'REAL OPTIONS' FRAMEWORK

TO ASSESS

PUBLIC RESEARCH INVESTMENTS

Nicholas S. Vonortas
Center for International Science and Technology Policy
&
Department of Economics
The George Washington University

Washington Research Evaluation Network

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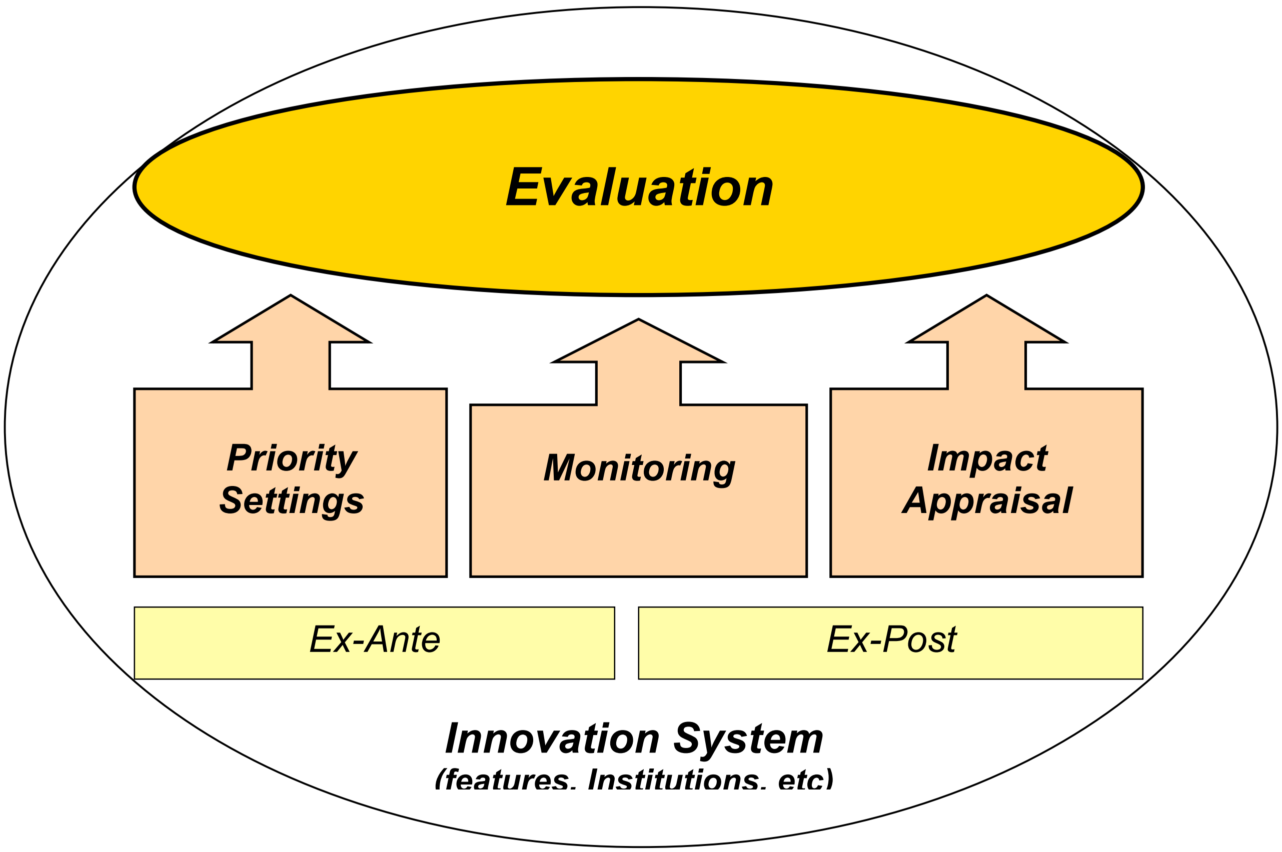


Figure 1. A Framework for Public Research Evaluation

VALUATION DEFICIT

Capital budgeting and *strategic planning* have historically been treated as two distinct domains of resource allocation. Capital budgeting deals with measurable returns (profits/cash flows) of a project and abstracts from more intangible strategic benefits associated with the project.

This distinction has resulted in a chronic **'valuation deficit'** between the calculated value of strategic, long-term projects and their 'true' value. The deficit is due to the oversight by the conventional analytical models – such as the net present value (NPV) and Internal Rate of Return (IRR) – of the inherent strategic value of the project and the flexibility associated with active management to alter the project's trajectory once undertaken.

Several factors are inadequately treated in the traditional approaches, including:

- Uncertainty of the outcome
- Timing of the investment
- Irreversibility of committed resources
- Inaccurate use of the discount rate

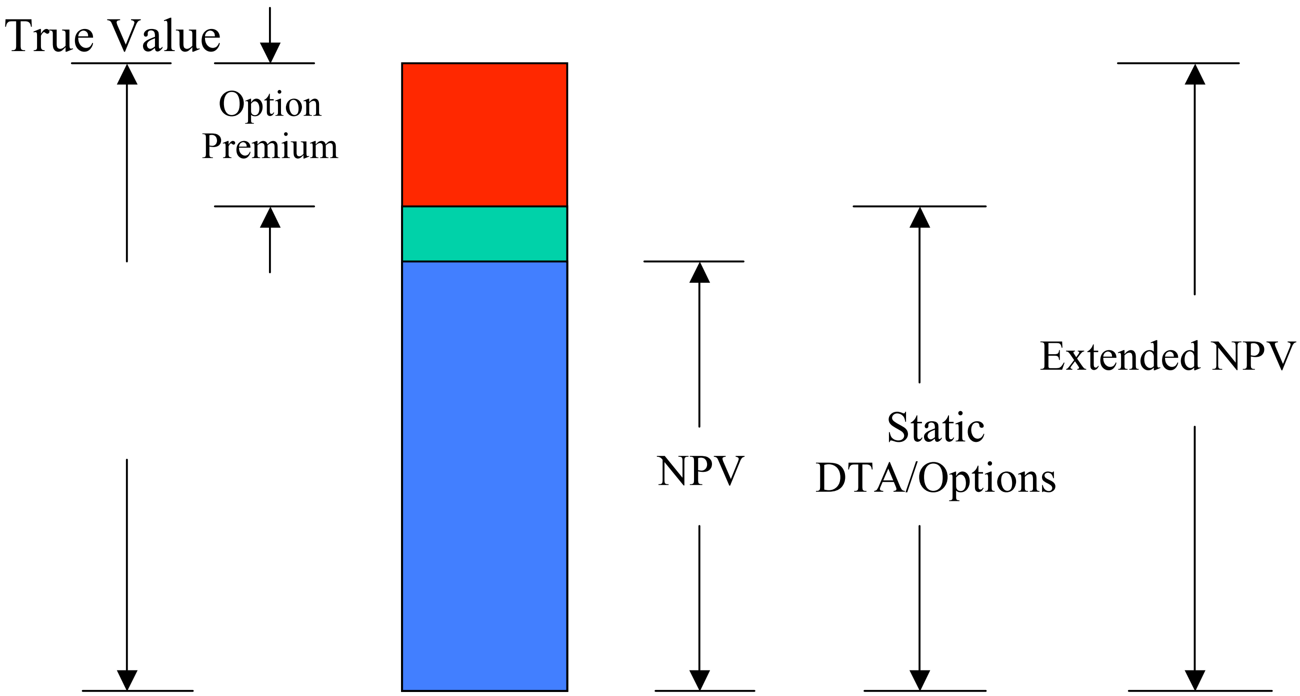


Figure 2. The Valuation Deficit

Real Options: Advantages

The *'real options'* methodology has significant strengths for the ex ante appraisal of R&D investments. *This methodology holds promise in combining capital budgeting and strategic planning.*

Given that the factors mentioned above are major characteristics of strategic, long-term R&D, inadequate accounting for them may seriously distort decision-making based on the potential benefits of investments in government sponsored R&D programs. The 'real options' methodology can deal with all these factors much more efficiently than anything available before it.

The 'real options' methodology has significant potential for creating a very valuable, rigorous analytical complement to the established expert review procedures for research priority setting and evaluation across the public sector. <u>Expert reviews and options appraisals of R&D programs should complement, leverage, and enhance each other.</u>

Compound Real Options for R&D

R&D projects generally involve multiple phases with or without overlapping.

If the investment is made in a phased manner, with the commencement of subsequent phase being dependent on the successful completion of the preceding phase, it is known as sequential investment.

Each stage provides information for the next thus creating an opportunity (option) for subsequent investment in a new technological area. Such projects can be valued using the techniques of **'Compound Options'**, also known as **'Option on Options'**.

By explicitly recognizing the 'choice to invest' aspect of earlier-stage R&D projects, this mechanism greatly enhances the ability of decision-makers to justify long-term R&D investments made by the public sector.

For example, an early R&D investment by the public sector in an emerging technological area may be considered the mechanism for enabling (establishing the option for) the private sector to undertake the follow-up investment required to innovate in that area. Moreover, by differentiating among the various stages in an R&D program, this mechanism allows the use of more appropriate discount rates that better reflect the differential risks of technologies in various stages of development.

Compound Real Options: Limitations

<u>Theory:</u>

Reviewed theoretical models treat R&D investment as a sequential compound option, where investments take place in a phased manner. It is widely known in the innovation systems literature, however, that this assumed 'linearity' is problematic because:

i. R&D phases very often take place in parallel or, at least, overlap significantly;

ii. There are significant feedback loops between *research stages* ***(learning)***.

In order to address issue (i) one needs to solve simultaneous compound options. This has only been achieved through the binomial approach until now. Continuous time 'real option' models remain on the future research agenda.
In order to address issue (ii) one will need to introduce significant complication to existing models. A recent theoretical paper by Berk, Green and Naik (2004) uses Bayesian approach to represent learning.

<u>Application:</u>

The 'real options' valuation methodology is still under development – i.e., it remains 'fluid' – adding to its natural complication.

DOE Study Objectives

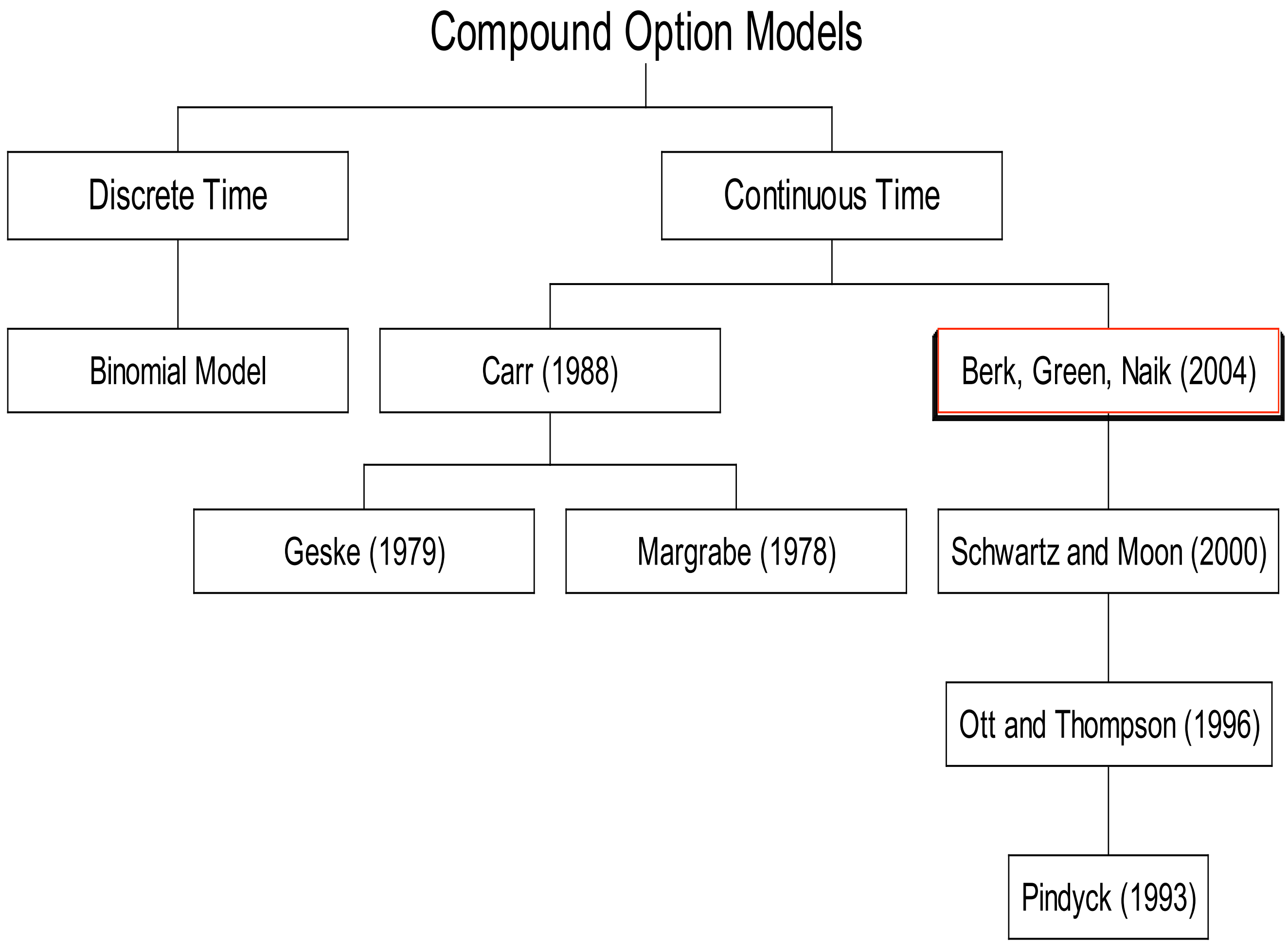
The overall objectives of the study are:

- Determine the feasibility of developing a succinct compound options model to support systematic priority-setting systems for DOE-sponsored research programs.

- Apply this tool to a specific research program within the Office of Science to demonstrate the significant benefits from research in energy and the environment.

The study contributes to the development of a methodology for investment portfolio analysis by the Department, using the Real Options approach.

The 'real options' methodology provides a rigorous analytical complement to the established expert review procedures for research priority setting and evaluation at DOE. <u>Expert reviews and options appraisals of R&D programs should complement, leverage, and enhance each other.</u>


Compound Option Models
Discrete Time
Continuous Time
Binomial Model
Carr (1988)
Berk, Green, Naik (2004)
Geske (1979)
Margrabe (1978)
Schwartz and Moon (2000)
Ott and Thompson (1996)
Pindyck (1993)

Model Choice

We have chosen the following compound real option models to use for the appraisal of long-term research programs supported by DOE:

Binomial

* Cox, Ross, Rubinstein (1979) – [Option-pricing model]

Shockley et al. (2003) - practitioners

Continuous Time

Berk, Green, Naik (2004)

* Schwartz and Moon (2000)

Davis and Owens (2003)

Reasons for Model Choice

Binomial

1. Relatively straightforward, easy to understand
2. Relatively easy to calculate
3. Provides back-of-the-envelope calculation
4. Gives fairly reasonable approximation
5. Extensively used by practitioners

Schwartz and Moon (2000)

1. Deals with 3 uncertainties:
    - cost to completion (technical uncertainty)
    - asset value uncertainty
    - possibility of catastrophic event
2. Provides not only the value of the project but also the optimum investment rule
3. Fits well to the environment of long-term R&D
4. Based on the critical writings of Pindyck (1993), Dixit and Pindyck (1994), and Ott and Thompson (1996)
5. Relatively familiar to DOE because it has also been used by Davis and Owens (2003)
6. Model sufficiently developed with R&D applications

Berk, Green and Naik (2004)

1. Advanced theoretical model (Bayesian approach for learning)
2. Closed-form solutions with *n* R&D stages in the absence of learning

EXAMPLE

Options Methodology (binomial)

Problem Setup

R&D project consists of two Phases:

	Phase I	Phase II
R&D Expenditure	$ 2 million	$ 5 million
Probability of Success	5%	50%
Time period of completion	1 years	1 years

Commercialization investment after the successful R&D:

$10 million

Expected value of the technological advancement X after the successful completion of R&D: $20 million

Cost of capital: 10%, Risk free rate of return: 5%

Objective: Find the net value of the R&D project at time 0

Decision Rule: Invest if net value positive

Summary: Analytical Steps

Step 1: Assume the examined R&D project is successful in producing a technological advancement X at time T (underlying asset). Compute the value of X at time T by discounting all its measurable net gains (revenues minus costs) in periods T+1, T+2, …. (commercialization stage).

Step 2: Discount the calculated value of X from Step 1 to time 0 (present time).

Step 3: Using the subjective probabilities of success (expert opinion) compute technical uncertainty (volatility).
[Binomial tree of R&D phases (tree #1)]

Step 4: Using the outcomes of Step 2 and Step 3 (discounted value of X and technical uncertainty), compute all possible end values of the R&D project (all scenarios).
[Binomial tree of the value of X (tree #2)]

Step 5: Using the end values obtained in Step 4 and the information on necessary investments at each stage of the project, compute the optimal R&D investment at each stage and for each scenario (*R&D options*). This set also includes the initial optimal R&D investment at time 0.
[Binomial tree of R&D investment (tree #3)]

Step 6: If the value of R&D project at time 0 from Step 5 is positive, then initiate the project.

Analysis

Step 1: Compute the value of the given R&D project at time 2, given success in producing a technological advancement X.

This value is found to be $20 million in this problem.

Step 2: Discount the calculated value of X from Step 1 to time 0 (present time).

In our case it is, = $20 million * exp (-0.10*2) = $16.375 million

Step 3: Using the subjective probabilities of success (expert opinion) compute technical uncertainty (volatility).

Black-Scholes formula:

$$N(d_2/Z) = \frac{\ln(S/Z) + (\mu - 0.5\sigma^2)T}{\sigma\sqrt{T}}$$

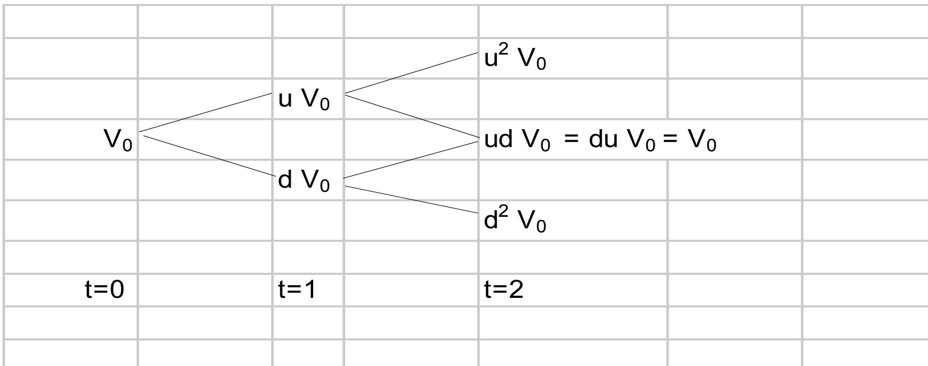
Where,

N (d2 / Z) = Joint subjective probability of success of the R&D project
= 5% * 50% = 2.5%
Z = Investment required for the commercialization stage = $10 million
S = Discounted value of X = $16.375 m
T = Total time to complete R&D project = 2 years
σ = Technical uncertainty of the R&D project (need to compute)
μ = Cost of capital (e.g., interest rate) = 10%

By solving the above for formula for technical uncertainty □ = 82%

Although of key importance, the subjective probability information above does not allow us to compute the value of R&D investment and make the decision. At this point, we transition to the option model.

Step 4: Using the outcomes of Step 2 and Step 3 (discounted value and technical uncertainty), we compute all possible end values of X (all scenarios).

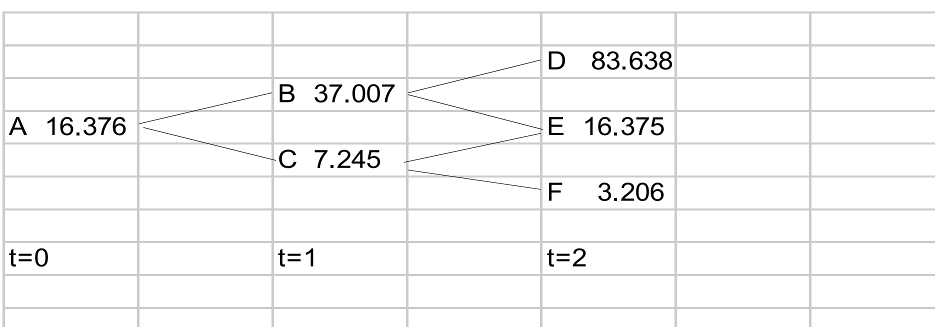


Find the value of up step (*u*) and the down step (*d*), assuming time duration between successive binomial jumps to be one year.

$$u = e^{\sigma\sqrt{t}} \quad = e^{-0.82\sqrt{1}} \quad = 2.26$$

$$d = e^{-\sigma\sqrt{t}} \quad = e^{-0.82\sqrt{1}} \quad = 0.442$$

Complete the Binomial tree of the value of X, by moving forward.



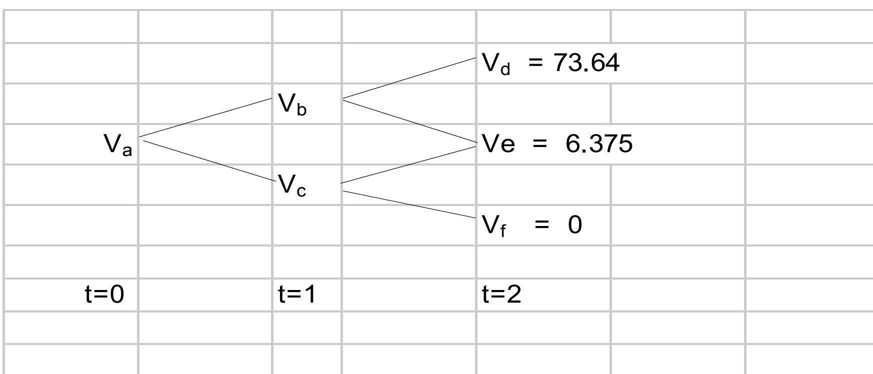
Step 5: Using the end values obtained in Step 4 and the available information on necessary investments at each stage of the project, and the options model we compute the optimal R&D investment at each stage and for each scenario. This set also includes the initial optimal R&D investment at time 0.

We are now moving from the end of the tree to the beginning. We use the principle that the *option value* can never be negative.

Value at node D: max (83.64–10, 0) = 73.64

Value at node E: max (16.37–10, 0) = 6.37

Value at node F: max (3.21–10, 0) = 0



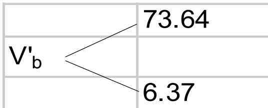
Our next objective is to calculate V_b and V_c.

Start from V_b. We use the two pieces of available information.

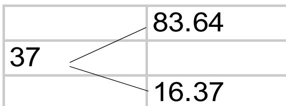
1) The availability of the risk-free investment at the rate 5%.

2) The possibility of investing $37.007 and receiving $83.64 in the good state of the world or $16.37 in the bad state of the world.

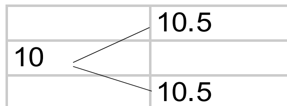
We will create a combination of these two investments that will allow us to obtain the given payoffs $73.64 and $6.37.



Investment A



Investment B (Risk free)



Lets take x units of investment A and y units of investment B.

$$83.64x + 10.5y = 73.64$$

$$16.37x + 10.5y = 6.37$$

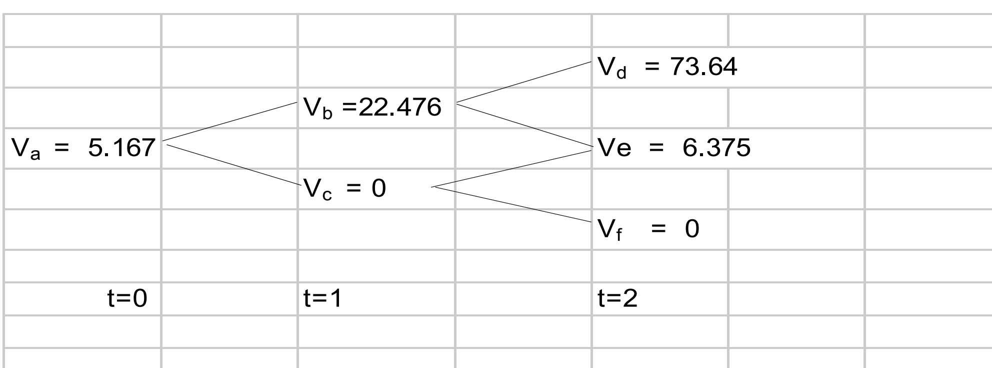
Solving the above two simultaneous equations will give, x = 1 and y= - 0.9524

$V_b^{'}$ = 37 * 1 + 10* (-0.9524) = $27.476

However, at node B, we have to make an investment of $5 million in order to move to Phase II of the R&D. Thus,

$$V_b = \max\left[V_b^* - 5,\ 0\right] = \max\left[22.476,\quad 0\right] = 22.476$$

Similarly we calculate for V_c , and then at time 0, V_a .



So, the option value of the R&D investment is **$ 5.167 millions**.

Data Requirements

The necessary variables for the calculations include:

- Value of technological advancement X (private and social returns)
- Interest rate (Cost of capital), (OMB discount rate?)
- Number of investment phases in the R&D project
- Expected cost per investment phase
- Time periods to completion for each phase
- Probability of success in each phase
- Investment required for commercialization (capital cost such as plant, etc.)

VOLATILITY:

A PRIMER ON REAL OPTIONS MODELING

Volatility (Uncertainty)

Volatility is a core input parameter in pricing of financial options such as options on stocks, bonds, index, currency, futures etc.

It is a measure of how much the value of the underlying asset can vary between the initiation and the expiration of the option.

In Real Options contexts – e.g., R&D project – the underlying asset is the (expected) output of the R&D project in question:

- Can include a new or improved product, service, or production process
- The R&D project itself is the real option to the specific scientific or technological field

The analogy to financial options is not perfect:

- There is uncertainty about not only the value of the underlying asset but about the successful completion of the R&D project itself (i.e., about the "options vehicle")

Types of Uncertainties in R&D Projects

Volatility in research projects can, then, be interpreted as the combination of two different types of uncertainty:

- ***Technical uncertainty*** reflecting the chances of successfully completing the research project

- **M*arket uncertainty*** reflecting the fluctuation in the value stream of the underlying asset – i.e., the fluctuation in the stream of returns to the output of the research

There are various ways of estimating technical uncertainty – the binomial example above used one – and market uncertainty – e.g., forecasting econometric models, Monte-Carlo simulations

Market Uncertainty for Research Output: How Different?

The "market" for research output is further development research, product prototyping and testing

That does not, however, make R a fundamentally different activity than D. It simply removes it from the market one (or more) additional steps

To the extent that research aims at one application (at least), then the "market information relating to that application(s) can be utilized to calculate volatility and the options value of the project

Any additional benefit to society that could not be articulated at the time of the calculation will simply be left out and considered an "externality". <u>Public policy cannot be formulated on the basis of ill-articulated value streams</u>. As the project develops and more information comes in, then it is quite possible to be able to articulate new uses and the calculation can be repeated to include them

Combined Technical and Market Uncertainties

- Relevant for the R&D projects
- Technical and market uncertainty seem unrelated at the first look. In reality, they interact and may be strongly correlated
- Differences in the degree of interaction between applications has serious analytical implications
- For simplicity, it can be argued that there are important differences between research aiming at “process” technologies and research aiming at “product” technologies
- By and large, the target technologies of DOE non-defense research are of the former kind: the final product (energy) is well understood. The search is for alternative ways of producing it cheaper and cleaner

Combined Technical and Market Uncertainties: New Process

Example I: Developing technology for building a new type of a power plant for electricity generation

- R&D related risks can be termed as technical uncertainty
- The price of electricity, the demand for electricity and the variable costs of electricity generation depend on market-wide factors
- During the R&D stage, information becomes available not only about the likelihood of successful completion of the R&D project but also about the market uncertainty parameters
- While technical uncertainty is not affected by the improved understanding of the market, the obtained information could well lead to a revision of previous estimates of the future value stream of the R&D output which, in turn, can affect the decision to continue or abandon the R&D project.

This is a case of <u>uncorrelated, but interacting</u>, technical and market uncertainties.

Combined Technical and Market Uncertainties: New Product

Example II: Early-stage biotechnology to identify a new pharmaceutical compound for a yet imperfectly understood viral disease

- R&D related risks can be termed as technical uncertainty
- The expected price of the new drug, the demand for the drug, and the variable costs of producing the drug depend on market-wide factors
- During the R&D stage information becomes available not only about the likelihood of successful completion of the R&D project as first defined. New information will probably relate to our understanding of the target virus itself. It may, for example, indicate new mutations of the virus which require modifications in the R&D program, in turn, affecting technical uncertainty. Moreover, such information also affects the market uncertainty parameters.
- The obtained information will lead to a revision of both the previous estimates of the chances of success of the R&D program and of the future value stream of the R&D output. These two together will affect the decision to continue or abandon the R&D project.

This is a case of <u>correlated</u> technical and market uncertainties.

Estimating Combined Technical and Market Uncertainties: New Process

- Q**uadranomial** approach (Copeland and Antikarov, 2001)

This essentially is a two-variable binomial tree:

- Suppose there are two variables A and B and both can have two values, each for up (success) and down (failure) states
- The four possible combinations of values complete the quadranomial tree

Thank You