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Price Protection Strategies for an Oil Company

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Abstract

Crude oil price volatility has a significant impact on the planning decisions and budgets of oil companies. Taking account of such major activities as supply, storage, transformation and transportation together with trading on the commodity markets, we investigate the influence of random prices and demands. Such problems may be formulated as dynamic stochastic programmes with robust first stage solutions in the face of future price and demand uncertainties. In this paper we describe the trading environment and investigate hedging policies in coordination with the logistics planning problem.

Keywords: risk management; dynamic stochastic programming; strategic planning; uncertainty modelling; real options

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1. Introduction

In this paper we attempt to link the results of our research into logistics planning for a consortium of oil companies with uncertain demands and prices, which has recently been carried out in a European Community ESPRIT project[1] [3, 4, 5], with our current work on risk management and real options evaluation. Logistics planning deals with supply, transformation, storage and transportation activities in a complex network structure over various planning horizons (strategic decisions for the long term and tactical for the medium term). As a feasible solution to such problems is seldom achieved initially, it is common practice in industry to search for a solution by minimizing the cost of infeasibilities and correspondingly adjusting constraints [9]. When internal resources of companies are exhausted (or in surplus) excess demand (or supply) may be handled externally by buying (or selling) the required products in the spot commodity markets.

In the course of our the ESPRIT project we observed the importance of trading activities and proposed elimination of infeasibilities through trading. This problem has been formulated as a dynamic stochastic programme with additional variables representing the trading activities and leads to robust first stage solutions in the presence of future price and demand uncertainties [3].

The volatility of crude oil prices has a significant impact on the planning decisions and budgets of oil companies. It is common for producing companies to develop some sort of financial plan called a *hedging program* just to insure that the company is protected against a collapse in crude oil prices. Here we propose to integrate such financial planning with logistics planning. We illustrate the importance of this integration with the example of the Metallgesellschaft (MGRM) financial collapse. This spectacular loss of nearly 1.9 billion dollars is usually presented as an example of a derivatives program gone wrong and is studied by risk managers [1, 7, 8, 11]. It is still debatable whether it was ‘unhedgeable risks, poor hedging strategy, or just bad luck’ [8] or was it simply speculation on the derivative markets? To answer this question we look at the Metallgesellschaft case as a stochastic optimization problem. Analysis of the MGRM case points to where the deficiencies in hedging occurred and leads to the formulation of an integrated logistics and financial planning problem.

[1] HChLOUSO: Hydrocarbon and Chemical Logistics under Uncertainty via Stochastic Optimization

A brief description of oil commodity markets and traded instruments is given in Section 2 of the paper, where the volatilities of oil price products are illustrated graphically. The case of Metallgesellschaft is analysed in detail in Section 3. A general stochastic programming framework which allows integration of logistics and financial decisions is proposed in Section 4. We conclude with some general remarks on the advantages and drawbacks of stochastic programming models in the area of corporate risk management, real options and strategic logistics planning.

2. Volatility of oil markets

As oil prices play a significant role in the planning decisions of oil companies, it is worth examining their behaviour throughout the years. Until the late 1960s, the price of oil – crude oil and petroleum products – was relatively stable and most oil companies were entering into long-term agreements with the oil producing countries in order to satisfy their needs. However, the formation of OPEC (Organisation of Petroleum Exporting Countries) in the 1960s marked a new era for oil prices. OPEC countries now produce around 40% of the world's crude oil and their oil exports represent about 60% of the oil traded internationally. By controlling supply OPEC have a great influence on oil prices and have a great impact on the oil industry.

Figure 1 shows the price of crude oil from 1948 to 2000. The figure shows a steady increase in the crude oil price until 1973. Between 1973 and 1974, the oil price increased suddenly from \$2.90 to \$12.00 per barrel due to an oil embargo, resulting from changes in resource ownership. Between 1974 and 1978, oil prices continued to rise more gradually, but the Iranian crisis of 1978 and 1979 caused a sudden increase in price from \$12 to \$30 per barrel. The OPEC decision to increase production of crude oil in 1986 caused a sharp decline in oil price to the level of \$12. The Gulf War is also easily identified on this historical picture of crude oil prices and all these political and economic factors exposed companies to significant price risk. The present price of crude oil at over \$32.00 (25.8.00) exceeds the level of 1979 and has become a significant factor in current economic policy.

In this paper we will analyse the bear market of 1992-95 which was marked by the MGRM affair. The definition of *hedging* as a means of protection against losses is very generic and actually leads to a variety of different strategies for companies. It has

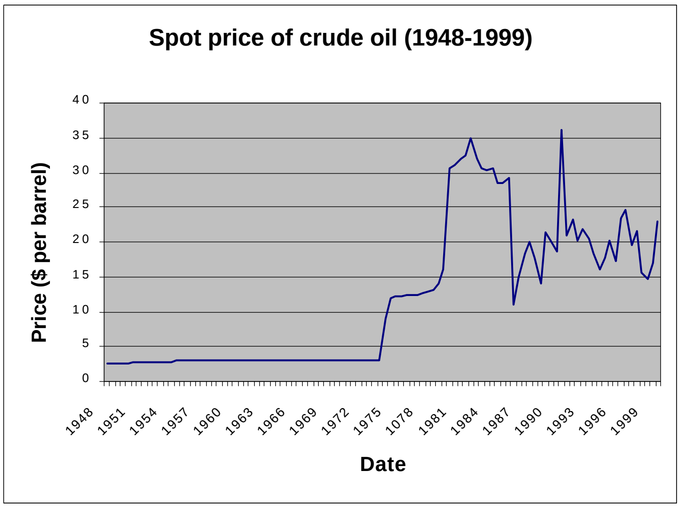

Figure 1. Spot price of crude oil

also led to the emergence of an oil derivatives market and a variety of hedging instruments – forwards, futures and options with different maturities. Nowadays oil futures are among the most actively traded futures in the world. Crude oil, heating oil #2, unleaded gasoline and natural gas are traded on the New York Mercantile Exchange (NYMEX) and Brent crude and gas oil are traded on London's International Petroleum Exchange (IPE). The data presented in Figures 2-4 (all traded on the NYMEX) shows 1-month, 2-month, …, 15-month crude oil futures from 1983 to 1999, heating oil #2 futures from 1978 to 1999, and unleaded gasoline futures from 1984 to 1999.The data is constructed from daily data by extracting all Fridays to obtain weekly data and estimating all missing data using linear interpolation.

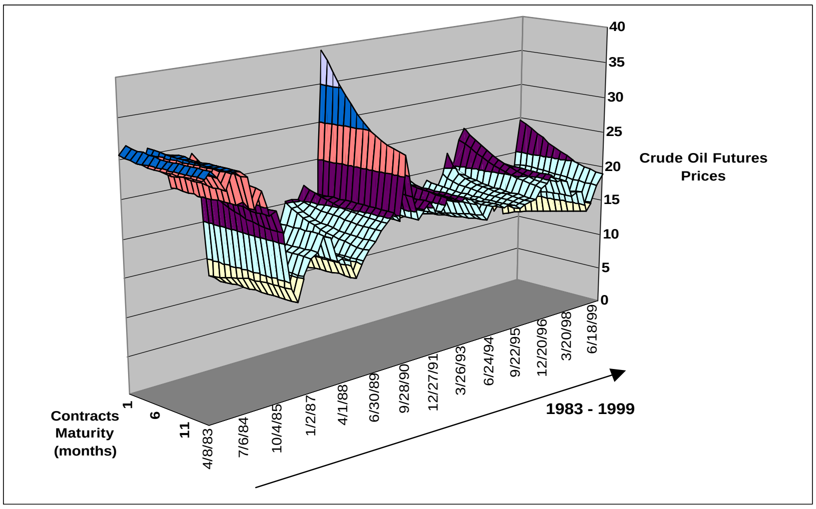

Figure 2. Crude oil futures prices

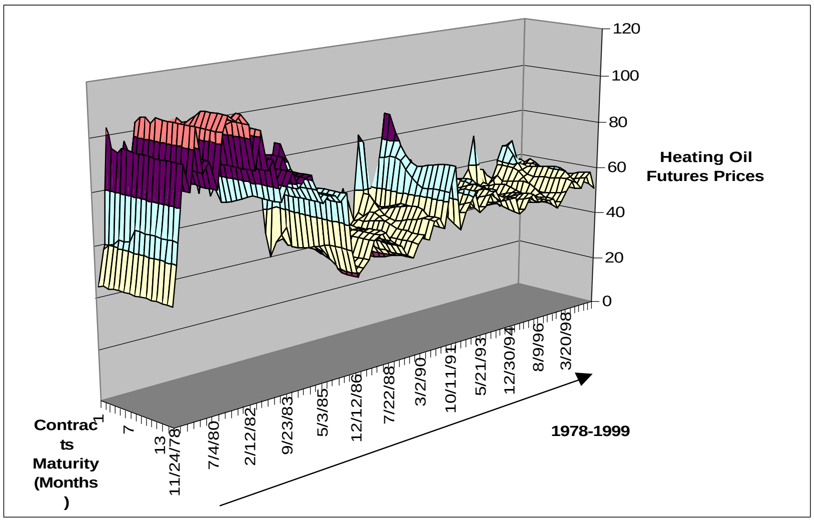

Figure 3. Heating oil #2 futures prices

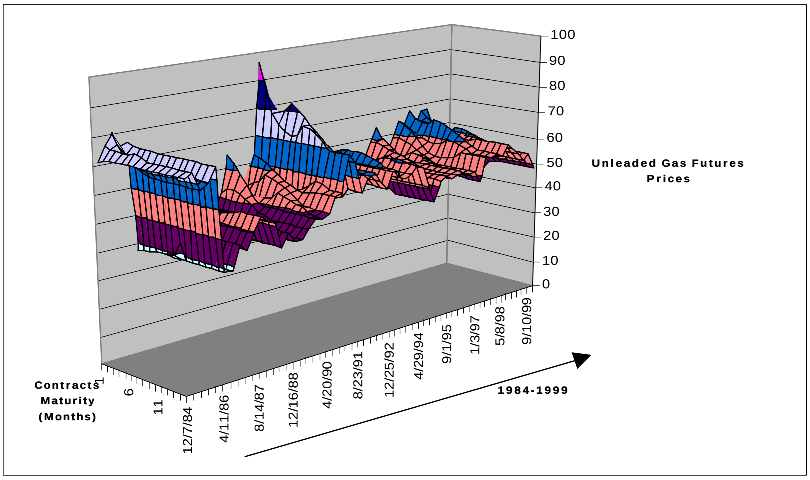

Figure 4. Unleaded gas futures prices

The relations between spot and future prices define market conditions. The market is in *backwardation* when futures prices are below the spot price and in *contango* when futures prices are above the spot price. For commodities such as oil products which incur significant costs of physical storage over time normal market conditions lead to backwardation.

Oil companies usually enter forward supply contracts which commit them to supply final product volumes, such as heating oil and unleaded gas, to end-users at specific time points in the future at fixed prices. The companies also enter forward contracts with their suppliers of crude oil, which commit them to buy crude oil at specific time points at fixed prices. If crude oil prices fall below the fixed price specified in a forward-supply contract, then the company finds itself in the unprofitable position of being contracted to buy crude oil at prices above spot prices. Similarly, if oil product prices rise above the fixed price specified in the contracts, then the company is in the position of having to sell its products at prices below spot prices at a loss of potential profit. Of course, when crude oil prices move appropriately the company may also find itself in a profitable position. In an ideal situation, one can achieve a so-called *perfect hedge* which completely eliminates the risk associated with a future commitment to deliver by taking an equal and opposite position in the futures market. However, this strategy implies the existence of futures contracts that exactly match the supply commitments. Depending on the maturities of forward contracts, the availability of matching futures and the creditworthiness of other derivative product alternatives varies. Even today, there is no oil futures contract with maturity greater than 36 months ahead (i.e. 3 years). Using merely long-term over-the-counter (OTC) -- i.e. tailor-made -- derivatives might expose the company to great credit risk -- setting aside the difficulty of `finding' an appropriate counterparty in the first place given the illiquidity of long-term OTC derivatives. In fact, choosing an appropriate hedging strategy to reduce price risk is a complex practical problem that needs careful consideration. It is important to examine the state of the futures markets when rebalancing any hedging portfolio and when deciding on the optimal *hedge ratio.* In the sequel we will consider situations when the market is either in *backwardation* or *contango* together with the effects of these states on the performance of the hedging strategy.

A recent RISK volume on crude oil hedging [] starts with the simple message: ‘there is no consistent easy way to obtain speculative profits from trading in crude oil financial markets’. The same could be said regarding the consistent success of an oil company’s strategies as an energy purchaser, energy transformer or energy producer. Existing complex strategies of large oil companies transform the company’s complete dependence on spot oil prices into a variety of exposures to forward, futures and option markets. The case of Mettallgeselschaft is one of such attempt which we next formulate as a stochastic optimization model.

2. The case of Metallgesellschaft

In 1993-1994, MG Corporation (the US subsidiary of Metallgesellschaft A G) lost on its positions in energy futures and swaps over $1.9 billion when prices for crude oil, heating oil and gasoline fell sharply. Some reports characterized MGRM's oil trading activities as 'a game of roulette', but another view is that its derivatives activities were in fact part of complex strategy -- a fully-integrated oil business in the United States. MGRM's efforts to develop a fully-integrated oil business in the United States are witnessed by the following facts:

- Long-term customer relationships based on forward-supply contracts: approximately 160 million barrels of gasoline and heating oil over 10 years at fixed prices -- $3 or $5 a barrel higher than spot prices with a 'cash-out' option for counterparties.
- MGRM acquired a 49% interest in Castle Energy, a US oil exploration company which then became an oil refiner.
- In order to assure a supply of energy products it purchased Castle's entire output of refined products (about 126,000 barrels a day) at guaranteed margins for up to ten years into the future.
- MGRM set out to develop an infrastructure to support the storage and transportation of various oil products.

As the financial part of their overall strategy, MGRM decided to maintain a *one-to-one hedge*, which means that MGRM's total derivatives position was equal to its forward-supply commitments, i.e. 160 million barrels. The hedging portfolio consisted of short-dated energy futures -- one-month or two-month futures contracts with underlying products being WTI crude oil, heating oil and gasoline, traded on the NYMEX -- and three-month OTC swaps, in the proportions 33% and 66% respectively.

Given their long-term forward supply commitments and their hedging portfolio of short-term derivatives, MGRM followed a *stack and roll* strategy. More particularly, four days before expiration, MGRM would close out its positions in the near-month futures and buy new futures contracts. On each settlement date, the total position in futures and swaps was reduced by the amount of product delivered to end-users during that period as part of the forward-supply agreements, maintaining always a one-to-one hedge.

At the end of 1993, MGRM reported large losses on its positions in futures and swaps. As a result of a fall in oil prices, margin calls on its futures positions and losses on the rollover costs of maturing futures and swap positions were incurred. Unfortunately for MGRM the oil futures market was in contango for most of 1993, which meant much larger costs than normal when it rolled its derivatives positions forward. Mathematical formulation of MGRM's hedging strategy clarifies the pitfalls encountered.

3.1 Mathematical formulation of MGRM's strategy

Sets

P = {products} = {crude oil, heating oil, gasoline}

D = {derivatives} = {monthly futures, OTC swaps}

$D^h = \{d \in D$: d is used to hedge exposure to heating oil prices}

$D^g = \{d \in D$: d is used to hedge exposure to unleaded gasoline prices}

F = {monthly futures}

S = {OTC swaps}

T = {time periods}

Parameters

$p^c_{p,t}$: cash *inflow* upon selling a unit of product p in period t (set in the forward-supply agreements).

$\boldsymbol{f}_{d,t}$: *price* of derivative contract d in period t. We assume that this is the random price of derivative d when it is *purchased* by MGRM.

$\boldsymbol{spot}_{d,t}$: *spot price* of the underlying product of derivative d in period t. We assume that this is the price of derivative d when it is *sold* by MGRM.

$demand_{p,t}$: fixed *demand* for product p in period t (in fact, the volume of the supply commitment for time period t).

$maturity_d$: the *maturity* of derivative d.

Variables

$V^+ := \{V^+_{d,t} : d \in D,\ t \in T\}$, where $V^+_{d,t}$ is the *volume* of derivative *d purchased* during time period *t* – (*purchasing*).

$V := \{V_{d,s,t} : d \in D,\ s,t \in T,\ s \leq t\}$, where $V_{d,s,t}$ is the *volume* of derivative *d* purchased during time period *s* and *held* during time period *t* -- (*holding*).

$V^- := \{V^-_{d,s,t}\ d \in D,\ s,t$ Î $T,\ s \leq t\}$, where $V^-_{d,s,t}$ is the *volume* of derivative *d* purchased in period *s* and sold in period *t* -- (*selling*).

Objective function

The objective of MGRM obviously was to maximize its profit over the 10 years. MGRM's *operating revenue* was given by its income from the fixed-supply contracts. However, the cost/profit inherent in its hedging strategy needs to be taken into account in deriving profit over the (actual 10 year) planning period. Thus the objective is to maximize

$$Expected\ \ Profit \qquad = \underbrace{\sum_{t \in T} \sum_{p \in P} p^c_{p,t} \times demand_{p,t}}_{\text{total inflow from forward supply contracts (assuming interest is zero)}}$$

$$- \text{E} \underbrace{\sum_{t \in T} \sum_{d \in D} \boldsymbol{f}_{d,t} \times V^+_{d,t}}_{\text{total outflow upon purchasing derivatives } d \text{ in period } t}$$

$$+ \underbrace{\sum_{t \in T} \sum_{s=1}^{t} \sum_{d \in D} spot_{d,t} \times V^-_{d,s,t}}_{\text{total inflow upon selling in period } t \text{ derivatives } d \text{ bought in period } s\text{£ } t} \quad .$$

Here boldface denotes random entities and E(·) denotes expectation.

Constraints

One-to-one hedge. MGRM's total derivatives position was at all times equal to its forward-supply commitments:

$$\underbrace{\sum_{d\in D^h}\sum_{s=1}^{t} V_{d,s,t}}_{\substack{\text{volume of heating}\\ \text{oil derivatives held}\\ \text{in time period } t}} = \underbrace{\sum_{t_1=t+1}^{T_{plan}} demand_{h.oil,t_1}}_{\substack{\text{total remaining demand}\\ \text{for heating oil from time}\\ \text{period } t \text{ onwards}}} \qquad \forall t\in T$$

$$\underbrace{\sum_{d\in D^g}\sum_{s=1}^{t} V_{d,s,t}}_{\substack{\text{volume of gasoline}\\ \text{derivatives held}\\ \text{in time period } t}} = \underbrace{\sum_{t_1=t+1}^{T_{plan}} demand_{gasoline,t_1}}_{\substack{\text{total remaining demand}\\ \text{for gasoline from time}\\ \text{period } t \text{ onwards}}} \qquad \forall t\in T \ .$$

Rollover. All positions in must be closed out just before expiration. This is because MGRM used futures only for hedging purposes and was never delivered the underlying product:

$$\underbrace{\sum_{t=s}^{s+maturity(d)} V^{-}_{d,s,t}}_{\substack{\text{volume of futures } d\\ \text{purchased in period } s \text{ and}\\ \text{sold just before maturity}}} = \underbrace{V^{+}_{d,s}}_{\substack{\text{volume of futures } d\\ \text{purchased in period } s}} \qquad \forall d,t\in D\times T \ .$$

Derivatives purchase inventory balance. The derivatives bought must be added to the hedgingportfolio:

$$V_{d,t,t} = V^{+}_{d,t} \qquad \forall d,t\in D\times T \ .$$

Derivatives sale inventory balance. The derivatives sold must be removed from the hedging portfolio:

$$V_{d,s,t} = V_{d,s,t-1} - V^{-}_{d,s,t} \qquad \forall d\in D,\ \forall s,t\in T \ .$$

Composition of the hedging portfolio. As stated above, MGRM's position in futures and swaps accounted for 33% and 66% of the hedging portfolio respectively.

$$\underbrace{\frac{1}{3}\sum_{d\in D}\sum_{s=1}^{t}V_{d,s,t}}_{\text{1/3 of the total derivatives volume held in period } t} = \underbrace{\sum_{d\in F}\sum_{s=1}^{t}V_{d,s,t}}_{\text{total futures volume held in period } t} \quad \forall t\in T \ .$$

3.2 Criticism of MGRM's hedging strategy

Above we have defined MGRM's strategy as a *dynamic stochastic programme* [3,5]. A small deterministic example – i.e. one *possible* future scenario -- is presented here in order to illustrate the weaknesses of MGRM's hedging model. For simplicity we assume that MGRM's hedging portfolio consists of futures *only*. This simple example involves two usable products -- heating oil and gasoline (products 1 and 2) -- and six time periods, each of which corresponds to two months. The company enters forward-supply contracts with its customers and, therefore, the demand for its products is `fixed' for the six periods. In particular, the demand for both heating oil and unleaded gas in periods 1, 2, 3 and 4 is equal to 0, but it is non-zero for time periods 5 and 6 ($demand_{1,5}$=700000, $demand_{1,6}$=650000, $demand_{2,5}$=500000, $demand_{2,6}$=450000). The price specified in the fixed-supply contracts is close to the spot price of the products when the contracts are entered into. More particularly, the price of heating oil is set equal to 53 cents per gallon and the price of unleaded gas is set equal to 52 cents per gallon.

The hedging portfolio consists of two-month futures with underlying products heating oil and gasoline, which are rolled forward just before expiration (i.e. near the end of the second month). We assume that the price of the two-month futures contracts and the spot price of the corresponding underlying products take the values illustrated in Figure 5 and summarized in Table 1.

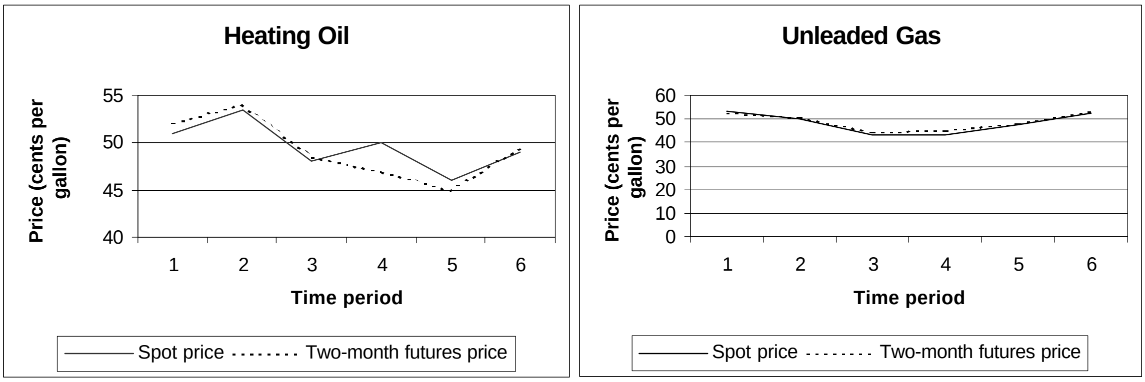

Figure 5. Spot price and two-month futures price for heating oil and unleaded gas.

Note that the market for heating oil is in *contango* for the first three periods and in the last period -- since the spot price of heating oil is less than the two-month heating oil futures price -- and in *backwardation* in periods 4 and 5. The market for unleaded gas is in backwardation in the first period and in contango in the remaining five periods. The *state* of the market will determine the scale of the *rollover costs*.

Period	Heating Oil		Unleaded Gasoline	
	Spot price	Two-month futures	Spot price	Two-month futures
1	51	52	53	52.5
2	53	54	50	50.5
3	48	48.5	43	44.5
4	50	47	43.5	45
5	46	45	47.5	48
6	49	49	52.5	53

Table 1. Spot prices and two-month futures prices (in US cents per gallon) for heating oil and unleaded gas.

The financial operations in each period corresponding to the implementation of MGRM's hedging strategy are summarized in Table 2. All decision variables not mentioned in the table have value equal to 0. It is easy to observe that the hedging portfolio hedges the forward-supply commitments *gallon-for-gallon* at all times. The volume of heating oil that the company is engaged to supply over the six time periods amounts to 1,350,000 gallons, 700,000 of which will be delivered in time period 5 and the remaining 650,000 gallons will be delivered in time period 6. Therefore, the heating oil futures held during the first 4 time periods correspond to 1,350,000 gallons, but in time period 5 the position is reduced by 700,000 gallons due to the supply of 700,000 gallons to customers. Finally, remaining positions in heating oil futures are closed out after satisfaction of the last heating oil contract. A similar situation holds for the position in unleaded gas futures.

Since forward-supply commitments are hedged with two-month -- one-period -- futures, the position in maturing contracts is closed at the end of each period and `new' two-month -- one-period -- futures are bought in order to maintain a one-to-one hedge. However, by selling maturing contracts at the *spot price* of the underlying product and by buying two-month futures at the *forward price* of the underlying, *rollover costs* / *benefits* are incurred. The scale of the rollover costs will be determined by the *state* of the market, that is, whether it is in contango or backwardation.

Time Period	Purchasing	Holding	Selling
1	$V^{+}_{1,1}$ =1,350,000	$V_{1,1,1}$ =1,350,000	
	$V^{+}_{2,1}$ =950,000	$V_{2,1,1}$ =950,000	
2	$V^{+}_{1,2}$ =1,350,000	$V_{1,2,2}$ =1,350,000	$V^{-}_{1,1,2}$ =1,350,000
	$V^{+}_{2,2}$ =950,000	$V_{2,2,2}$ =950,000	$V^{-}_{2,1,2}$ =950,000
3	$V^{+}_{1,3}$ =1,350,000	$V_{1,3,3}$ =1,350,000	$V^{-}_{1,2,3}$ =1,350,000
	$V^{+}_{2,3}$ =950,000	$V_{2,3,3}$ =950,000	$V^{-}_{1,2,3}$ =950,000
4	$V^{+}_{1,4}$ =1,350,000	$V_{1,4,4}$ =1,350,000	$V^{-}_{1,3,4}$ =1,350,000
	$V^{+}_{2,4}$ =950,000	$V_{2,4,4}$ =950,000	$V^{-}_{2,3,4}$ =950,000
5	$V^{+}_{1,5}$ =650,000	$V_{1,5,5}$ =650,000	$V^{-}_{1,4,5}$ =1,350,000
	$V^{+}_{2,5}$ =450,000	$V_{2,5,5}$ =450,000	$V^{-}_{2,4,5}$ =950,000
6			$V^{-}_{1,5,6}$ =650,000
			$V^{-}_{2,5,6}$ =450,000

Table 2. Value attached to decision variables

For our six-period example, the rollover costs are detailed in Figure 6. The figure shows that, apart from the cost of establishing the initial position in futures in time period 1, the outflows outweigh the inflows in the first three time periods. This is because in periods 2 and 3 the markets for heating oil and unleaded gas are in contango, so costs are incurred when rolling forward. In time periods 4 and 5, the market for heating oil is in backwardation and the benefit derived when rolling heating oil futures forward outweighs the cost of rolling gasoline futures forward. Moreover, in period 5 the position in futures is reduced, so that outflows are reduced further. However, due to the fall in the price of heating oil over the five periods, the cash inflow received in time period 5 is less than the outflow incurred in time period 1 when the initial position was established. Finally, in time period 6, all our remaining positions in futures are closed out.

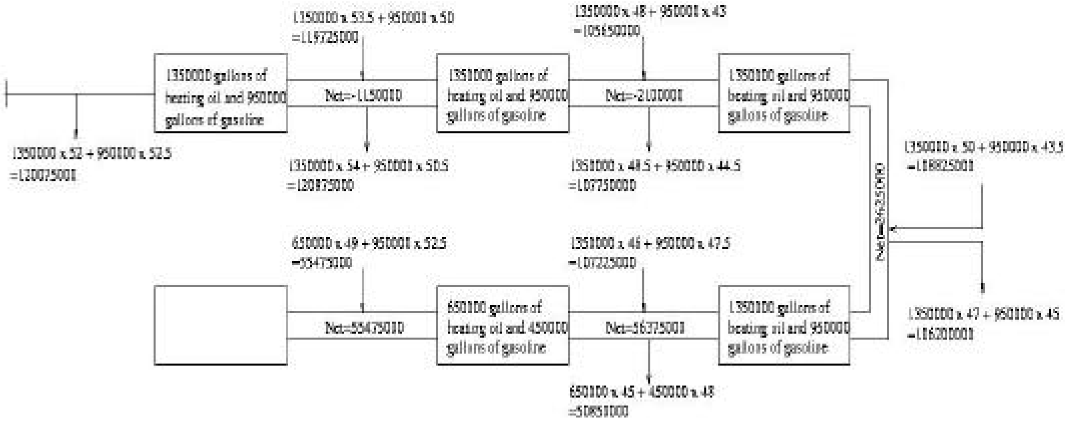

Figure 6. Cost of establishing the initial futures position and rollover costs.

It is immediately apparent that MGRM's hedging strategy is *not* at all *flexible*. It corresponds to a fixed algorithm specified by the constraints presented in Section 3.1. *Any* objective function would give us the *same* solution for eash price scenario, since there is just *one* feasible solution determined by each market state. No knowledge of hedging, market dynamics or the company's objectives is therefore needed -- the hedging policy is *at the mercy of realized market prices!*

Apart from being inflexible, MGRM's strategy is *not adjustable* to market conditions. Our small example shows the scale of *rollover costs* during the first three time periods when the market was in contango. In a real situation, *margin calls* due to futures position mark-to-market in a regime of falling prices should be taken into account as well. When MGRM's strategy was put into practice in 1993, the company's forward-supply commitments and the corresponding derivatives positions spanned a horizon of 10 years during which prices could move in any direction and the prevailing market state (i.e. market in contango or backwardation) could be reversed. As noted above although oil markets are usually in backwardation, there have been extended periods during which they were in contango. In fact, oil prices fell sharply during the end of 1993 and oil futures markets were in a contango price relationship for the whole of 1993. MGRM's non-adjustable hedging strategy turned out to be very costly, at least in the short-run. For this reason the rollover risk should be taken into account in designing a hedging strategy, which should be flexible enough to allow the minimization of rollover losses when the market is in contango.

Furthermore, the stacking strategy used by MGRM was characterized by *cash flow asymmetry* over time between futures outflows and inflows from forward-supply commitments. This is clear in our small example as well, where the long-term contracts produce cash inflow only during the last two periods. If we think of the delivery/hedging strategy *as a whole* and consider the total outflows from buying futures and rolling them forward together with the total inflows from the forward-supply contracts during the six time periods, a profit of $112,100,000 is made -- ignoring operating costs. Similarly, if we consider MGRM's situation over the 10 years of contractual arrangements, then it would probably have broken even or made a profit. However, one has to think of the cash flow timing in the short-run as well, because cash flow asymmetry can lead to *funding risk*. In fact, funding risk proved very critical in the case of MGRM -- especially when the management decided to liquidate the hedge prematurely.

Finally, another risk associated with MGRM's strategy is *credit risk*. The futures contracts could be considered as a safe investment since they are traded on an exchange and especially in the case of short-dated futures contracts, one doesn't expect any default. The OTC swaps entail credit risk to a greater extent, but again, provided they are short-dated, counterparty default could be considered minimal. In fact, MGRM used three-month OTC commodity swaps. However, long-term forward contracts do involve credit risk and this should be taken into account in designing a hedging policy.

4. **Problem formulation via stochastic programming**

The debate over MGRM’s hedging program has been mainly carried out in the risk management literature with an emphasis on the use of derivatives and stemming from different assumptions about the goals of the hedging program [11].

We add to this debate a new question: Should physical activities such as production, storage and transportation be used to fulfil forward supply contracts when market conditions are such that the current hedging program suffers losses? This has been partially considered in the case of Metallgesellschaft in [1, 8]. The term ‘synthetic storage’ means that the company is holding oil derivatives rather than physically storing oil. Synthetic storage is beneficial to producers who can achieve the lower costs of storage embodied in the futures price rather than paying their own actual costs of physical storage. The main question: ‘Is the goal of any hedging program to keep losses at minimum or profit at maximum?' brings back the semantic issue of what constitutes 'hedging' and what constitutes 'speculation'.

In our view these considerations open a new direction in corporate risk management by integrating strategic planning with hedging. Dynamic stochastic programming provides techniques for solving such a challenging problem (Figure 7). More particularly, representation of the uncertain future by a *scenario tree* allows the inclusion of all relevant market conditions in the data path generator and updates the hedging portfolio simultaneously with the optimization of major physical activities. In such a representation the optimal decisions at the *implementable* stage of the stochastic problem consist of the 'portfolio' of optimal levels of physical activities, forward delivery contracts and a variety of energy futures and swap positions. The major drawback of MGRM's strategy that it was *fixed* may be improved upon by allowing a *flexible hedge ratio* to be determined optimally. The resulting decisions will depend on the *market* prices of oil products as compared with the *fixed* prices specified on the company's forward-supply commitments. Hedging will occur *only* when the market moves in an unfavourable direction. More particularly, our model will be sensitive to both current market conditions and the *expected* future market evolution as it is given by scenario tree for the relevant price processes.

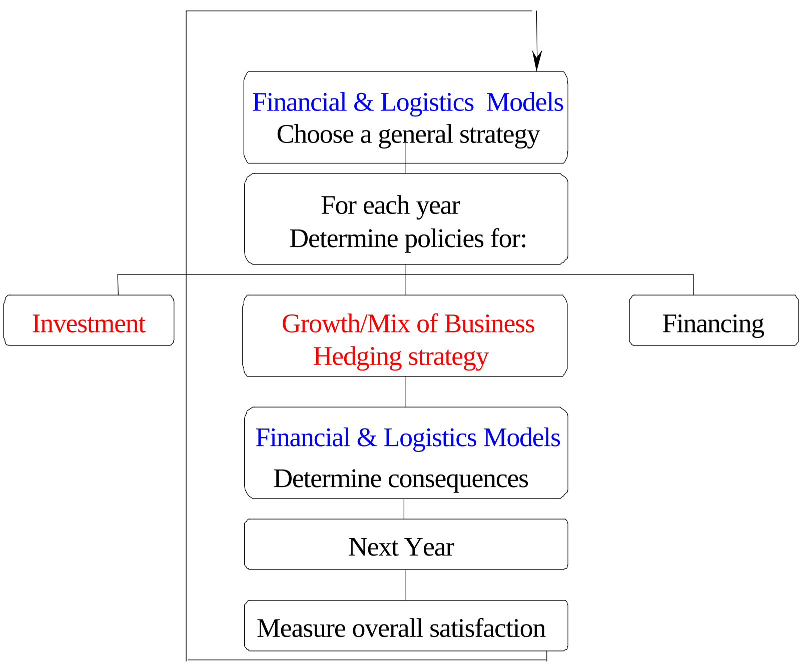

Figure 7. Integrated logistics and financial planning

In the dynamic stochastic programming formulation the hedging strategy will allow rebalancing of the hedging portfolio at specific points in time (corresonding to the *stages* of the stochastic problem). The specific types of investment allowed may be strengthened/weakened in the presence of new information translated into appropriate model changes – for example, the range of hedging instruments may be expanded. MGRM's hedging strategy used short-dated (one-month, two-month) futures and (three-month) OTC swaps which were only closed out four days prior to maturity. Our model can include other derivatives in the hedging portfolio, such as options, longer-term futures and/or swaps. The choice of hedging instruments at each time point will depend on market conditions and the expected future market evolution. The stochastic program itself is able to choose the instrument mix optimally without any further specification.

The mathematical representation of our proposed integrated model will include all constraints of the logistics model (e.g. the product-balance constraint, capacity bounds etc.), constraints that control the amounts of derivatives held in the hedging portfolio, constraints that control the financial operations at each time point and constraints that control cash flows per period. The objective function will maximize the overall profit over the planning period including the profits/losses obtained from the use of derivative instruments.

The objective function

$$\text{Max} \quad Profit = \underbrace{\sum_{t\in T}\sum_{p\in P} p^{c}_{p,t} \times demand_{p,t}}_{\text{total inflow from forward supply contracts (assuming interest is zero)}}$$

$$- \sum_{n\in N}\sum_{p\in P_1}\sum_{t\in T} c^{x}_{n,p,t} \times X_{n,p,t} \qquad \text{SUPPLY}$$

$$- \sum_{r\in R}\sum_{f\in F_r}\sum_{t\in T} c^{z}_{r,f,t} \times Z_{r,f,t} \qquad \text{REFINING}$$

$$- \sum_{p\in P}\sum_{m\in M}\sum_{(i,j)\in L_m}\sum_{t\in T} c^{e}_{i,j\ p\ m,t} \times E_{i,j,p,m,t} \qquad \text{TRANSPORTATION}$$

$$- \sum_{n\in N}\sum_{p\in P}\sum_{t\in T} c^{s}_{n,p,t} \times S_{n,p,t} \qquad \text{STOCK}$$

$$- \sum_{n \in N} \sum_{p \in P_1} \sum_{t \in T} c^{spot}_{n,p,t} \times X^{spot}_{n,p,t} \qquad \text{SPOT PURCHASE}$$

$$+ \sum_{n \in N} \sum_{p \in P_2} \sum_{t \in T} p^{spot}_{n,p,t} \times Y^{spot}_{n,p,t} \qquad \text{SPOT SALE}$$

$$- \sum_{d \in D} \sum_{t \in T} p^{+}_{d,t} \times V^{+}_{d,t} \qquad \text{DERIVATIVE PURCHASE}$$

$$- \sum_{d \in D} \sum_{t \in T} \sum_{s=1}^{t} p^{-}_{d,s,t} \times V^{-}_{d,s,t} \qquad \text{DERIVATIVE SALES}$$

$$+ \sum_{d \in D} \sum_{t=s}^{s+maturity(d)} r_{d,s,t} \times V_{d,s,t} \qquad \text{POSITIVE MARK-TO-MARKET}$$

$$- \sum_{d \in D} \sum_{t=s}^{s+maturity(d)} s_{d,s,t} \times V_{d,s,t} \qquad \text{NEGATIVE MARK-TO-MARKET}$$

subject to constraints:

- *Hedging exposure to crude oil prices.*

$$\underbrace{\sum_{d \in D^c} \sum_{s=1}^{t} V_{d,s,t}}_{\substack{\text{volume of derivatives} \\ \text{with underlying product} \\ \text{crude oil) added to the} \\ \text{portfolio in period } t}} \leq \underbrace{\sum_{t_1=t}^{Tplan} \sum_{p \in P_1} supplied_{p,t_1}}_{\substack{\text{total remaining supply of} \\ \text{crude oil from time period} \\ t \text{ onwards}}} \quad \forall t \in T \ .$$

- *Hedging exposure to final product prices.*

$$\underbrace{\sum_{d \in D^f} \sum_{s=1}^{t} V_{d,s,t}}_{\substack{\text{volume of derivatives} \\ \text{with underlying final} \\ \text{product) added to the} \\ \text{portfolio in period } t}} \leq \underbrace{\sum_{t_1=t}^{Tplan} \sum_{p \in P_2} demand_{p,t_1}}_{\substack{\text{total remaining demand for} \\ \text{final products from time period} \\ t \text{ onwards}}} \quad \forall t \in T \ .$$

- *Controlling cash inflows and outflows.*

$$\underbrace{\sum_{p\in P} p^{c}_{p,t}\times demand_{p,t}}_{\text{total revenue from contractual sales of oil products}} + \underbrace{\sum_{n\in N}\sum_{p\in P_2} p^{spot}_{n,p,t}\times Y^{spot}_{n,p,t}}_{\text{total revenue from selling oil in the spot market}} + \underbrace{\sum_{d\in D}\sum_{s=1}^{t} p^{-}_{d,s,t}\times V^{-}_{d,s,t}}_{\text{total revenue from selling derivatives}}$$

$$-\underbrace{\sum_{n\in N}\sum_{p\in P_1} c^{x}_{n,p,t}\times X_{n,p,t}}_{\text{total cost of buying crude oil from suppliers}} - \underbrace{\sum_{n\in N}\sum_{p\in P_1} c^{spot}_{n,p,t}\times X^{spot}_{n,p,t}}_{\text{total cost of buying crude oil in the spot market}} - \underbrace{\sum_{r\in R}\sum_{f\in F_r} c^{z}_{r,f,t}\times Z_{r,f,t}}_{\text{total cost of refining oil products}}$$

$$\underbrace{-\sum_{p\in P}\sum_{m\in M}\sum_{(i,j)\in L_m} c^{e}_{i,j\,p\,m,t}\times E_{i,j\,p\,m,t}}_{\text{total cost of transporting oil products}} - \underbrace{\sum_{n\in N}\sum_{p\in P} c^{s}_{n,p,t}\times S_{n,p,t}}_{\text{total cost of storing oil}} - \underbrace{\sum_{d\in D} p^{+}_{d,t}\times V_{d,t}}_{\text{total cost of buying derivatives}}$$

$$\geq bound \qquad \forall t\in T\ .$$

Trading products at spot prices in local markets may be viewed as a simple hedging policy: losses or opportunity costs due to lack of internal resources or surplus positions are covered by trading. In our model -- DROP -- developed in the course of HChLOUSO project [3, 4, 5] we optimize the cost of major activities over a specified time horizon and reach feasibility using product market trading at spot prices. We ran our model on number of data instances. Analysis of the optimal decisions {X, S, E, Z, Xsp ,Ysp }-- the amounts to *supply*, to *store*, to *transport*, to *refine*, and to *buy* or to *sell* – over time identified cases which had one or another activity absent and replaced by amounts traded on the oil markets.

The following two figures illustrate the solution corresponding to two different cases of the same problem.

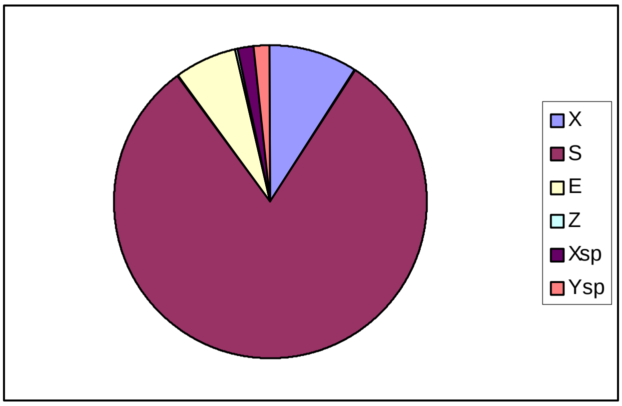

Figure 8. Case 1: Storage is the dominating activity

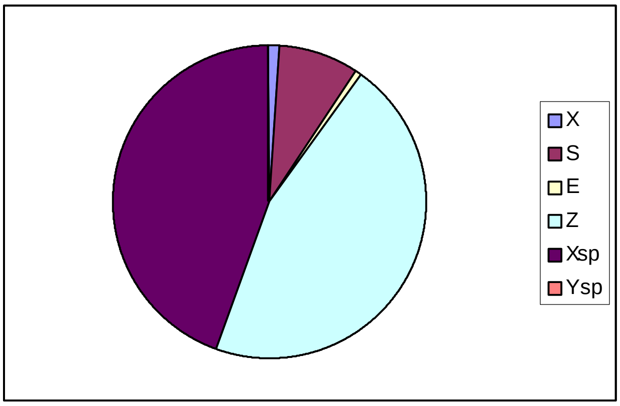

Figure 9. Case 2: Refining is the dominating activity

Figure 8 shows that the oil company satisfies most of its needs for crude oil by entering contractual agreements with potential suppliers --- operators. The amount of crude oil supplied by operators is represented by the variable *X*. Clearly, the proportion of crude oil supplied through contracts *X* is greater than the proportion of crude oil bought in the spot market *Xsp*. As a result, the oil company may need to store the supplied crude oil for an extended period before distributing it to its customers. The great amount of storage needed is apparent on the diagram – storage *S* is the dominating activity. Moreover, if we compare the amount of storage needed with the amount of product refined *Z*, we see that the company uses a lot of effort storing products rather than producing them!

Figure 9 illustrates a case in which it is preferable for the company to satisfy its crude oil needs by buying crude oil in the spot market – spot market purchases are represented by *Xsp*. The amount supplied through contractual agreements *X* is limited. As a result, the oil company does not need to store crude oil for extended periods of time and hence the storage volume S is now considerably limited. In contrast, the refining activity --- represented by Z --- becomes the dominating activity.

We see that the two cases differ in the emphasis they give on spot market transactions. Although, in the first case it is more beneficial for the oil company to enter forward contracts, in the second case price movements encourage the company to perform most of its transactions in the spot market. In effect, the company hedges its exposure to oil prices by deciding on the appropriate division of its finances for crude oil supply between spot and forward transactions with full knowledge of the optionalities involved in the price paths of the scenario tree. Most importantly, the volume of spot supplies as compared to the volume supplied through forward contracts has a direct effect on the scale of other activities such as storage and refining. The above example thus illustrates that it is indeed necessary to combine hedging with strategic logistics management for the optimal implementation of the company's activities. This is the bridge to 'real options' valuation which we are exploring in our current research.

5. Conclusions and future research directions

Our analysis of the MGMR case using a stochastic optimization formulation of the company's hedging strategy led us to think about hedging in co-ordination with physical activities. Combining hedging with logistics management should improve the effectiveness of strategic planning decisions. In the presence of volatile energy markets, this is a very challenging problem.

We have attempted the mathematical formulation of the problem and have illustrated the different solutions that one should expect using a small example. The implementation and solution of our proposed model relies on the existence of organised derivatives markets for trading. In fact, the growing number of energy derivatives and the existence of established markets for trading them creates new opportunities for risk management.

Moreover, research areas such as `Real Options' and their underlying theories are increasingly becoming accepted by the industry. This should enable the adjustment and subsequent implementation of our model in real situations faced by corporations and will determine the success of our proposals. Moreover, if we see the emerging theory of Real Options in the general context of decision making under uncertainty --- studied for over 40 years --- then certainly more contributions will emerge.

However, it should be emphasized that a correctly formulated integrated problem, whereby a sophisticated hedging strategy is combined with complex logistics operations' management, is difficult to implement and solve accurately. The difficulties encountered include obtaining confidential data on the cost of physical operations, simulating the forward market accurately, formulating clearly the company's overall objectives and, most importantly, implementing such a computationally intensive problem solution.

Dynamic stochastic programming has provided us with the framework for formulating such a problem and for evaluating the `real options' involved by selecting at each node of the scenario tree the most optimal path according to the overall goal. Data on the cost of operations has been provided to us by the industry. We have already completed the modelling and implementation of the stochastic behaviour of commodity prices using a Kalman filtering technique. We are currently working on the solution of large problems using parallel machines and new computational techniques for attacking such massive problems of high complexity are also under development.

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