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Review paper

Economic Evaluation of Oil Exploration Projects

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PROCEEDINGS

Key words: Economic evaluation, Reserve size, Monte-Carlo simulation.

Abstract

This paper has a goal to describe, in brief, the mathematical calculations in economic evaluation of oil exploration projects. Described are calculation of geological risks, reserve size, development costs, production curves, production sharing and discounting. Mathematical methods include expected value theory, probability theory and Monte Carlo simulation. All is put together in the form of a computer data input sheet, as a single procedure with the purpose of giving the answer is expected profit from a potential prospect big enough to justify the risk and money invested in exploration.

Ključne riječi: ekonomska procjena, veličina rezervi, Monte-Carlo računica.

Sažetak

Rad ima za cilj opisati matematički postupak u ekonomskoj ocjeni naftnih istražnih projekata. Opisano je računanje s geološkim rizicima, računanje količine zaliha, razradnih troškova, krivulja proizvodnje, računanje podjele proizvodnje i diskontiranje. Uključene su postavke teorije očekivane vrijednosti, teorije vjerojatnosti i Monte-Carlo simulacije. Sve je objedinjeno u jedinstveni postupak, u obliku kompjutorskog programa, koji ima za cilj odgovoriti na pitanje je li očekivana dobit projekta dovoljno velika da opravda ulaganje kapitala u istraživanja.

1. INTRODUCTION

The economics of oil exploration is the topic of many articles and academic discussions. There are many computer programs available on the market, some of which are very complex and can compute profitability in detail. In exploration projects, which prove to be unprofitable to develop, the cause of failure is most frequently the incorrect evaluation of geological factors. However, it can be the case that insufficient and/or overcomplex economic evaluation is the cause of such unprofitability, especially in marginal projects. The method described here is recommended for the evaluation of exploration projects because of its simplicity and versatility of use in diferent fiscal-tax regimes.

2. DEFINITION OF PHASES

The procedure of economic evaluation of oil exploration projects can be divided into the following phases:

Phase 1. Geological estimates of the probability of success (factors for: the existence of a valid trap, reservoir quality, seal, source rock, favourable migration - - coincidence of factors to produce a hydrocarbon accumulation);

Phase 2. Evaluation of exploration costs (bonuses, seismic, drilling);

Phase 3. Evaluation of reserve parameters (acreage, bed thickness, accumulations);

Phase 4. Evaluation of field development parameters (price of oil, price of development well, required number of wells, cost of other development, well life, percentage of the oil sharing and the participation in the profit, taxes, choice of the discount rate);

Phase 5. Compilation and integration - calculation (probability theory, expected values and Monte Carlo multiplication's) and conclusion.

3. EXPLANATION OF THE CALCULATION PROCEDURE IN EACH PHASE

Disregarding the problem of the evaluation of a parameters' sizes, the calculation procedure for each phase is as follows.

PHASE 1

The probable factors are:

- existence of a valid trap;
- reservoir quality;
- seal;
- source rock;
- favourable migration - coincidence of factor to produce a hydrocarbon accumulation.

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Geological estimates of probabilities are expressed as a percentage and, assuming that the evaluated geological probabilities are independent, we can apply the multiplication theorem which will give the complex value - discovery probability.

Each probability factor can be subdivided into more components but in such a case the overall probability of success (discovery probability) will be lower.

As a rule each factor is expressed on a scale from 5-90%. 80-90% probability indicates a good factor (very low risk), 60-80% is probable (low risk), 40-60% is possible (medium risk), 20-40% is likely (high risk) and 5-20% represents the unlikely presence of a factor (very high risk).

The comparison of different exploration projects has sense only if probabilities are expressed using the same number of factors.

PHASE 2

The exploration costs are evaluated from experience and current market prices. The sum of these also represent the risk that will have to be taken in case of failure as expressed financially. Many otherwise attractive projects with a high expected value can be dropped because of this parameter alone, as the investor simply feels the amount of risk money is to high for him to take.

PHASE 3

Profit evaluation starts with the evaluation of the size of the reserves. Here it is possible to:

a) evaluate the size of the reserves based on neighbouring fields so in this case no further complicated calculations are necessary.

b) evaluate the parameters of reserve calculations, and by multiplication using the volumetric formula, reach the total size of the reserves.

Reserves (m^3) = acreage x bed thickness x porosity x oil saturation x percentage of recoverability of total reserve x volumetric factor.

c) Many authors consider that the evaluation of parameters such as a unique size does not represent the possible size of reserves, (as we can not be certain that the chosen size is realistic), but they recommend the parameters to be evaluated in the range from-to with or without stress on the most probable value, and that the use of the special multiplication procedure known as "Monte Carlo simulation" leads to the most probable reserves sizes.

The Monte Carlo calculation procedure can be explained in the following way:

- imagine a graph with X and Y axes;
- the first parameter is put on X axis and its smallest and biggest value should be marked;
- Y axis represents probability in the range from 0% to 100%;

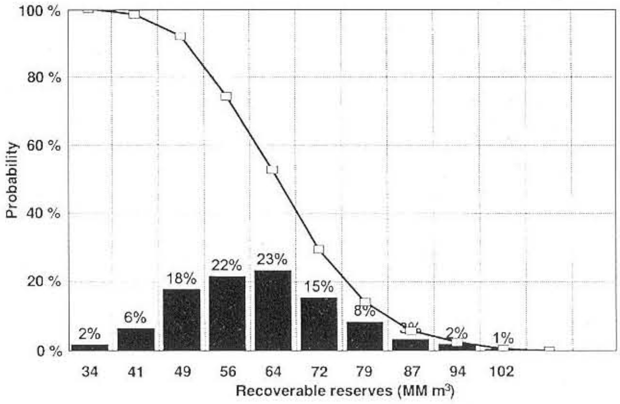

Fig. 1 Recoverable reserves for Prospect "A", North Africa.

- the cumulative probability is set for all the parameter values on the X-axis starting from the smallest one, by answering to the question "how sure are we that the parameter value is at least that great". We should get a declining line with the 100% values on the Y-axis up to 0% for the largest value;
- a random number in the range from 0 to 1 is chosen. If the chosen random number is i.e. 0.23, the value 23% on the Y axis must be found;
- from the drawn cumulative probability (declining lines) parameter values should be read on the X-axis;
- the procedure is repeated for all the parameters;
- when the values are read off on the basis of the random number for all the parameters entering the formula, the value is calculated and the result is written down. It is necessary to mention that it is not correct to multiply all the parameters with the same random number. When the same random number is used all the time, then the small value of one parameter would be multiplied with a small value of other parameters, and the aim that we want to accomplish is the result of testing with all the possible combinations of the incoming parameters (the biggest x the biggest, the biggest x the smallest, the smallest x the smallest);
- the procedure should be repeated until a satisfactory number of written results is reached, usually 1000-1500 times;
- the written results are summed and the arithmetic average is calculated through the probability distribution in the following way:
- the groups are established (classes) in which the single results are sorted and this provides us the information of how many single results each group contains. If the procedure is shown graphically through the columns, the class with the highest column is so called modal class or the class where the most common probability is found;
- the class is calculated as a percentage of the total number of cases and this number is multiplied with the middle number (lower class boundary + (upper - lower boundary) / 2) of each class;

GEOLOGICAL PROBABILITIES			
valid trap			60%
reservoar quality			60%
seal			80%
source rock			90%
favourable migration			65%
Total			16.8%
EXPLORATION EXPENSES			MM$
bonus			0.200
seismic			1.000
well			2.500
Total costs:			3.700
RESERVES PARAMETERS			
	min	mode	max
area (sq.km)	5	10	20
net pay	independant variable		
oil recovery	0.001861	0.00271	0.006577
- density	1	1	1
- porosity %	3.5%	4%	6%
- (1-Sw)	65%	70%	75%
- Rf %	9%	12%	19%
- Bo	1.1	1.24	1.3
- gas fact.(z)			
CORRELATION			
independant var.		dependant variable	
net pay		init.prod (m^3/day)	
Cumm.probab.	metres	min	max
0%	200	115	120
10%	190	100	110
50%	150	85	95
90%	110	80	90
100%	100	50	80

Acres*4047=square metres
Feet*0.3048=metre
Metric ton*7.454=barrels of 36 dg.API oil
Cubic feet*0.02832=Cubic metre
Cubic metre*35.31=Cubic Feet
Kcal*0.252=BTU
BTU*3.968=Kcal
BTU per cubic foot*8.90196=Kilocal per c.m.
Kcal per cubic metre*0.112335=BTU per c.f.

DEVELOPMENT PARAMETERS:			
		min	max
oil price ($/$m^3$)		90	120
initial production per well		dependant variable	
min. production per well (m^3/day)		5	10
well cost (MM$)		1.6	1.8
dry well cost (MM$)		1.1	1.3
other development (MM$)		18	22
opex ($/$m^3$)		40	50
CONSTANTS:			
well life (years)			20
discount rate			10%
cost-oil rate			40%
Contractor's share of production			69.40%
working interest			100%
tax (% of profit)			50%
SIMULATION RESULTS:		1300	00:00:24
	min	mean	max
reserves (MMm^3)	1.8	8.7	18.1
number of wells	9	29	75
profit (MM$)	-4	52	261
EXPECTED VALUE OF LOSS (MM$)			3
EXPECTED VALUE OF PROFIT (MM$)			9
EXPECTED VALUE OF PROJECT (MM$)			6
Graph:			

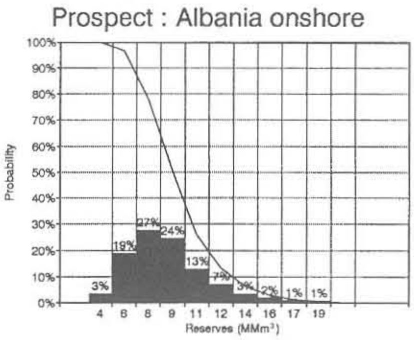

Fig. 2 Economic evaluation by Monte Carlo simulation; Prospect: Albania onshore.

- the sum of the results gives the expected value or arithmetic average of all the results.

The advantage of the Monte Carlo method versus the evaluation of reserve size based on the most probable parameter value (described in b) is that it also takes into consideration all minimal and maximal parameter values. In the described example (Fig. 1) instead of a value of 53 x 10^6 m^3 for the most probable reserve size we reached the value of 64 x 10^6 m^3. Using the Monte-Carlo simulation we proved that a higher value of reserves was probable.

PHASE 4

The required number of wells and the expected profit is calculated simultaneously to the quantification of expected reserves. The number of wells is determined from the data of initial and minimal daily production of each well (NEWENDORP, 1975). Using "Darcy's Law" a correlation is made between the expected value of the bed thickness and the initial daily production. The formula for the exponential production curve is being used and it is corrected for the number of expected negative wells (NEWENDORP, 1975). The result of the possible well number can be checked on the basis of data on the usual density of the development wells grid applied to study area. Profit is calculated on the basis of the contractual terms detailing the production percentages of profit share and is discounted at the chosen rate.

4. CONCLUSION (PHASE 5)

The ultimate aim is a comparison of expected gain versus risk. In order to do this the expected value of profit (arithmetic average of profit multiplied by the probability of discovery) was compared with the excepted value of loss (multiplication of the exploration cost with the probability of a negative well). If the expected profitability value is higher than the expected loss value a decision can be undertaken as to either undertaking the risk or further evaluation.

Two cases are described as illustrations: the Albania onshore (Fig. 2) and offshore Africa (Fig. 3). The figures also represent computer data input sheets. Results are given in graphical and numerical form (minimum, maximum and most likely size of reserves). Expected value of loss and profit are expressed in monetary units of US$.

GEOLOGICAL PROBABILITEIS			
valid trap			90%
reservoar quality			70%
seal			85%
source rock			90%
favourable migration			30%
Total			14.5%
EXPLORATION EXPENSES			MM$
bonus			
seismic			3.999
well			6.978
Total costs:			10.977
RESERVES PARAMETERS			
	min	mode	max
area (sq.km)	31	33	34
net pay	independant variable		
oil recovery	0.012802	0.02	0.03432
- density	1	1	1
- porosity %	18.0%	20%	22%
- (1-Sw)	55%	60%	65%
- Rf %	15%	20%	30%
- Bo	1.16	1.2	1.25
- gas fact.(z)			
CORRELATION			
independant variables		dependant variable	
net pay		init.prod (m³/day)	
Cumm.probab.	metres	min	max
0%	100	500	600
10%	95	450	490
50%	80	35	450
90%	65	200	300
100%	60	100	150

Acres*4047=square metres
Feet*0.3048=metre
Metric ton*7.454=barrels of 36 dg.API oil
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Cubic metre*35.31=Cubic Feet
Kcal*0.252=BTU
BTU*3.968=Kcal
BTU per cubic foot*8.90196=Kilocal per c.m.
Kcal per cubic metre*0.112335=BTU per c.f.

DEVELOPMENT PARAMETERS:			
		min	max
oil price ($/m³)		100	119
initial production per well		dependant variable	
min. production per well (m³/day)		38	50
well cost (MM$)		2.1	2.8
dry well cost (MM$)		1.1	1.2
other development (MM$)		65.3	85.5
opex ($/m³)		7.9	20
CONSTANTS:			
well life (years)			16
discount rate			14%
cost-oil rate			35%
Contractor's share of production			35.00%
working interest			100%
tax (% of profit)			0%
SIMULATION RESULTS:		1300	00:00:24
	min	mean	max
reserves (MMm³)	29.4	69.5	110.3
number of wells	36	82	287
profit (MM$)	51	529	1151
EXPECTED VALUE OF LOSS (MM$)			9
EXPECTED VALUE OF PROFIT (MM$)			76
EXPECTED VALUE OF PROJECT (MM$)			67

Graph:

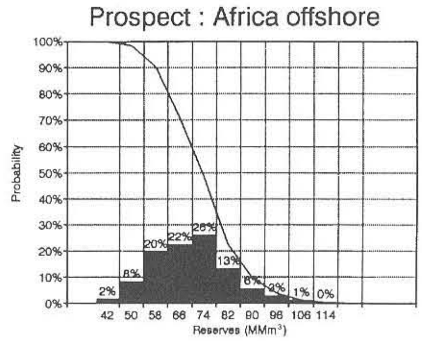

Fig. 3 Economic evaluation by Monte Carlo simulation; Prospect: Africa offshore.

One inadequacy of the method is that the political and financial risks are not being evaluated. Also only the expected value of a single prospect is considered so it does not include the total geological potential of the area. This can be overcome by applying separate evaluations of political and financial risk (choosing an higher discount rate for example for those prospects which have such higher risks). For total evaluation of the geological potential of the area a series of calculations as described herein have to be taken for each potential prospect and, by summing the expected values, a measure of the total geological potential of a certain area can be achieved.

5. FORMULAS AND DEFINITIONS

1) Definition of probability:

$$P(D) = m/n$$

The probability of the event D is the ratio of all the favorable cases (m) to the number of all possible cases (n), where P = probability.

2) Complex probability equals the probability product of each event

$$P(D1\&D2\&...\&Dn) = P(D1)xP(D2)x...xP(Dn)$$

Probability "i-i", multiplication theorem. If the events D1, D2, ... Dn are independent, but they are not mutually exclusive, in other words all of these or several of these, can appear sequentially, then this probability is called complex probability.

3) Formulas for establishing the parameter values (NEWENDORP, 1975) based on the random number (cf) if the known is:

a) minimal and maximal value of parameter x:

x = xmin+cf*(xmax-xmin);

b) minimal, maximal and the most probable value of parameter x:

- for the x values ≤ xmode

x=xmin+(xmax-xmin)*sqrt(cf*(xmode-xmin)/(xmax-xmin))

- for the x values ≥ xmode

x=xmin+(xmax-xmin)*(1-sqrt((1-cf)*(1-(xmode-min)/(xmax-xmin)))) considering that if cf ≤ (xmode-xmin)/(xmax-xmin) the first equation is used, and if cf ≥ (xmode-xmin)/(xmax-xmin) the second one is applied.

c) if the known cumulative parameter frequency is written in the shape of :

value of variable:	146	150	154	163	174	181
cumulative frequency:	0	0.4002	0.7959	0.9006	0.9674	1

the formula is:

x=x(n)+(cf-cf(n))*(x(n+1)-x(n))/(cf(n+1)-cf(n))

the calculation procedure is as follows:

the random number is chosen cf (from 0 to 1)

the test is made if cf ≤ cf (2)

if so than n=1 and solve the equation for x
if not question whether cf ≤ cf (3)

if so than n=2 and solve the equation for x
if not question whether cf ≤ cf (4)

if so than n=3 and solve the equation for x
if not question if cf ≤ cf (5)

if so than n=4 and solve the equation for x
if not than n=5 and solve the equation for x

4) Formula for the exponential declining production curve (used while calculating the reserves per well):

$$a=\ln(q_1/q_2)/t$$

where a = declining coefficient; ln = natural logarithm; q_1 = initial well production (tons/year); q_2 = final well production (tons/year); t = production time (year).

5) Recoverable reserves per well

$$deln = (1/a)*(q_1-q_2)$$

6) Number of wells per field:

number of wells = total reserves / deln

7) Number of negative development wells
if the number of wells > 20

neg = (2/15)*number of wells+3.33

if the number of wells ≤ 20

neg = (4/15)*number of wells +0.67

(the numbers are empirical)

8) time needed for the completion of the development wells

time = number of wells (positive and negative)/16

(time in years) assuming that 16 wells per year can be completed

9) discounted value of the development costs:

$$npvdcost = development\ cost*e^{-0.16*time/2}$$

10) discounted production value

$$income = reserves*price\ (a/(a+j))*((1-e^{-t*(a+j)})/(1-e^{-t*a})$$

a = exponential curve coefficient; j = discount rate; t = time in years (field duration)

11) discounted income

$$npvincome = income*e^{-0.16*time/2}$$

12) Definition of the expected value 4):

The expected value of some event is the multiplication of the events probability and the profit value of the same event.

e.g. emv = 20%*3 MM$ = 0.6 MM$

The expected value of the decision whether or not to accept the risk (expected value of a decision alternative) is the sum of the expected values of all the possible events that are the subject of the decision.

e.g. 50%*$2MM = $1MM Expected profit value
50%*-$1MM = -$ 0.5MM Expected value of loss
$1MM-$0.5MM = $0.5MM

As the expected profit value is higher than the expected loss value the decision of accepting the risk should be made.

6. REFERENCE

NEWENDROP, P.D. (1975): Decision analysis for petroleum exploration.- Penwell Books, Tulsa, 561p.