A Real Options Approach for Investments in Low-Carbon Energy Research & Development

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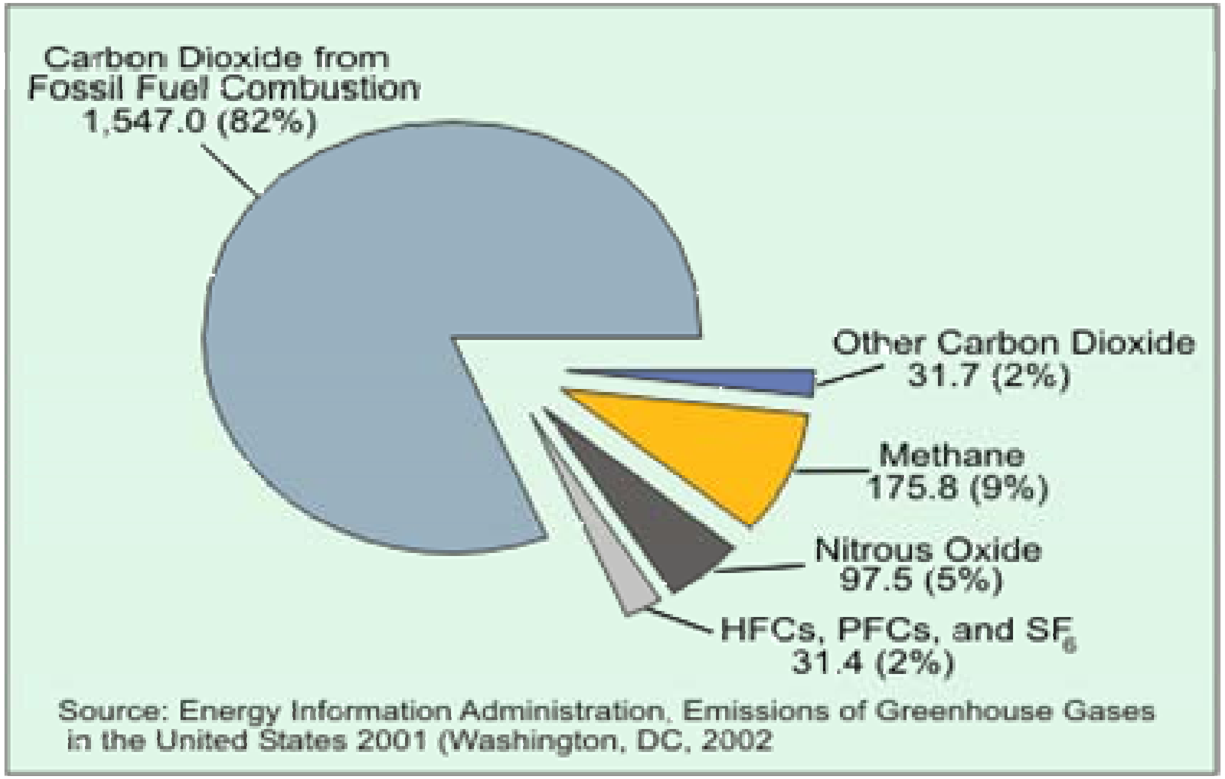
Outline

- Overview of low-carbon energy alternatives
- Short background on real options
- Small example of real options for low-carbon R&D investments
- Extended example with budget and funding flexibility
- Application for United States Department of Energy
- Summary

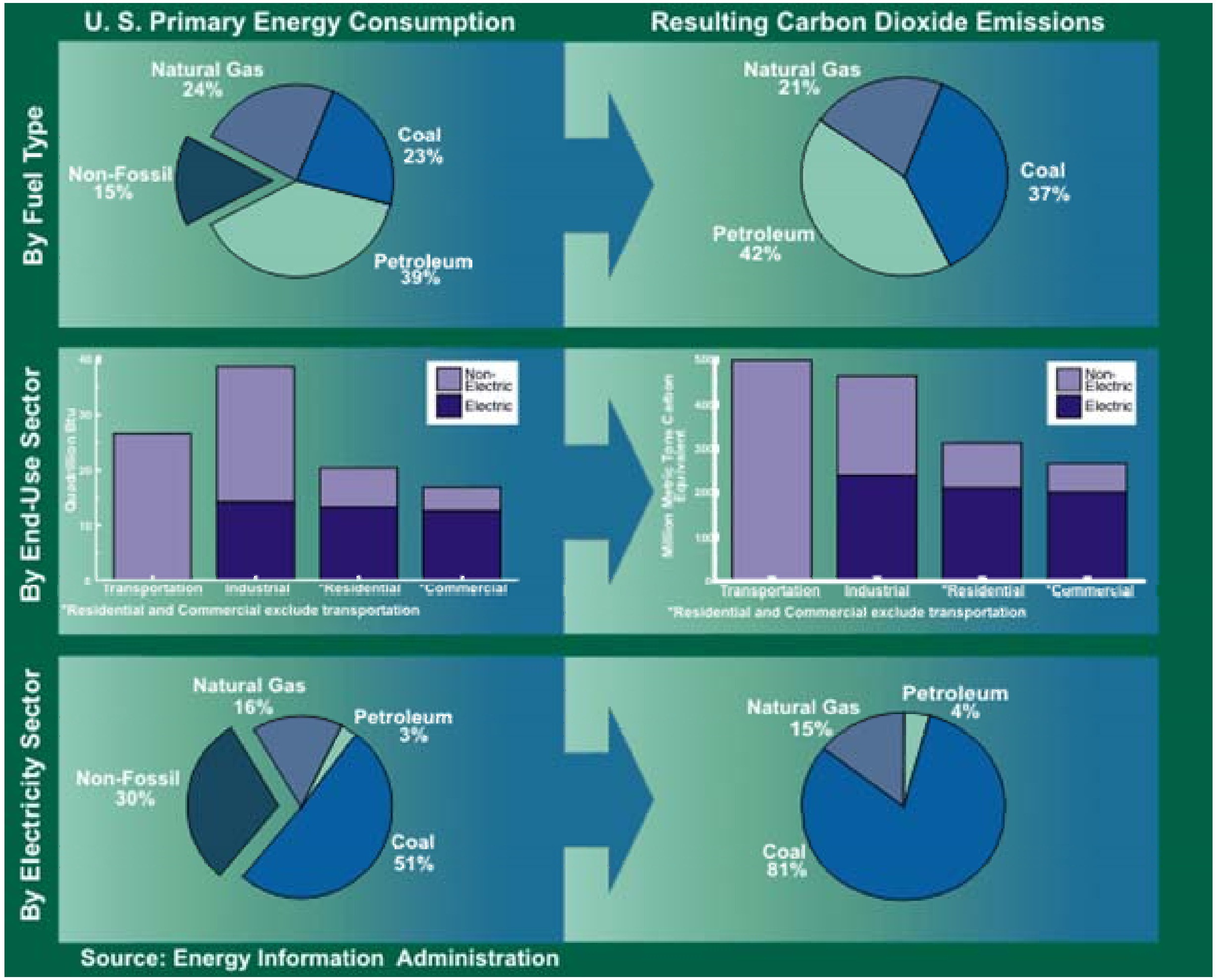
Overview of Low-Carbon Energy Alternatives

- Most carbon emissions (in the US) comes from burning fossil fuels
- U.S. Anthropogenic Greenhouse Gas Emissions by Gas, 2001 (Million Metric Tons of Carbon Equivalent)



Overview of Low-Carbon Energy Alternatives

- U.S. Primary Energy Consumption and Carbon Dioxide Emissions (2001)



Overview of Low-Carbon Energy Alternatives

- Ever-increasing need and awareness of carbon dioxide emissions from power generation (and otherwise)
- Need for low-carbon technologies to be more prominent
- Examples:
  - Carbon capture and storage (e.g., sequestration)
  - Natural gas and combined cycle turbines
  - Hydroelectric power
  - Wind power
  - Solar power
  - Nuclear power
  - Geothermal power
  - Tidal power
- Different levels of research and development (R&D) for each of these low-carbon options
- Different possible payoffs and costs, different levels of risk

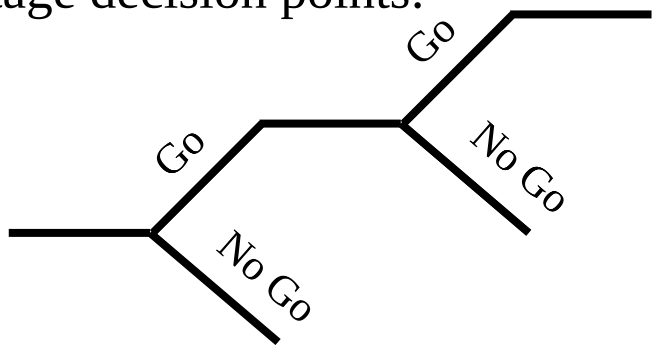
Overview of Low-Carbon Energy Alternatives

Central Questions:

- From the government's perspective, how should they fund R&D in these low-carbon technologies for power generation?
- Need to take into account that there is limited investment capital
- While many of these technologies are currently used or well-established, maybe it makes sense to investment in R&D improvements to make them more efficient
- Maybe the capital would be better spent on investing in new but potentially promising areas (e.g., tidal power)
- This is essentially a real options question to deal with R&D investment under uncertainty

Real Options Concepts

- Comparison between NPV and real options
- Broad literature on real options methods for R&D decisions
  - e.g., Dixit & Pindyck (1994), Perdue et al. (1996), Trigeorgis (1996)
- Consider uncertainties in expected market value or price
- Consider the value of increased managerial flexibility through real options:
  - Delaying investment until conditions improve/reduced uncertainty (e.g., wait until certain environmental regulation is passed)
  - Continuing investment funding
  - Abandoning R&D investments as an option
- Consider multi-stage decision points:

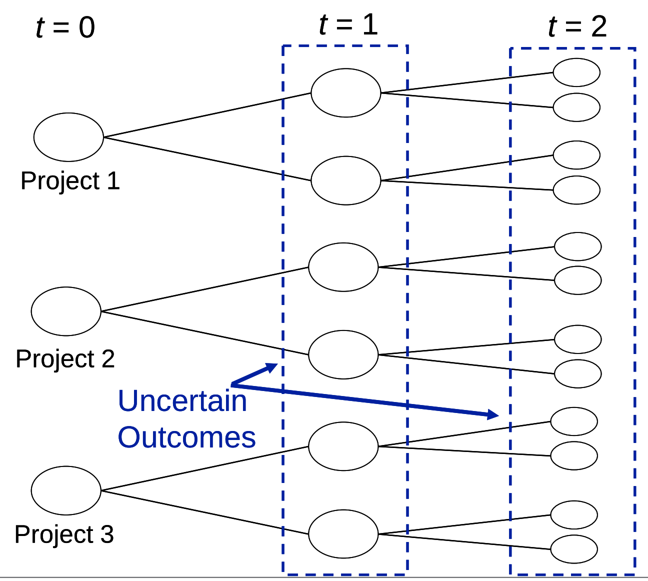


Real Options for Public Sector

- Can consider the investment in low-carbon R&D either in the public sector as shown before or in the private sector (e.g., private energy company)
- Public sector investments often non-market traded goods
  - Difficult to value
  - Discount rate? Constant vs. Variable?
  - Public investments often have no abandonment option absent massive overruns in cost or schedule: *investments continue until capability is achieved or no longer required*
- Vonortas & Hertzfeld (1998) apply option method to attribute social benefits to NPV calculations in support of R&D decisions

A Possible Real Options Approach for Low-Carbon R&D Investments From the Government Perspective

- Consider the problem as a multi-stage, multi-project competition ideal problem for real options framework:
  - Stages can be years; “projects” can be R&D efforts either for separate technologies (e.g., tidal or wind power), different directions for same technology, or combinations thereof
  - Each potential project represents an option to the energy research manager
  - The cost of exercising each option is the amount of funding required for each project’s development
  - An option is exercised through the award of a continuation of funding.
- Solution is the optimal portfolio of options (energy projects) to fund at each stage to maximize overall capability success.
- Can use stochastic dynamic programming to solve.



Real Options Example: TRL as Metric

- Formulating a value for each option requires a measurement of every project's current and expected technological maturity
- Technology Readiness Level (TRL) is a measurement system used by US government agencies, especially NASA and the Department of Defense, to assess the maturity of evolving technologies
- For our example, we will use the TRL system to describe the success of R&D projects at each stage of a competition (could use other methods, could use less then eight levels with TRL as well)

TRL	Definition
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof of concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment
7	System prototype demonstration in an operational environment
8	Actual system completed and qualified through test and demonstration
9	Actual system proven through successful operations

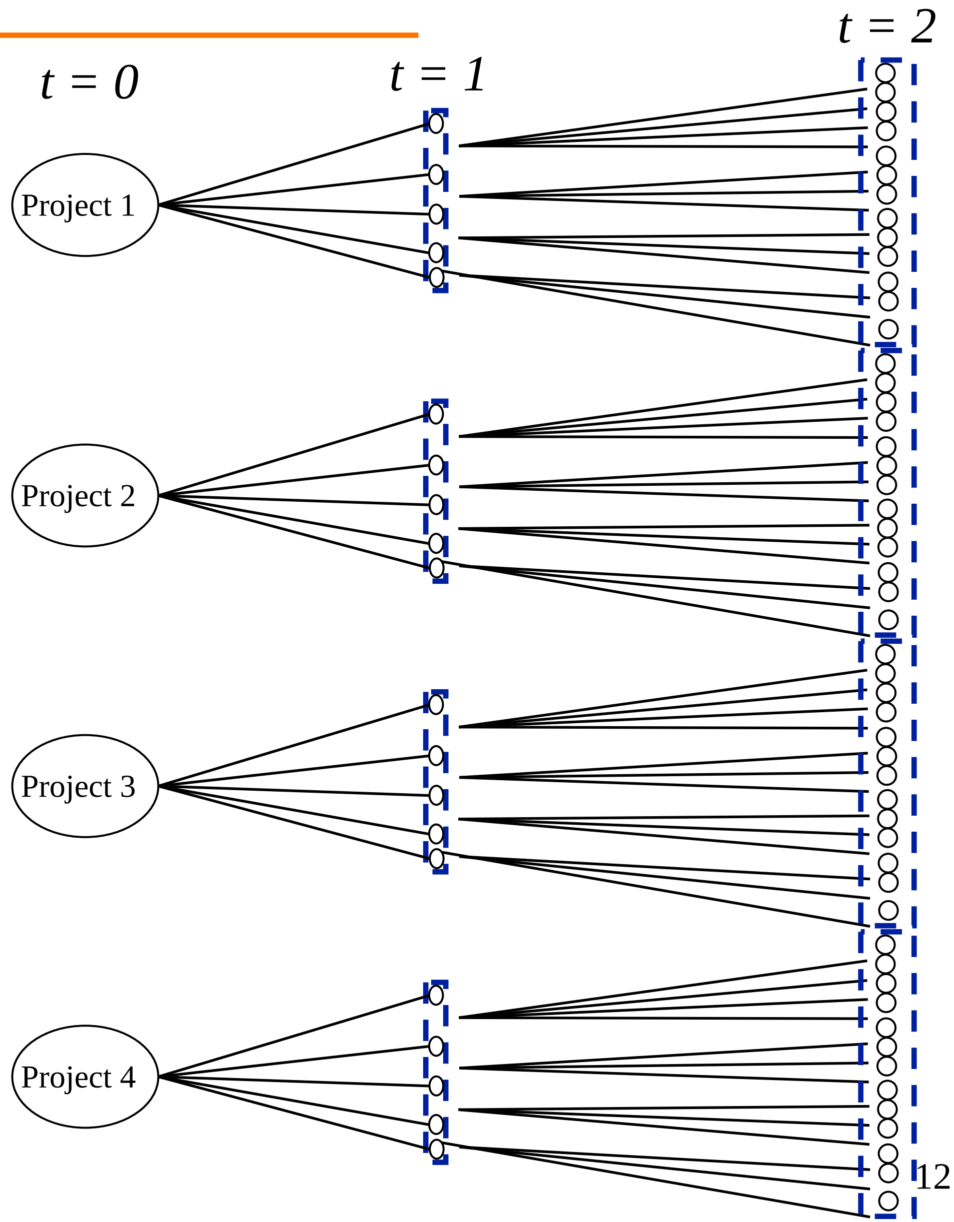
Real Options Example: Description

Simple Project Formulation

- Objective Function: Maximize probability of achieving TRL 8 after 2 stages (time periods), states are TRLs for each project
- Two-stage, multi-project competition
  - Solved for *i* project, *t* stage problem
- Stage 1: Technology Development (goal is to achieve TRL 6)
  - Each project has a specific probability of achieving TRLs 4-8 as a function of allocated budget. Probabilities could be a
    - Function of discrete budget / TRL pairs
    - Continuous step-function of budget and TRL outcomes
- Stage 2: Capability Development (goal is to achieve TRL 8)
  - Each project has a specific probability of achieving TRLs 4-8 conditional upon TRL achieved in Stage 1 and allocated budget
  - Hence, we need to realize the outcomes from Stage 1 before making Stage 2 decisions

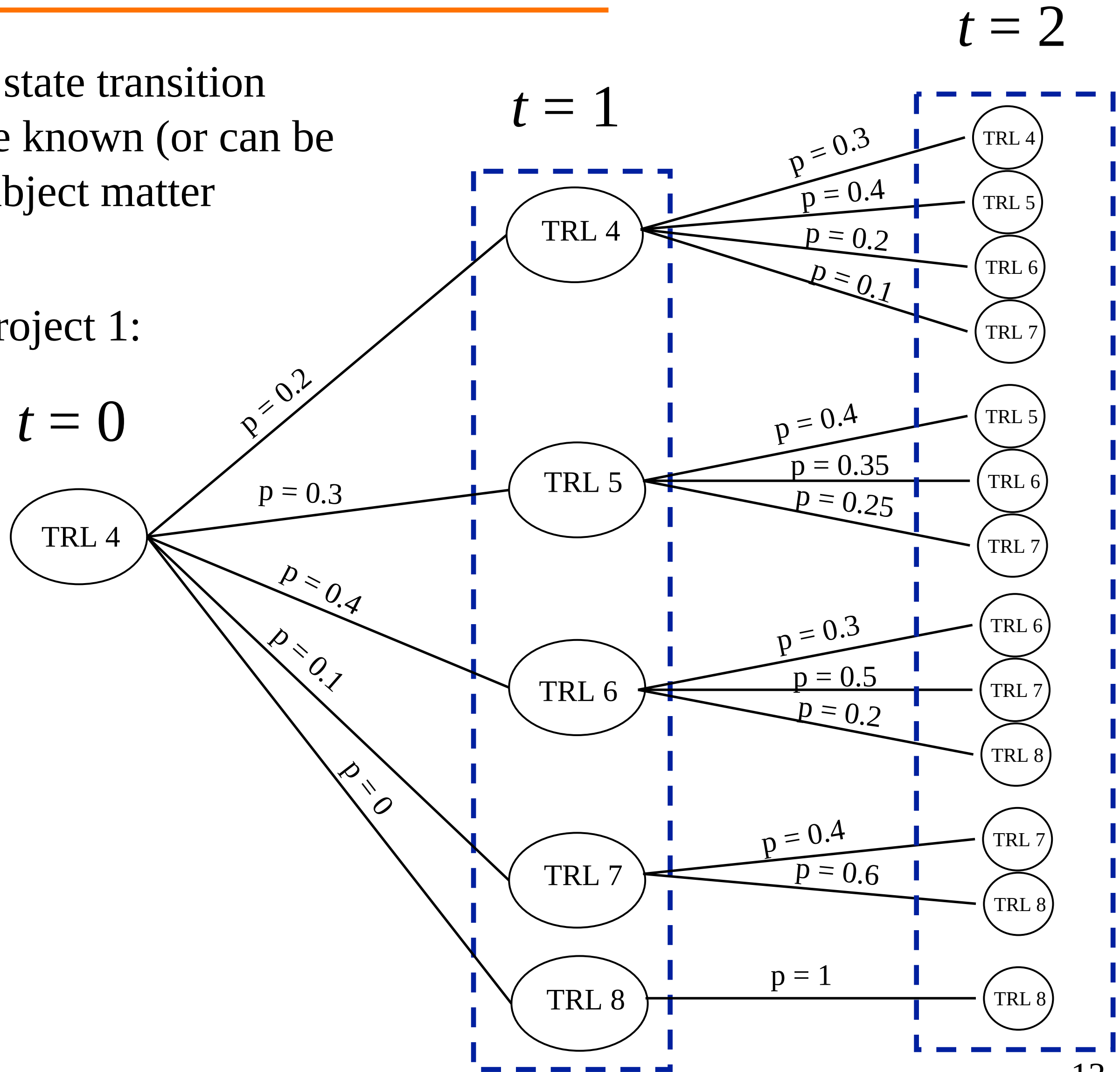
Real Options Example: Overall Structure

- Which energy R& D projects should be funded in *t=0?*
- Which project should be funded in *t=1?*
- Goal: Maximize the probability of achieving the desired TRL level for at least one of the projects



Real Options Example: Transition Probabilities

- We assume the state transition probabilities are known (or can be elicited from subject matter experts)
- For example, Project 1:



Real Options Example

Suppose the potential funding level for each project at every stage is fixed; decision is whether to fund that project. The budget at each stage is fixed (Eckhause, Hughes and Gabriel 2008).

- Let $C_{it} \in S_i$ be the state of project i at time period t
- Let $X_{it} \in \{0,1\}$ be the decision variable of whether to fund project i at time period t
- Let α_{it} represent the cost of funding project i at time period t
- Let B_t represent the R&D budget available for time period t

We assume the state transition probabilities are known:

$$\mathbf{P}\{C_{i,t+1} = s_2 \mid C_{it} = s_1, X_{it} = 1\} \quad \forall s_1, s_2$$

Example: 4 Projects, 2 Time Periods

Project Costs	Time Period (Stage) 1	Time Period (Stage) 2
Project 1: Advanced Wind Turbines	3.5M €	4.0M €
Project 2: Carbon Sequestration	3.7M €	6.9M €
Project 3: Tidal Power	5.0M €	10.4M €
Project 4: Solar Power	2.3M €	6.3M €
Total for all 4 Projects	**14.5M €**	**27.6M €**

Program Budget Constraints

- Total budget for Stage 1: **10 M €**
- Total budget for Stage 2: **20 M €**
- Clearly we cannot fund all four projects within the existing annual budgets

Simplest Case Example

- Stage 2 transitions:

Second Stage Outcomes	Stage 2 TRL	Stage 1 TRL Achieved	Prob
Project 1	4	4	0.30
	5	4	0.40
	6	4	0.20
	7	4	0.10
	5	5	0.40
	6	5	0.35
	7	5	0.25
	6	6	0.30
	7	6	0.50
	8	6	0.20
	7	7	0.40
	8	7	0.60
	8	8	1.00
Project 2	4	4	0.10
	5	4	0.30
	6	4	0.40
	7	4	0.20
	5	5	0.30
	6	5	0.20
	7	5	0.50
	6	6	0.20
	7	6	0.70
	8	6	0.10
	7	7	0.35
	8	7	0.65
	8	8	1.00

Second Stage Outcomes	Stage 2 TRL	Stage 1 TRL Achieved	Prob
Project 3	4	4	0.20
	5	4	0.40
	6	4	0.20
	7	4	0.10
	8	4	0.10
	5	5	0.40
	6	5	0.35
	7	5	0.15
	8	5	0.10
	6	6	0.30
	7	6	0.40
	8	6	0.30
	7	7	0.30
	8	7	0.70
	8	8	1.00
Project 4	4	4	0.40
	5	4	0.30
	6	4	0.20
	7	4	0.10
	5	5	0.50
	6	5	0.30
	7	5	0.10
	8	5	0.10
	6	6	0.40
	7	6	0.30
	8	6	0.30
	7	7	0.50
	8	7	0.50
	8	8	1.00

Real Options Example: Solution

- Solution to SDP indicates that we should fund Project 3 and Project 4 in the first stage.
  - In stage 1, Project 3 is most expensive; Project 4 is least expensive.
  - The probability of success is 0.56.
- Note one could fund Projects 1, 2, and 4 in the first (and second) stage within budget
  - However, probability of success is only 0.47.
  - Real options approach illustrates that “more options is better” does not always hold.

Extension: Budget and Funding Flexibility

Fixed Total Budget at Beginning B_1

- Can spread budget between each phase:

  B_t denotes budget *remaining* at time period t
- Projects may be funded at multiple levels (not just on/off)
  - Discrete, step-wise function
  - Limited to number of state transition probabilities reasonably definable by subject matter experts (SMEs)
- Let α_{itl} denote the cost of funding vendor i at time period t at level l
- Let $X_{itl} \in \{0,1\}$ be the decision variable of whether to fund vendor i at

  time period t at level l
- Decisions:
  - Which options to purchase and exercise in each stage
  - How to spread the budget optimally
- Must discretize budget between periods

Extended Problem Example

- 2 Stage, 3 Funding Level, 4 Vendor Problem:

Project Costs	Time Period 1 Low	Time Period 1 Middle	Time Period 1 High	Time Period 2 Low	Time Period 2 Middle	Time Period 2 High
Project 1	2.5M €	3.5M €	5.0M €	3.0M €	4.0M €	5.0M €
Project 2	3.2M €	3.7M €	5.2M €	6.9M €	6.9M €	7.9M €
Project 3	3.0M €	5.0M €	9.2M €	10.4M €	10.4M €	10.4M €
Project 4	1.8M €	2.3M €	2.8M €	5.3M €	6.3M €	7.3M €

Extended Problem Example

- Program Budget Constraint
  - Total budget can be spread over both stages:
    10 M € + 20 M € = 30 M €
- The “middle” funding case corresponds to the previous problem in terms of costs and probabilities
- State transition probabilities correspond to funding levels. Higher funding levels increase the probability that the project reaches success state.

Extended Problem's Solution

- Solution to SDP indicates that we should fund in this stage:
  - Vendor 1 and Vendor 3 at highest level
  - Vendor 4 at the middle level
- Under optimal selection, probability of reaching TRL 8 by end of second stage is 0.71.
- By allowing budget flexibility and multiple funding levels, the likelihood of success increases from 56% to 71%

Application: U.S. Dept. of Energy (DoE)

- One use for this model can be for funding decisions for the Office of Energy Efficiency and Renewable Energy (EERE)
- EERE has many programs working to both competing and complementary objectives
  - Geothermal
  - Solar
  - Wind
  - Biomass

Application: U.S. Dept. of Energy (DoE)

- One approach is to focus on one program. For example, biomass projects from cellulosic material (e.g., switch grass)
  - Currently, there are 6 potentially R&D plants that can work on these technologies
  - Which plants to fund?
  - At what level do we fund them?
  - What are the technology progression metrics from which we measure success?

Summary and Extensions

- Approach presents an analytical framework for valuing multi-project, multi-stage R&D investments for low-carbon technologies for power production
- The stochastic dynamic programming formulation can be easily extended to include:
  - Different objective functions
  - Optimal number of identical project to fund to hedge risk
- An integer programming (IP) approach can be used for certain problems
  - Although computationally more complex (in general), an IP approach could be helpful for certain analyses, such as budget sensitivities