

Implications of flexibility on R&D planning



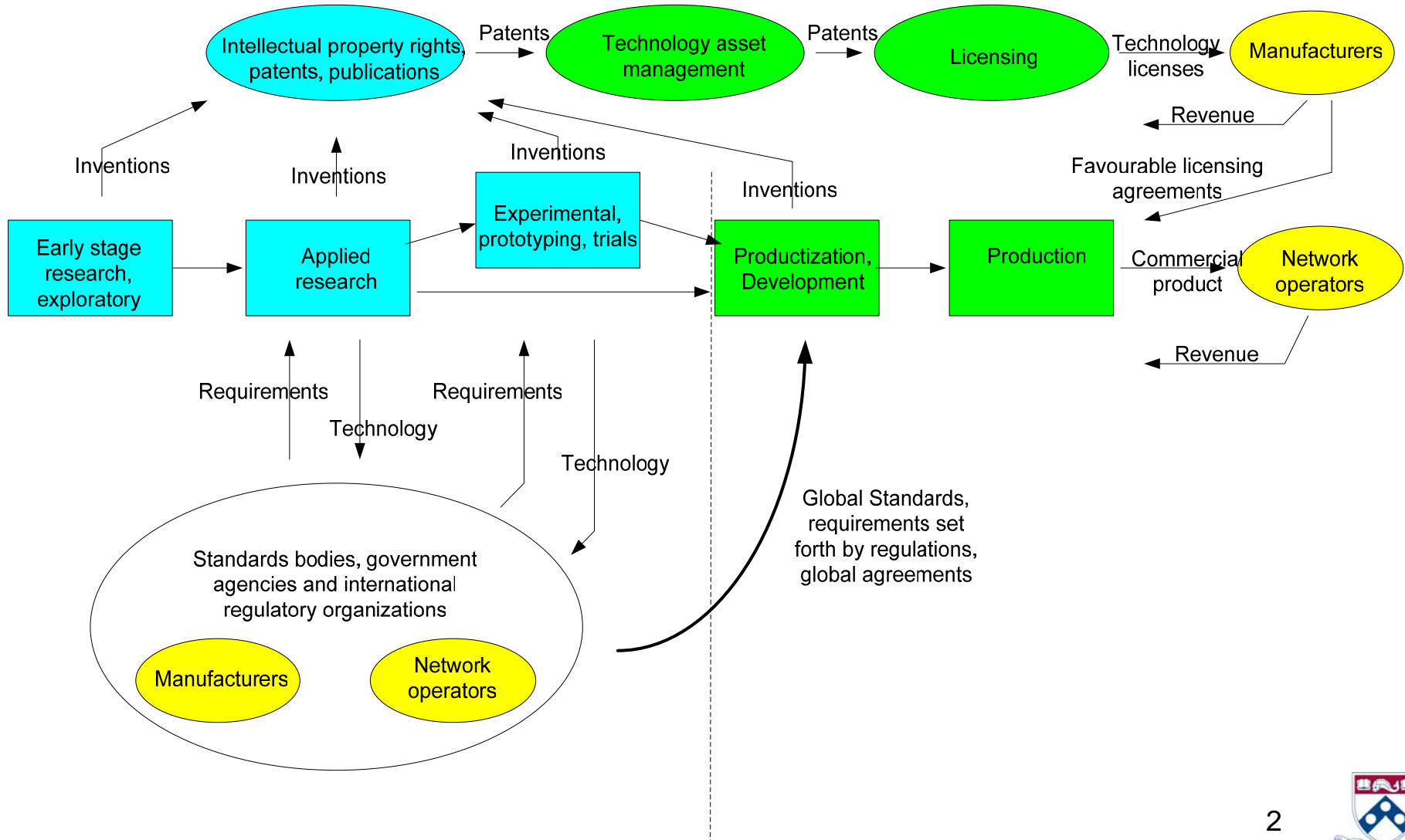
Lecture at University of
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Simplified value chain for manufacturer

Many ways to create value



Timing of resource allocation is key to R&D success

Value creation/destruction dependent on term structure

- The farther into the future the expected utility value, the greater the risk due to uncertainty
 - Technical risk
 - Market risk
 - Regulatory risk
 - Opportunity cost
 - Cost of capital
- One of the most common errors in technology management is not differentiating resource allocation along the term structure of the investment

Consider the time value of money

What's today's value of tomorrow R&D return?

- Present value of a cash flow stream = the present payment amount that is equivalent to the entire stream – sum of discounted cash flow over all periods
- Discrete or continuous compounding method:

$$PV = \sum_{t=1}^N \frac{C_t}{(1+k)^t}$$

$$PV = \sum_{t=1}^N C_t e^{-kt}$$

C_t = cash flow at time t

k = nominal interest or discount rate

N = total number of year periods



Where does k come from?

k is the firm's cost of capital

- Discount rate k is the cost of money to the firm
- **Modigliani & Miller (MM) Proposition 2 theorem** states that you can add the un-levered cost of capital to the product of the debt to equity ratio, difference between cost of equity and cost of debt times (1 minus the corporate tax rate)

$$k_e^L = k_e^U + \frac{D}{E} (k_e^U - k_d) (1 - t)$$

- The un-levered cost of equity may be directly computed using the **Capital Asset Pricing Model (CAPM)**:

$$k_e^U = r_f + (r_m - r_f) \beta^U$$

Where:

$$\beta^U = \frac{\sigma_{im}}{\sigma_m^2} = \text{Un-levered variability of return rate}$$

$$\sigma_{im} = \text{Covariance of firm } i \text{ with market portfolio}$$

$$\sigma_m^2 = \text{Variance of market portfolio}$$

$$r_m = \text{Return of market portfolio}$$

$$r_f = \text{Risk-free interest rate}$$

$$k_e^U = \text{Un-levered rate of return for equity}$$

$$k_e^L = \text{Levered required rate of return}$$

Let's look at the other way around

What is the future value of our project?

- Future value = sum of the sum of all present cash flow values times the incremental time value of money based on the discount rate
- Future value of an R&D project can be viewed as the project's "required rate of return"

$$FV = \sum_{t=1}^T PV_t (1 + k)^t$$

What does this mean to you?

Same \$30mil investment – drastically different outcomes!

r	0.14							
Year	0	1	2	3	4	5	6	7
PV initial investment	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000			
FV of Year 0 investment	\$6,000	\$6,840	\$7,798	\$8,889	\$10,134	\$11,552	\$13,170	\$15,014
FV of Year 1 investment		\$6,000	\$6,840	\$7,798	\$8,889	\$10,134	\$11,552	\$13,170
FV of Year 2 investment			\$6,000	\$6,840	\$7,798	\$8,889	\$10,134	\$11,552
FV of Year 3 investment				\$6,000	\$6,840	\$7,798	\$8,889	\$10,134
FV of Year 4 investment					\$6,000	\$6,840	\$7,798	\$8,889
Required return for zero profit	\$6,000	\$12,840	\$20,638	\$29,527	\$39,661	\$45,213	\$51,543	\$58,759

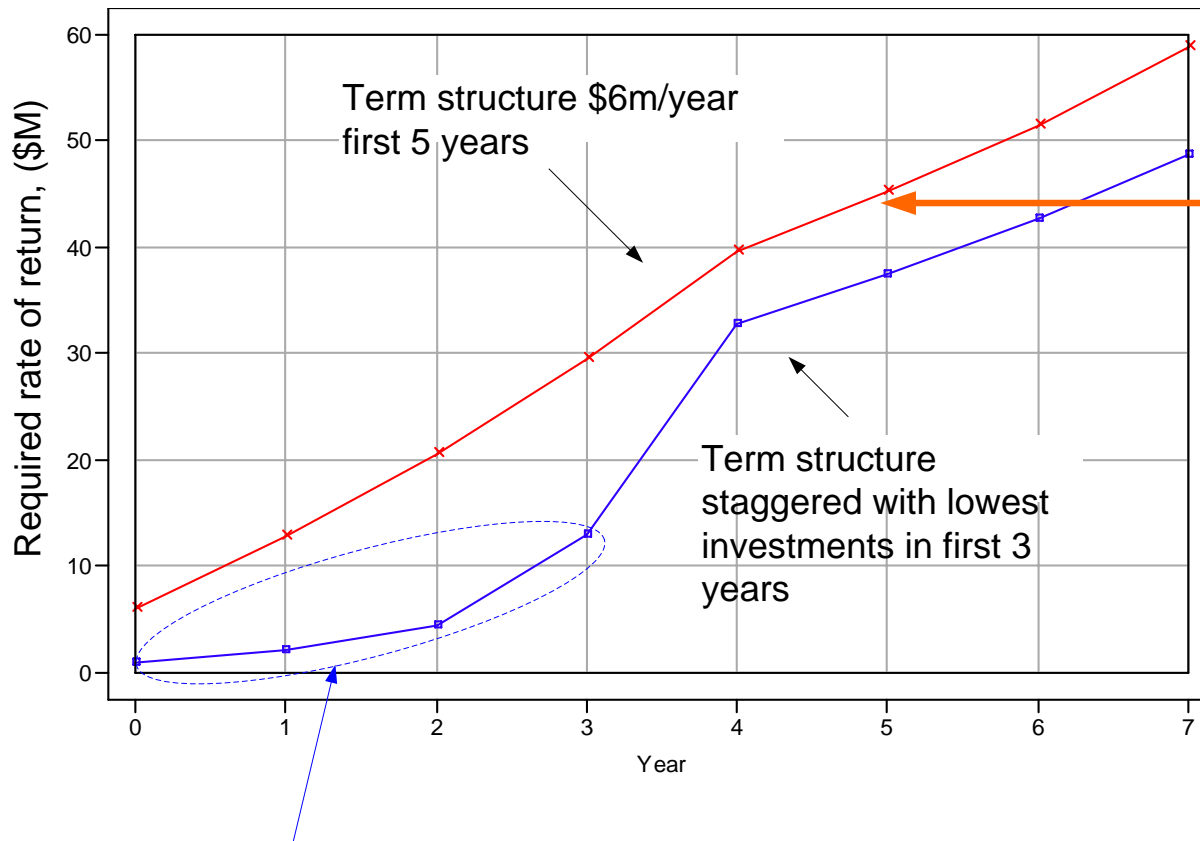
Year	0	1	2	3	4	5	6	7
PV initial investment	\$1,000	\$1,000	\$2,000	\$8,000	\$18,000			
FV of Year 0 investment	\$1,000	\$1,140	\$1,300	\$1,482	\$1,689	\$1,925	\$2,195	\$2,502
FV of Year 1 investment		\$1,000	\$1,140	\$1,300	\$1,482	\$1,689	\$1,925	\$2,195
FV of Year 2 investment			\$2,000	\$2,280	\$2,599	\$2,963	\$3,378	\$3,851
FV of Year 3 investment				\$8,000	\$9,120	\$10,397	\$11,852	\$13,512
FV of Year 4 investment					\$18,000	\$20,520	\$23,393	\$26,668
Required return for zero profit	\$1,000	\$2,140	\$4,440	\$13,061	\$32,890	\$37,494	\$42,743	\$48,728

Same investment – drastically different required rate of return



Different view of the same two projects...

Keeping initial investment low is clearly preferable



After 5 years, a return of \$45m can create two outcomes:

- 1) a loss of \$1m for R&D deal having top term structure
- 2) a profit of \$8m for R&D deal having bottom term structure

Total investment amount is the same for both deals: \$30m

Extra flexibility in earlier stages – easy to change direction or cancel if required

Term structure summary

R&D project structure

- A common error in technology management is to treat research projects like development projects
- Create a term structure to R&D projects based on risk
- Stay small especially up front – it's easier to show economic profits after it's all over with

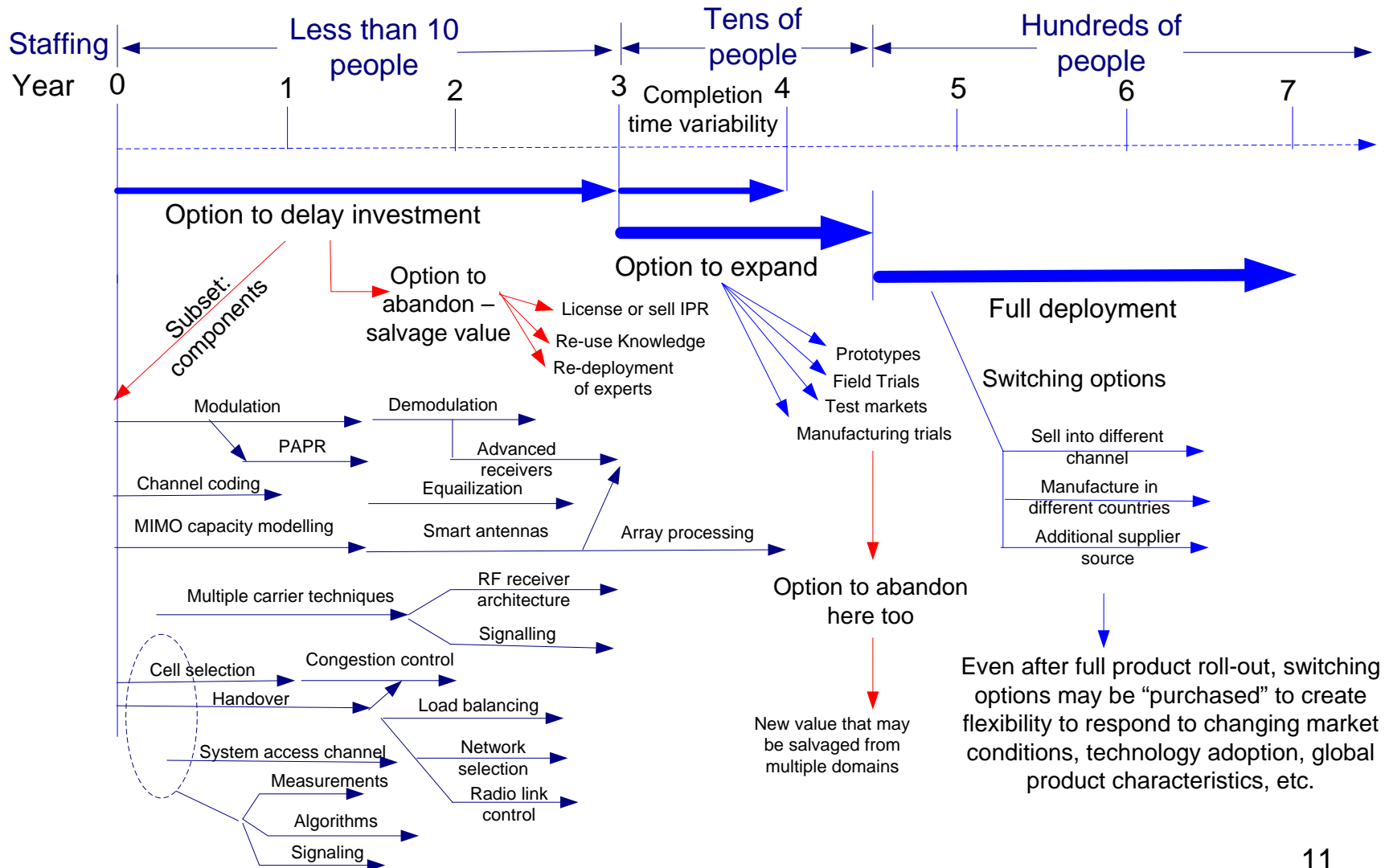
Developing option scenarios

Several kinds of flexibility

- Option to delay investment
 - Advanced survey missions
 - Applied research
 - Prove or disprove a concept
 - Valuation like a call option
- Option to expand
 - Prototyping efforts
 - Small-scale, inexpensive deployment
 - What can we learn from mini-deployment?
 - Valuation like a call option
- Option to abandon
 - Cancelled projects
 - Salvage value
 - Re-use of lessons learned and intellectual property
 - Valuation like put option
- Option to switch
 - Change in direction
 - Switch technologies, manufacturing techniques, market segments, product approaches
 - Valuation is complex – requires multinomial models

Structuring R&D options – example for wireless

How we think about flexibility is key



Valuation of flexibility – well known, fairly simple

But you need to estimate the parameters accurately...

- A reasonable means to model uncertainty is to use Geometric Brownian motion

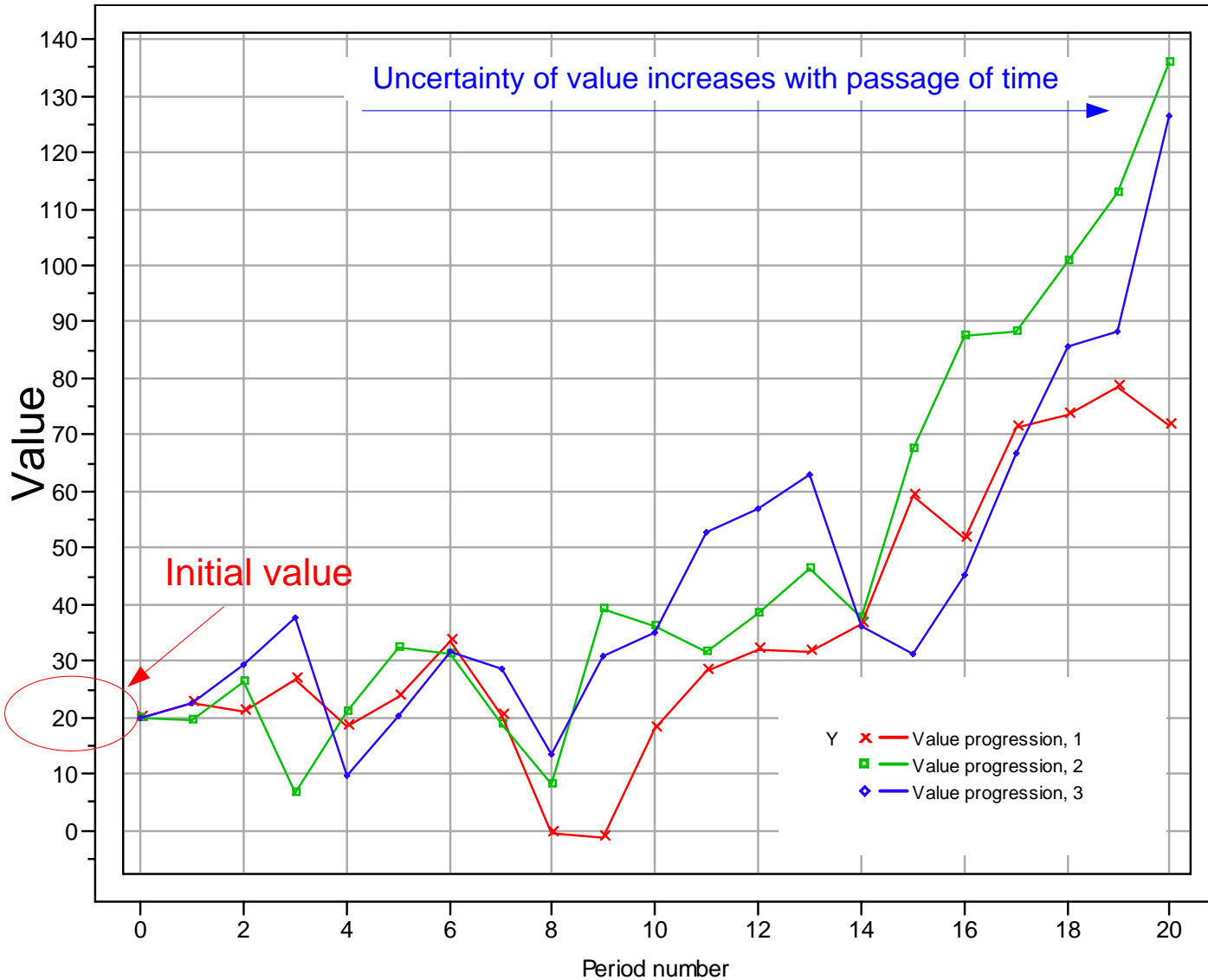
- Comprises a) drift component and b) stochastic component
- If uncertainty is restricted to single source in isolation
- Next value in time is product of current value and growth factor
- Frequently used to model price progression of stocks, futures contracts, options

$$\frac{\delta V}{V} = g(\delta t) + \sigma V \sqrt{dt}$$

- Where:
- V = value
- t = time period (days, weeks, years, etc.)
- g = normally distributed growth rate having i) \bar{g} constant expected growth and ii) standard deviation σ

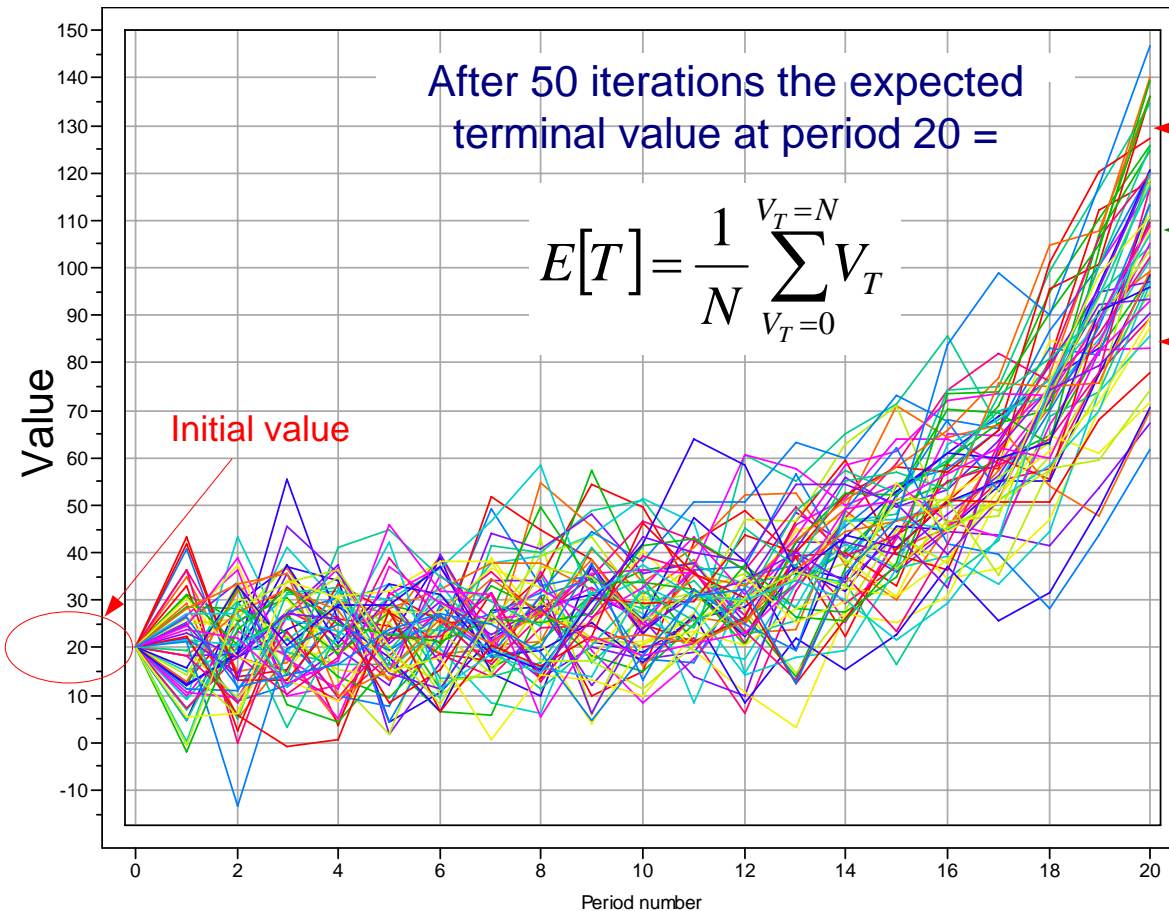
Geometric Brownian Motion

Three value progressions over time



Full Monte Carlo simulation

Requires > 1 million value progressions



$$upper(V_T) = V_T e^{\bar{g}T + 2\sigma\sqrt{T}}$$

$$E[T] = 109$$

$$lower(V_T) = V_T e^{\bar{g}T - 2\sigma\sqrt{T}}$$

Confidence intervals: we are 95% confident that the true expected value resides between upper() and lower() - that's why more iterations = better confidence of terminal value

Valuation fairly easy, estimating volatility (σ) difficult ...and volatility greatly effects value

- For exchange-traded shares or contracts, the notion of implied volatility is used
 - This technique uses optimization theory to minimize the mean squared difference between traded option values and the theoretical value of the options based on simulation or other techniques
- For R&D projects, estimating volatility is much more difficult
- If the uncertainty is expected to follow an invariant growth pattern, then the sum of the periodic growth rates is replaced with the product of the average growth and the total number of periods.
- Then, if i) the general form of uncertainty has been determined and ii) the expected trajectory data have been incorporated into the model, then project volatility may be estimated if management is able to answer the following question:

- “At the end of the entire period T , what do you expect for the value of each of the upper and lower 95% confidence intervals?”
- If this question can be reasonably answered by management, then the volatility of the growth rate may be estimated as follows simply by rearranging the equation and solving for σ :

$$\sigma = \frac{\log n \left(\frac{V_T^{Upper}}{V_0} \right) - \sum_{i=1}^N g_i}{2\sqrt{T}} = \frac{\sum_{i=1}^N g_i - \log n \left(\frac{V_T^{Lower}}{V_0} \right)}{2\sqrt{T}}$$

V_T^{Upper}, V_T^{Lower} = Projected values of terminal values at upper and lower 95% confidence intervals respectively.

V_0 = Initial value of uncertainty

g_i = Growth rate r at period i

N = Total number of periods

T = Entire period of analysis

Lessons learned in estimating σ

Not a simple recipe

- Volatility estimate has great impact on final valuation
- If underlying asset is marked to the market, e.g. oil price, volatility estimation is fairly straightforward and accurate
- If underlying asset is NOT marked to any liquid market, e.g. an R&D project, volatility estimation ranges from extremely difficult to almost impossible
- Volatility of a project is not the same as the volatility of the firm
 - Typically volatility of firm will be lower
- Try comparables
 - Past projects having similar risk characteristics and time-frame estimates
 - How do completed projects compare *a posteriori* to the volatility of the firm?
 - How does the proposed project differ from the past comparables?
 - Estimate variability relative to comparables

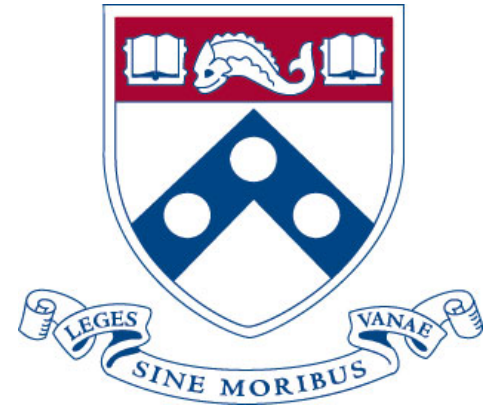
Summary

Real options

- Options = flexibility
 - To delay
 - To abandon
 - To expand
 - To switch
- The concept of real options in the context of wireless R&D is
 1. Less about valuation modelling
 2. More about understanding risk and creating flexibility
- Even though valuation is imperfect, use real options as a framework to create flexibility
- Flexibility enables you to create multiple paths to value creation rather than getting stuck in a sure path to failure

Appendix A

Option Characteristics and Valuation Notes



**The University of Pennsylvania
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Option to delay investment

Confine scope of high-risk exploration

- Fundamental to applied research
- Permits inexpensive exploration into:
 - Technical feasibility
 - Economic models and business designs
 - Manufacturing methods and alternatives
 - Market segmentation and distribution channels
 - Economic and technical substitution possibilities
 - Build/buy decisions
- Generates intellectual property and information that de-risks future development and provides quantitative basis for business decisions
- Valuation like a call option

Option to expand

Move toward implementation

- Move from applied research domain to prototyping
- Permits practical studies centering around trials:
 - Theory/practice boundary issues
 - Economic and business design small trials and pilots
 - Manufacturing trials
 - Market segmentation and distribution trials
 - Economic and technical substitution trials
 - Build/buy trials
- Generates additional intellectual property and information that de-risks future development and provides quantitative basis for business decisions
- Valuation like a call option

Option to abandon

Salvage whatever is possible

- Rational basis for project cancellation
- Salvage whatever value possible
 - Consider the sale or license of unused Intellectual Property Rights (IPR)
 - Implementation recipes
 - Any knowledge, expertise or other resources that are potentially re-usable
- Prevents over-commitment to failing project
 - Technical risks may not be surmountable
 - Market conditions e.g. too many entrants to be worthwhile
 - Economic infeasibility, e.g. hurdle rate tied to underlying commodity market values
 - Regulatory environment may have changed
 - Manufacturing may be infeasible
- Valuation like a call option

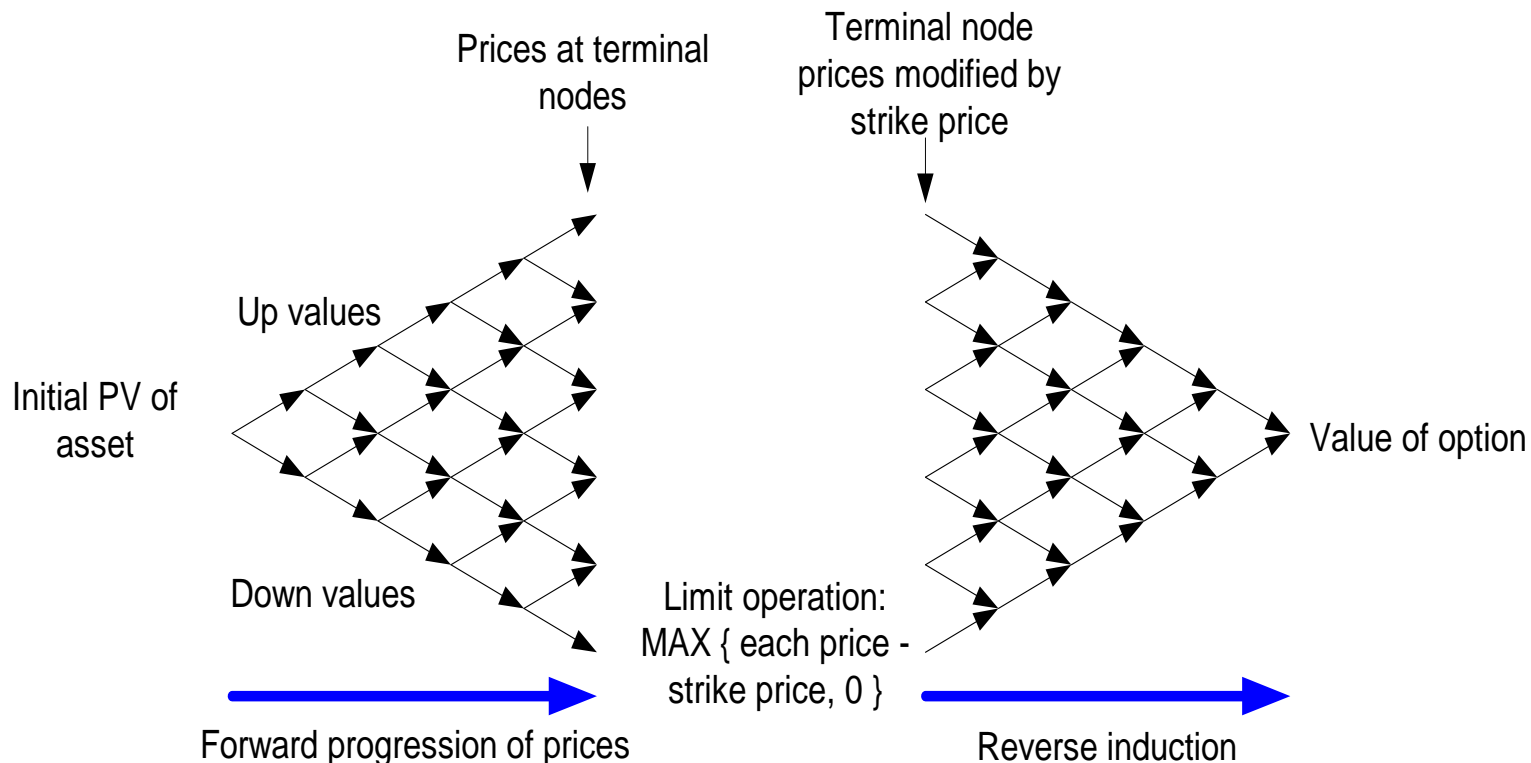
Option to switch

Evaluation of changing approaches

- Rational basis for change in project/program direction
- Evaluate switching costs before long-term commitment
 - Technology
 - Manufacturing methods
 - Product characteristics
 - Suppliers
 - Services
 - Market segments, distribution channels
 - Geographical switching and associated currency and transportation risks
- Adds flexibility to ongoing commitments – prevents commitment to an obsolete approach
- Valuation is complex and multi-dimensional

Binomial tree technique for option valuation

Robust, pretty accurate, computationally simple



Still uses Geometric Brownian motion – three basic ideas:

1. Forward progression of underlying asset
2. Limiting the terminal values of asset by strike price (implementation costs)
3. Backward induction of strike-adjusted terminal values to the present time using risk-neutral probability assumption

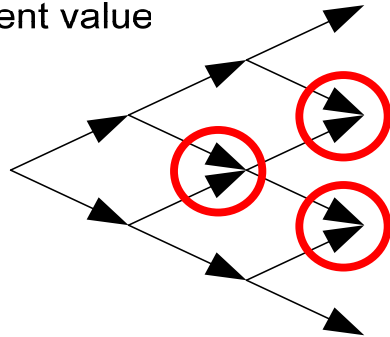
Folding a binary tree

Complexity tremendously reduced

Recombining tree: each node having two transitions are combined to an equivalent value

Processing complexity:

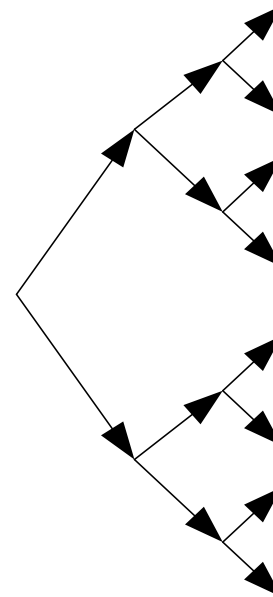
$$\sum_{i=1}^N i + 1$$



Binary tree: much higher complexity, but able to handle asymmetric up/down ratio

Processing complexity:

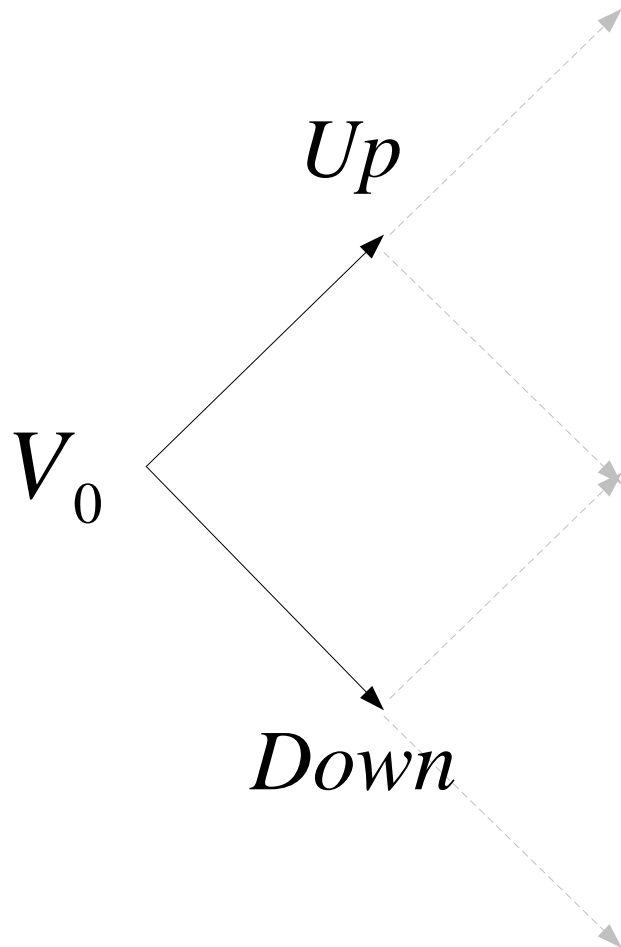
$$2^N$$



- Maybe not as versatile as full binary tree, but much simpler computationally
 - As long as up/down ratio is the same

Forward progression of prices

Assumes symmetry between up/down function



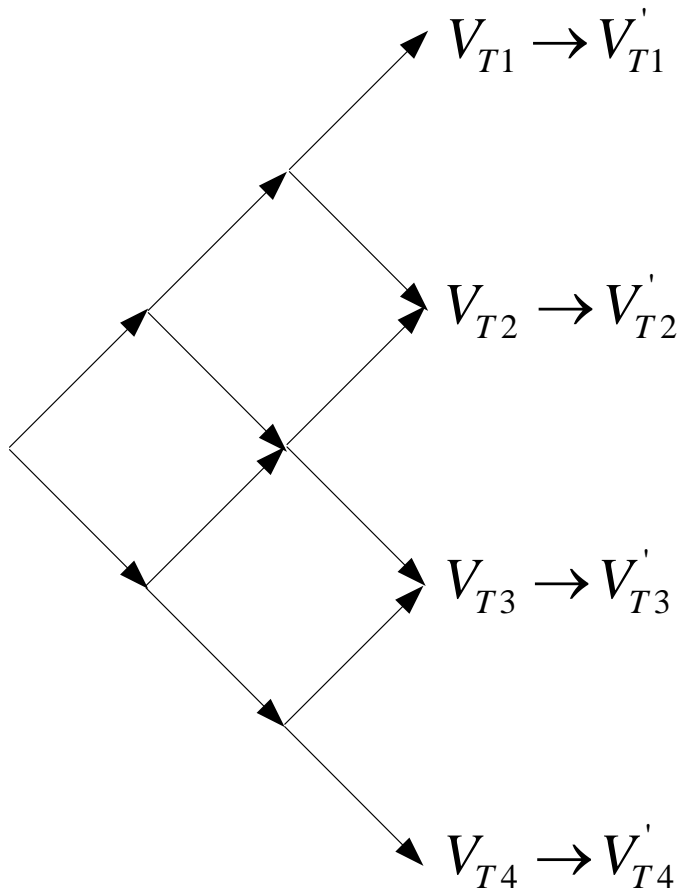
Forward value progression

$$Up = e^{\sigma\sqrt{\delta t}}$$

$$Down = e^{-\sigma\sqrt{\delta t}}$$

Terminal prices require processing

Limit terminal values by strike price



After progressing values, the terminal values are limited by the strike price, or implementation cost

For an option to delay investment (same as a call option) the terminal values are converted as follows:

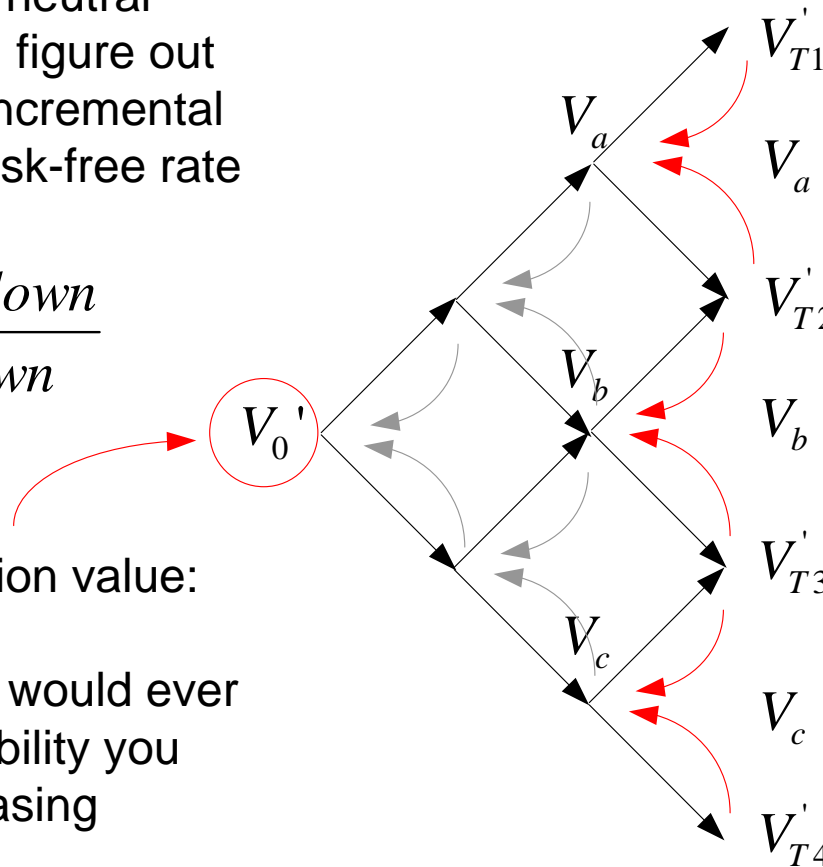
$$V'_T = \text{MAX} \{V_T - X, 0\}$$

Option value is determined by backward induction

Risk-neutral valuation equation

Principle of risk-neutral valuation equation: figure out previous value by incremental discounting by the risk-free rate

$$v = \frac{e^{-r_f \sqrt{\delta t}} - \text{down}}{\text{up} - \text{down}}$$



$$V_a = [vV_T^1 + (1-v)V_T^2] e^{-r_f \delta t}$$

$$V_b = [vV_T^2 + (1-v)V_T^3] e^{-r_f \delta t}$$

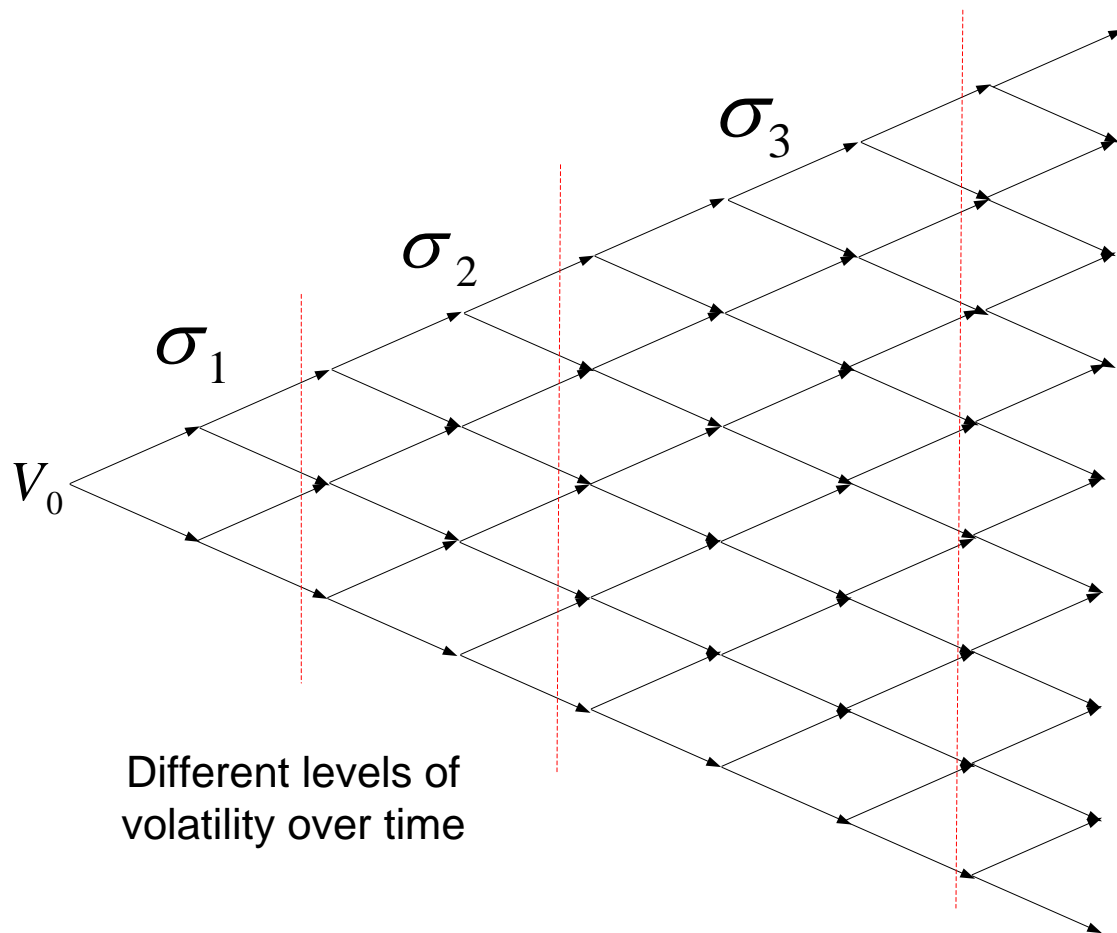
$$V_c = [vV_T^3 + (1-v)V_T^4] e^{-r_f \delta t}$$

This is your option value:

The MOST you would ever pay for the flexibility you consider purchasing

Binomial tree method is pretty robust

Can be made to handle variant volatility levels



- You can segment your valuation into intermediate values having separate volatility levels
- Multinomial trees are also possible – used for switching options and other exotic valuation

A real tree to play around with

Embedded spreadsheet – value your own options

	0	1	2	3	4	5		
						191.76		
					152			
				120.48		120.48		
			95.498		95.498			
		75.696		75.696		75.696		
Start PV (S)	60		60		60		American Call option	
		47.559		47.559		47.559	Years to expiration	3
			37.697		37.697		PV of equity (S)	60
				29.881		29.881	Stddev (sigma)	0.3
					23.685		Num periods (T)	5
						18.774	Fraction of T per leaf (delta)	0.12
							Risk-free rate (rf)	0.04
						121.76	Strike price (X)	70
					83.657			
				53.76		50.48	$u = \exp(\sigma \cdot \sqrt{\text{delta} \cdot t})$	1.262
			33.067		27.158		$d = \exp(-\sigma \cdot \sqrt{\text{delta} \cdot t})$	0.793
		19.713		14.454		5.6959	$p = \exp(\text{rf} \cdot \text{delta} \cdot t) - d / (u - d)$	0.494
Option value	11.479		7.6248		2.7468			
		3.9926		1.3247		0		
			0.6388		0			
				0		0		
					0			
						0		

Mark Pecen

- Mark Pecen serves as Vice President, Advanced Technology for Research in Motion Limited (RIM), makers of the BlackBerry wireless devices, systems and services. He is responsible for long-term corporate strategy for advanced wireless technology investments and customer collaboration on future technology deployment.
- Pecen is the founder of the RIM Wireless and Networking Advanced Research Centre and founder of RIM CTO Board. Current priorities include development of technologies for the evolution of existing and creation of Next Generation wireless systems. His labs are active in applied information theory, smart antennas, cross-layer wireless network design and protocols, mobility management, radio link control, statistical analysis and simulation and modeling of wireless systems.
- Prior to joining RIM in 2005, Pecen held the title Distinguished Innovator and Science Advisory Board Associate (SABA) member, representing the top 1% of technology leaders at Motorola, Inc. Since 1988, Pecen has invented a number of technologies adopted in global standards for the Global System for Mobile telecommunication (GSM), General Packet Radio Service (GPRS), Enhanced Data for GSM Evolution (EDGE), Universal Mobile Telecommunication System (UMTS) and various Wireless Local Area Networks (WLAN) standards.
- He serves on the boards of several technology-focused industrial, academic and governmental associations in North America and Europe and is the board chairman of Quantum Works, a consortium that funds and manages applied research into quantum computing across a network of universities in Canada.
- Pecen holds more than 70 patents in the areas of mobile communication, networking and computing, and is a graduate of the University of Pennsylvania, Wharton School of Business and the School of Engineering and Applied Sciences.

