1. Introduction

In this paper we present a preliminary approach to the evaluation of policies and projects based on current thinking on cost benefit analysis and real option methodology and the authors’ recent work on the same subject. We start from the assumption that economic agents undertake investment projects in order to create and exploit opportunities for increasing profits, growth, wealth and, ultimately, their welfare. These opportunities are options, rights and not obligations to take some action in the future. They include not only projects undertaken, but also projects that could be adopted in the future, and opportunities that can be further created or destroyed by this adoption. From the point of view of the welfare of an entire economy, opportunities enlarge the set of actions that may contribute to national wealth. Not only this is increased by the net flow of discounted benefits generated by new ventures, but also by the net value of the options created and destroyed by investment behavior. When companies develop investment opportunities, therefore, they contribute to national welfare in a more subtle, but not less important way, than when they are actively set to exploit some of these opportunities. By recognizing the direct contribution to country wealth of project design and planning, option theory may thus substantially change the theory and practice of decision making about capital investment.

The conventional approach implicitly theorizes that investment decisions can be reversed if the conditions change or that they are now-or-never propositions. In contrast, the new way of thinking of investment opportunities as options, changes the premise: irreversibility, uncertainty and the choice of timing alter the investment decisions in critical ways. The real option approach, differently from the traditional tools of project evaluation and capital budgeting, promises to establish a richer framework, both for decision makers and for managers, who should be enabled to address these issues in a more transparent and coherent way.

In accordance to this theory, the agent with an opportunity to invest is holding something akin to a financial call option: it has the right but not the obligation to buy an asset at a future time of its choosing. When an agent makes an irreversible investment expenditure, he “exercises” his call option, and doing this it effectively “kills” the option. In other words, by deciding to go ahead with an expenditure, the

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agent gives up the possibility of waiting for new information that might affect the desirability or timing of the investment (he cannot disinvest should the market condition change adversely).

The lost option value is an opportunity cost that must be included as part of the cost of the investment. Thus the simple rule of the NPV, to evaluate an investment decision, needs to be modified: instead of just being positive, the present value of the expected stream of cash from a project must exceed the cost of project by an amount equal to the value of keeping the investment option alive.

Numerous studies have shown that the investment cost is highly sensitive to uncertainty over the future value of the project, so that it can affect investment spending more than the change of the interest rate. Moreover, the conventional NPV rule ignores the value of creating options; sometimes an investment that appears uneconomical when viewed in isolation, can create options that enable the company to undertake other investments in the future should market conditions turn favorable.

More importantly, by aiming at producing and delivering public goods, public projects may be often construed as creators of opportunities for the private sector, rather than investments that directly produce material goods. Thus, one might argue that in a market economy, the primary business of the public sector is to expand the options of private citizens, while it is ultimately up to them whether exercise or not these options.

In sum, these propositions suggest that also welfare economics and the practice of cost benefit analysis should be affected in a major way by the real option approach. Just as the value of a company is formed as the sum of its expected cash flows from the projects adopted and from the options held on the new ones to be adopted, the welfare of a country should also be a function of the options held by the economic agents that it comprises, including, in particular, the government. Adopting a project that irreversibly commits resources should thus be scrutinized, from a national point of view, not only on the basis of what it is expected to yield in terms of expected material increases in production or incomes, but also of the opportunities that it creates or destroys for the country. These opportunities are ultimately to be linked to economic policies, since it is the design of policies and projects that constitutes the essence of a good government and of a successful development strategy.

2. Conceptual foundation for NPV and Real Options

As background for discussing the applications of real options, it is necessary to clarify the differences and similarities between real option investment valuation and conventional decision analysis or NPV (Net Present Value). A project’s NPV is simply the difference between the project’s value and its cost, both expressed in terms of discounted cash flows (DCF). According to the NPV method, the decision maker should accept all projects with NPV positive (greater than zero).

The NPV \DCF method is built on the following assumptions:
- the investment is reversible
- if the investment is irreversible, it is a now-or-never proposition (if the agent doesn’t make the investment now, it will lose the opportunity forever)

Even though it is considered superior to other methods of valuation, the NPV / DCF methodology fails as a general method to valuate correctly investment decision, because only some investments fall into those categories, while most do not. In most cases, in fact, investments are irreversible and, above all, capable of being delayed (it can profoundly affect the decision to invest). From the NPV faulty assumptions arises the most important distinction between real options and conventional decision-making: “the fact that the standard net present value rule does not take into account the ability to delay an irreversible investment expenditure can really affect the decision to invest” (Dixit and Pyndick 1994).

The NPV does not recognize the managerial alternative of waiting or delaying the start of the project, or phasing a project; differently, the real options approach recognizes that the decision can be deferred, involving the issue of the managerial contingency to alter course in the future. It is the “managerial flexibility” that is indicated as very important in structuring the project analysis, because of it is often a source of additional value in the investment decision. This flexibility is inherently valuable: it increases the upside and limits the downsides of strategies, enhancing their value.

For this reason, an option approach to valuation of a sunk cost investment always will be greater than or equal to the NPV approach for valuing the same project.
The only cases in which the project’s option value is the same as its NPV are when time is run out (i.e. when the real option has expired or when there is not uncertainty) and when the investment decision can no longer be deferred:

\[ \text{NPV} = (\text{Value of Project Asset}) - (\text{Expenditure Required}) \]

\[ \begin{align*}
\text{This is } S \\
\text{This is } X \\
\text{So: } \text{NPV} = S - X
\end{align*} \]

Conventional NPV

**Option Value**

When \( t = 0 \), \( R \), and \( \delta \) do not affect call option value. Only \( S \) and \( X \) matter.

At expiration, call option value is \( S - X \) or 0, whichever is greater.

Here we must decide “go” or “no go”

Here it’s “exercise” or “not”

In conclusion, when future outcomes are well known and future decisions are obvious, standard NPV methods adequately represents the business’s value. On the other hand, when new information will likely become available and management can make decisions to exploit it over the time, adjustments should be made to reflect the value of the new opportunities. Therefore, we can view real options valuation as a complement to standard NPV valuation, considering the business’s total value as sum of its NPV value and the value of additional real options. Considered in this way business strategies\(^1\) as well as economic policies are much more like a series of options (compound options) than a series of static cash flows.

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\(^1\) Implementing a strategy almost always involves making a sequence of major decision: some actions are taken immediately, while others are deliberately deferred, so that managers can optimize as circumstances evolve.
3. **Real Options**

In finance, an option is defined as the faculty, but not the obligation, to purchase (sell) an underlying asset at a given price within a given time horizon. As a simple extension of this concept, a real option can be defined as the faculty, but not the obligation, of undertaking a given action or set of actions carrying a given expected net benefit at a given cost. This is a wide encompassing definition that can cover a plurality of real life situations, where uncertainty and the passage of time are both important. At the same time, the broadness of the definition notwithstanding, only a small number of basic real options appear to be relevant in economics. These are (see Box 2 for more details):

(i) the option to abandon,
(ii) the option to contract,
(iii) the option to switch,
(iv) the option to wait,
(v) the option to expand,
(vi) the option to grow.

These are the specific options that we focus on, in order to fully develop a scenario from its initial form based on the factor component definition and the SWOT analysis.

**BOX 2: The main classes of options**

*Regardless of the agent who is holding them, it is notable that the most important real options can be grouped into only six general categories*

- abandon options;
- contract options;
- switch options (input, output or processes);
- defer or wait options
- expand options
- invest or growth options
**Abandon** options are important in capital intensive industries where management would like to have the flexibility to capture the value for the assets if their in-use value to the company falls; also in high variable cost industries, the option to shut down is valuable. From a policy making point of view, the option to abandon a given policy, say a fixed exchange rate, may be limited by existing institutions, vested interests, reputation and adjustment costs. The option to either **contract** or **expand** scale is a flexible means of dealing with changing demand. The option to **switch** encompasses the ability to change the product mix, land use flexibility, and the ability of a plant to switch between coal and natural gas, in response to changing input and output prices. **Timing** option (**wait/defer**) are valuable in natural resource industries and many capital investment, or anywhere resource commitments or policy actions are irreversible. More in detail:

**Abandon** option: this option exists when, if market conditions decline severely, management has the opportunity to abandon current operations and obtain the resale value of capital equipment and other assets in the second-hand market. In the case of economic policies, policy makers should be able to abandon by obtaining some gains from the assets that become available as a consequence of the abandon (for example, a policy of privatization can be construed as the abandon of the presence of the public sector in certain industries).

**Contract/expand** option: this option exists when, if market conditions turn out more favorable than expected, the firm has the opportunity to expand. Conversely, if conditions are less favorable than anticipated, the firm can reduce the scale of operations.

**Switch option**: this option exists when an agent (a firm or a country) has product flexibility and can change its output mix if prices or demand change unexpectedly. Alternatively, the firm could have process flexibility and adjust the types of inputs in response to changes in costs/supplies.

**Defer/wait** option: this option exists in the situations where the decision maker holds rights on valuable resources, including land, capital, know how, specialized information and planning. The decision maker can wait a certain length of time to see if exogenous, uncertain conditions (e.g. market prices) justify constructing a building or a plant or developing a new venture of some sort.

**Invest/growth** option: this option is present when an early investment (i.e. R&D, lease on undeveloped land or oil reserve, strategic acquisition, information network) is the prerequisite or link in a chain of interrelated projects, and thereby opens up future growth opportunities.

Because options to abandon, contract, or switch current operations all involve selling a current investment, they are called put options. They become “in the money” when the value that could realize by selling the real underlying asset is greater than the value of the asset in the way it is currently deployed. Decision to defer an investment, expand a current investment, or make a new investment are
called call options. They go “in the money” whenever the present value of the new investment exceeds the present value of its costs.

Real options are implicitly held by agents who manage their business and investment opportunities; both at the level of the individual company and at the country level, they are pervasive in real life as management’s flexibility and ability to respond to developments over time. As valuable intangible assets, they are not only a prerogative of firms and business agents. In contingent evaluation studies, for example, consumers are reported to be willing to pay for the “option” to use a wide range of public goods. From the country point of view, real options arise both from individual behavior and from the flexibility that policy makers can exercise as they “wait and see” the evolving of economic events in an uncertain environment.

Because options to abandon, contract, or switch current operations all involve selling a current investment, they are called put options. They become “in the money” when the value that could realize by selling the real underlying asset is greater than the value of the asset in the way it is currently deployed. Decision to defer an investment, expand a current investment, or make a new investment are called call options. They go “in the money” whenever the present value of the new investment exceeds the present value of its costs.

The following table shows the mains characteristics of the options, putting in evidence for each of them the management goals reachable and the common owners or industries where they can be better exercised.

<table>
<thead>
<tr>
<th>Real Option</th>
<th>Abandon</th>
<th>Contract</th>
<th>Switch</th>
<th>Defer</th>
<th>Expand</th>
<th>Invest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option Type</td>
<td>Put</td>
<td>Both</td>
<td>Either</td>
<td>Either</td>
<td>Increase Upside</td>
<td>Call</td>
</tr>
<tr>
<td>Management Goal</td>
<td>Limit Downside</td>
<td>Both</td>
<td>Limit Downside</td>
<td>Business that can Accelerate or Postpone Revenues</td>
<td>Business that can Switch Inputs or Outputs</td>
<td>Business that can Accelerate or Postpone Revenues</td>
</tr>
</tbody>
</table>
4. The value of Real Options

The name “real option” refers to an economic good which is similar to a financial option, but whose underlying asset is constituted by real activities. Because of the analogy to financial options, many of the evaluation techniques used for the real options derive from the practice in financial markets.

Six crucial variables are needed to estimate real option values. The first two are the asset value (S) and the strike price (X): these are important because their difference determines whether or not the option is “in the money”. For real options, the asset value is the economic value of the business or project being evaluated (It can be evaluated by using the stock price for a public company or by using the NPV approach for a private company). The strike price or exercise price is the value of the investment (the sunk cost) necessary to fund the business or project.

The next two factors affect asset values and strike prices over time: any payment, such as the dividend payments (D) on the underlying stock, reduces the appreciation of the asset and, in the call option case, the likelihood that it will go “in the money”. Therefore the higher this value, the lower the value of a call. On the other hand, when the strike price of the real option is constant over time, it provides the holders with an interest –free loan on the strike price. The higher the interest rate (Rf), the higher the value of this free loan and the more valuable the call option (in the put option case the effects are reversed).

The next factor is the time (T) to the expiration date; for real options this is the time by which the decision maker has to choose whether or not to make or sell the investment; the longer the time, the more valuable the option.

The last factor is the volatility (δ), that, by widening the gap between the variable possible gain and the given possible loss, actually increases the value of options². For real options, volatility is a measure of how much the value of the underlying asset (the right to claim an expected net benefit over time) changes in a period of time. For a public company, it can be measured by calculating the standard deviation of its stock price return. For private company, it can be estimated by using the appropriate statistics from public company “peer”, but if similar peers are not available, simulation analysis can be used on a NPV valuation to calculate a business’s value probability distribution from which the standard deviation can be calculated. Similar techniques can be used for country policies and public projects.

In summary the characteristics of the underlying asset and the terms of the option themselves have an impact on option value, as shown below (as increase each of terms):

² Volatility is a measure of risk We have to distinguish two elements of risk: unique risk and market risk. The first concerns project evaluation, while the second refers to the kind of business. Is possible to estimate the unique risk from the corporate database, technical publication or industry benchmarking. Obviously the higher the unique risk the lower the value of the option.
As the table shows, the real options are most valuable when:

- the underlying asset value is high/low (call/put), volatile and not subject to erosion from payments (only for call)
- the strike price is low/high (call/put)
- interest rate is high/low (call/put)
- the time to expiration is long

In order to evaluate a project, or a policy, we have to establish a correspondence between their characteristics and the six variables that determine the value of an option. Below this kind of correspondence is shown for a corporate investment project, seen as a call option:

<table>
<thead>
<tr>
<th></th>
<th>Call Option</th>
<th>Put Option</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Asset Value</strong></td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td><strong>Strike Price</strong></td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td><strong>Dividends</strong></td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td><strong>Time to Expiration</strong></td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td><strong>Interest Rate</strong></td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td><strong>Volatility</strong></td>
<td>↑</td>
<td>↑</td>
</tr>
</tbody>
</table>
5. Evaluation Methods

There are three common ways to evaluate real options:

- Decision tree analysis
- Binomial analysis
- Black & Scholes analysis

Each has different required inputs and is appropriate in different situations. In particular, the decision tree and binomial method work well for complex options that involve a number of risks with multiple expiration dates and volatilities that change over time. The binomial approach is limited to two outcomes per period, but corrects for the discount rate imprecision involved with the decision tree approach. The Black & Scholes approach is the best choice for simple options that arise from single, market-priced sources of risk and are exercised at maturity.

The decision tree method: this method is interesting to value staged investments with multiple options to abandon, as it is typical for research and innovation. The value of these investments can only be understood and captured by considering both current and potential future decisions. By identifying optimal responses to future contingencies before they occur, the decision maker can gain clarity about how and when to make future investment decisions, thus greatly reducing the likelihood of making a bad decision. Decision tree valuation is thus a good tool to value scenarios concerning decisions for research and innovation and should therefore be used to support the strategic management/policy process of organizations that are investing significantly into innovation. The value of the option will stem out from the path in the decision tree which ends at the point at which the option is exercised.

This method, however, has several limitations:

- it can only model future decisions that have outcomes that can be identified;
- it needs to estimate the probabilities of future outcomes, and in many circumstances, this is rather difficult;
- it implicitly assumes that decision makers make the right decisions along the way;
- it discounts options at the same rate, when they can be more or less risky than the underlying business.

The binomial method: this method assumes that the value of the asset follows a binomial distribution. Starting at time zero, in one time period $\Delta t$, $S$ may rise to $uS$ with probability $q$ or fall to $dS$ with probability $1-q$, where $d<1$, $u>1$, and $d<rf<u^3$. The terminal value of a call option on $S$ which matures in $\Delta t$, is

\[ C = \max(S - K, 0) \]

\[ C = C(T/N) \]

The parameters $u$, $d$ have the following representation: $u = e^{\delta \sqrt{T/N}}$ and $d = 1/u^3$.
(1) \( Cu = \max[0, uS-X] \) or \( Cd = \max[0, dS-X] \)
with probability \( q \) and \( 1-q \), respectively.
By setting \( p = \frac{r-d}{u-d} \), the current value of the call option can be written as:
(2) \( C = pCu + (1-p)Cd / (1+Rf) = \max[0, uS-X] + (1-p)\max[0, dS-X]/(1+Rf) \)

where \( p \) is called risk neutral probability\(^4\).

Basically, the binomial method requires setting up a tree of possible price paths with risk neutral probabilities, determining the paths over which the option will be exercised, and then discounting the cash flows of the optimally-exercised option at the risk free rate.

In detail the steps to follow are:
1. derive the risk neutral probabilities by deriving probabilities that give an expected future price which differ from the present price by only the risk-free rate;
2. determine the value of the option, if it is exercised;
3. notice that the exercise price of the option is the cost of the investment. Determine cash flows of optimally-exercised options;
4. take expected value over risk neutral probabilities;
5. discount at the risk-free rate.

The number of nodes can be increased by dividing the horizon into multiple periods, each with an up or down possibility. As the number of nodes increases, the binomial method converges to the solution provided by the Black&Scholes formula.

Insert Graphic Example(CS)

Black & Sholes approach: the formula uses the variables defined above in the following way:

\(^4\) We can think at risk neutral probabilities as specific probabilities, which are adjusted for the risk associated with the particular event: the benefit of doing this is that we can then just do the discounting at the risk-free rate.
\( C = SN(d1) - X(e^{-r} N(d2)) \)

\[
d1 = \ln(S/X) + (R_f + \frac{\sigma^2}{2})t
\]

\[
d2 = d1 - \sigma \sqrt{t}
\]

where \( N(.) \) denote the normal distribution. Amram & Kulatilaka offer the following interpretation for the groups of terms in the right-hand side of equation 1: 

- \( SN(d1) \) represents the expected value of the current underlying asset, if the current value is greater than the investment cost at expiration.
- \( N(d2) \) represents the risk-neutral probability that the current value of the underlying asset will be greater than the cost of the investment at expiration (therefore it represents the probability to exercise the option).

This method assumes that the value of the asset (S) is lognormally distributed and that either that there is a set of optimally diversified no arbitrage markets or that investors are risk-neutral. The latter, alternative assumptions eliminate the need to estimate the opportunity cost of capital of the option. It enables present value discounting of the expected payoffs from the option by \( R_f \), the continuously compounded risk-free rate of return, independent of risk preferences or market equilibrium considerations.

The B&S model implicitly requires that S be traded and no arbitrage opportunity exist, so that the analyst’s experience is prevented from entering the analysis. This contrasts with traditional project evaluation, where the opportunity cost of capital reflects what the analyst perceives to be the balance between the risk and reward characteristics of the project.

Unlike the binomial method, B&S requires an explicit measure of the variance of the underlying asset return, rather than risk-neutral probability. Even though the B&S formula is the easiest method to use to price options, it has some limitations: it is based on the European financial model, under which options can be exercised only at the terminal date and no dividends are paid\(^5\) during the option’s life.

The following table shows a comparison of approaches to valuing real options and summarizes the main key points:

\(^5\) That’s much more restrictive than the American system, where options can be exercised at any time prior to terminal date.
<table>
<thead>
<tr>
<th>Types of Options</th>
<th>How Risks are Reflected</th>
<th>Discount Rate</th>
<th>Common Application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DCF with Decision Tree Analysis</strong></td>
<td>Complex</td>
<td>Cost of Capital</td>
<td>Staged Investments and Projects with Defined Decisions and Risks</td>
</tr>
<tr>
<td><strong>Binomial</strong></td>
<td>Complex</td>
<td>Risk-Free Rate</td>
<td>Projects with Multiple Risks that are Well Represented by Upsides and Downsides</td>
</tr>
<tr>
<td><strong>Black &amp; Sholes</strong></td>
<td>Simple</td>
<td>Volatility</td>
<td>Public Company, Projects Involving Commodities</td>
</tr>
</tbody>
</table>
6. Solution Process for the Application of Real Options to Project Evaluation

While financial options are clearly identified and evaluated, real options may be much harder to treat. It order to define a clear methodology to identify and evaluate the options, we propose a framework that allows to evaluate a whole project, considering, simultaneously, its certain and uncertain components.

The framework proposed involves three macro-steps:
1. Identifying the options
2. Analyzing the options
3. Evaluating the opportunity of acting or exercising the option

Identifying the options. An option can be interpreted as a combination of certain capabilities (the realization of raw capacities as a consequence of an investment process) and of corresponding opportunities (the conditions under which the capabilities can be usefully displayed). In order to identify the project options, it is thus necessary to determine the consequences of project implementation on the capabilities and opportunities of its key agents (its stakeholders). One way to explore the effect of the project on these two dimensions is to divide the path to the objectives pursued into distinct stages. For each stage, preliminary estimates have to be obtained of costs, benefits and uncertainties associated with the decision opportunities.

Analyzing the option: the analysis of the business and/or policy opportunities can itself separated into three tasks:

- developing the project as a plan for action in an average scenario: in the case of a private investment, this task can consist of drawing a business plan. For a public project, it can consist of the design of the different components of the project. The first step is to draw a preliminary plan, based on annual forecast of benefits and costs for the duration of the project. This step is identical to the traditional analysis developed by the feasibility study of the NPV method.
- assessing risks and opportunities: the most important idea about risks and opportunities is that they can be to two general categories, which can work in opposite ways: endogenous and exogenous. The first, inherent in the individual situation of the agent (company, country, other types of institutions) and partially subject to the control of the decision maker, can be expressed in terms of probabilities or expected values and can be estimated by expertise and data. It is usually associated with three aspects of the enterprise considered: the likelihood of success, the possibility of cost overruns and the influence on the potential area of expansion (e.g. degree to which the new project or product could expand to the overall market). The second form of risk, also

[6] In the ethical drug industry for example, the analysts can derive statistics from the thousands of perspective new drugs that go through clinical trial. Otherwise, they can obtain the probability of success from experts, which is perhaps the more typical process in practice.
called volatility, is not under the control of the decision maker or the managers, but depends on exogenous circumstances\textsuperscript{\textit{7}}.

- applying the options algorithms to calculate the option values.

Acting or exercising the option: decide to exercise the option or to wait to have additional information about input or output data. The evaluation process should incorporate a sensitivity analysis, to test the implications of the initial assumptions. In this way is possible to evaluate, not only the economic value of the project, but also its strategic value, that is the value of the options created by the project and embedded in it.

\textsuperscript{7} For example, in decisions involving the development of oil fields, market risk is ultimately associated with the overall market for oil. In earlier phases of the process such as exploration, however, risk would more appropriately concern the market for proven oil leases, but information about these trades may not be readily available (Siegel 1987, Paddock 1988).
7. **Some Applications**

Applications to this day of the real option method to project evaluation has mostly occurred in industries such as natural resources, energy, pharmaceuticals and technology, which have a higher degree of uncertainty in business-process investment, as well as for valuation and strategic decision-making for the construction industry in developing country.

The cases of real options presented in this section aim at presenting the different evaluation methods and, in particular how to treat the real options problem and the main findings of the analysis. Because most of applications have occurred in the private sector, almost all the cases presented would concern more the IFC than other Bank operations. The following industry contexts are considered:

- R&D Project
- Pharmaceutical
- Information Technology
- Software Engineering Project
- Construction Industry in Developing Countries
- The Environment

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8 For example, in the oil-drilling industry, uncertainties include issues such as what the cost of leased land will be. How large are the oil reserves? What is the proper price for the lease on the reserve? What will the price of the oil be?
7.1. **R&D Projects**

Consider an agent, a company or an individual, holding the rights on a new R&D product, which requires the undertaking of an investment project to be brought to the market. The project requires an initial investment of 6.5 Mio$ on product development in two years that should be doubled in the third year, for 15 Mio$; the expected cash flow, if the launch successfully occurs, is estimated to be 25Mio$:

Evaluating this project by calculating the NPV, we obtain:

\[
NPV = \sum_{t=1}^{T} \frac{FCF_t}{(1+r)^t}
\]

Assumption:  
Interest Rate \( r = 5\% \)

<table>
<thead>
<tr>
<th>Quarter</th>
<th>J1-Q1</th>
<th>J1-Q2</th>
<th>J1-Q3</th>
<th>J1-Q4</th>
<th>J2-Q1</th>
<th>J2-Q2</th>
<th>J2-Q3</th>
<th>J2-Q4</th>
<th>J3-Q1</th>
<th>J3-Q2</th>
<th>J3-Q3</th>
<th>J3-Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cash Flow Revenues</td>
<td></td>
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<td></td>
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<tr>
<td>Investments</td>
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<tr>
<td>Present Value (CF Revenues)</td>
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</tr>
<tr>
<td>Investments</td>
<td>-0.50</td>
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<td>-0.73</td>
<td>-0.72</td>
<td>-0.95</td>
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<td>-0.93</td>
<td>-0.89</td>
<td>-0.83</td>
<td>-0.62</td>
<td>-13.57</td>
<td></td>
</tr>
<tr>
<td>Sum of PV (CF Revenues)</td>
<td>-13.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum of PV (Investments)</td>
<td>-13.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Value (DCF)</td>
<td>-0.38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Value of the project using net present value = -0.38m

The feasibility study is based on a discounted cash flow analysis, assuming that all stages of investment are adopted. If we apply the real option approach, considering the uncertainty of the expected cash flow, due the uncertainty of the market prices and the technology strength, the problem changes:
The first step is to consider the market uncertainty, and therefore to take it in account whether to decide to go on with the investment:

Using the Black&Scholes method to evaluate the waiting option, that we call “market launch option”; the following table shows the assumptions, the correspondence between the characteristics of the project and the terms of the call option. The value of the project is also shown, as given by difference between the option value and the present value of the investment before the launch:
Comparing the two different analysis we have:

- project’s value, through NPV, negative of 0.38 Mio$
- project’s value with market launch option positive of 1.07

At the end of the first two years, the development agent has the opportunity to abandon the R&D project if the technology should result weak. If we arrange the schedule for decision-making more realistically, we can assume that in each quarter (milestone) the agent can abandon the project: as a consequence, he holds both the market launch option and the abandon options.

The binomial method is used to calculate the project’s value with the following hypothesis:

\[
RO = S \cdot e^{-\delta \cdot t} \cdot \{N(d_1)\} - X \cdot e^{-r \cdot t} \cdot \{N(d_2)\}
\]
The project’s value, considering also the managerial flexibility, is absolutely positive.

R&D Projects and the Provision of Public Goods

Knudsen and Scandizzo (2002) examine the case of R&D projects from the point of view of a public project aiming at improving the provision of a public good: an efficient and fair judicial system. They consider the possibility that the pursuit of the R&D project may determine a possible damage to third parties, thereby offering them the opportunity to claim compensation through the court system. This liability option may be measured by a damage variable, i.e., an index of damages.
effectively or potentially inflicted to other parties by the subject undertaking the project. As an index of potential damages, it may be based on the experience from other projects or on new statistical and/or scientific evidence. Its volatility may be interpreted as an index of the uncertainty surrounding the existence, nature and site of the danger, as well as of the probability, that once the damage is claimed by the damaged, the judicial system will allow the recovery of compensations and/or punitive damages. For a given state of the arts, therefore, uncertainty can be changed by the legislator or the court system. The legislator may stipulate in more specific terms the extension and the limits of the liability incurred by the investor under alternative conditions. She may impose insurance or the institution of a compensation fund. She may detail the rules that have to be followed both to minimize the risk and to document the damage claimed.

The court system, on its part, by ruling on the different cases, will also act, in time, to consolidate the de facto rules that govern liability management and control on the part of the subjects who may be liable and of those who may be damaged. By converging toward a consistent interpretation of the letter and the spirit of the law, a well functioning court system will progressively reduce the turbulence surrounding the largely unknown consequences of new discoveries in the most delicate fields of research and development.

What are the effects of this reduction in uncertainty and is it, in fact, worth pursuing it because it is socially desirable? The analysis developed shows two different sets of results, which may seem paradoxical, because they appear to run counter to each other.

First, a reduction in the overall uncertainty surrounding the possible success or failure of the project, enhances project worth both for its NPV value, if it has been adopted, and for its option value, if it has not. This means that the effect of a reduction of environmental uncertainty on liability may push the project (or its development phase) towards a more secure implementation, if it has been started already, while it may push it further away from adoption, if it has not.

Second, lower uncertainty on liability unambiguously increases the option value of research, if both the research and the development options are alive and so is the option to sue by the damaged party. Furthermore, the impact on research as a call option will be larger, the larger the value of the development option, the smaller the value of the project option and the larger the size of the damage indicator, compared to its “threshold of action”, i.e. the level that would be considered as a trigger for individual or collective action against the party liable. In other words, if no decision about adopting the project is warranted yet, and, as a consequence, no decision is taken by the party who could be damaged, any increase in information on the likelihood and the size of potential damages, or any improvement in the law or the court process would enhance project worth and such an enhancement would be greater for projects where the bulk of investment were concentrated in the research phase and whose potential damages appear to be comparatively higher.

### 7.2. Pharmaceutical Industry

A pharmaceutical company is deciding whether or not to invest in a clinical trial for a new drug. The costs are well known, but the drug’s efficacy and future revenues are uncertain. Even if this trial were successful, additional clinical trials would be required before the drug could be sold.
This case is analyzed by using the decision tree approach to help the management’s company to decide whether or not to invest in a clinical trial of a new drug: whether to invest into a new product innovation project.

The clinical trial that was considered was the first in a series of three trials that would be necessary to verify the drug’s efficiency. If the drug made it through the three clinical trials, it would then have to be reviewed by the FDA for final approval. Based on scientific evidence and academic research, the probabilities of passing each of the three phases were 75%, 50% and 65% respectively (unique risks). The FDA approval probability, assuming it had passed the trials, was 85% (unique risks). The estimation of the costs of the entire trial and approval process would be $23 million (Strike Price or Exercise Price).

Given all this information about risks and costs, we try to apply the tree decision method: first, we create a decision tree incorporating all possible outcomes of future trials and all of management’s decisions in each event. Then the net present value (NPV) of each possible “end state” is calculated using the standard discounted cash flow (DCF) model. Then starting with the final year of the evaluation phase and working backwards, the assumption is, that management chooses the highest NPV alternative at each decision point. This process clarifies whether or not it makes sense to abandon, re-trial or proceed should any of the trials fail.

As the figure below shows, it turned out to be optimal to reformulate if the first trial phase failed, repeat the second trial phase if it failed, and abandon the drug if the third trial phase failed. To calculate now the NPV for the phase 1 trial, one has to eliminate the (unchosen) lower NPV scenarios to arrive at an adjusted NPV of $ 9.3 million (75% x 13.2 + 25% x –2.5).

Compared with a simple DCF analysis, which is not using the decision tree and is resulting in a negative NPV of -$1.8 million\(^\text{10}\), the value of the decision tree valuation is significant higher, because it recognizes the value of the real options consisting in the flexibility of management to choose at each decision point (in the event of failure in the respective phase) the remaining option that has the highest NPV value. In fact, the NPV method ignores the company’s option to abandon the process after each phase, and not incur the cost of the next phase, and also the option to re-trial, or re-formulate and re-trial in the event that the product fails one or more trials.

\(^{10}\) The calculation goes like this: first you calculate overall probability of success (75% x 50% x 80% x 83% = 25%) and of failure (100% - 25% = 75%) and then the DCF value itself (25% x $62 million + 75% x -$23.1 million = -$1.8 million)
In 1987, Yankee 24 evaluated the business case for providing POS debit card network to member firm in New England, in addition to its traditional business of switching automated teller machine (ATM) transactions. At that time the POS debit card business involved considerable uncertainty: the perceived environmental risk and Yankee’s lack of maturity as a ATM service provider.

The strategic vision of growth potential of Yankee’s electronic banking services encompassed growth outside the limited field of ATM banking, for example, in the POS debit cards. We can thus that Yankee had the option to wait to achieve the best timing to entry in POS debit card business, and that the decision was matter of timing. In fact, given the uncertainty about the acceptance of POS debit service in Yankee’s market of New England and the viability of additional irreversible network infrastructure, waiting would resolve the investment uncertainty. On the other hand, by waiting Yankee would lose some revenue and, more dangerously, waiting too long might lead to market share gains by competitors with no prior presence in the market.

Given this context, the key question for Yankee was: how long should it wait to enter the POS debit card market?

By analyzing the problem as a real options application, Yankee’s ability to defer this roll out can be viewed as an American call option; the model used to evaluate this option is the Black&Scholes formula, in a version adjusted to consider an American call option maturing at time T, where the underlying asset pays a
dividend D at time t, with 0 < t < T. This approximation requires using Black&Sholes to calculate the prices of European options that mature at T an t, CT and Ct and then setting the American price to be higher of these two.

To analyze the investment decision that Yankee faced in 1987, interview data from senior managers are used to arrive at specific assumptions concerning the parameters needed by the Black&Scholes model. Based on the earlier POS debit experience in California and managers’ opinions, the New England market was estimated to be 25% the size of the California market for POS debit transactions (that was known). Another concern was to estimate the range of potential revenues on the high and the low end, the distribution of revenues (i.e., normal, or skewed to the high or the low side), the perceived variance or volatility (σ) of potential revenues (if there was any), and the uncertainties that might be resolved and thus contribute to volatility. Interview questions were geared towards revealing the various estimates, assuming that the actual entry would occur sometime between 1987 and 1990. The interview process revealed an estimate the volatility parameter, σ, of between 50% to 100%. The estimates were based on crucial uncertainties about when the State of Massachusetts, representing one-half of the overall market potential, would deregulate POS debit entry by firms outside the state. For the present analysis, we chose to use the low end estimate, which may underestimate the actual uncertainties that Yankee faced with Massachusetts state law.

Using Black&Scholes, we estimated the option value for different exercise dates ranging from zero to four years at intervals of one-half year.

The results can be summarized as follows:

- The value of the project investment option, CT, exercised at maturity, T=4, is $65,300, as shown in Row CT;
- The value of the option, Ct, maturing at time t<T, is greater than its value at maturity for deferrals between 1.5 to 3.5 years, as shown in Row Ct. (Ct is calculated based on values for At that reflect the loss of revenues and passage of time.)
- The value of the deferral option, Ct, reaches its maximum for a deferral of three years at $152,955, as shown in bold in Row max (Ct, CT).

These results suggest two conclusions, assuming that the New England market size is 25% of California’s and σ is as high as 50%. First, Yankee is better off by not waiting to implement the POS debit project for four years, so long as the roll out occurs after the end of the first year (CT < Ct, for 1 < t < 4). Second, the optimal time to defer is three years (C3 = $152,955 > Ct, for all t except 3).

7.4. Software Engineering: Extel’s Web-phone Project
Managers at Extel have proposed to enhance the browsing feature of their cellular products. They plan to introduce a pointing device similar to those available on PDAs, for navigation purposes. This enhancement would require a major redesign of the hardware and some enhancement of the software. The company is currently the leader in the cell phone market. However, by introducing the new phones, it faces stiff competition from PDA vendors.

We evaluate the project using NPV, Decision Trees and Real Options Modeling and explain the fundamental differences among the results.

NPV analysis: managers estimate that the initial investment is $100 million. At the end of the first year, the expected revenue is $50 million. Further development requires $800 million and the generated revenue in the following two years are both $500 million. Suppose the risk-free interest is 5%. The cash flow is then discounted by a factor of $1/(1+5\%)$ every year.

As shown below, the computed NPV turns out to be negative:

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Projections</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revenues</td>
<td>50</td>
<td>500</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Expenditure</td>
<td>100</td>
<td>800</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Cash Flow</td>
<td>-100</td>
<td>-750</td>
<td>450</td>
<td>400</td>
</tr>
<tr>
<td>Discount Factor</td>
<td>1.000</td>
<td>0.952</td>
<td>0.907</td>
<td>0.863</td>
</tr>
<tr>
<td>PV (by year)</td>
<td>-100</td>
<td>-714</td>
<td>408</td>
<td>345</td>
</tr>
<tr>
<td>NPV (sum of all years)</td>
<td>-61</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this case, the management will discard the project immediately, but because of the revenues in the table can change drastically, given the current uncertainty about future acceptance of web-phones, the managers need some tools to measure this uncertainty before they discard the project.
Decision Tree Analysis: to setup the decision tree, we start drawing the tree with a decision that needs to be made. This decision is represented by a small square, from which we draw lines towards the right for each possible resolution, and write that resolution along the line. At the end of each solution line, consider the results; if the result of taking that decision is uncertain, draw a small circle, otherwise if the result is another decision that needs to be made, draw another square. Write the decision or factor to be considered above the square or circle. If a complete solution has been identified at the end of a line, it may be left blank.

We have added expenditures below the lines and revenues above the lines (see figure below). At year zero an expenditure of $100 million is incurred to develop the new phones. At the beginning of the second phase, a revenue of $50 million is generated, resulting in a net value of $750 million, discounted by 5%, to return $714 million. We now get to a circle where an uncertainty arises (market reaction). We then compute the probabilities related to taking one of three possible outcomes: Favorable acceptance, Moderate Acceptance, and Poor Acceptance of the new phones each with probabilities 0.4, 0.4, and 0.2 respectively. At the end of this phase, there are expected revenues of $750 million, $500 million, and $300 million, all of which are discounted by (5%) 2. These numbers are added to the tree. In the last phase, the final expected revenues are computed and added along the lines. These are $750 million, $500 million, and $300 million, respectively. Again, these numbers are discounted by (5%) 3. The final tree and its corresponding table are given below:

<table>
<thead>
<tr>
<th>Year 0</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>50</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>800</td>
<td>0.4</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>50</td>
<td>0.4</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>300</td>
<td>0.2</td>
<td>300</td>
<td>300</td>
</tr>
</tbody>
</table>

The decision tree related to Extel’s project

Real Option Approach: the problem of Extel is of making irreversible investments under uncertainty: it is facing the problem of investing a substantial amount of software and hardware in its mobile phones to make them browser ready (web-phones), when at the present it is unclear how often people would be using web-phones for browsing.
In the future, new applications could come in the market that can change the way people would like to browse. If web-phones indeed become popular, Extel can make billions by being early in this market. Since the investment requires huge amounts of capital, it would be unwise to invest in web-phones right now. By delaying Extel can learn more about the future and resolve some of the uncertainties, but waiting too long can be fatal as other competitors can grab the whole market share.

To solve this dilemma, Extel can do the following: “It can make an investment small enough to keep the costs under failure reasonable and big enough to give it a competitive edge if the market reacts positively to phone browsing”. In financial terms Extel is considering buying an American call option by making the small investment today. By investing now, Extel will have the option to purchase the market share in the future by making a full investment. To justify the initial investment, Extel has to quantify the value of this real option, so the initial investment would make sense only if this real option has more value than the initial investment.

Extel should first determine the value of real option of entering into web-phone market, next it should decide when to buy this option; it cannot defer this decision forever otherwise the current small players might acquire the ability to start web-phone investments. To simplify the analysis, we assume that Extel has decide to exercise its option to buy the web-phone real option this month, hence we have only to calculate the real option value. To do this, we apply the Black&Sholes model, as a framework to look-up the value of the option, calculated by using two values, NPVq and \( \sigma \sqrt{T} \); the first is \( S \div PV(X) \), where \( S \) is the present value of the project’s assets (web-phone market) and \( X \) is the expenditure required to acquire the project assets, and \( PV(X) \), is the discounted present value of \( X \). The second is the volatility of the market under consideration and \( T \) the time until the option expires.

To analyze Extel’s project we divide the project into two phases. The first phase involves purchasing the web-phone real option and the second phase involves exercising the web-phone real option: we compute the NPV of each phase separately.
In the first phase the investment is being made now, so there is no future uncertainty. The NPV of phase 1 is the traditional NPV of $-8.4$ million.

### Phase 1

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Projections</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash Flow</td>
<td>0.0</td>
<td>50</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Investment</td>
<td>-100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discount Factor</td>
<td>1.000</td>
<td>0.952</td>
<td>0.907</td>
<td>0.863</td>
</tr>
<tr>
<td>PV (Cash Flow)</td>
<td>0.0</td>
<td>47.5</td>
<td>22.6</td>
<td>21.5</td>
</tr>
<tr>
<td>PV (Investment)</td>
<td>-100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPV (sum of years)</td>
<td>-8.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To calculate the NPV of phase 2 we use the framework developed in (1) – (3). In this example $S = 708.8$ and $X = 800$. The rate of discount is assumed to be 5% as before. Lets assume that $\sigma$ is 40% and $t$ is 1 year. Now we can combine these values and compute the rate of return for phase 2.

$$NPV_q = \frac{708}{\frac{800}{(1.05)^1}} = 0.931$$

And

$$\sigma \sqrt{t} = 0.4 \times \sqrt{1} = 0.4$$

The option value consistent with these values gives a rate of return of 13%. This implies that the value of web-phone real option is 13% of the value of the underlying assets $S$. Therefore, the NPV for phase 2 is $92.14$ million.

The NPV of the entire proposal is the sum of the NPVs of the two phases. This gives

Overall NPV = $-8.4 + 92.14 = $83.74$ million
This is substantially more than what was calculated by traditional NPV method and Decision Tree Method.
7.5.  Construction Industry in Developing Countries

The importance of the construction industry in developing countries can be seen from recent estimates putting the share of the industry in developing country economies at between 5 and 10%. About half of this may be in civil engineering projects, that are usually large projects involving substantial amounts of capital. Construction also plays a major role in providing capital, accounting for over 50% of gross capital formation in the economy. The industry in developing countries has inherited from colonial powers its fragmented and hierarchical structure, with professions heading the production team comprising of contractors and suppliers who have further links down the chain to sub-contractors.

Construction industries in developing countries have similar characteristics to those in other parts of the world but display also their own unique characteristics:

- a dual structure of indigenous and exogenous contractors;
- a large informal sector;
- underdeveloped human resources capacity characterized by little training and manpower development;
- reliance on external funding for major infrastructure developments;
- fluctuating workloads in the industry;
- the predominance of the public sector as a client;

We can look at the application of real options valuations in developing countries from the perspectives of the three broad interest groups in the construction industry: developers, contractors and the industry professions.

Developers: the government as a construction client deals in public projects, which usually form the largest single source of infrastructure investments in developing countries. Low gross domestic product and competing needs for scarce funds require that optimal use of these resources be ensured. The real options that we can identify are:

- Flexibility options: the option to switch creates value out of uncertain events. It may make the construction of a building previously thought of as too expensive profitable. For example, if a building has only one use as a warehouse, valuation of the potential income to a developer may show its lack of viability. Recognizing that the use of the building can be changed to production in times of demand incorporates the dimension of flexibility, which creates added value.
- Learning options: where uncertainty can be resolved by a learning process, these processes can be broken down into stages, and the real options approach can be used to value the contingent decisions and structure each stage for a higher value. In the planning for a housing estate, the question may arise as to which architectural design or type of houses will be more marketable. If in the first phase of construction one type proves to be more in demand and attracts
better prices, the subsequent make-up of the estate can be changed to reflect that discovery.

- Exit options: the exit option introduces the option to abandon a project. In the development of a new project, the size of the market may worry the company. Real options analysis can be used to value the option to walk away from the project should it not show promise. This is applicable both to contractors (as investors) and for developers.

- Evaluating market strategies: real options way of thinking expands the vision and alternatives used in creating strategies, and real options tools translate strategic thinking into an investment plan.

- Options to defer: for example, management may defer the investment while awaiting better market conditions.

- Options to default during staged construction: this refers to instances where a project is being implemented in stages. Each stage can be seen as an option on previous stages. The initial outlay creates the asset and the developer has the option to default should conditions prove negative.

Contractors: the primary focus of a real options approach to contractors would be in the evaluation of investment choices. Given the unpredictable nature of workloads in the industry and the predominance of the traditional procurement method in developing countries (which forces contractors to compete afresh for each new project thus adding uncertainty to individual contractor workloads), it becomes even more imperative to put available funds to the most efficient use possible. Should a contractor invest in treasury bills or property? Should they add to the firm’s resources by purchasing plant? If plant, which would be a better option?

Examples of real options in the construction industry for contractors are:

- Growth and expansion options: a sector of the construction industry is booming. Should a construction company invest in equipment and plant in order to take advantage of any upcoming projects? As Trigeorgis points out, when a firm buys plant and equipment, land for development or sets up in a new location, it takes out an option for future growth. Investment in plant and equipment is expensive, but it could lead to increased capacity and the ability to undertake previously undoable projects. Conversely, the scaling down of operations creates the option to contract.

- Takeover and merger options: should a construction company desire to take over or merge with another, what would be an accurate valuation of the target company?

- Competition and strategy: strategy development requires a long-term cause and effect model, that is better cast in the framework of real options. An investment can thus be pursued on the basis of the options it opens up. The value of a diversification strategy (into, say, materials supply) can be incorporated into the present investment decision by a construction company to purchase a quarry.
The real option approach has found applications in different industries such as energy, electronics, mining and exploration and airlines, but have yet to make an impact on construction, especially in the developing country, where is more difficult to estimate the risks associated to the projects.

Government. As the main customer of the value chain of the whole industry, the government is mostly interested in evaluating policy and investment choices from the point of view of the welfare of present and future generations. Investment in the construction industry is important because it has direct and indirect productive consequences, it has important multipliers effect on the other sectors of the economy, and is relevant from the point of view of the environment and the quality of life. Examples of real options in the construction industry that may be important for governments in developing countries are:

- Growth and expansion options: in a growing economy, should resources be shifted to infrastructure to sustain development, by reducing transportation and maintenance costs, thereby creating a more attractive environment for domestic and foreign investors? Should projects more directly productive, such as large irrigation schemes, be favored?
- Flexibility options: expending in infrastructure build up and maintenance can be used to boost the economy in times of slow down, through demand led policies. Public work programs can also be used to provide unemployment relief and insurance and to reduce poverty.
- Development strategies: alternative strategic options may be chosen to combine domestic building capacity with foreign expertise and capital. Infrastructure development may thus become a way of developing particular industries, strategic partnerships with other countries and or direct foreign investment.

8. World Bank Project Case Studies

We consider now the application of the real option methodology to a group of real projects, financed by the World Bank in the recent past. The analysis has been developed from the documentation of the projects as well as from statistics and other estimates directly obtained by the authors.

8.1. The Chad Cameroon Pipeline
**Country Scenarios**

**Scenario 1.** Prompted by raising oil revenue, the government engages in a vigorous program of public works, that gives a boost to employment and income in the short run and open long term options for further growth both in the oil and non oil sector. The infrastructure built increases comparative advantage in the agricultural and export sector and diversifies the economy. Because of low capacity for governance, and corruption, however, social tensions arise. The government finds difficult to cur these tensions, because of limited investment in the social sector and lagging institutional performance.

**Scenario 2.** Increased oil revenue is mostly used to foster human and social capital formation. Investment is concentrated in social programs, health, education and provision of basic needs. This long run strategy, however, has little effect in the short run, and the economy suffers from a Dutch syndrome, with resources concentrating on an oil sector whose productivity progressively declines.

**The project.**

The project involves the development of Chad’s Doba oil fields, including drilling of about 300 wells and construction of associated facilities and infrastructures (Field System); and the construction of a pipeline 760 mm 30(inch) in diameter and 1,070 Km in length from Doba oil field to Cameroon’s Atlantic coast and 11 Km of submarine pipeline from the Cost to the vessel (Export System).

The analysis focuses on the direct revenues generated by the project trough the sale of crude oil in international markets. Two scenarios are analyzed. In the first scenario, oil prices are assumed to rise continuously over time, with the historical volatility recorded in the past 20 years (17%). As a consequence, oil exploration proceeds at a more moderate rate, as higher prices give the possibility of maintaining revenue levels without increasing the sales. In the second scenario, oil prices are assumed to follow a mean reverting process, first drifting away and then gradually returning to average base forecasts, with a volatility of 20%. **The costs considered include:** exploration, predevelopment and upstream development expenditures in Chad, pipeline construction in Chad and Cameroon. **The revenues include:** direct revenues generated by sailing the crude on international market. The analysis has been carried out using a rate of discount equal to 10%.

Given the two basic scenarios, a Monte Carlo simulation (1000 trials) was used to generate a full range of stochastically distributed scenarios, using the following hypotheses:

- **Oil prices:** In the first scenario this variable follows a geometric Brownian motion process, i.e. is log-normally distributed with annual mean and variance increasing every year. The standard deviation increases linearly over time by a factor of 10% per year. The maximum range for this variable is between 12 and 50. In the second scenario this variable follows a mean reverting process.

- **Crude sales:** This variable is normally distributed with annual mean equal to the value reported in table 2 and standard deviation equal to 5%. The standard deviation increases linearly over time by a factor of 7% at year. In order to maintain the volume of crude sold in the international market consistent to the expected value of the oil reserves, this variable is positively correlated with the oil price (correlation factor 1). The volume of crude sold on the market over the
operating period has a range of variation between 839 and 994 Mbbls. This hypothesis has been introduced in the model to take into account the uncertainty surrounding the volume of oil reserves. In the original cost benefit analysis, carried out by the project team, three different cash flow models had been built in order to assess the impact of different levels of oil reserves on the project performance. The sensitivity analysis was originally carried out for values ranging between 595 and 1037 Mbbls.

- **Operating costs:** This variable is triangularly distributed with mode equal to the value reported in Table A1 and MAX an MIN equal to the 98% of this value. The standard deviation increases over time by a factor of 10%. This variable is positively correlated with the production volume (correlation factor 0.93). The results of the simulations for the two alternative scenarios are reported in Table A1.

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base NPV</td>
<td>1192</td>
<td>1209.84</td>
</tr>
<tr>
<td>Mean</td>
<td>1255</td>
<td>1257</td>
</tr>
<tr>
<td>Stdev</td>
<td>206</td>
<td>209</td>
</tr>
<tr>
<td>Min</td>
<td>602</td>
<td>688</td>
</tr>
<tr>
<td>Max</td>
<td>1960</td>
<td>1896</td>
</tr>
</tbody>
</table>

Tables A2 and A3 report the results of real option analysis. The value of the option to wait is indeed very large in the case of a Brownian process, where the positive drift in the oil prices increases the probability that waiting will significantly reduce the risks, while increasing the opportunities. In the case of mean reversion, instead, the option to wait does not make much difference and the traditional NPV seems adequate.
### Table A2: option to wait

<table>
<thead>
<tr>
<th></th>
<th>Brownian motion</th>
<th>Mean reverting process</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Underlying</strong></td>
<td>4,188.66</td>
<td>4,206.76</td>
</tr>
<tr>
<td><strong>Strike</strong></td>
<td>2997</td>
<td>2997</td>
</tr>
<tr>
<td><strong>Time to maturity</strong></td>
<td>5, 10, 15</td>
<td>5, 10, 15</td>
</tr>
<tr>
<td><strong>Volatility</strong></td>
<td>29%, 29%, 29%</td>
<td>30%, 30%, 30%</td>
</tr>
<tr>
<td><strong>Discount rate</strong></td>
<td>10%, 10%, 10%</td>
<td>10%, 10%, 10%</td>
</tr>
<tr>
<td><strong>Dividend</strong></td>
<td>3%, 3%, 3%</td>
<td>3%, 3%, 3%</td>
</tr>
<tr>
<td><strong>Option value</strong></td>
<td>763.55, 1,066.85, 1,199.75</td>
<td>15.00, 43.69, 55.04</td>
</tr>
<tr>
<td><strong>NPV</strong></td>
<td>1,191.73, 1,191.73, 1,191.73</td>
<td>1,209.84, 1,209.84, 1,209.84</td>
</tr>
<tr>
<td><strong>ENPV</strong></td>
<td>428.19, 124.88, -8.02</td>
<td>1,194.83, 1,166.15, 1,154.80</td>
</tr>
</tbody>
</table>
CASE STUDY: A POWER PLANT IN VIETNAM

Vietnam today is not importing energy. With an estimated 650 bcm of recoverable reserves it appears to have an opportunity to be a net exporter of energy. The Vietnam Energy Generation Plan considers the possibility to exploit reserves by implementing the construction of power plants running on gas. So far the implementation of the transport infrastructure needed has not started and gas might not be available in the near future. Three power plants running on gas, however, are supposed to start operating in 2006. Given this constraint, the construction of the power plants should involve enough flexibility to run either on gas either on another fuel.

The aim of this case study is assessing which technology allows the higher cost reduction and gives the flexibility to manage the uncertainty surrounding gas availability. For this purpose four project scenarios are analyzed:

1) Investing in CCGT burn diesel until gas becomes available. (project A)
2) Investing in Fuel Oil Fired Steam with the option to convert to Gas (Project B)
3) Investing in steam turbine which can burn heavy fuel oil with the option to convert to gas; (project C)
4) Investing in steam turbine that can burn heavy fuel oil with the option to convert to CCGT; (project D).

The study is organized as follows: we assume a not competitive market in which the central planner aims to minimize the production costs. Therefore every alternative will be analyzed only on the cost side. Pure technology-based management of uncertainty will be discussed in this section.

The analysis will be performed in three steps:

- Construction of a cost/cash flow model for each technological alternative,
- Monte Carlo simulation,
- Real option analysis.
Cost flow model assumptions

In order to assess which alternative allows the higher cost reduction we have built a cost flow model for every alternative. Table B1 shows the main assumptions that have been made to construct each model.

Table B1: Assumptions

<table>
<thead>
<tr>
<th>Costs</th>
<th>Plant</th>
<th>CCGT running Diesel</th>
<th>CCGT running Gas Fired Steam</th>
<th>Fuel Oil Fired Steam</th>
<th>OCGT running distillate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Capacity (MW)</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>100</td>
</tr>
<tr>
<td>Station Use (%)</td>
<td>4%</td>
<td>7%</td>
<td>5%</td>
<td>5%</td>
<td>3%</td>
</tr>
<tr>
<td>Building Period (years)</td>
<td>3</td>
<td>3</td>
<td>3.0</td>
<td>3.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Life of plant (years)</td>
<td>25</td>
<td>25</td>
<td>30</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Planned Outage (days/yr)</td>
<td>21</td>
<td>21</td>
<td>40</td>
<td>40</td>
<td>21</td>
</tr>
<tr>
<td>Forced Outage Rate</td>
<td>4%</td>
<td>5.5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Availability</td>
<td>91%</td>
<td>91%</td>
<td>85%</td>
<td>85%</td>
<td>90%</td>
</tr>
<tr>
<td>Total capital cost ($/kW net)</td>
<td>604.17</td>
<td>623.65</td>
<td>890.05</td>
<td>837.70</td>
<td>391.75</td>
</tr>
<tr>
<td>Annualised capital cost @ 10% DF ($/kW net/yr)</td>
<td>66.56</td>
<td>68.70</td>
<td>94.42</td>
<td>88.86</td>
<td>46.02</td>
</tr>
<tr>
<td>Total fixed cost ($/kW net/yr)</td>
<td>81.66</td>
<td>84.29</td>
<td>116.67</td>
<td>109.80</td>
<td>55.81</td>
</tr>
<tr>
<td>Fuel calorific value (GJ/tonne)</td>
<td>44.95</td>
<td>44.96</td>
<td>44.96</td>
<td>44.96</td>
<td>44.96</td>
</tr>
<tr>
<td>Fuel cost ($/GJ)</td>
<td>3.03</td>
<td>3.34</td>
<td>3.34</td>
<td>3.03</td>
<td>3.03</td>
</tr>
<tr>
<td>Heat rate (kJ/kWh)</td>
<td>6,696.43</td>
<td>10106.97</td>
<td>9,791.26</td>
<td>9,424.08</td>
<td>10,603.83</td>
</tr>
<tr>
<td>Unit efficiency net net (%)</td>
<td>54%</td>
<td>0.35</td>
<td>37%</td>
<td>38%</td>
<td>34%</td>
</tr>
<tr>
<td>Fuel cost (¢/kWh)</td>
<td>2.03</td>
<td>3.37</td>
<td>3.27</td>
<td>2.86</td>
<td>3.22</td>
</tr>
<tr>
<td>Variable O&amp;M cost (¢/kWh)</td>
<td>0.19</td>
<td>0.19</td>
<td>0.24</td>
<td>0.24</td>
<td>0.19</td>
</tr>
<tr>
<td>Total variable cost (¢/kWh)</td>
<td>2.22</td>
<td>3.56</td>
<td>3.51</td>
<td>3.10</td>
<td>3.41</td>
</tr>
</tbody>
</table>

Under these assumptions we have constructed 2 cost flow models for every alternative. In the first one gas is available since the first year, in the second one gas is never available during the operating life of the project. Through this first analysis we can get a first overlook on what would be the cost of producing 1 KWh at the gross of investment costs, depending on both the technology and the fuel used. Table 2 shows the main findings of this analysis: CCGT is the technology that achieves the best performance between all the gas plants, with respect to the plants running on other fuels the oil fired had the best performance followed by CCGT running on oil.

---

The assumptions regarding CCGT running diesel and OCGT running distillate are based on our computation.
### Table B.2: cost flow analysis results

<table>
<thead>
<tr>
<th>Unit</th>
<th>Project 1</th>
<th>Project 2</th>
<th>Project 3</th>
<th>Project 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CCGT gas</td>
<td>CCGT oil</td>
<td>Oil Fired Steam</td>
<td>Gas Fired Steam</td>
</tr>
<tr>
<td>Costs PV</td>
<td>MUS$</td>
<td>535.95</td>
<td>755.47</td>
<td>772.20</td>
</tr>
<tr>
<td>Costs PV</td>
<td>MW/#years active</td>
<td>71.46</td>
<td>100.73</td>
<td>85.80</td>
</tr>
</tbody>
</table>

### Risk analysis

Risk analysis of the project is based on a dynamic cash flow model for each technological alternative. During the analysis we take into account two sources of uncertainty: gas availability and fuel cost. The analysis has been carried out using a Monte Carlo simulation.

### Gas availability

We have introduced in the model a 0/1 variable for each operating year in order to calculate the impact of a delay in gas availability.

When the variable assumes a value equal to 1 gas becomes available and the plant starts operating running on gas. Its operating costs will change according with this assumption. The probability distribution of the variable changes over time with the probability for gas to become available increasing over time. The picture below shows the evolution of the probability distribution over time.

---

4 According with the main findings of the static cash flow model, gas is assumed to be the less expensive alternative
5 In particular $P(gas) = \frac{1}{\log T}$, $T=$time
$P(oil) = 1 - P(gas)$
**Fuel price**

Fuel price changes over time following a mean reverting process\(^6\). In this first draft standard deviation and volatility of each fuel are based on our own computation\(^7\).

For every type of fuel, we have assumed as mean of the mean reverting process the data provided by “The screen curve Least-Cost Analysis for Typical New Plant Generation Projects in Vietnam (2008-2015)” provided by the team that is working on the project.

The volatility of Gas has been calculated on the basis of the data contained in the “International Energy Agency” (IEA) database. In particular we have used the world series of natural gas in public power plant calculated in TJ. The volatility of oil has been fixed at 18%.

On the basis of these assumptions a simulation has been run for every technological alternative. This analysis is performed in order to understand which project is more sensitive to the uncertainty concerning gas availability. Analyzing the cost effectiveness CCGT is again the better technology, followed by Gas/Oil Fired Steam, otherwise the latter is less sensitive with respect to gas availability. Project 3 has the worst performance with respect to the cost effectiveness while

\[ \frac{dx}{\sigma dt} = \eta (\bar{x} - x) + \sigma dz \]

Where \( \eta \) is the speed of the mean reversion, \( \bar{x} \) is the “normal” level of \( x \) that is the level at which \( x \) tends to revert, \( \sigma \) is the standard deviation of the project and \( dz \) is the increment of a Weiner process (normal distributed 0-1 random variable).

\(^6\) In particular we could not find historical data about gas and oil price on Vietnam market. As soon as we will have more data available we can modify the analysis in order to achieve a better measurement of the uncertainty surrounding the project.
project 4 is the riskiest considering that when gas is not available the cost of producing 1MW/h is 19.26$\textsuperscript{8}.

Table B.3 shows the main findings of the risk analysis

<table>
<thead>
<tr>
<th>Static Cost PV running on gas</th>
<th>Project 1</th>
<th>Project 2</th>
<th>Project 3</th>
<th>Project 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>CCGT</td>
<td>Fired Steam</td>
<td>OCGT</td>
<td>OCGT/CCGT</td>
</tr>
<tr>
<td>MUS$</td>
<td>535.95</td>
<td>696.43</td>
<td>232.86</td>
<td>598.80</td>
</tr>
</tbody>
</table>

Average simulated Costs PV

| Stdev | MUS$  | 32.60   | 14.63   | 9.31     | 43.99     |

Range Maximum

| Range Maximum | MUS$  | 719.73  | 770.52  | 280.52   | 596.66    |

Range Minimum

| Range Minimum | MUS$  | 520.12  | 669.32  | 228.44   | 362.07    |

Real option analysis

The follow options have been identified: for projects A, B and C, the option to switch, while for project D the value of the growth option \textsuperscript{9}.

Option to switch

A switch option is a call option that allows the owner to switch at fixed cost between two operating practices. The option to switch, in our case, is generated by implementing a multi-fuel power plant with flexibility to switch from one fuel burnt to another.

The feasibility of switching crucially depends on when gas will be available. Given that so far we don’t have any forecast about when the gas pipeline will be operating, we will use the year when gas availability reaches 40% likelihood as baseline case to calculate our option value that will be calculated as call vesting options. The following parameters will be used:

\textsuperscript{8} See table 2

\textsuperscript{9} During the analysis we have also considered the value of the waiting option as a compound, but given that its value was always equal to 0 it has not been included in the final report.
• **Underlying:** savings depending on technology/fuel plus investment needed to build flexibility
• **Strike:** costs associated with switching (investment required to build the flexibility)
• **Vesting time:** 5 years
• **Volatility:** volatility of fuel price\(^{10}\): \[ \text{Var}(X - Y) = \text{Var}(x) + \text{Var}(y) - 2(\text{Var}(x))(\text{Var}(y)) \]
• **Date of decadence:** expected project operating life
• **Dividends\(^{11}\):** 2%

### Table B. 4: Switching option

<table>
<thead>
<tr>
<th>Option to switch</th>
<th>Unit</th>
<th>Project 1: CCGT</th>
<th>Project 2: Fired Steam</th>
<th>Project 3: OCGT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underlying</td>
<td>$\text{MWh}$</td>
<td>5.00</td>
<td>1.19</td>
<td>4.04</td>
</tr>
<tr>
<td>Strike</td>
<td>$\text{MWh}$</td>
<td>0.01</td>
<td>0.02</td>
<td>0.004</td>
</tr>
<tr>
<td>time to maturity</td>
<td>Years</td>
<td>31.00</td>
<td>31.00</td>
<td>31.00</td>
</tr>
<tr>
<td>Volatility</td>
<td>%</td>
<td>19%</td>
<td>19%</td>
<td>19%</td>
</tr>
<tr>
<td>vesting period</td>
<td>Years</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
</tr>
<tr>
<td>risk free rate</td>
<td>%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Dividends</td>
<td>%</td>
<td>2%</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>Option value</td>
<td>$\text{MWh}$</td>
<td>4.52</td>
<td>1.07</td>
<td>4.04</td>
</tr>
<tr>
<td>PV</td>
<td>$\text{MWh}$</td>
<td>13.59</td>
<td>12.12</td>
<td>19.26</td>
</tr>
<tr>
<td>EPV</td>
<td>$\text{MWh}$</td>
<td>9.08</td>
<td>11.06</td>
<td>15.22</td>
</tr>
</tbody>
</table>

**Growth/Expansion Option**

The growth option is the capability to expand from a current existing one to a larger or expanded state by paying a fixed cost.

Project 4, an OCGT power plant, creates the possibility of expanding operating size by 200 MW by adding a Heat Recovery Steam Generator (HRSG) and a steam turbine to the existing Gas Turbine.

---

\(^{10}\) We assume gas and oil price to be coupled, for instance the correlation factor is equal to 1.

\(^{11}\) The value of dividends has not been calculated as \( PV \ cost_{gas} / PV \ cost_{oil} \) because the ratio was too high (30%). For instance the value of dividends has been fixed at 2%.
Table B.5: Option to expand

<table>
<thead>
<tr>
<th>Strike</th>
<th>cost Inv</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option to expand</td>
<td>Unit</td>
<td>Project 4 OCGT-CCGT</td>
</tr>
<tr>
<td>Underlying</td>
<td>$MWh</td>
<td>8.39</td>
</tr>
<tr>
<td>Strike</td>
<td>$MWh</td>
<td>0.07</td>
</tr>
<tr>
<td>Time to maturity</td>
<td>Years</td>
<td>31.00</td>
</tr>
<tr>
<td>Volatility</td>
<td>%</td>
<td>19%</td>
</tr>
<tr>
<td>Vesting period</td>
<td>Years</td>
<td>5.00</td>
</tr>
<tr>
<td>Risk free rate</td>
<td>%</td>
<td>10%</td>
</tr>
<tr>
<td>Dividends</td>
<td>%</td>
<td>2%</td>
</tr>
<tr>
<td>Option value</td>
<td>$MWh</td>
<td>7.55</td>
</tr>
<tr>
<td>PV</td>
<td>$MWh</td>
<td>19.26</td>
</tr>
<tr>
<td>EPV</td>
<td>$MWh</td>
<td>11.72</td>
</tr>
</tbody>
</table>

Tables B.6 and B.7 summarize the main findings:

Table B.6: Cost EPV

<table>
<thead>
<tr>
<th>Unit</th>
<th>Project 1</th>
<th>Project 2</th>
<th>Project 3</th>
<th>Project 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option to switch</td>
<td>$MWh</td>
<td>4.52</td>
<td>1.07</td>
<td>4.04</td>
</tr>
<tr>
<td>Option to expand</td>
<td>$MWh</td>
<td>9.08</td>
<td>11.06</td>
<td>15.22</td>
</tr>
</tbody>
</table>

Table B.7: Percentage of cost reduction

<table>
<thead>
<tr>
<th>Unit</th>
<th>Project 1</th>
<th>Project 2</th>
<th>Project 3</th>
<th>Project 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option to switch</td>
<td>% Cost PV</td>
<td>33%</td>
<td>9%</td>
<td>-</td>
</tr>
<tr>
<td>Option to expand</td>
<td>% Cost PV</td>
<td>-</td>
<td>-</td>
<td>39%</td>
</tr>
</tbody>
</table>
References


