Economic valuation of complex projects exhibiting both technical and economic uncertainty[i]

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Introduction

During the last three to five years, real option valuation methods have received considerable attention in the academic literature, as well as gaining increased acceptance in the business world as well. While real option methodology is clearly a valid approach when correctly applied, it is not the only valuation metric in the arsenal of the Chief Financial Officer. This article focuses on four valuation metrics. If correctly applied, these valuation metrics should allow for the valuation of virtually any capital budgeting project a company may encounter.

Not all uncertainties should be treated equally

According to Dixit and Pindyck [1994] the distinction must be made between two types of uncertainty: *economic* and *technical* uncertainty. Copeland and Antikarov [2001] also make this distinction in their recent book on real options.

Economic (or market) uncertainty is a function of factors *exogenous* to the project, such as general market conditions. In other words, economic uncertainty is correlated with the general movements of the economy. As a result, in situations with a high degree of economic uncertainty, management may decide to delay the start of a project until more information is available.

Conversely, technical (or project related) uncertainty is a function of factors *endogenous* to the project, such as the quantity of copper contained in a copper mine or the success in different phases of research and development (R&D). Thus, technical uncertainty is not correlated with the general movements of the economy. As a result, in situations with a high degree of technical uncertainty, management may decide to start the project in order to collect additional information. Technical uncertainty can only be reduced by actually undertaking and completing the project.

An alternative way to illustrate why technical and economic uncertainty should be treated differently for valuation purposes has to do with the timing of the investment outlays in relation to the resolution of the uncertainty. As mentioned before, in the case of technical uncertainty, the uncertainty can only be reduced by actually undertaking and completing the project. This implies that the investment decision occurs before the resolution of the uncertainty (see figure 1a) and that management is exposed to the downside, because they will only find later whether the project was successful. Economic uncertainty on the other hand may allow management to postpone the decision until more information is available. This implies that the investment decision occurs after the resolution of the uncertainty (see figure 1b). As a result management is not anymore exposed to the downside, because under the rational expectation hypothesis, they will only decide to make the additional investment when conditions prove to be favourable.

Figure 1a: Technical uncertainty[ii]

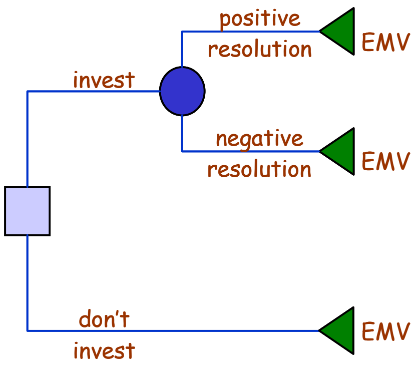
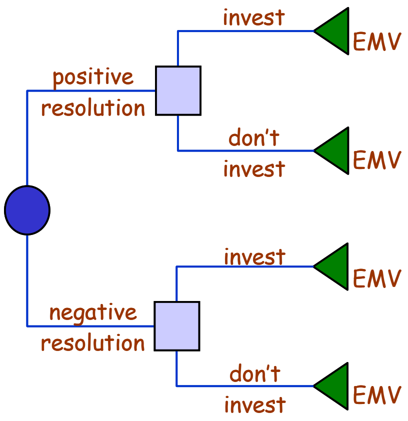


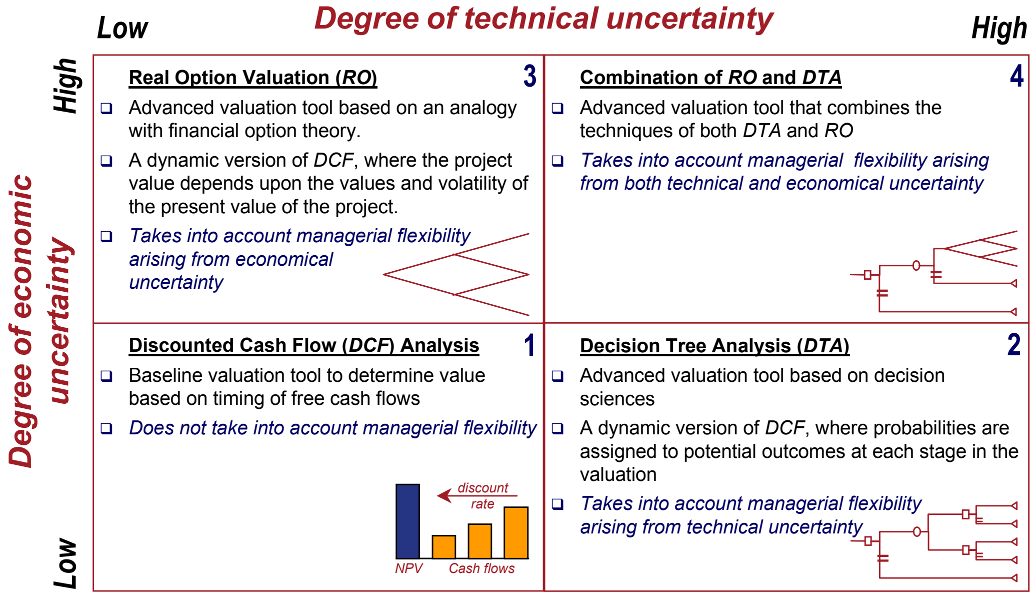
Figure 1b: Economic uncertainty



As an example, consider a company active in oil exploration, such as Exxon-Mobil or Shell. Assume that an oil field has just been discovered and the company in question considers its exploration. However, the company faces considerable economic uncertainty (the price of oil changes as a function of supply and demand), as well as technical uncertainty (the quantity of oil contained in the oil field is not known with certainty). The price of oil today is known with certainty. Future oil prices are, however, unknown until the future arises. As a result, in the case of economic uncertainty, additional information about the uncertainty can only be obtained by waiting. This situation can be interpreted as “learning by waiting.” On the other hand, while the quantity of oil contained in the oil field is unknown, its true quantity will not change over time. Consequently, the oil company may decide to invest in learning – through, for example, the use of advanced seismic technologies – to obtain a better estimate about the quantity of oil contained in the oil field. By doing so, a company can reduce the technical uncertainty. It should be noted that in the case of technical uncertainty, waiting would not bring any new information. This situation can be interpreted as “learning by investigation.”

A company should select the most appropriate valuation metric depending on the types of uncertainties that are encountered in a given project (see figure 2).

Figure 2: Optimal valuation metrics



Real Option Valuation (*RO*) 3
- ☐ Advanced valuation tool based on an analogy with financial option theory.
- ☐ A dynamic version of *DCF*, where the project value depends upon the values and volatility of the present value of the project.
- ☐ *Takes into account managerial flexibility arising from economical uncertainty*

Combination of *RO* and *DTA* 4
- ☐ Advanced valuation tool that combines the techniques of both *DTA* and *RO*
- ☐ *Takes into account managerial flexibility arising from both technical and economical uncertainty*

Discounted Cash Flow (*DCF*) Analysis 1
- ☐ Baseline valuation tool to determine value based on timing of free cash flows
- ☐ *Does not take into account managerial flexibility*

Decision Tree Analysis (*DTA*) 2
- ☐ Advanced valuation tool based on decision sciences
- ☐ A dynamic version of *DCF*, where probabilities are assigned to potential outcomes at each stage in the valuation
- ☐ *Takes into account managerial flexibility arising from technical uncertainty*

The discounted cash flow (DCF) technique is appropriate in situations with low degrees of both economic and technical uncertainties. DCF is a commonly used baseline valuation tool.[iii] The objective of DCF is to sum the cash outflows and inflows and discount them at the weighted average cost of capital (WACC) therefore resulting in a net present value ($\mathrm{NPV}_{\mathrm{static}}$). The DCF decision rule states that a company should invest in those projects that have a positive $\mathrm{NPV}_{\mathrm{static}}$. However, an undesirable characteristic of the DCF method is that it does not take into account the value of flexibility.

Alternatively, decision tree analysis (DTA), developed in the 1950s[iv], is suitable for the valuation of projects that have a high degree of technical uncertainty and a low degree of economic uncertainty. DTA is dynamic version of DCF, where objective probabilities are assigned to potential outcomes at each stage in the valuation. It happens that projects with technical uncertainty have a symmetric pay-off structure. As a result, it is possible to assign objective probabilities to the various outcomes, making DTA the most appropriate valuation technique for these types of projects.

In a transcript of a roundtable discussion on Real Options and Corporate Finance held at the University of Maryland and subsequently published in the Journal of Applied Corporate Finance (2003), Adam Borison, reasons along the same lines and state:

> *"In most of the valuation challenges I run across, the right solution is to combine elements of both real options and old-fashioned decision analysis. Real Options can be used to address those parts of the problem that involve so-called 'market' or 'public' risks. But many projects also involve 'technical' or 'private' risks, where decision analysis is more applicable. This decomposition of the problem into private and market risks is, to me, a necessary condition for gaining broader acceptance of real options."*

The difficulty with DTA is to obtain reliable discrete probabilities of success at each stage in the valuation. A first approach requires the availability of a team of technical experts as suggested by Copeland and Antikarov [2001] and Loch and Bode-Greuel [2001]. An alternative approach suggests a statistical analysis of past projects. The benefit of using statistical analysis is that, in general, only three pieces of information are required: the mean, standard deviation and the form of the probability distribution. For example, the extended Pearson-Tukey method as described by Keefer and Bodily [1983] allows for the estimation of discrete probabilities and outcomes for use in DTA.

Real options valuation (RO) is a relatively new methodology and is suitable for the valuation of projects that have a high degree of economic uncertainty and a low degree of technical uncertainty. RO evolved from the financial option theory developed by Black and Scholes in 1973. The Black and Scholes model calculates the value of a European call on a non-dividend paying stock as a function of five variables: the stock price, S; the exercise price, X; the time to expiry, t; the risk-free rate of return, r; and the volatility of stock prices, σ. In the same year, Merton [1973] extended the formula to incorporate dividends, δ. This financial option analogy was illustrated by Luehrman [1994], who established a mapping between project characteristics and financial option value drivers (see figure 3).

Figure 3: Establishing a mapping between project and financial option value drivers

Financial option value drivers	**Variable**	**Real option value drivers**
Exercise price	X	Investment cost
Stock price	S	Present value of expected cash flows
Time to expiry	t	Time to expiry
Volatility of stock price movements	σ	Volatility of expected cash flows
Risk-free interest rate	r	Risk-free interest rate
Dividends	δ	Cost incurred to preserve the option

- *The investment cost* is analogous to the exercise price (X). Keeping the other variables fixed, an increase in the investment cost will decrease the overall value of the project because it will reduce the net present value without flexibility (NPV_{static}) and, as a result, the real options NPV (NPV_{RO}).
- *The present value of expected cash flows* is equivalent to the stock price (S). An increase in the stock price will increase the overall value of the project because it will increase the NPV_{static}, and as a result the NPV_{RO} will also increase.
- *The time to expiry* (t) is equivalent to the time to maturity of a financial option. In real options, it is the maximum period that an investment can be deferred without loosing the embedded flexibility. The longer the investment can be deferred, the higher the value of the project because the likelihood of receiving additional information about the uncertainty is realistic.

- *The volatility of expected cash flows* (σ) will increase the value of the project in an environment where management can respond in a flexible way to economic uncertainty.
- *The risk-free rate* (r) will increase the value of the project because it will reduce the present value of the investment cost.
- *The cost incurred to preserve the option* (δ) is similar to dividend payouts in a financial option situation. As it is a cash outflow, it will reduce the overall value of the project.

Having established this mapping, the project value can now be calculated using the Black-Scholes formula:[v]

$$C = Se^{-\delta t} N(d_1) - Xe^{-rt} N(d_2)$$

where,

$$d_1 = [\ln(S/X) + (r-\delta+\sigma^2/2)t]/\sigma\sqrt{t}$$

and

$$d_2 = d_1 - \sqrt{t}$$

This call option analogy must, however, be applied with caution. In financial options, the volatility of stock price movements is a function of the uncertainty of stock price movements, because flexibility is built into the financial instrument. In real options, however, the volatility of expected cash flows is a function of the uncertainty of expected cash flows and the ability of management to respond to new information. Generally, in most cases flexibility is not necessarily built into the project and it may very well be that although management is operating in a very uncertain environment it has no, or limited, flexibility to respond. This is an important distinction to be made, because otherwise the possibility exists that projects without flexibility value would be overvalued.

For example, an electric utility considers investing in a Combined Cycle Gas Turbine (CCGT) power plant. Management wonders whether it should invest in a large 450 MW single shaft turbine or in a cluster of three smaller 150 MW machines, due to the fact that the company faces both seasonal and daily uncertainty of demand. While the single shaft power station requires a smaller upfront investment than the alternative, it has no embedded flexibility, because it is virtually impossible to adapt the output of the single shaft power plant in line with the changes in demand. As a result, management will prefer to invest in the cluster of smaller modules, if the benefits of the additional flexibility over the life cycle of the project outweigh the differential investment cost. This case clearly illustrates that in order to have a real option situation, one needs both a high degree of flexibility and uncertainty. Not surprisingly, the DCF method is most appropriate to value the single shaft turbine alternative, while RO is most appropriate to value the cluster of the 3 smaller machines. In fact, one can see real options as an extension of the traditional DCF method, where $NPV_{RO} = NPV_{static} +$ flexibility value (FV).

Finally, a hybrid of RO and DTA is most appropriate in situations characterized by both a high degree of technical and economic uncertainty. It is an advanced valuation tool, which requires the combination of DTA and RO, executed in sequence. Our experience shows that in most real life situations, management faces both economic and technical uncertainty. As a result, management will often have to resort to the hybrid of RO and DTA. Pharmaceutical companies, for example, face a high degree of technical uncertainty in their drug development processes and a high degree of economic uncertainty in their product sales and marketing processes. The same is true for companies in technology and research-intensive industries as well as for natural resource companies.

Figure 4 below gives an overview of technical and economic uncertainty and resulting valuation approaches in different sectors.

Figures 4: Technical and economic uncertainty in different sectors

	Pharmaceuticals	**High Tech**	**Oil and gas**	
			Oil	**Gas**
Technical uncertainty driver	Probability of success in the various stages of R&D	Probabilities of success in the various stages of R&D	Probabilities associated with recoverable reserves volumes of either oil or gas	
Estimation method	Either by capturing the knowledge of experts or through statistical analysis of past projects	Either by capturing the knowledge of experts or through statistical analysis of past projects	Collection and Appraisal of 3D seismic data[vi]	

Economic uncertainty	Success in marketing a drug once FDA approval has been obtained	Success in marketing the new product	Forward looking prices of oil No uncertainty around the future demand for oil (oil companies sell entire production output)	Forward looking prices of gas Future demand for natural gas (North American market in full development)
Estimation method	Either based on data of similar projects or through Monte Carlo simulation	Either based on data of similar projects or through Monte Carlo simulation	Monte Carlo simulation	Monte Carlo simulation
Appropriate valuation methodology	A hybrid of DTA and RO (if flexibility to address economic uncertainty exists)	A hybrid of DTA and RO (if flexibility to address economic uncertainty exists	DTA (limited ability to address the uncertainty surrounding oil prices)	A hybrid of DTA and RO (future demand uncertainty can be addressed by staging investments in LNG trains.[vii]

DTA illustrated

Consider a company – FibreTech – active in the development and marketing of carbon fibre compounds. Carbon fibre compounds have a set of unique properties. They are extremely strong, can easily absorb shocks but are very expensive and difficult to make. Currently, FibreTech only produces carbon fibre compounds for the car racing industry. The safety regulations in car racing are very stringent and carbon fibre compounds are, for example, used to make the cockpit of Formula One racing cars. Racing car drivers in Formula One have survived impacts of up to 300 kph indicating the unique properties of the carbon fibre compounds used in making the cockpits. FibreTech also wants to bring this technology to the consumer car market but needs to develop a new cheaper compound in order for the consumer car industry to be interested.

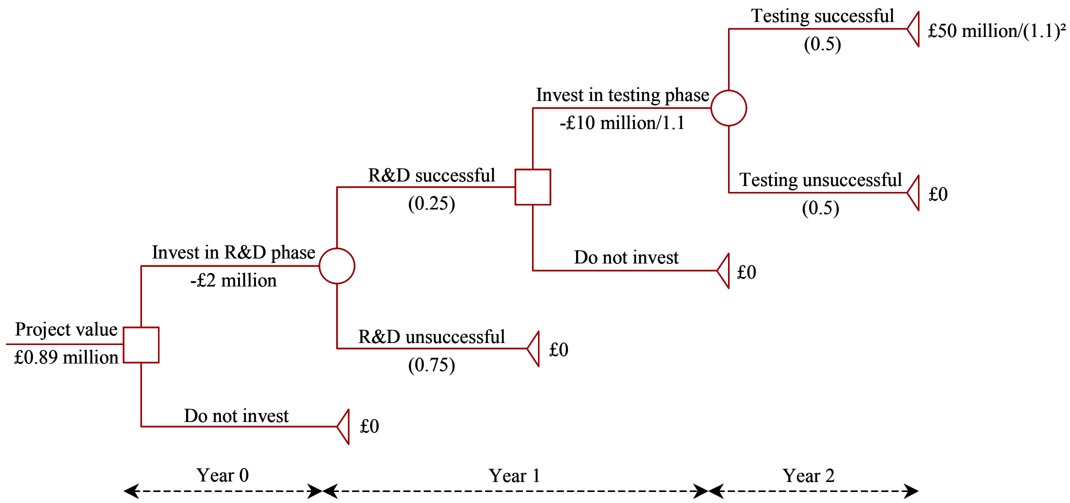
Assume that for the time being, FibreTech faces only technological uncertainty and is unsure about what to do:

1. The research and development (R&D) phase requires an investment of £2 million and has a 25% probability of yielding a successful compound. It is estimated that the R&D phase will require 1 year to complete.

2. The safety-testing phase requires an investment of £10 million and has a 50% chance of succeeding. The safety-testing phase requires such a large investment because several prototypes need to be made in order to be able to carry out the tests. The safety phase will take an additional year.
3. The licensing phase will yield a one-time cash inflow at the end of the safety-testing phase of £50 million.

From the above description it is clear that DTA is the most appropriate valuation tool to be used. Figure 5 depicts the decision tree for our example.[viii]

Figure 5: Decision tree to model technical uncertainty



Assuming a 10% discount rate, the net payoff resulting from the safety-testing phase is £12.73 million [(£50 million /1.1 * 0.5) - £10 million]. Likewise, the net payoff resulting from the R&D phase is £0.89 million [(£12.73 /1.1 * 0.25) - £2 million]. From this it can be concluded that FibreTech should invest in the R&D phase of the project. However, FibreTech should not make today the decision to invest in the safety-testing phase. Only in the case that the R&D phase yields a successful compound should the company invest in the next phase.

Valuing the project using the DCF method, the project has a value of -£5.93 million. This is a very different result from that obtained when valuing the project using DTA. This is because, in the DCF, it is assumed that the investments in both the R&D and testing phases are committed, while in the DTA method, the investment in the testing phase will only occur if the R&D phase yields a successful carbon fibre compound. This is depicted below in figure 6.

Figure 6: Valuing the project using the DCF approach

Year	**0**	**1**	**2**
Project phase	Research & Development	Testing	License carbon fibre compound
PV of cash flows	-£2 million	-£10 million / 1.1	$(0.25*0.5*£50$ $million)/1.1^2$
NPV	**-£5.93 million**		

Extending the problem to include economic uncertainty

This R&D example can now be extended to include economic uncertainty as well. Previously, it was assumed that FibreTech would be able to licence the carbon fibre compound for an amount equal to £50 million. Suppose that in this revised example, FibreTech is not considering licensing the carbon fibre compound technology, but instead to manufacture the product in-house. To achieve this, FibreTech needs to invest a further £40 million at the end of year 2 in order to start production one year later. The problem is that FibreTech is unsure at what price the compound will sell and there is a general belief that the price will largely depend on the general condition of the economy. Here, it is assumed that the present value of expected cash flow is £110 million and that the volatility of these cash flows is 30%.

This makes the problem much more difficult to value as there are now two sources of uncertainty. As a result, a hybrid approach of RO and DTA is most appropriate. This is because DTA is well equipped to deal with the symmetric payoff nature of the R&D-related uncertainties while RO is well equipped to deal with the asymmetric payoff nature of the market-related uncertainty.

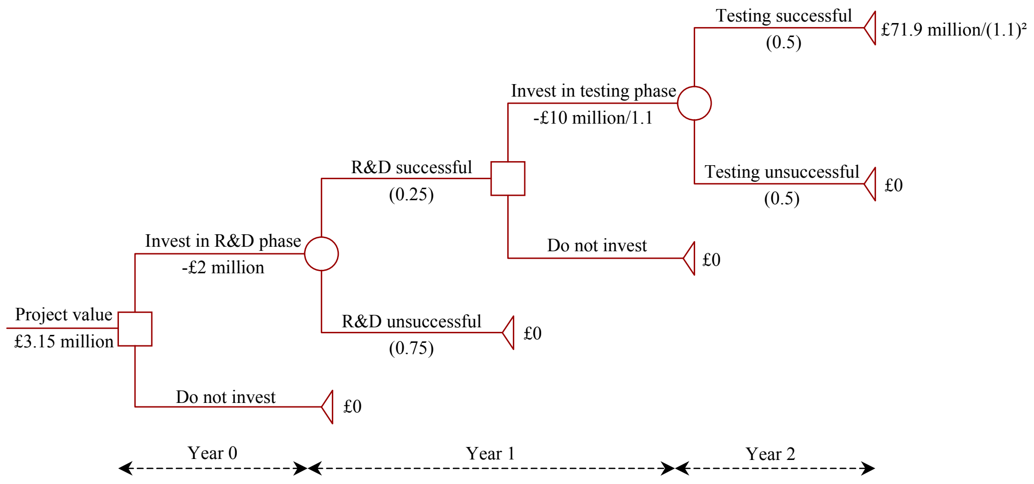
The first step is to calculate the value of the option to invest in the manufacturing plant. Assuming a risk-free rate of 5%, the project value drivers can be mapped against the financial option value drivers (see figure 7), then the Black-Scholes option pricing formula can be used to calculate the expected net payoff at the start of the construction phase.

Figure 7: Mapping our project value drivers and financial option value drivers

Financial option value drivers	Variable	Real option value drivers
Exercise price	£40 million	Investment cost
Stock price	£110 million	Present value of expected cash flows
Time to expiry	1 year	Time to expiry
Volatility of stock price movements	30%	Volatility of expected cash flows
Risk-free interest rate	5%	Risk-free interest rate
Dividends	0%	Cost incurred to preserve the option

The expected net payoff at the start of the construction phase is £71.9 million. This value can now be inserted in the decision tree to calculate the value of the project using decision tree analysis, as illustrated in figure 8.

Figure 8: Revised decision tree



Assuming a 10% discount rate, the net payoff resulting from the safety testing phase is £22.68 million [(£71.9 million /1.1 * 0.5) - £10 million]. Likewise, the net payoff resulting from the R&D phase is £3.15 million [(£22,68 /1.1 * 0.25) - £2 million]. From this it is concluded that FibreTech should invest in the R&D phase of the project.

Comparing the results of these two variations of the same case would favour in-house manufacturing over licensing to a third party. However, FibreTech should not make that decision today. Instead, it should wait for two years and make a decision based on the outlook of the economy. Clearly this flexibility is extremely valuable to the company.

Conclusion

Managers have a wide variety of valuation metrics at their disposal. However, choosing the most appropriate valuation metric can be a daunting task because no single valuation metric is equipped to deal with all the various real-life situations, especially in an increasingly uncertain and rapidly evolving environment. The framework suggested here, which makes a clear distinction between technical, or project related, uncertainty and economic, or market related, uncertainty should help in simplifying this task. It has also been demonstrated that employing the wrong valuation metric could lead to very misleading results.

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[i] An earlier version of this articles was presented at 5th Annual Conference of the Swiss Society for Financial Market Research on March 22, 2002 in Basel, and at the 4th Annual Energy Conference in Dubai on 24-25 May, 2004.

[ii] EMV stands for Expected Monetary Value and is expressed as the present value of future expected cash flows.

[iii] Kim, Crick, and Kim [1986] conducted a survey of the Fortune 1000 companies on their use of the DCF method. 90% of their 367 respondents used the DCF method in their valuation process, while 70% used the method as the primary valuation method for capital budgeting purposes.

[iv] Although decision tree analysis was developed as a technique in the 1950s, we had to wait until Magee [1964] applied it to capital budgeting at the project level.

[v] A more flexible alternative to the Black-Scholes formula is the binomial method, developed by Cox, Ross and Rubinstein [1979]. While the Black-Scholes formula is a continuous-time financing model, the binomial method falls into the category of discrete-time financing models. This makes the binomial method more suitable to model complex real options' situations, such as those with intermediate cash in- and outflows.

[vi] 3D seismic is a technology used by geophysicist to obtain an image of the subsurface area. From this image it is possible to see the degree of variation within the geology. The use of 3D seismic modelling techniques allows for a more accurate assessment of recoverable reserves in the oil or gas field.

[vii] LNG stands for Liquefied Natural Gas.

[viii] Note that a decision is represented in a decision tree by a square or decision node, while a circle represents an uncertainty.