Types of Flexibility = Options

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Theme for this Presentation

- To place Concept of Flexibility in Design into perspective of “Options” in Finance/Economics
- Note that “options” in this context has a specific meaning ≠ “alternative”
- Wide literature on “options” in economics and finance. Topic closely related to flexibility in design – but with important differences!
- In general:
  Flexibility in design = “real option”
Organization

- Formal definition of Options, along with basic types ("calls" and "puts")

- Drivers of Option Value
  - Uncertainty, combined with
  - Asymmetry in Pay-offs

- Decision Analysis Illustrates process

“Options” Embody Idea of Flexibility

- “Option” : one formal way of defining flexibility

- “Option” has a specific technical definition

- Semantic Caution:
  - The technical meaning of an “option” is much more specific and limited than …
  - ordinary meaning of “option” in conversation... where “option” = “alternative”

- Pay careful attention to following definition!
Technical definition: An Option is...

- A right, but not an obligation...
  - "Exercise", that is "use", only if advantageous
  - Asymmetric returns -- “all gain, no pain”
  - Usually acquired at some cost or effort

- to take some action...
  - to change system, buy or sell something, etc,

- now, or in the future...
  - May be indefinite
  - Can be for a limited time only

- for a pre-determined condition ("strike" price)
  - Cost of action separate from cost of option

Illustration of option definition

Spare tire on car is an “option” because it

- provides right, but not an obligation...
  - Operator can use it or not
  - Acquired at some cost – price of tire, loss of space

- to take some action...
  - to change the tire

- now, or in the future...
  - In this case, whenever desired

- for a pre-determined condition ("strike" price)
  - Time, effort of jacking up car, replacing tire, etc.
Types of Options

- **Two basic types of options**
  - **CALL**: right to take advantage of an opportunity (e.g., ability to expand garage if demand is high)
  - **PUT**: right to limit losses of a bad situation (which is what an insurance policy provides)

- **Options in design can be complicated**
  - **NESTED**: one after another
    - successful research => option on development;
    - successful prototyping => option on production
  - **SIMULTANEOUS**: (e.g.: successful fuel cells research => options on hybrid cars and home use)

Real Options are Everywhere

- **Examples:**
  - **Lease equipment with option to buy**
    - Action is to buy at end of lease (or to walk away)
    - Lease period defined up-front (typically 2-3 years)
    - Purchase price defined in lease contract
  - **Flexible manufacturing processes**
    - Ability to select mode of operation (e.g. thermal power by burning either gas or oil)
    - Switching between modes is action
    - Continuous opportunity (can switch at any time)
    - Switching often has a cost (e.g.: set-up time)
Generic Real Options

- **Call-like**
  - Capture benefits from increases in project value
  - Exercise typically involves putting money into project
  - Exercise when expectations of positive return increase

- **Put-like**
  - Insure against losses from decreased project value
  - Exercise may involve short-term costs or salvage value
  - Exercise when expectations of losses

- **Compound (nested)**
  - Projects might contain multiple options
  - Exercise decisions based on overall profit maximization

- **In detail...**

Call-Like Real Options

- **Waiting to Invest**
  - A project might be profitable today, but better tomorrow
  - Leaving investment opportunity open ~ holding a call
  - Deciding factors: uncertainty resolution; foregone profits
  - Choice based on: Max [immediate investment, waiting, 0]

- **Expand -- Accelerate effort or level of involvement**
  - Allows greater participation in upside
  - Cost of expansion is like strike price
  - Choice based on: Max [status quo, expanded project]

- **Restart Temporarily Closed Operations**
  - Similar to waiting to invest or expand (a special case)
  - Choice based on: Max [remain closed, re-open]
Put-Like Real Options

- **Abandon**
  - Ability to halt investment eliminates further losses
  - might include shut-down costs and salvage values
  - Choice based on: Max [continuing, abandoning]

- **Contract -- Decelerate or narrow involvement**
  - Reduces participation level and exposure to losses
  - Often incurs short-term scale down costs
  - Choice based on: Max [status quo, contracted]

- **Temporarily Shut Down Operations**
  - A special case of contraction
  - Eliminates losses, but can incur shut-down costs
  - Choice on: Max [status quo, temporarily shut-down]

“Real” Options

- “Real” because they refer to projects
  - Contrast with financial options that are contracts

- **Real Options are focus of interest for Design**
  - They provide flexibility for evolution of system

- **Projects often contain option-like flexibilities**
  - Rights, not obligations (e.g.: to expand garage)
  - Exercise only if advantageous

- **These flexibilities are “real” options**

- Let’s look at possibilities…
Compound or Nested Options

- Combinations of Options
  - Many real options exist simultaneously
  - E.g.: those to abandon, contract, or temporarily shut down
  - Complex problem: value of multiple options are often interdependent and in general not additive
  - Use may make others valueless (abandon ends project)

- Switching Between Modes of Operation
  (example: dual fuel burner case)
  - Flexible systems contain an infinite series of options
  - Allow continual switching between modes of operation
  - If switching modes has a cost, it acts like a strike price

- For compound options, must value as system

Real Options “IN” and “ON” projects

- Those “real” because, in contrast to financial options, they concern projects, they are “ON” projects
  - E.g.: the option to open a mine (Antamina case)
  - These do not concern themselves with system design
  - Most common in literature

- Those “real” because they concern the design elements of system, they are “IN” projects
  - EX: options for expanding garage
  - These require detailed manipulation inside a system
  - Most interesting to system designers

Financial options  
Options ON projects  
Options IN projects

Real Options

These need knowledge of system
Real Options “ON” projects

- These are financial options, but on technical things
- They treat technology as a “black box”
- Example: Antamina mine (see previous discussion)
  - option to open the mine after a two-year exploration period
  - Uncertainty concerns: amount of ore and future price
  - => uncertainty in revenue and thus in value of mine
  - Option is a Financial Call Option (on Mine as asset)

- Differs from normal Financial Option because
  - Much longer period -- financial option usually < 2 years
  - Special effort needed to model future value of asset, it can't
    be projected simply from past data (as otherwise typical)

Real Options “IN” projects

- These create options by design of technical system
- They require understanding of technology
- Example: Parking Garage
  - Designers can create option for expansion of capacity by
    way they configure original structure
  - Technical skill needed to create and exercise option

- Differ from other “real” Options because
  - Special effort needed to model feasible flexibility within
    system itself (e.g.: modeling of technical system)
Drivers of Option Value

- 2 Major Drivers

- Uncertainty is Principal Driver
  - The greater the uncertainty, the higher the value

- Time is second driver
  - The longer the option is available, the higher the value

Financial Options

- Focus first on financial options because
  - This is where options and valuation developed
  - Technical terms based on finance

- Financial Options
  - Are tradable assets
    (see: [http://finance.yahoo.com/q/op?s=GOOG](http://finance.yahoo.com/q/op?s=GOOG))
  - Sold through exchanges similar to stock markets
  - Are on all kinds of goods
    - Stocks, that is, shares in companies
    - Commodities (oil, meat, cotton, electricity...)
    - Foreign exchange, etc., etc.
Types of Financial Options

- In addition to basic types of options
  - Call: right to BUY asset for a set price
  - Put: right to SELL asset for a set price

- Financial options can get very complicated
  - In addition to Nested and Simultaneous
  - Exotic possibilities (“Asian”, “Bermudan”, “caput”, “collar”….)
  - see en.wikipedia.org/wiki/Exotic_option
  - Not in this course!

Standard Option Terminology

- \( S \) = fluctuating market price of “underlying asset”
- \( S^* \) = \( S \) at the moment owner of option takes advantage of right (when option is “exercised”)

- \( K \) = Strike price

- PAYOFF = owner’s net from a having the option, this is consequence we need to understand
- Let’s examine what payoff looks like…
Call Option Payoff

- Call Option gives person right to buy an asset for a predetermined “strike” price, K
- Only rational to exercise right when price of asset is greater than “strike” price: S > K
- If exercised, option owner pays price of K to get asset worth S* => Payoff = S* - K
- If unexercised, Payoff = 0
- Formally, payoff = Max of either 0 or S* - K
  \[ \text{Payoff} = \text{Max} \{0, S^* - K\} \]

Payoff Diagram for Call Option
Example of Current Call Option

- **Example: A Call Option to**
  - buy 100 shares of Google (shares of Google constitute the “underlying asset”)
  - at $590 per share (this is the “strike price”)
  - through Jan. 10, 2010

- **On Nov 18, 2009, prices were (yahoo web site)**
  - 1 share of Google = $576.50
  - option to buy 1 share = $15.40
  - NOTE: option price > immediate value of exercise = $28.90

- **Here’s what the payoff diagram looks like...**

Payoff Diagram for Call Option

- Payoff Per share ($)
- Price of Google
- Current Google Price
- Payoff of Option
- S - K
- K = $590
- Price of Google share ($)
Put Option Payoff

- Put Option gives person right to sell an asset for a predetermined "strike" price, K

- Only rational to exercise right when price of asset is LOWER than "strike" price: \( S < K \)

- If exercised, option owner GETS agreed price of K for asset worth \( S^* \) => Payoff = \( K - S^* \)

- If unexercised, Payoff = 0

- Net payoff for put = \( \text{Max}[0, K - S^*] \)

Example Financial Option

- Example: A PUT Option to
  - SELL 100 shares of Google
  - at $590 per share (the "strike" price)
  - Through Jan 10, 2010

- On Nov 15, 2008, prices were (CBOE)
  - 1 share of Google = $576.50
  - option to sell 1 share = $30.70
  - NOTE: option cost > value of immediate payoff = $-17.40
Payoff Diagram for Put Option

![Payoff Diagram](image)

Asymmetry of Option

- For Call Option, if asset price > strike price... owner then makes profit – that could be unlimited

- Owner not required to exercise option, so... Loss limited to cost of buying option ( $28.90/share in Google example)

- Value of option not symmetric
  - For owner of call option: All gain, No pain
  - Note: This applies once you have option. Usually, you pay for option, so net value of option (after purchase) may have a loss

Asymmetry is key to option value
What drives option value?

- How much should you pay for an option?
- Payoff diagrams show for a given strike price
  - Call payoff increases with asset price increases
  - Put payoff increases with asset price decreases
- Payoff does not reflect full value of option
- Why is that?
  - Owner exercises only when advantageous
  - In general, owner can wait for a higher price
  - Value is Max[ immediate exercise, waiting]

Boundaries on Price

Some logical boundaries on value of call option that can be exercised any time (American)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price ≥ 0</td>
<td>Otherwise buy option immediately</td>
</tr>
<tr>
<td>Price ≤ S</td>
<td>Option yields S - K</td>
</tr>
<tr>
<td>Price &gt; S - K</td>
<td>Or buy and exercise immediately</td>
</tr>
</tbody>
</table>

Upper Bound: Call Value Equals Asset Price
Lower Bound: Call Value Equals Payoff
Why Payoff and Value Differ

- Consider an option whose current asset price equals strike price: \( S = K \) (it is "at the money"). Immediate exercise payoff is zero.

However, if you wait:
Payoff might be higher.
Worst is zero payoff.

Value of waiting not reflected in immediate exercise, to be added.

\[ o = \text{value of option} \]

Value for All Stock Prices

- Value exceeds immediate exercise payoff.
- Asymptotically nears immediate payoff for increased \( S \).
- If no upside: value (expectations) = 0 = value (option).
Option Value Increases with Volatility

- Two "at the money" options (S=K) on different assets
  Both have immediate payoff = 0
  Asset A with greater volatility has higher P(larger net payoffs) => higher expected value

Asymmetric value favors high variation (limited losses)

Life Time of Options

- Two basic types in finance:
  - "European" options: oldest type, have fixed date for use ("exercise")
  - "American" options: you can use them any time over life – which generally has a definite end date (see Google examples)

- For DESIGN – Options are typically "American" with no end date
Impact of Time

- More time to expiration increases value of “American” options
  - Waiting increases chance of value increase
  - Longer-term contains shorter-term options + more time cannot be worse, can only be better

- Compare a 3 and 6 month American call
  - Can exercise 6 month call at same time as 3 month
  - Can wait longer with 6 month
  - Which is more valuable? Must be longer one...

- Time impact not obvious for European options
  - Could miss out on profitable opportunities

Generalized Value of American Call

- For a set strike price, value increases with
  - Stock price increases
  - Volatility
  - Time

- Increased strike price
  - Reduces likelihood of payoffs
  - Reduces call option value
Decision Analysis Example: Project R&D Risk

- Start R&D project for $100,000 (0.1M)
- $1,100,000 (1.1 M) to complete development
  - Commercial feasibility determined by initial R&D results
  - Plan to sell (license) technology to highest bidder
- Revenue estimate
  - 50% chance to sell technology for $2,000,000 (2M)
  - 50% chance to sell for $100,000 (0.1M)
- Assume constant 10% discount rate applies
- Fund project?

Traditional NPV Valuation of R&D

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Cost</td>
<td>(0.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development</td>
<td></td>
<td>(1.1)</td>
<td></td>
</tr>
<tr>
<td>License Revenues</td>
<td></td>
<td></td>
<td>0.5*2</td>
</tr>
<tr>
<td>Present Value</td>
<td>(0.1)</td>
<td>(1)</td>
<td>0.868</td>
</tr>
</tbody>
</table>
Tree for NPV Valuation of R&D

- NPV = - 232
- Project should be rejected

Flexibility Perspective of R&D

- Develop only if $2M license is expected

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<td></td>
</tr>
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<td>License Revenues</td>
<td></td>
<td>0.5*2</td>
<td>0.5*0</td>
</tr>
<tr>
<td>Present Value</td>
<td>(0.1)</td>
<td>(0.5)</td>
<td>0.826</td>
</tr>
</tbody>
</table>
Tree for Flexibility View of R&D

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

![Decision Tree](image)

Lessons from R&D Example

- **Ability to abandon project has significant value**
  - Limits downside; Continue only if advantageous

- **NPV misses option value completely**
  - Fails to consider effect of intelligent management

- **NPV distorts value when there is risk**
  - Assumes NPV with expected values = expected NPV
  - "Flaw of the Averages" see article by Savage
  - But: Consequences of scenarios have asymmetries
    - E.g., production costs often not linear with volume

- **Decision analysis has the advantage of recognizing value of flexibility**
Summary of Introduction to Options

- Options embody formal concept of flexibility
- Options are not “alternatives”
- 4 step Mantra “right, but not obligation, to act”
- “Calls” for opportunities, “puts” for risks
- Asymmetric returns => source of value
- Many “real” options available to designers
- “Real” Options “ON ” and “IN” systems