Evaluation of real options in an oil field

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Abstract: The subject of this paper is the application of real options models for valuing an offshore oil property in the North of Africa. Three different approaches were used – one based on the traditional Black-Scholes model, the Marketed Asset Disclaimer (MAD) model, and the Risk Integration approach. These approaches lead to significantly different results. The paper discusses the reasons for these differences and the pros and cons of the three models.

Keywords: Real options; oil fields; investment appraisal; capital budgeting; decision analysis.

1. Introduction
This paper analyses an investment project in an oil field. The aim is to appraise the project using the real options analysis taking into account the different uncertainties. There are, however, different approaches to appraise real options. The information, the kind of risks and the uncertainties encompassed in each appraisal may differ. The purpose of this paper is to discuss these differences.

Our study is based on a typical ‘Production Sharing Contract’ granted by a Portuguese petroleum company. In these kinds of contracts the different members of the consortium and the host country establish the percentage of the net production that each member will receive after deducting the costs involved in the initial investment. The appraisal of an oil field is of interest not only to ascertain the economic viability of the business but also to gauge the acquisition value of the supply. A very conservative analysis has little chance of success in an acquisition tender. On the other hand, an overly optimistic analysis can lead to losses for the tender winner.

This paper is organised as follows: section 2 gives a brief description of the oil field and defines the kind of option under analysis; section 3 analyses the real option appraisal approaches, their conditions and assumptions; the paper ends by comparing the results obtained by the three alternative approaches and presents the conclusions.

2. Description of the project
The investment under analysis is an offshore oil field located in Sub-Saharan Africa. Offshore oil fields involve extremely high investment and exploration costs compared to onshore fields. There are six aspects that have an impact on the success of oil fields – the oil price; the depth; the geographical location; the area of the field; the exhaustion rate; and the technology [7]:

- The price functions as a reference point for the economic viability of the field. Oil will only be extracted if it is economically viable to do so, and hence a lot of wells will be left with oil reserves untapped.
- The depth has an impact on the exploration costs, which grow exponentially as you go deeper, hence leading to drilling only in oil fields of selected depths.
- Oil has more chance of existing in certain zones of the planet than others, meaning the success is variable depending on the geographical location.
- The area of the oil field affects the probability of success insofar as the larger the area to explore the greater the probability of finding a well with oil.
- The exhaustion rate of the resources is linked to the fact that the wells with most reserves are the first to be extracted, thus creating a decline in the production rates of the oil field.
- Advances in exploration and drilling technology lead to less mistakes in discoveries and lower investment costs.

As regards the probabilities of success there are three common probabilities in the oil industry. These probabilities are usually estimated after some exploratory investigation and confirmed after a series of analyses. Proven reserves have a 90% likelihood of existing, probable reserves a 50% likelihood of existing and possible reserves a 10% likelihood of existing. In the United States companies can only present the reserves that are classified as proven in their reports and publications.

The tender winner has six years to explore for the existence of oil. If the consortium is successful the
process moves on to the development and production phase. In the opposite case the consortium must drop the project at the end of six years, losing all the exploration investment. For contractual reasons, from the moment the consortium decides to go ahead with the development and production, it no longer has any options. The exploration phase currently costs 79 million dollars, including 0.2 million dollars to train technicians and 2 million dollars to acquire the exploration rights. After the exploration phase, and if it is successful, the next step is the development phase. In this phase the best oil extraction method is selected and installed, which depends on the location and number of oil wells in the field (examples of oil platforms are the Compliant Towers and the Floating Production, Storage and Offloading rigs (FPSO)). The development phase lasts four years to be implemented, and the investment sum is 1754 million dollars.

Having installed the extraction structure, the last phase of the process begins – the production. In this final stage the oil is extracted, stored and offloaded to an oil tanker. During the production phase more information about the size of the oil reserves is acquired and consequently a more precise appraisal of its reserves. In the oil industry, for the purposes of analysis, a fixed and constant oil price is usually used throughout the duration of the project. The oil price used in this field is 35 dollars. The production revenue is subject to royalties imposed by local government.

The operating costs are 5 dollars per barrel and there is an annual training investment of 0.3 million dollars. These costs are constant over time. As well as the royalties, the profits are subject to tax (the benefit of the amortisation on the tax is already included in the tax value, table 1). The production rate has a tendency to decline over time as is very common in oil fields (see figure 1). This phase lasts eighteen years. In the last production year there is a disassembly cost of 624 million dollars and in the first two years there is a total bonus of 13 million dollars, which is the price to acquire the development and production rights.

To analyse the cash-flows a real discount rate of 10% is considered. As can be seen in Table 1, the Net Present Value is 650 million dollars. This is the value of the project without flexibility, which will serve as a reference for comparison with the real options approaches.

3. Analysis of the investment option

The oil field under analysis has an investment option. The cost of the exploration phase is the cost of the option and at the end of six years of exploration the company has to decide if it is going to invest or not in the development and production phases. This decision depends on what is learned during the exploration phase. The option is similar to a European call, with a maturity of six years – the time of the exploration – and an exercising cost equal to the development cost.

There are two uncertainties in this project: the oil price and the reserves in the oil field. The oil price varies in line with supply and demand in the international markets. The estimation of the reserves depends on the measurements carried out. Initially these are very superficial and subject to error. However, as more measurements are made the estimation of the reserves improves. Hence, during the exploration years, both the price of oil and the reserves vary over time. The appraisal of the project today could be very different from that at the end of the exploration phase. The interest in the application of the options comes from the uncertainty regarding the value of the project. When new information emerges and the uncertainty about the future gradually disappears, the management may change the strategy they had initially proposed [14].

The uncertain phase of the project is the production phase. Owing to contractual commitments, when a decision is made to move on to the development and production phases, the project can no longer be abandoned, and so the option to acquire the exploration rights has to be viable from the perspective of covering the exploration costs. We now outline three different approaches to assess the option in the oil field under analysis. In all of them the same free-risk interest rate of 3.62% is used, corresponding to the yield of Portuguese government bonds with six-year maturity at the time of the analysis.

3.1 Classic Black-Scholes Model

Using the classic Black-Scholes model, the option is appraised with market information, similarly to a financial option. This approach is described in detail in [1]: finding a financial asset that is perfectly correlated with the project, on the assumption that it is possible to create an equivalent portfolio based on this asset, guaranteeing that there is no arbitrage. Likewise, it is

![Figure 1: Evolution of the production of the oil field under analysis](image)
assumed that the present value of the project follows a Geometric Brownian motion.

Moving on to our case, based on oil and natural gas companies listed in the stock market, Nobel Energy Inc was identified as the firm that had the most similar characteristics to the project under appraisal. The core business of the company, based in Houston, USA and with shares listed in the NYSE (New York Stock Exchange), is the exploration and production of oil and natural gas, namely in Africa (Cameroon and Equatorial Guinea). Nobel is listed at 55.63 dollars and has a market value of 9643 million dollars (May 2009). The volatility of the company can be obtained by looking at the historical prices. The historical volatility varies between 39% and 41% in line with the period of time under consideration. Hence, a volatility of 40% is considered a good estimate for the purposes of the analysis. Furthermore, Nobel has proven reserves of 864 barrels of oil (Nobel Energy Inc. Annual Report (10-K), 2008) and the oil field under study has proven reserves of 560 million barrels. Therefore the value of the project under analysis is worth 65% of Nobel, with a current market value of 6250 million dollars. As such, the option has the following parameters:

- Present value: 6250 million dollars
- Investment: 1754 million dollars
- Risk-free interest rate: 3.62%
- Volatility: 40%
- Maturity of the option: 6 years

The project, using the Black-Scholes equation, has a value of 4834 million dollars, 4184 millions above the base case net present value of the project without option. However, despite the methodology being similar to financial options, it does not always make sense in real projects. It is very complicated to find an underlying asset that is listed and which behaves in the same way as the project under analysis, given that the companies in the oil and gas industry always have a wide-ranging portfolio of exploration and production projects. They also explore and produce natural gas, sometimes with very different prices to oil prices. Therefore, the financial asset that has the same characteristics as the project under analysis is, in most cases, a weak analogy to guarantee the condition of non-arbitrage [6]. Also, in the case of oil fields, the forecasts made before the exploration phase may be very inaccurate. Consequently, the size and the value of the oil fields can be clearly under or over estimated.

3.2 MAD – Marketed Asset Disclaimer

The MAD [6] is an alternative approach. It assumes that the current value of the project without flexibility (no option) is itself the underlying asset able to be used to calculate the value of the option: “what can be more correlated with the project than the project itself?” [6].

The methodology involves three steps:

1. Calculate the present value of the project without flexibility:

   \[ V_0 = \sum_{i=0}^{n} \frac{C_i}{(1 + r)^i} \]  

(1)

2. Estimate the volatility of the project through a Monte Carlo simulation. The cash-flows are simulated and discounted to year 1 (V₁) as follows

   \[ V_1 = \sum_{i=1}^{n} \frac{C_i}{(1 + r)^{i-1}} \]  

(2)

so that the annual returns can be computed,

\[ Z = \ln\left(\frac{V_1}{V_0}\right) \]  

(3)

The standard deviation of the simulated Zᵢ (t = no. of iteration) is used as the project’s volatility.

3. Finally, a binomial lattice is constructed based on the assumption that the variations in the value of the project follow a random walk in accordance with a Geometric Brownian Motion.

In the analysis of the oil field we may start by estimating the present value of the project without flexibility and the volatility of the project. To calculate the present value of the project one only has to add up the discounted post-exploration cash-flows from year 11 to year 28 (table 1): 2483 million dollars (step 1).

To obtain the volatility of the project one has to define how the uncertainty varies over time. Oil field reserves frequently follow a lognormal distribution [10]. In our case, reserves follow a lognormal distribution with an average of 1446 million barrels of oil and a standard deviation of 952 billions. As for the oil price, it is taken as an industry without growth, and at a value of 35 dollars (value established by the company and commonly assumed in this sector). The calculated volatility of the oil price is 26%, based on the Brent prices (the standard deviation represents the volatility of the oil price that was estimated based on the Brent spot price since 1987. Using the Crystal Ball software to simulate the different cash flows according to the two uncertainties – oil prices and reserves (10 000 iterations used, using the Crystal Ball software) a volatility of the option of 84% was obtained (step 2). So the option has the following parameters:
• Present value: 2483 million dollars
• Investment: 1754 million dollars
• Risk-free rate: 3.62%
• Volatility: 84%
• Maturity of the option: 6 years

As in [6], the binomial lattice was computed (figure 2). The ROA (Real Options Analysis) value net of exploration costs is now 1842 million dollars\textsuperscript{1} (step 3), 1193 million dollars above the net present value of the project without options.

\begin{tabular}{cccccccc}
0 & 1 & 2 & 3 & 4 & 5 & 6  \\
1921 & 4854 & 12038 & 29280 & 69842 & 163872 & 381755  \\
639 & 1720 & 4538 & 11688 & 29164 & 69722 & 11567  \\
163 & 480 & 1404 & 4058 & 11567 & 729 & 0  \\
22 & 70 & 226 & 729 & 0 & 0  \\
& & & & & & 0  \\
\end{tabular}

Figure 2: MAD with 2 uncertainties. Binomial lattice; units in millions of dollars.

In this case the volatility is very high given the simultaneous uncertainty concerning the oil prices and the oil reserves. Another computation was then performed with the same approach but considering only the uncertainty associated with the evolution of the oil prices. After 10 000 iterations a volatility of the option of 54% was obtained (step 2). Similarly, the parameters are:

• Present value: 2483 million dollars
• Investment: 1754 million dollars
• Risk-free rate: 3.62%
• Volatility: 54%
• Maturity of the option: 6 years

The new binomial lattice can be found in figure 3. The ROA value is now 1499 (=1578 – 79) million dollars, 849 million above the net present value.

\begin{tabular}{cccccccc}
0 & 1 & 2 & 3 & 4 & 5 & 6  \\
1578 & 3085 & 5892 & 10969 & 19895 & 35250 & 61640  \\
668 & 1399 & 2861 & 5677 & 10853 & 19774 & 5557  \\
221 & 509 & 1154 & 2568 & 5557 & 729 & 0  \\
42 & 109 & 281 & 729 & 0 & 0  \\
& & & & & & 0  \\
\end{tabular}

Figure 3: MAD with 2 uncertainties. Binomial lattice; units in millions of dollars.

3.3 Risk integration

The risk integration methodology (see [12], [13], [3]) appraises the projects by separating the types of risks. The market risks are those with market equivalents and function in a balanced market (like share or oil prices). On the other hand, the private risks are those that do not depend at all on the market conditions, but rather on the technical and scientific issues (such as reserves in an oil field or R&D in medicine). Market risks that have market equivalents are appraised with the neutral risk probabilities (real options) and the private risks are appraised with subjective probabilities (such as in decision analysis).

Smith and Nau (1995) do not suggest any method to calculate the volatility when this has different periods or a range of uncertainties. However, Brandão, Dyer and Hahn (2005b), after comments from Smith (2005) on Brandão, Dyer and Hahn (2005a), suggested a different method from Copeland and Antikarov (2001) to calculate volatility: the uncertainty in this method is simulated in the period 1 of the project, instead of being simulated in all the periods. Here only $C_1$ is stochastic, and $C_2, \ldots, C_n$ have expected values conditioned by the values of $C_1$:

\begin{equation}
 z = \ln \left( \frac{C_t + \sum_i E[C_i] - C_t | C_1]}{V_0} \right)
\end{equation}

To assess the option, the project is simulated using (1) and (4) using solely the oil price as the single uncertainty (the expected value of 560 million barrels was considered for the oil reserves). As in the MAD methodology, the volatility of the oil price is 26%. Therefore, the volatility of the oil field is now 37%.

The option has the following parameters:

• Present value: 2483 million dollars
• Investment: 1754 million dollars
• Risk-free rate: 3.62%
• Volatility: 37%
• Maturity: 6 years

The ROA value in this case is 1268 million dollars, 539 million above the static NPV.

3.4 Discussion

We outlined three different approaches in the domain of real options, distinguishing them in three important aspects: information, kind of risk and volatility.

Information – In the Black-Scholes method only the information concerning the capital markets is gathered.
Alternatively, in the two other approaches, MAD and risk integration, the information comes both from the capital market and directly from the cash-flows of the project. 

**Type of Risk** – In the Black-Scholes model there is always a market equivalent and the possibility to create an equivalent portfolio with this asset. The MAD methodology is based on the principle that the updated cash-flows are the underlying asset. Therefore it is not possible to build the equivalent portfolio because the underlying asset cannot be traded. The MAD approach also assumes that the project follows a Geometric Brownian Motion, but in truth not all variables subject to uncertainty (especially those that do not have a market equivalent) follow a Geometric Brownian Motion. Smith and Nau (1995) and Smith and McCardle (1998) propose the risk integration methodology, where the market risks (risks with a market equivalent) are appraised with the real options framework and the private risks are treated as subjective probabilities as in decision analysis.

**Volatility** – The Black-Scholes model uses the stock price volatility. Leuhman (1998) says that the volatility of uncertainties best represents the volatility of the project. However, as Lima and Suslick (2006) show, the volatility of the uncertainties is not the volatility of the project. The volatility of the project has a tendency to be higher than the sum of the volatilities of the uncertainties individually. Copeland and Antikarov (2001) present a solution based on Monte Carlo simulation, used in the MAD approach. This solution is disproportional, especially in long-term projects where the volatility can reach very high values (Smith, 2005). As mentioned in the risk integration methodology, the adjustment proposed by Brandão, Dyer and Hahn (2005b) is coherent and robust, even for long periods.

4. Conclusions

Table 2 summarises the results with the different approaches and the net present value. The main conclusion is that the different approaches lead to substantially different results but it is clear that the option to invest or not in the development and production phases adds value to the project. Our preference leans towards the risk integration methodology as the approach that best assesses the real option for the reasons outlined above.

<table>
<thead>
<tr>
<th>Assessment Method</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case NPV</td>
<td>650</td>
</tr>
<tr>
<td>Classic Black-Scholes</td>
<td>4834</td>
</tr>
<tr>
<td>MAD with 2 uncertainties</td>
<td>1842</td>
</tr>
<tr>
<td>MAD with 1 uncertainty</td>
<td>1499</td>
</tr>
<tr>
<td>Risk Integration</td>
<td>1268</td>
</tr>
</tbody>
</table>

Table 2: Summary of approaches (in 10^6 dollars).

References:
### Table 1: Chart of cash-flows. (*The value of the taxes already includes the deduction of the tax benefit of the amortizations).

| Year | 0 | 1-6 | 7-10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
|------|---|-----|------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Production | 36 | 70 | 70 | 58 | 49 | 43 | 39 | 34 | 29 | 25 | 22 | 20 | 18 | 15 | 12 | 9 | 6 | 5 |
| + Revenue | 1176 | 2274 | 2229 | 1824 | 1325 | 1163 | 1054 | 919 | 784 | 607 | 534 | 485 | 437 | 364 | 291 | 218 | 146 | 131 |
| Oil Price | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 |
| Royalties * | 7% | 7% | 9% | 11% | 23% | 23% | 23% | 23% | 31% | 31% | 31% | 31% | 31% | 31% | 31% | 31% | 31% | 31% | 31% | 31% | 31%|
| - OPEX | 180 | 348 | 348 | 292 | 245 | 215 | 195 | 170 | 145 | 125 | 110 | 100 | 90 | 75 | 60 | 45 | 30 | 27 | 15 | 11 |
| - Training | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| = EBITDA | 996 | 1926 | 1880 | 1532 | 1080 | 947 | 859 | 749 | 639 | 482 | 385 | 347 | 289 | 231 | 173 | 115 | 104 |
| - IRC/AA* | 0 | 254 | 243 | 152 | 325 | 285 | 259 | 226 | 192 | 144 | 127 | 115 | 104 | 86 | 69 | 52 | 35 | 31 |
| = EBIT x (1-t) + Amort. | 996 | 1672 | 1637 | 1379 | 754 | 662 | 600 | 523 | 446 | 338 | 297 | 270 | 243 | 203 | 162 | 121 | 81 | 73 |
| - Disassembly cost | 2 | 7 | 6 |
| - Investment Bonus | 3419 |
| Exploration Development | 3419 |
| = Cash Flows | -87² | -3419³ | -87² | -3419³ | -989 | 1666 | 1637 | 1379 | 754 | 662 | 600 | 523 | 446 | 338 | 297 | 270 | 243 | 203 | 162 | 121 | 81 | -655 |
| = Present Value | 650 | -79 | -1754 | 347 | 531 | 474 | 363 | 181 | 144 | 119 | 94 | 73 | 50 | 40 | 33 | 27 | 21 | 15 | 10 | 6 | -45 |

² FC_i + FC_{i+1}(1+r)^1 + FC_{i+2}(1+r)^2 + FC_{i+3}(1+r)^3 + FC_{i+4}(1+r)^4 + FC_{i+5}(1+r)^5 = 26 + 6/(1,1)^1 + 1/(1,1)^2 + 1/(1,1)^3 + 41/(1,1)^4 + 41/(1,1)^5 = 87 million dollars.

³ FC_i + FC_{i+1}(1+r)^1 + FC_{i+2}(1+r)^2 + FC_{i+3}(1+r)^3 = 980 + 980/(1,1)^1 + 980/(1,1)^2 + 980/(1,1)^3 = 3419 million dollars.