Motivation for Options: Valuation of Flexibility in Systems Design

Outline of Options Section

- Motivation and Basic Concepts
  - Need to value flexibility
  - Traditional Methods inadequate for Valuing Flexibility
  - Concepts of Options: Financial and Real

- Valuation of Options
  - Decision Analysis vs. Option Theory
  - Black-Scholes and Binomial

- Practical Analysis of Real Options
  - Alternative Approaches
  - Merck, Kodak, Hybrid (Neely)

- Extensions and Examples
Outline of Motivation

- Need to Value Flexibility
  - Flexibility adds value
  - When does added value justify the cost?
- Traditional Methods Insufficient
  - Net Present Value of Project is Inadequate
  - Example: Project Risk of Research and Development
  - Decision Analysis May be Impractical
  - Example: Market Risk of Flexible Plant
- Options Analysis Indicates Solution
  - Basic Types of Options: Calls and Puts
  - Applications to Systems Design: Real Options

Flexibility Adds Value

- Flexible systems
  - Allow owner to adapt operating conditions
- Flexibility can reduce total operating costs
  - Costs less to adapt to variability and change
- Allows advantageous use of inputs or production of outputs
- Example: flexible manufacturing systems
  - Allow fast product change-overs
  - Accept a variety of raw materials
  - Can efficiently process a wide range of batch sizes
Flexibility Costs

- **Money**
  - Equipment might require special configurations
  - Extra Space for Expansion

- **Complexity**
  - Production or management systems more complex

- **Time**
  - Design and Planning Efforts take time

Central Design Issue

- **What Flexibility should we incorporate in System?**
  - The question is in effect: What elements of flexibility are more valuable than their cost?

- **How do we value flexibility?**
Traditional Methods are Insufficient

- Net Present Value is Inadequate
  - Assumes a single cash flow, and misses flexibility
- Decision Analysis may be Impractical
  - Analysis too complicated
  - Also, inadequate basis for Choosing discount rate
- The need for a better Method is the Motivation for Options Analysis
- Options Analysis is a method for valuing flexibility
  - Recent development subject of Nobel Prize
  - Now being introduced into engineering systems design

Net Present Value is Inadequate

- Example: Project Risk of Research and Development
- Decisions not Fixed at Start of Project
- Projects often have Built-in decision points
  - Do we move from research into development?
  - When do we launch product?
- Choices are made after Observation of Results so far
- Standard NPV however unrealistically assumes
  - a single cash flow
  - NPV of average situation = Expected NPV of project
Example: Project Risk of Research and Development

- Start R&D project for $100
- $1100 more will be required to complete development
  - Must decide whether or not to continue after observing initial results
  - Commercial feasibility determined by initial R&D results
  - Plan to sell (license) technology to highest bidder
- Revenue estimate
  - 50% chance to sell technology for $2000
  - 50% chance to sell for $100
- Assume constant 10% discount rate applies

- Fund project?

Traditional NPV Valuation of R&D

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Traditional NPV Valuation of R&D (con’t)

- \( NPV = -232 \)
- Project should be rejected

Flexibility Perspective of R&D

- Develop only if $2000 license is expected

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**Flexibility Perspective on R&D (cont’)**

- **NPV = +226**
- **Should accept project**

![Decision Tree Diagram]

**Lessons from Example with Project Risk**

- **Ability to abandon project has significant value**
  - Limits downside
  - Continue only if advantageous
- **Standard NPV misses option value completely**
  - Fails to consider range of possible outcomes
- **Standard NPV distorts value when there is risk**
  - Assumes that: NPV with expected values = expected NPV
  - However: Consequences of scenarios have asymmetries
  - Example, production costs often not linear with volume
- **Decision analysis has the advantage of recognizing value of flexibility**
Decision Analysis May be Impractical

- **Analysis may be too complicated**
  - Situation may change too often so that analysis too confused
  - Example: Prices for Basic Resources fluctuate rapidly up and down

- **Inadequate basis for Choosing discount rate**
  - When nature of risk constantly changing
  - This implies that discount rate should be changing too
  - No single discount rate would adequately cover situation
  - See Presentation on Valuation for details

Example: Market Risk of Production

- **Case of Flexible Burner on Power Plant**

- **Turbines for electric power generation can be powered by**
  - Gas burners
  - Oil burner
  - Flexible burner (accepts either oil or gas)

- **Fixed technologies (gas or oil) cost less to acquire than more complex flexible burner**

- **Under what conditions might flexible systems be valuable?**
Specifics of Flexible Burner Example

- Based on Kulatilaka and Marcus paper

- Discount cash flows at 10%
- Price of gas remains fixed at $1 per energy unit
- Price of oil increases over time
  - At present oil costs $0.75 per energy unit
  - Price increases by 5% per year
- Installation occurs in Year 0
- Operations start in Year 1
- Revenues are independent of technology
- What is the NPV for each burner?

Base Case: Oil and Gas Prices assumed Known with Certainty

- Oil burner cheaper to operate until Year 6

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Base Case Prices:
- Oil
- Gas
Cash Flows Under Certainty

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Results of Certainty Case

- Rank of technologies
  - Oil -- Flexible -- Gas

- Oil burner captures early cost advantages over gas
  Time value of money means early gains more significant than later losses

- Oil burner also better than flexible
  Both capture cost advantages early-on
  Flexible advantageously switches to gas in Year 6
  Additional costs of acquiring flexible overshadow later gains

- Critical assumption: input prices are predictable
Realistic Case: Market Uncertainty in Oil Prices

- What if oil could follow one of three price paths?

![Graph showing oil prices over time with three scenarios: High, Medium, Low.]

Cash Flows with Uncertainty

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<th>Year</th>
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NPV 0.24 0.63
Results of Uncertainty Case

- Rank of technologies
  - Flexible -- Oil -- Gas

- Flexible technology enabled advantageous switching
  - For high oil price case, do better than oil burner
  - For high gas prices, do better than gas burner
  - Benefits accrue early on when uncertainty in prices is considered
  - Operating cost savings outweigh additional acquisition costs

Lessons from Example of Market Risk

- Real Situation Vastly more complicated
  - Prices Change Rapidly
  - They may go up and down in many pathways
  - The switch between fuels can be exercised often

- Decision Analysis can be Impractical
  - Simple Example Situation Already Difficult

- Example Analysis unrealistically assumed a fixed Discount Rate, But
  - Discount rate should reflect volatility of prices
  - As risk changes, so should discount rate
  - Cannot change discount rate in decision analysis

- Another Method Required!!!
“Options” Define Value of Flexibility

- An Option is a formal way of defining flexibility
- Options valuation well developed for financial markets
- Emerging field of real options applies theory to real projects
  - Future decisions have features similar to financial options
  - Financial options valuation frameworks can be extended to project flexibilities
- Real options correct deficiencies in NPV & decision analysis
  - Will detail these deficiencies shortly
  - Will also consider potential drawbacks to real options

What is an Option?

- A right, but not an obligation...
  - Asymmetric returns
  - Exercise only if advantageous
  - Acquired at some cost

- to take some action...
  - Often buy or sell something

- now, or in the future...
  - Usually limited timeframe
  - Option expires after time limit

- for a pre-determined price.
  - Price of action separate from option acquisition cost
  - Can be compared to instantaneous benefit of action
Example Financial Option

- Example: A Option to buy 100 shares of ATT at 60 through January
- Option allows, does not force owner to buy
- The right is to buy shares at a specified price
- The right is for a specific time (through January)
- Purchase price is set in advance (at $60)

- Note implications:
  Owner of Option Likely to exercise right to buy stock if it trades above $60 (owner then makes profit on difference between current price and $60)
  Owner not required to exercise losses are limited

Example Real Option

- Example: You have a spare tire in your car
- You can do something with it, but do not have to
- The right is to change the tire
- The right in this case has unlimited time
- The “cost” of exercising the option is the effort of changing the tire

- Note Similarity to Financial Option
  - You will change tire only if you need to
  - You do not have to do a thing about it
Financial Options Basics

- Focus on stock options because this is where theory developed
- Stock Options
  - Stock options are tradable assets (See Financial Pages)
  - Sold through exchanges similar to stock markets
  - Options on other assets (e.g. currencies) are similar
- Many Types of Stock Options
- All options have similar basic features
  - Option provides right to buy or sell stock
  - Time period during which option can be exercised is limited
  - Strike price at which stock is bought or sold is pre-determined

Financial Options: Basic Types

- Two basic types of stock options
  - Call: right to buy stock for a set price
  - Put: right to sell stock for a set price
- The set price is known as the “strike” price
- Options can get much more complicated
  - nested, one following another
  - simultaneous, opposing each other
  - very exotic -- not for now!
Financial Options: Timing Limitations

- Constraint on exercise defines 2 types
  - European
  - American

- European: can only exercise on expiration date
- American: can exercise at any time on or before expiration date
- American Options are much more realistic, generally
  - Most decisions can be made at any time
  - Remaining discussion focuses on American options, unless otherwise specified

Definitions of Key Features of Options

- \( S = \) stock price at any time
- \( S^* = \) price at time you exercise option
- \( K = \) strike price at which stock can be bought (call) or sold (put)
- \( t = \) time remaining until option expires
- \( \beta = \) standard deviation of returns for stock (volatility)
- \( r = \) risk-free rate of interest
Financial Options: Payoff

- **Payoff:** is the amount you get if you exercise the option

- **Call Option Payoff**
  - If exercised, call option owner buys stock for a set price
    - Get stock worth $S^*$ dollars
    - Pay strike price of $K$ dollars
    - Net position $= S^* - K$
  - If unexercised, net payoff is zero
- **Net Payoff of Call Option:**
  - Maximum of either 0 or $S^* - K = $ net payoff for call
  - Expressed as: $\text{Max} [0, S^* - K]$

Financial Options: Value

- **Value often exceeds Payoff**
  - Because variability of stock price can increase payoff of option
  - There is thus an expectation of greater value than immediate payoff

- **Calculation of Value**
  - requires sophisticated analysis
  - Determination of method for calculating value of options won Nobel Prize
  - Subject of Next Lecture
Options Not Limited to Traded Securities: 
"Real Options" for Systems

- **Lease car with option to buy**
  - Leasee decides at end of contract
  - Action is to buy car at end of lease (or to walk away)
  - Lease period defined up-front (typically 2-3 years)
  - Car purchase price defined in lease contract

- **Flexible manufacturing processes**
  - Ability to select mode of operation (e.g. heater that burns gas or oil)
  - Switching between modes is action
  - Continuous opportunity (can switch at any time)
  - Switching modes often entails some cost (e.g. set-up time)

Real and Financial Options Differ

- **Real options do not refer to traded assets**
  - The option to change manufacturing process (use a different fuel) rather than to buy a stock

- **This means that there is no obvious history to value of asset**
  - Stocks are traded regularly and have a long record of: average price and variability

- **Real substitutes for this history not obvious**
  - If real option concerns traded commodities (such as fuels) a suitable history may be available
  - In other cases it may be quite impractical

- **Financial Methods of Valuing Options need adjustment when applied to real systems**
Summary of Introduction to Options

- Flexibility has value, because of risk
- Good Systems Design will incorporate flexibility to respond to risk
- Issue is: How do we value flexibility?
- Approach is through Options Analysis
- This Method well developed in Financial Markets
- Needs adjusting to engineering systems