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

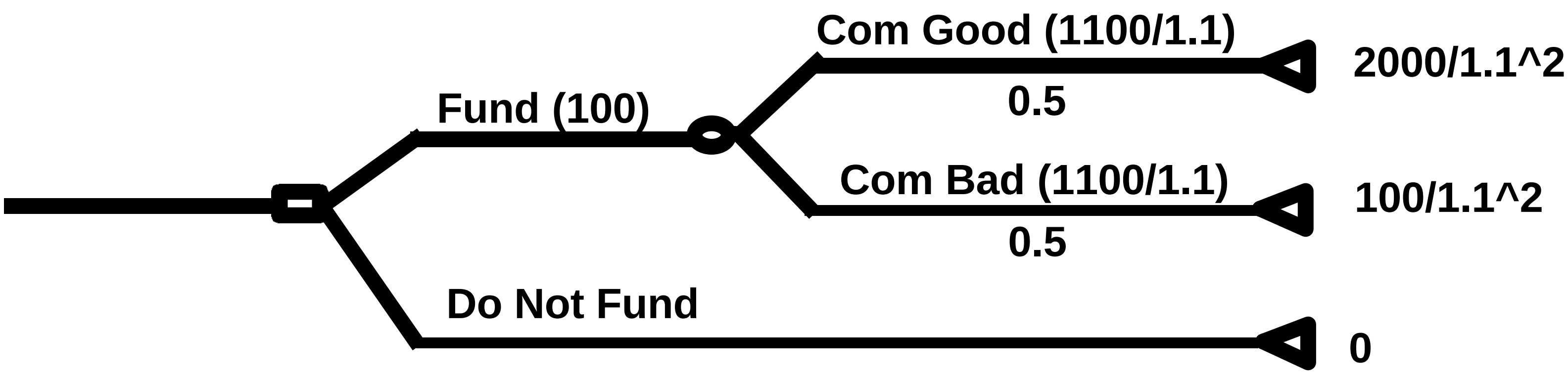
- *Fund project?*

Traditional NPV Valuation of R&D

Year	0	1	2
Initial Cost	(100)		
Develop-ment		(1100)	
License Revenues			0.5*2000 0.5*100
Present Value	(100)	(1000)	868

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

- ***NPV = -232***
- ***Project should be rejected***



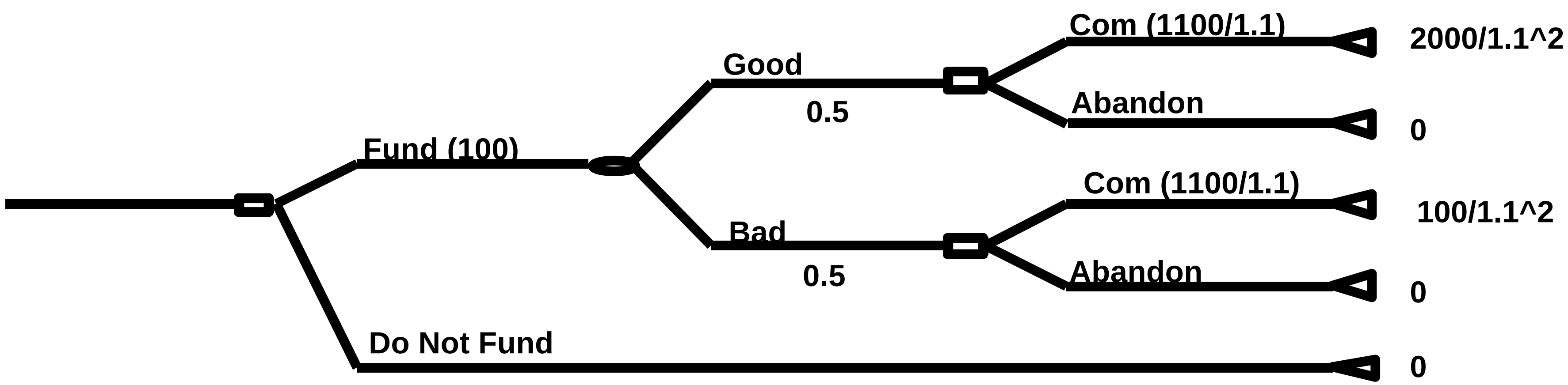
Flexibility Perspective of R&D

- Develop only if $2000 license is expected

Year	0	1	2
Initial Cost	(100)		
Develop-ment		0.5*(1100)	
License Revenues			0.5*2000 0.5* 0
Present Value	(100)	(500)	826

Flexibility Perspective on R&D (cont')

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



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 anaysis 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

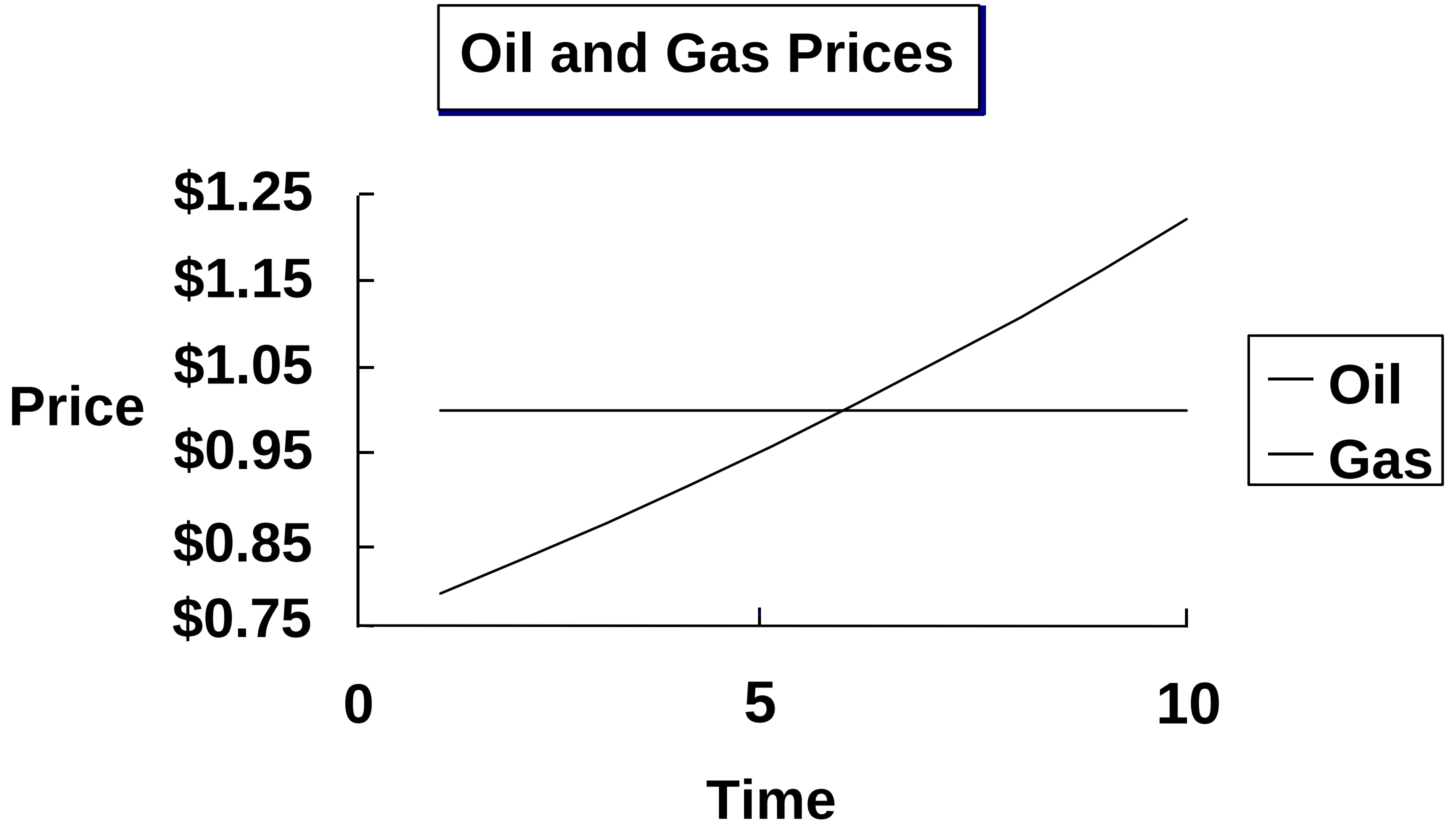
- Case of Flexible Burner on Power Plant
- Turbines for electric power generation can be powered by
  - Gas burners
  - Oil burner
  - Flexible burner (accepts either oil or gas)
- Fixed technologies (gas or oil) cost less to acquire than more complex flexible burner
- Under what conditions might flexible 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



Cash Flows Under Certainty

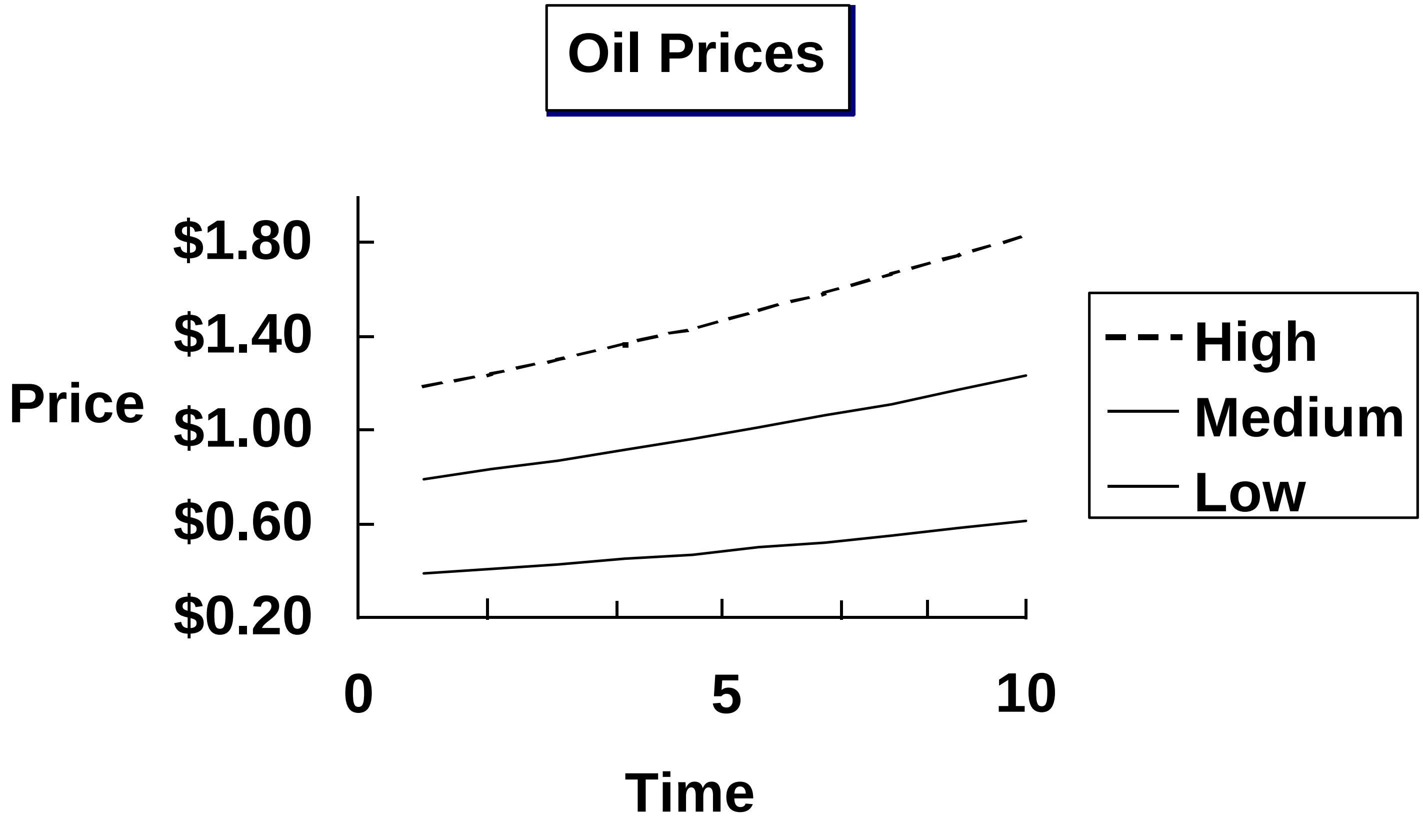
Year	0	1	2	3	4	5	6	7	8	9	10
Gas Plant											
Revenue		1.16	1.21	1.27	1.34	1.40	1.47	1.55	1.63	1.71	1.79
Cost	2.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PV Net Cash Flow	-2.50	0.15	0.17	0.20	0.23	0.25	0.27	0.28	0.29	0.30	0.30
NPV	-0.05										
Oil Plant											
Revenue		1.16	1.21	1.27	1.34	1.40	1.47	1.55	1.63	1.71	1.79
Cost	2.50	0.79	0.83	0.87	0.91	0.96	1.01	1.06	1.11	1.16	1.22
PV Net Cash Flow	-2.50	0.34	0.32	0.30	0.29	0.27	0.26	0.25	0.24	0.23	0.22
NPV	0.24										
Flexible Plant											
Revenue		1.16	1.21	1.27	1.34	1.40	1.47	1.55	1.63	1.71	1.79
Cost	3.00	0.79	0.83	0.87	0.91	0.96	1.00	1.00	1.00	1.00	1.00
PV Net Cash Flow	-3.00	0.34	0.32	0.30	0.29	0.27	0.27	0.28	0.29	0.30	0.30
NPV	-0.03										

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?



Cash Flows with Uncertainty

Year	0	1	2	3	4	5	6	7	8	9	10
Oil Plant											
Revenue		1.16	1.21	1.27	1.34	1.40	1.47	1.55	1.63	1.71	1.79
Cost (High) p=0.3	2.50	1.18	1.24	1.30	1.37	1.43	1.51	1.58	1.66	1.74	1.83
Cost (Medium) p=0.4	2.50	0.79	0.83	0.87	0.91	0.96	1.01	1.06	1.11	1.17	1.23
Cost (Low) p=0.3	2.50	0.39	0.41	0.43	0.45	0.47	0.50	0.52	0.55	0.58	0.61
Cost (Avg.)	2.50	0.79	0.83	0.87	0.91	0.96	1.00	1.05	1.11	1.16	1.22
PV Net Cash Flow	-2.50	0.34	0.32	0.30	0.29	0.28	0.26	0.25	0.24	0.23	0.22
NPV	**0.24**										
Flexible Plant											
Revenue		1.16	1.21	1.27	1.34	1.40	1.47	1.55	1.63	1.71	1.79
Cost (High) p=0.3	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cost (Medium) p=0.4	3.00	0.79	0.83	0.87	0.91	0.96	**1.00**	1.00	1.00	1.00	1.00
Cost (Low) p=0.3	3.00	0.39	0.41	0.43	0.45	0.47		0.52	0.55	0.58	0.61
Cost (Avg.)	3.00	0.73	0.75	0.78	0.80	0.83	0.85	0.86	0.86	0.87	0.88
PV Net Cash Flow	-3.00	0.39	0.38	0.37	0.37	0.36	0.35	0.36	0.36	0.36	0.35
NPV	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 to 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* is 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
- ß = 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: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