,i} r_{S_i}, \qquad (14)$$

where S_i are the stochastic risk factors that affect the present value of positions and r_{Si} is the risk factor return measured over 10 trading days. If returns of the underlying risk factors are multivariate normally distributed, it can be shown that the profit is normally distributed with a standard deviation of

$$\boldsymbol{s}_p = \sqrt{\frac{\P PV}{\P S} S \sum S \frac{\P PV}{\P S}}, \qquad (15)$$

where r is the vector of current risk factor values and $\sum$ is the variance covariance matrix of risk factor returns measured over 10 days. If expected risk factor returns are set to zero, the worst loss within a one sided 99% confidence interval can be determined as the appropriate percentile of the normal distribution function:

$$VaR = 2.33 \boldsymbol{s}_p. \qquad (16)$$

In the case of MGRM, the underlying risk factors were the price of the physical delivery contracts with customers and the one month futures price of the hedge contracts used. For the value at risk calculation, we neglect the option component of the delivery contracts. The resulting present value functions are thus simply the product of positions size and the appropriate future prices. One problem in estimating MGRM´s value at risk is the fact that MGRM made physical delivery contracts of a large variety of refined oil products, some of which are not traded on any futures

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[32] Bank for International Settlements (1995).

[33] The analysis neglects the option components of the delivery contracts which would introduce some convexity risk.

exchange (for example aviation gasoline).[34] For our risk estimation we assume that MGRM had only physical delivery positions in gasoline and heating oil for which futures prices exist. Of course, this assumption neglects some spread risks and is therefore likely to underestimate true risk. Another problem lies in the unavailability of long term futures prices necessary to value MGRM´s delivery contracts. We therefore assume that the futures price with the longest available maturity (i.e. 12 month futures for gasoline and heating oil) is a reasonable proxy for the long term forward prices. Since two thirds of MGRM´s positions were established in 1993 and had mostly original maturities of 5 and ten years, this assumption clearly underestimates the risk of MGRM. One peculiarity of MGRM´s hedge strategy was the fact that hedge positions were established in either the gasoline, heating oil or crude oil market. By shifting the hedge positions from market to market, MGRM intended to profit from short term price imbalances.[35] We account for this fact by calculating value at risk for alternative choices of the hedge markets. Finally, the exact distribution of physical delivery contract over the various oil products is not publicly available. We thus assume different combinations of gas and heating oil commitments that sum up to the total commitment as reported in the special auditors report.

Finally an evaluation date for which value at risk shall be determined must be chosen. We take the 30th September 1993 as the evaluation day, because the annual balance sheet was derived for this day so that we can compare MGRM´s value at risk with MG´s equity at that day. Furthermore the total amount of delivery contracts apparently reached its peak during autumn 1993. We use the volume of delivery contracts reported in the Special Auditors Report for September 1993 which is 154 Million barrels.

For the historical simulation, the profit and loss from risk factor changes over historical 10 day periods is calculated with the same approach as for the variance covariance approach. After ordering the resulting profits and losses, value at risk is determined as the 99% percentile of the resulting empirical frequency distribution. Both the historical simulation and the variance covariance method use 400 (overlapping) 10 day return observations covering a time interval between February 1992 and September 30th 1993.

For different alternative hedge strategies, the resulting value at risk figures are shown in the following table:

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[34] See special auditors report (1995), p. 31.
[35] Special Auditors Report (1995), Ma (1995).

No.	Description	Comment	Delivery contract Position*		Hedge Position*			Value at Risk**	
			Heating	Gas	Heating	Gas	Crude	Var/Cov	Hist. Sim.
1	no hedge		-154	0	0	0	0	169	161
2	"		0	-154	0	0	0	291	464
3	"		-77	-77	0	0	0	200	258
4	1:1 hedge		-154	0	154	0	0	230	278
5	"		0	-154	0	154	0	284	301
6	"		-77	-77	77	77	0	188	193
7	"		-77	-77	0	0	154	137	140
8	Min. Variance	no crude futures	-77	-77	65	19	0	114	125
9	"	only crude futures	-77	-77	0	0	101	103	125
10	"	only heating futures	-154	0	59	0	0	117	102
11	"	only gasoline futures	0	-154	0	80	0	226	373
12	"	all futures	-77	-77	23	4	73	100	124
13	"	1:1 hedge, all futures	-77	-77	15	7	132	136	121
14	Max. Variance	1:1 hedge, all futures	-77	-77	0	154	0	283	240
			* in Mio barrel					** in Mio. $	

The first three positions derive value at risk for different physical delivery contract scenarios under the assumption that no hedge position had been entered into. The following 4 positions assume some possible 1:1 hedge alternatives that may have been chosen by MGRM. Positions 8 through 12 show the minimum value at risk that could have been reached by hedging in the three available hedge markets without the 1:1 hedge restriction. Finally, position 13 and 14 shows the minimum and maximum value at risk that might have been obtained by using a 1:1 hedge strategy.

The table reveals that MGRM's value at risk of MGRM was huge in comparison to its equity base for most cases considered. MG´s equity capital was 1,118 Million DM, which in September 1993 was equivalent to less than 700 Million $. Under BIS guidelines, the equity base must exceed tree times its value at risk such that MG's equity was able to cover at most a value at risk of 233 million $. In many cases, the value at risk exceeded this limit. This is especially true if risk were measured by the historical simulation method. The generally higher figures for the historical simulation method reflect strong deviations of some oil future returns from the normal distribution. Even if the oil program of MGRM was the only risky activity of the whole MG group, MG´s equity under some scenarios did not fulfil the future BIS regulation. In light of the fact that our analysis is likely to underestimate the true risk and given the fact that MGRM was by far not the only risk taking unit of MG, it appears that MG was grossly undercapitalized as compared to the BIS regulative guidelines.

Given the large value at risk figures, it is interesting to investigate whether the simpler „standard method“ proposed by the Bank for International Settlements[36] may result in lower equity requirements. The standard approach derives the required equity cushion as a simple linear function of the nominal positions. Risk reducing effects from hedge transactions with the same product are acknowledged with a simple reduction formula that depends on the maturity difference between the offsetting transactions. (Forward Gap Formula). The Bank for International Settlements proposes to considers two products to be the same if their correlation coefficient exceeds 0.9. Since the return correlations between crude oil , heating oil and gasoline are all below 0.9, MGRM´s required equity depends on whether the hedges were executed in the same product or a cross market. Under the most favourable assumptions, the resulting equity capital turns out to be 566 Million $. If all hedge deals were placed in cross hedges, both hedge deals and physical commitments would be treated as simple open positions producing equity requirements of as much as 2,533 Million $!

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[36] Bank for International Settlements (1995).

The table also shows that a 1:1 hedge strategy was able to significantly reduce value at risk as compared with the no hedge alternative *if* the hedge was placed in the right hedge products. When delivery contracts were evenly divided between gasoline and heating oil contracts, the 1:1 hedge could have reduced value at risk from 200 to 136 million $ according to the variance covariance method. When risk is measured with the historical simulation method, risk could have been reduced even more (by 53% from 258 to 121 million $). By giving up the 1:1 hedge restriction, it is possible to further decrease value at risk, albeit only by a smaller extent (a further 26% from 136 to 100 according to the variance covariance method). We can thus conclude that the 1:1 hedge strategy had the potential to effectively reduce risk even when risk is measured over a short time horizon. The inclusion of cross hedges thus reverses the Edwards/Canter result according to which a 1:1 hedge strategy tends to increase risk. The main reason for this result is the fact that the risk minimizing hedge strategy makes heavy use of cross hedges in crude oil contracts which were not considered by Edwards and Canter. Cross hedges are attractive because 12 month gasoline future returns have a much stronger correlation with front month crude oil prices than with front month gasoline prices.[37] As a consequence, a risk minimizing hedge of gasoline delivery contracts will obviously include crude oil futures.

Although a 1:1 hedge strategy had the potential to effectively reduce risk, this effect is by no means guaranteed. By placing the hedge in „wrong" hedge products, it is even possible to substantially increase value at risk as compared to the no hedge alternative. (Value at risk under the variance covariance method increases by 36% for the case of heating oil contracts.) This demonstrates that MGRM's risk management guidelines were not an effective tool to control its oil price risk. By only prescribing a 1:1 hedge restriction without further restricting the hedge products, the guidelines left so much freedom to MGRM's traders that these could either increase or decrease value at risk as compared to the no hedge alternative.

6   Conclusion

The diverging views on the appropriateness of MGRM´s 1:1 hedging strategy that have appeared in the literature can be traced back to different underlying time horizons that are implicitly assumed. This paper shows that investors with long time horizons will consider a much higher hedge ratio as risk minimizing as compared to short horizon investors. Using a historical simulation which simulates final contract pay offs at maturity we find that a 1:1 hedge ratio was capable to substantially reduce MGRM´s oil price risk over the long run.

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[37] This result is empirically robust in respect to the considered time period. See for example the similar correlation patterns used by MGRM for the period 1985 - 1994 which are reproduced in Ma (1995).

Furthermore, the existing literature neglects the effects of cross hedges as employed by MGRM. When cross hedges are included in the analysis, it is shown that even over a short time horizon, a 1:1 hedge ratio had the potential of significantly reducing the risk assumed by MGRM. However, the 1:1 hedge strategy was not able to guarantee an effective hedge because it did not specify the hedge products to be used. There exist 1:1 hedge strategies which even lead to a higher short term risk as compared to the no hedge alternative. MGRM's risk management guidelines thus were not effective in forcing traders to use the futures markets in a way that reduced its overall oil price risk.

While the exact composition of MGRM's portfolio is not known, it is safe to say that the short term risk was very large in comparison to MG's equity base. If MG would be subject to the future BIS regulation of market risk for banks, MG had probably not been able to run such large positions.

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