Evaluating Price Risk Mitigation Strategies for an Oil and Gas Company

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1 Introduction

Oil and gas (O&G) companies' earnings are substantially affected by the price fluctuations of crude oil, natural gas and refined products, which lead these companies to find ways to minimize their exposure to price risk. The work on investments and selection of efficient portfolios [9], along with the deregulation of energy markets in the United States in the 1980s, exponentiated the derivatives use in energy trade, to reduce companies' price risk exposures [1]. This research intends to evaluate the differences between hedging at business units (BU) level and hedging at company level, assuming that the risk tolerance at company level inherits the logic of the BU risk attitudes, through the "theory of syndicates" [15]. In this paper we use as case study a European O&G company, which manages its price risk separately at each BU. The axioms for utility as a decision criterion defined by von Neumann and Morgenstern [14] assured solid ground for the relation between financial measures, utility functions and corporate risk tolerance [6].

The remainder of this paper is organized as follows. Section 2 describes relevant measures and methods, Sect. 3 presents the results, Sect. 4 discusses them and presents the conclusions.

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2 Relevant Measures and Methods

2.1 Earnings Formulation

The company is organized in three business units: the Exploration unit, the Refining unit and the Natural Gas unit. Since this research is focused on price risk, we take as reference the gross margin, calculated as the difference between the value of the goods bought and sold (crude oil, refined products and natural gas). The Exploration gross margin m_e is given by:

$$m_e = e_p \cdot p \ + \ e \ , \tag{1}$$

where e_p is the *Entitled Production* quantity in barrels of crude oil (bbl) for "Production Sharing Contracts" regimes, p is the crude price ($/bbl) and e are the earnings ($) in "Concession" regimes. The Refining gross margin m_r is given by:

$$m_r = \left(\sum_{i=1}^{n} y_i \cdot x_i - p \right) \cdot q_r \ , \tag{2}$$

where y_i is the yield (the oil industry name for the percentage of each i refined product taken from a unit of crude), x_i is the unitary price of each refined product i, p is the unitary price of crude and q_r is the yearly crude quantity refined (in tonnes). The Natural Gas gross margin m_g is given by:

$$m_g = \left(\sum_{i=1}^{n} z_i \cdot s_i - \sum_{j=1}^{k} w_j \cdot b_j \right) \cdot q_g \ , \tag{3}$$

where s_i and b_j are respectively the selling and buying price indexes, z_i and w_j are respectively the selling and buying yields, and q_g is the yearly total quantity of natural gas, measured in m^3 or kWh. As the goal underneath this research is to assume at least 1 year term hedging, we will choose the most traded derivatives in the OTC (over the counter) energy market: swap contracts. For each BU i, considering the yearly gross margin m_i, the yearly earnings e_i are given by:

$$e_i = m_i + \sum_{t=1}^{12} (f_i - s_{i_t}) \cdot q_i \ , \tag{4}$$

where f_i is the initial agreed fixed price for the swap, usually the average forward prices for the contract duration, s_{i_t} is the respective spot price at each future settlement month t and q_i is the swap notional quantity, having the same unit (bbl, weight, kWh) as the physical underlying item for each BU i.

2.2 Stochastic Prices Models and Risk Measures

Crude and refined products prices are modelled by their past monthly price returns [11].The historic price return r_t (in %) for crude or each refined product is:

$$r_t = \ln\left(\frac{p_t}{p_{t-1}}\right) , \tag{5}$$

where p_t is the average price in month t and p_{t-1} is the average price in month $t-1$. Each future stochastic price f_{t+1} under a GARCH(1, 1) process [4], with no-arbitrage and no-dividends assumptions, depends on the previous s_t price:

$$f_{t+1} = s_t \cdot \exp\left(r_t\right) , \tag{6}$$

where r_t is the stochastic price return, modelled by a combination of a GARCH(1, 1) process [4] and a t-copula function [13], the Copula-GARCH model [7]:

$$r_t = \left[\omega + \alpha \cdot r_{t-1}^2 + \beta \cdot \sigma_{t-1}^2\right]^{1/2} \cdot T_d\theta\left[t_d^{-1}\left(u_t\right)\right] \tag{7}$$

where ω is the constant term for variance, the conditional variance σ_{t-1}^2 assumes an autoregressive moving average process (ARMA), with α weighing the moving average part and β affecting the auto-regressive part, T is the t-copula with d degrees of freedom and correlation matrix θ, t^{-1} is the inverse Student's t distribution with d degrees of freedom and u_n are the variables' marginal distributions (the price returns residuals). The SIC-Schwarz and the AIC-Akaike information criteria were used as goodness of fit measures for GARCH and Copula [5], confirming the kurtosis excesses and fat tails characteristics in the referred prices' returns. Unlike the Gaussian copula, t-copulas preserve the tail dependence in extreme events. The Copula-GARCH method was implemented trough a multi-period Monte Carlo simulation [10] varying t from 1 to 12 months.

Conditional Value-at-Risk (CVaR) is a coherent risk measure [12], appraising how large is the average earnings (or losses) into the left and right distribution tails.

$$CVaR_{(\alpha)} = \frac{\int_a^b e \cdot f(e)\mathrm{d}e}{1-\alpha} \tag{8}$$

where $f\left(e\right)$ is the earning density function with F^{-1} being the inverse of the $f(e)$ cumulative distribution. For the left tail, $\alpha = 1\,\%$ (the level of significance assumed), $a = -\infty$, $b = F^{-1}(1\,\%)$. For the right tail, $\alpha = 99\,\%$, $a = F^{-1}(99\,\%)$, $b = +\infty$.

In fact, for all investors, swap contracts hedging is all about giving up potential upper gains (right tail) in exchange for having lower losses (left tail), so both extreme CVaR matter.

2.3 Risk Tolerance and Optimization

The selection of the optimal derivatives portfolio is influenced by the decision-maker's attitudes towards financial risk. The expected value of an utility function is the utility of the *certainty equivalent* (CE) [3] considering the exponential utility function as the most appropriate [8], we have:

$$CE \approx E(x) - \left(\frac{\sigma^2(x)}{2\rho}\right), \tag{9}$$

where x is the stochastic earnings variable, $E(x)$ is the earnings expected value, $\sigma^2(x)$ is the earnings variance and ρ is the risk tolerance, evaluated trough one questionnaire assessment for each BU. The selection of the optimal derivatives portfolio is achieved by stochastic optimization [10], having the swap notional quantity q_i in (4) as the decision variable "inside" each BU earning e_i.

$$\text{Max } CE_i \approx \text{Max } \left(E(e_i) - \frac{\sigma^2(e_i)}{2\rho_i}\right) \tag{10}$$

After obtaining the optimal derivatives portfolio for each BU i, we enter each i solution in an additive corporate hedging simulation, which we named Program 1.

In a second approach, named Program 2, we consider the company's earnings e_c given by $e_c = e_e + e_r + e_g$, where e_e, e_r, e_g are respectively the exploration, refining and natural gas earnings. According to the Theory of Syndicates [15] the risk tolerance of the company (ρ_c) can be assumed to be the sum of each BU risk tolerance ρ_i. Therefore, replacing e_i by e_c and ρ_i by ρ_c in expression (10) will allow us to maximize, assuming exponential utility functions for each BU. The Certainty Equivalent for the whole company.

3 Results

The results from Monte Carlo simulation before hedging are presented in Table 1. Tables 2 and 3 present the results of Program 1 and Program 2, respectively. The "*% of Hedge*" solution for each BU is the ratio between the notional amounts of swap contracts q_i and the respective BU yearly physical production.

Table 1 Results before hedging (in $ million)

Measures	Refining	Natural gas	Exploration	Company
E(e_i)	273	124	424	821
$\sigma(e_i)$	102	3	12	98
$CVaR_{99\,\%}(e_i)$	665	113	469	1220
$CVaR_{1\,\%}(e_i)$	−87	116	393	488

Table 2 Program 1, results after BU hedging (in $ million)

Measures	Refining	Natural gas	Exploration	Company
E(e_i)	268	125	423	815
$\sigma(e_i)$	33	0	2	33
$CVaR_{99\,\%}\ (e_i)$	436	125	431	985
$CVaR_{1\,\%}\ (e_i)$	161	125	418	713
ρ	173	3	22	198
CE	264	125	423	813
% of Hedge solution	79	100	35	81

Table 3 Program 2, results after Company hedging (in $ million)

Measures	Refining	Natural gas	Exploration	Company
E(e_i)	269	125	424	817
$\sigma(e_i)$	37	0	11	35
$CVaR_{99\%}\ (e_i)$	447	125	461	1003
$CVaR_{1\%}\ (e_i)$	153	125	395	722
ρ	173	3	22	198
CE	265	125	421	814
% of Hedge solution	69	100	0	72

4 Discussion and Conclusions

The results in Table 2 present a significant decrease in the company's earnings uncertainty from the initial unhedged situation in Table 1. The earnings standard deviation reduces sharply from $ 98 million to $ 33 million and the minimum gains, measured by $CVaR_{1\,\%}$, increase from $ 488 million to $ 713 million at the cost of the maximum gains, measured by $CVaR_{99\,\%}$, shrinking from $ 1220 million to $ 985 million.

Comparing the results of Table 2 with Table 3, we observe that the certainty equivalent and the standard deviation have negligible changes. However, in Table 3 the extreme tails shows both higher gains and the optimal solution (i.e. the *% of Hedge*) reduces from 81 to 72 %, implying less payout exposure. Under Program 2, the Exploration crude price risk is absorbed (0 % *of Hedge*) by Refining, eliminating the risk overlapping and reducing the Refining hedge from 79 to 69 %.

We conclude that hedging at company level (Program 2) clearly outperforms the BU individual hedging (Program 1). Since the certainty equivalents of both programs are quite similar, we propose further research to include other criteria to evaluate the final hedging results. Multi-Attribute Value Theory [2] should be applied to assess decision-makers' preferences upon extreme tails and payout exposure changes.

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