Risk and Investment Analysis applied to the Petroleum Industry

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Abstract

In Brazil, for the last four decades, Petrobrás, a state-owned company, had retained a monopolistic concession for the exploration of Oil & Gas prospects, when, in 1998, the law was changed and a broad range of opportunities were created. Since then, Petrobrás has been offering a series of Join Venture opportunities for foreign oil companies to farm in.

Presently, a number of international oil companies installed offices locally and started to participate in the upstream sector. ANP, the National Petroleum Agency, is offering for tender various blocks both offshore and onshore. The first bid round was a major success, in mid 1999, the second bid round being scheduled for the third quarter of year 2,000.

Blocks leased in the first bid round are now being explored by means of 2D and 3D seismic, and the first exploratory wells will be soon drilled.

This article presents a framework to perform an economic evaluation of oil&gas prospects, taking into account the risk factor. The Net Present Value of each block is first computed based upon an average value. Following that, *Monte Carlo* simulation is used to compute the downside risk. The inputs are determined by means of probability distributions. Reservoir parameters, capital and operating costs and oil prices are fed into the program, revealing the NPV sensitivity to each factor.

The problem is further structured by means of decision trees. The Expected Monetary Value, based upon perceived probabilities of success, is estimated, utility functions being used to account for risk aversion. The optimum level of participation in each prospect is determined, using the so-called Certainty Equivalent concept. Finally, the formation of an

optimum portfolio is discussed, so that any oil company can establish its strategy in joint bids and farm ins.

Four hypothetical prospects are evaluated; with different levels of investment and risk profiles, namely, from higher probability of success to new frontier, lower probability of success. The correspondence with real life may be, respectively, the Campos Basin, where 70% of Brazilian oil production comes from, and basins like Pelotas, where there are no producing wells, with little seismic available.

The framework suggested in this work could be useful for any company that is currently involved with exploration activities. Additionally, it may be used for analysing any investment with a certain degree of uncertainty or volatility.

Introduction

The contemporary Brazilian scenario offers opportunities of investments to foreign petroleum companies, normally in the upstream sector which until recently, was restricted to Petrobrás.

This article shows the methodology to take decisions that involve risk. When there is no such thing as a variety of results, uncertainty or risk, the decision criteria can be based only upon the net present value.

We will work on an example that has four different prospects, with different internal rates of return and four standard deviations for these rates. Prospect A has an internal rate of return of 23% per annum, and a standard deviation of 13% per year. Prospect B has an IRR of 29% and deviation of 24%. The alternative C has an IRR of 37%, and a standard deviation of 41% and finally, prospect D has an IRR of 19% and a deviation of 7%. The probability of success for each prospect also varies.

We will analyse these different options, coming to some results that will a basis for building up the optimised investment portfolio.

Geological Risks:

The main factors and mechanisms that control petroleum accumulations are:

- Existence of trap
- Source rock
- Thermal maturation
- Migration and timing
- Reservoir (storage capacity)
- Seals
- Productivity

To each of these events are attributed probabilities of success and failure, based upon vague or registered experiences. As there is a lack of significant data based on which inferences of future risks may be made, the vague experience (or professional experience) is strongly used in the determination of the probabilities of the occurrence of the events.

The probability of the existence of oil in a given place may be described as the product of all the probabilities of each event occurring individually.

PS = G*E*R*S*M*T

Where:

PS = Success Probability;
G = Generator
E = Structural or Stratigraphic trap
R = Reservoir;
S = Seal;
M = Migration; and
T = Timing.

Economic Risks

These risks are established from the analysis of the parameters which determine the size distribution (area and volume) of the possible accumulations of oil (structure area, width, porosity, oil saturation), redistributing the indices of success in probabilities of finding fields of different sizes.

The volume of recoverable oil is given by the formula:

$V = A * E * \Phi * S_o * R$,

Where:
A = Accumulation area;
E = Reservoir thickness;
Φ = Effective reservoir porosity;
S_o = oil saturation; and
R = Recovery Factor.

It is possible to compute this volume through by means of a spreadsheet, with hypothetical data, in two different manners:

a) Deterministically, with expected values or averages, resulting in a constant value and
b) With probability distributions for the values, resulting in different values for V.

In the first alternative (a), the computation is made with the best estimator of the formula components. Nothing can assure that the computed number is going to be accurate, for there is an imprecision or uncertainty in the estimated parameters.

In the second case (b), some scenarios can be taken from the cumulative frequency curve, as pessimistic, realistic and optimistic. These could be the reserve values for the 10%, 50% and 90% percentiles, that is, figures that leave 10% of the cases below (pessimistic); 50% (realistic); and 90% (optimistic).

Production Forecasting Risks

Once the recoverable reserves are established, we need to estimate how fast the production, or the exploitation, or the depletion of the reserves of oil and gas will take place. Some important factors for these items are:

- Number of wells;
- Percentage of dry holes or success ratio (*);
- Drainage area or recovery per well;
- Productivity index per well;
- Operating constraints on production rates;
- Initial decline rates;
- Abandonment rates or other abandonment conditions; and
- Prices of products;

(*) Note: In the 1980's, with the advent of 3D seismic surveys, the exploratory risks were strongly reduced. The probability of success in drilling was raised from 40% to approximately 60%.

One of the most commonly used formulas for production forecasting is the exponential decline curve:

$$q = q_i \, e^{(-at)}$$

This deterministic model can be converted in a stochastic or probabilistic model, treating the two parameters, $\mathbf{q_i}$ and **a,** which represent respectively, initial production and rate of decline, as random variables instead of adopting constant values. The time, in years, is given by the variable **t**, and the production in each year, **q**, is declining year after year.

To obtain the results simulated in the graphic, the rate of decline **(a)** used, as entry data was a normal distribution with medium value of 10% per year, and standard deviation of 0,5%. The initial production value ($\mathbf{q_i}$) is the result of a spreadsheet previously calculated, and is already a random variable. The simulated outputs of one spreadsheet are the inputs of another one.

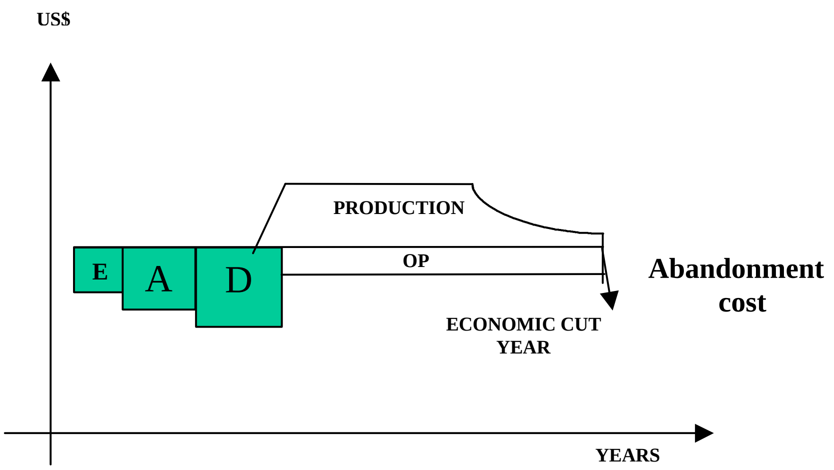


FIGURE 1- Investment and income during exploration phases of n oil wells

Figure 1 shows US$ capital expenditures (CAPEX) invested in exploration (E), Appraisal (A) and development (D), along the years. A number of wells are drilled, and the Revenue curve starts with production, which in turn generates operational expenditures (OPEX).

The level of production grows up fast, during the early years, then stabilises for 3 to 4 years, and then decreases following the decline curve.

There is an economic cut point cut point, when revenues are lower than costs. Finally, there are abandonment costs, due to environmental reasons.

Cash Flow:

The cash flow of a typical upstream investment is shown on the table 1, which follows.

TABLE 1-Upstream Cash Flow

Simplified cash flow for oil exploration projects

Ano	Preço óleo	Produção óleo	Investimento (MM$)			Custos Oper	Faturam	Royalties (MM$)	Faturam	Parcela do Governo		Custo Adm	Imposto	Fluxo de cx.	Fluxo de c
	$/bbl	MM bbl	Exp.	Aval.	Desen.	(MM$)	bruto (MM$)	15%	Acumul.(MM$)	%	US$	MM$	de Renda	a / imposto	Anual
1998	15,0	0	5,4	0	0	0	0	0	0	0,0%	1,5	0,00	0,0	-6,90	-6,90
1999	15,0	0	6,3	0	0	0	0	0	0	0,0%	2,0	0,00	0,0	-8,30	-8,30
2000	15,0	0	10,4	0	0	0	0	0	0	0,0%	2,0	0,00	0,0	-12,40	-12,40
2001	15,0	0	0	0	0	0	0	0	0	0,0%	0,0	2,00	0,0	-2,00	-2,00
2002	15,0	0	0	4,6	0	0	0	0	0	0,0%	0,0	2,00	0,0	-6,60	-6,60
2003	15,0	0	0	9,6	0	0	0	0	0	0,0%	0,0	2,00	0,0	-11,60	-11,60
2004	15,0	0	0	0	45,3	0	0	0	0	0,0%	0,0	2,00	0,0	-47,30	-47,30
2005	15,0	0	0	0	144,4	0	0	0	0	0,0%	0,0	2,50	0,0	-146,90	-146,90
2006	15,0	8,5	0	0	122,7	16,8	127,5	19,1	128	0,0%	0,0	3,15	59,0	-34,28	-93,25
2007	15,0	12,7	0	0	68,1	22,2	190,5	28,6	318	0,0%	0,0	3,15	91,1	68,48	-22,62
2008	15,0	17,3	0	0	68,1	28,7	259,5	38,9	578	0,0%	0,0	3,15	125,9	120,63	-5,25
2009	15,0	20,2	0	0	66,8	33,6	303	45,5	881	0,0%	0,0	3,15	147,3	154,00	6,73
2010	15,0	26,4	0	0	66,8	38,1	396	59,4	1277	0,0%	0,0	3,15	197,0	228,55	31,55
2011	15,0	31,1	0	0	32,9	41,3	466,5	70,0	1743	6,4%	20,6	3,15	221,1	298,55	77,47
2012	15,0	28,5	0	0	0	40,2	427,5	64,1	2171	6,3%	20,4	3,15	199,9	299,66	99,79
2013	15,0	25,6	0	0	0	37,2	384	57,6	2555	6,4%	18,5	3,15	178,4	267,54	89,09
2014	15,0	23,4	0	0	0	35,9	351	52,7	2906	6,6%	17,3	3,15	161,4	241,98	80,58
2015	15,0	21,9	0	0	0	33,6	328,5	49,3	3234	6,7%	16,5	3,15	150,8	226,02	75,26
2016	15,0	19,7	0	0	0	31,3	295,5	44,3	3530	7,0%	15,4	3,15	134,3	201,33	67,04
2017	15,0	17,4	0	0	0	30,2	261	39,2	3791	7,2%	13,8	3,15	116,5	174,70	58,18
2018	15,0	16,8	0	0	0	28,1	252	37,8	4043	7,6%	14,1	3,15	112,6	168,81	56,21
2019	15,0	15,1	0	0	0	27,2	226,5	34,0	4269	7,9%	13,1	3,15	99,5	149,11	49,66
2020	15,0	13,6	0	0	0	25,9	204	30,6	4473	8,2%	12,1	3,15	88,2	132,26	44,04
2021	15,0	12,9	0	0	0	24,4	193,5	29,0	4667	8,2%	11,5	3,15	83,7	125,44	41,77
2022	15,0	11,7	0	0	0	23,3	175,5	26,3	4842	7,4%	9,3	3,15	75,6	113,41	37,77
2023	15,0	10,2	0	0	0	22,7	153	23,0	4995	6,8%	7,3	3,15	64,6	96,90	32,27
2024	15,0	9,5	0	0	0	21,8	142,5	21,4	5138	6,2%	6,2	3,15	60,0	90,02	29,98
2025	15,0	8,7	0	0	0	20,9	130,5	19,6	5268	5,6%	5,0	3,15	54,6	81,83	27,25
2026	15,0	8,3	0	0	0	19,7	124,5	18,7	5393	5,1%	4,4	3,15	52,4	78,58	26,17
2027	15,0	6,4	0	0	0	17,3	96	14,4	5489	3,8%	2,4	3,15	39,2	58,71	19,55
2028	15,0	4,8	0	0	0	13,8	72	10,8	5561	3,1%	1,5	3,15	28,5	42,78	14,25
TOTAL		370,7	22,1	14,2	615,1	634,2	5560,5	834,075			214,9	82,95	2541,5	3143,00	601,46
VPL															
Taxa de	7,50%	R$ 115,99	R$ 20,26	R$ 10,13	R$ 324,80	R$ 189,56	R$ 1.739,81	R$ 260,97				R$ 27,82	R$ 808,90	R$ 845,16	R$ 36,26
Desconto	10%	R$ 82,46	R$ 19,72	R$ 9,10	R$ 266,28	R$ 133,61	R$ 1.236,93	R$ 185,54				R$ 20,88	R$ 577,56	R$ 559,31	(R$ 18,25)
(ao ano)	12,50%	R$ 59,74	R$ 19,22	R$ 8,20	R$ 219,70	R$ 96,22	R$ 896,13	R$ 134,42				R$ 16,16	R$ 419,97	R$ 371,82	(R$ 48,15)
														A/ Imposto	D/ Imposto
													TIR	31%	9%
													(ao ano)		

The phases of exploration, appraisal and development may succeed, resulting in the continuation of the production. There are risks, however, of an early abortion in these phases, generating only losses.

Decision Trees

In decision making, it is common to use decision trees, which consist in a graphic representation of the options and all its consequences, in an organised and clear way, simplifying the work of the decision-maker. To design the tree, it is necessary to list the options and quantify them as much as possible. One example of a simplified tree is in figure 2.

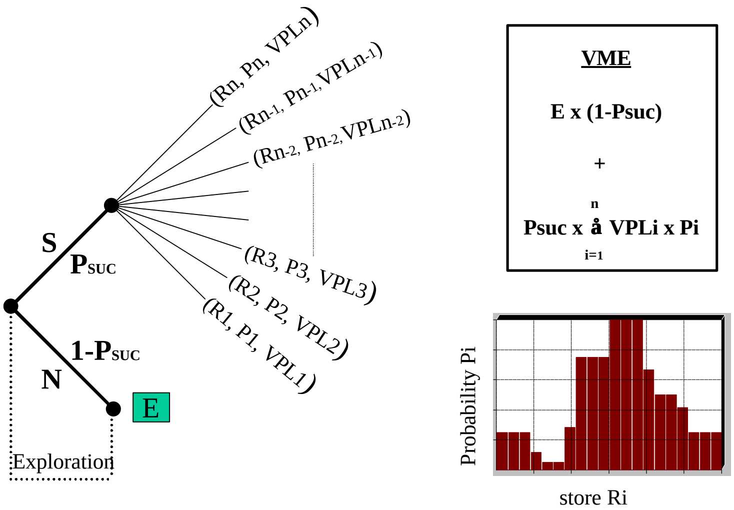


FIGURE 2- Simplified Risk Tree

Expected Monetary Value (EMV)

The expected monetary value is a weighted average of profits and losses multiplied by their probabilities.

Mathematically speaking, it is given by the expression:

VME = p*VPL1 + (1-p)*VPL2

Where VPL1 and VPL2 would be the net present values of cash flows with success and loss in the exploration. Obviously, there would be many other options for the flows (bigger or smaller amount, variability in the costs).

The EMV method does not reduce or eliminate the risks, but is a tool to make better evaluation, understanding and quantification of the risks to which the company may be exposed. In most cases, it is very complex to define the best project through the EMV. This tool is generally used in companies that does not have capital restriction. The EMV does not show the projects probability of success; neither does it reproduce the human behaviour in risk situations.

Preference Theory: Utility Functions

One way to express the preference in relation to risk activities is through the Utility Functions that are constructed giving upper values to better results of an investment, and lower values to worse results. With the intermediate values, it is possible to plot the value of the investment *versus* utility function value. This curve is a parable with concavity down, in the case of risk-averted managers, a straight line to the managers indifferent to the risk and a parable with upper concavity to risk-taking managers.

This function can be defined empirically or analytically. The empirical part can be done by means of an interview, the analytic, using a linear, exponential, logarithmic or square root function.

To apply the preference theory method, two concepts are important: the certainty equivalent and the function of risk-aversion associated with the utility function. The certainty equivalent is the value in money that an investor would take, without risk, as a return for a risky choice, that is, a comparison between risky and not-risky investments.

The exponential utility function (the only that shows constant risk-aversion) may be used as substitute for other utility functions under some conditions, and this function is very important in valuation and implementation of risk analysis in petroleum exploration projects.

This function is defined as $U(x)= 1-e^{-c.x}$, where c is the risk-aversion coefficient of the decision-maker and x represents the participation of the company in the project, in percentage.

Certainty equivalent

Sometimes, a risky option can be compared with one that does not imply risk. The Executives may ask themselves: What would be the lowest money value that I would accept, without risk, as a return for the risky option with this expected value? This value is the certainty equivalent of the risky choice.

For those who do not like risk, the certainty equivalent is most of the times, lower than EMV. The difference between the certainty equivalent and the EMV is the "Risk Prize": the money value of the uncertainty as it is perceived by whom is willing to take it. The formula for the certainty equivalent is:

$$EqC(X) = -1/c * \ln\left[p_1 e^{-c(x)VPL_1} + p2e^{-c(x)VPL_2}\right]$$

Where:

c is the level of risk aversion of the decision-maker;

EqC = Certainty Equivalent of the project in million dollars;

pi = Probability of success of the event i;

VPL1 = Net present value of event 1 (Success);

VPL2 = Net present value of event 2 (Failure);

c = Coefficient of risk aversion (= 1/ R ; R = risk tolerance)

x = Level of monetary participation of the company in the project (%)

The relation between these concepts, utility function and certainty equivalent is better understood when we are willing to incorporate the utility functions in a model, for to do so we need to follow these steps:

1) Use the utility function to calculate the utility of each possible result.
2) Calculate the expected utility for the specific example. In our case, we will use example A.
3) To convert the expected utility in the certainty equivalent, we use the inverse of the utility function.

That is, the certainty equivalent is obtained through the inverse function of the utility function. This idea will be better understood with an example.

In example A, we have:

VPL1 = 228.42
VPL2 = -160.00

Using R=150 and substituting in the formula:

$$\mathbf{U\ (x) = 1 - e^{-c\ (x)}}$$

We get:

U (X) = 0.78 (for VPL1 = 228.42) e
= -1.90 (for VPL2 = -160.00)

Therefore the expected utility of our example is -0.29.

At last, if we compute the inverse function of the utility function (using the obtained value (-0.29)), the value for the certainty equivalent of the example A is finally obtained.

Selection of the Investment Portfolio

We will take as an example the investments A, B, C and D, consisting of the exploration (E), development and production phases, with investments, revenue and operational costs (R/O). The internal rates of return of these prospects and their standard deviations were already described in the introduction. As a matter of simplicity, instead of using cash flows 30-year long, the ones shown here will be only 5-year long.

Such cash flows are shown in deterministic and probabilistic forms. The simulated results were generated through the software a Monte Carlo simulation software, an Add-in to spreadsheet models.

The final objective of this work is to provide a guidance for investment selection, according to the risk profile (given by the utility function) and the risk tolerance (given by R, in million of dollars). An empirical study in the United States, analysing 50 independent petroleum companies from 1981 to 1990 concluded that the risk tolerance is generally ¼ of the exploration capital of the company.

In our example, we adopted R= US$ 150 million, and an exponential utility function, as described earlier.

Following the criteria of maximising the Net Present Value in the decisions, prospect A is selected through the Decision Tree software. Note the word TRUE in branch A and an EMV of US$ 73 million, approximately, the biggest among the branches A, B, C and D. So, the decision is to invest and invest in the A prospect. This decision results from an analysis that ignores risk.

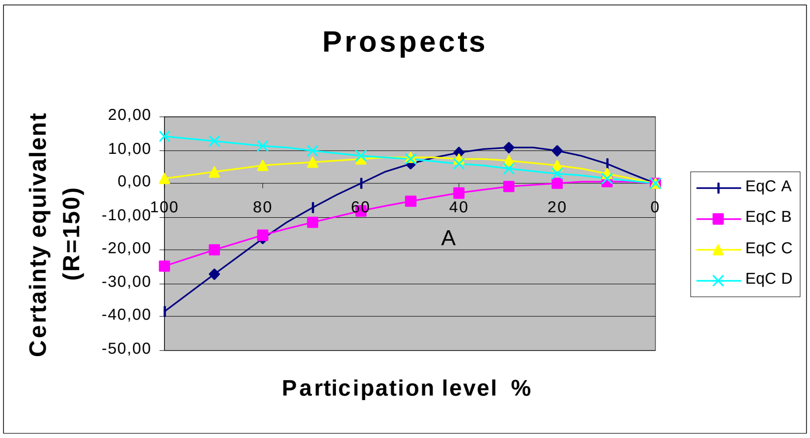


FIGURE 3- Variations of the certainty equivalent (R=150)

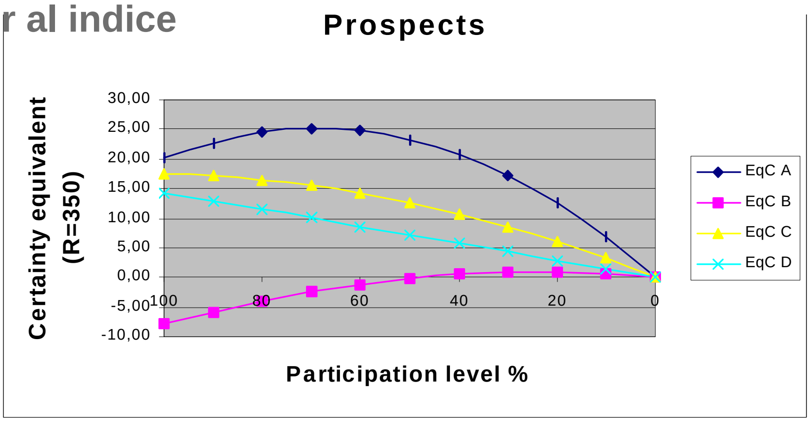
In figure 3, the variation of the certainty equivalent for each level of investment participation in the prospects A, B, C and D (from 0 to 100%) is shown (note that the x axis grows from right to left). R is constant, and has a value of US$ 150 million.

FIGURE 4- Variations of the certainty equivalent (R=350)

It is implicit that the prospects allow a percentage participation of any company. In other words, companies can associate in the enterprise.

Note that the best participation (shares) are those maximising the certainty equivalent, for each prospect. In the example, for the prospect A, the best share is 30%; for B, 10%; for C, 50%; and for the prospect D, 100%.

In figure 4 there is another example of variations of the certainty equivalent, in this case with a risk tolerance of US$ 350 million. The shares for each prospect A, B, C and D vary from 0% to 100% (note that the x-axis grows from right to left, again).



In this second example, the best share for each prospect is for A, 70%; for B, 20%; for C, 100%; and for D, 100%. Comparing the two examples, it is possible to understand how the best shares are established according to risk tolerance.

Conclusion

The methodology described in this article uses the most modern software tools available, and gives answers to the uncertain problem. Many companies penalise projects using a basic discount rate, generally equal to the capital cost (*WACC-Weighted Average Cost of Capital*), increased by a prize for the risk (*spread*). The discount rate is also known as *Hurdle Rate* and establishes an exceeding cash flow penalty in long-term investments, as those of the petroleum industry in the *upstream sector*, which can easily last for 30 years and more.

The approach proposed assumes a basic discount rate, without any *spread* increase. Risk treatment will be done using the utility function and its inverse: the Certainty Equivalent.

The problem could still be extended through a sensitivity analysis of the parameters, or though the use of linear programming to study all the portfolio possibilities with different risk tolerance coefficients (R).

For ANP’s second bid round, this methodology could be very handy for petroleum companies.

With the objective of preparing human resources for the petroleum industry, these concepts have been presented in the undergraduate Production Engineering Course of the School of Engineering at UFRJ and in the course *Master of Business in Petroleum* of COPPE/UFRJ.