Managing uncertainty in the innovation process

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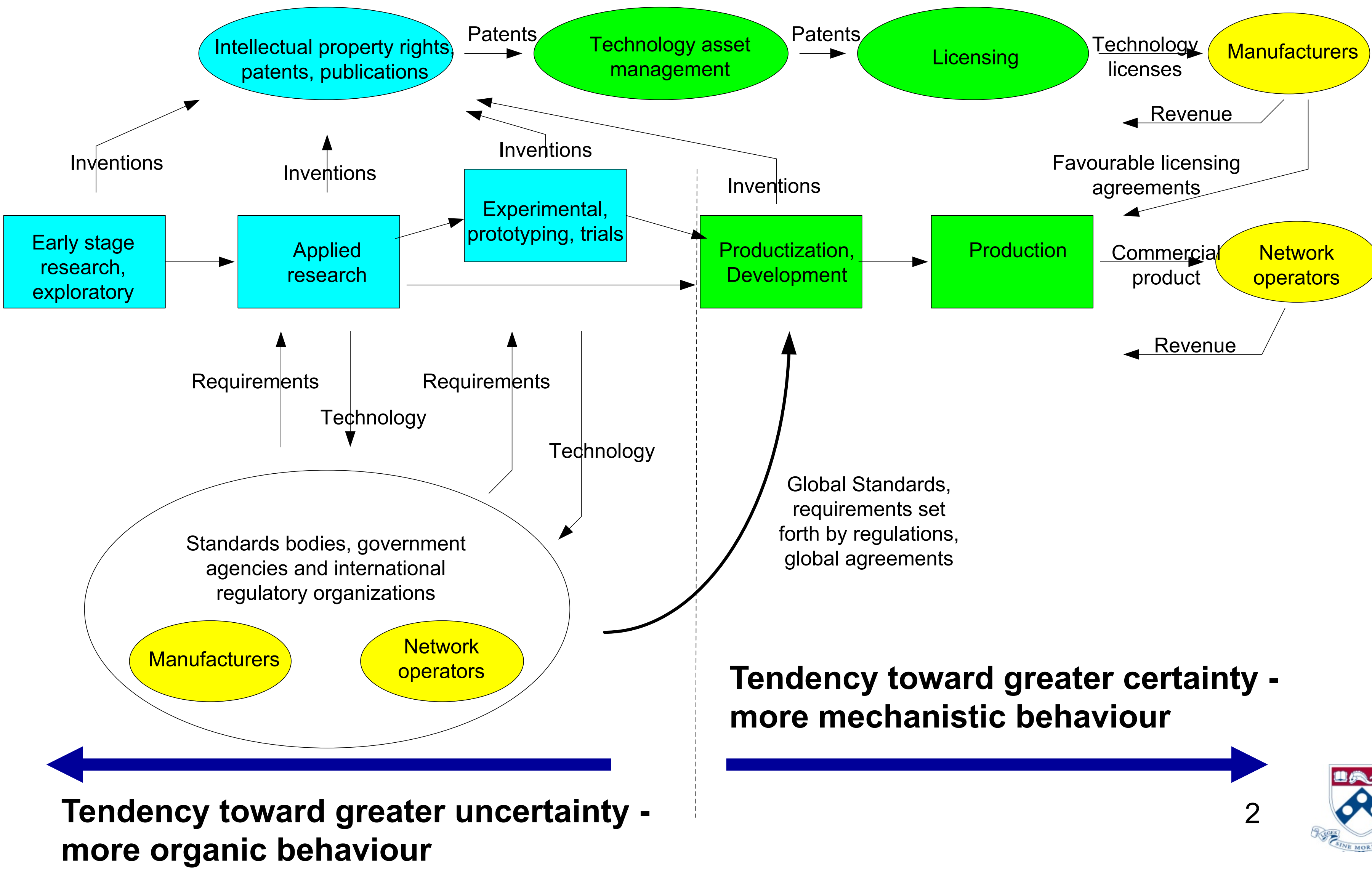
Simplified value chain for wireless manufacturer
Many ways to create value



The character of uncertainty changes over time
Not just the amount of uncertainty, but the domain

- Successful innovation depends on continuous de-risking over the lifetime of the R&D process
  - In the research phase, the questions usually revolve around
    - Is the concept achievable?
    - If so, what might the next step be?
  - In the development phase, the questions to answer include
    - How best can we commercialize the concept?
    - What do we vertically integrate? What do we purchase?
    - How do we architect a practical product and distribution channels?
  - In the production phase, yet different questions include
    - How do we create our supply chain?
    - Where are the production risks and how do we mitigate them?
    - How can we sustain our production and channel efficiency?
- As concept moves from idea to production, it becomes less of a "research project" and more of an "engineering problem"

Sources of uncertainty

There are many more, but these are the ones that keep coming up…

- Technical risk
  - Is technology commercially applicable?
  - Can it be productized in a cost-effective manner?
- Market risk
  - Does the target market segment exist today?
  - Is intended product appropriate for target market segment?
- Regulatory risk
  - Can product be legally manufactured in target geographic area?
  - Can a country's/region's regulatory policy de-rail the entire business design, e.g. cause a distribution channel to evaporate?
- Opportunity cost
  - Are there better investment opportunities available?
- Cost of capital
  - Can economic profits be achieved, i.e. potential to earn more than cost of capital within the target time-frame to productize and realize revenue?

Timing of resource allocation is key to R&D success
Value creation/destruction dependent on term structure

- Production managers tend to think in the immediate term
  - Today's problems to solve
- Development managers think slightly longer-term
  - 1 to 3 years in the wireless device business
- Research managers think farther out
  - 3 to 10+ years in wireless, 20+ years in biotech is common

- One of the most common errors in technology and innovation 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:

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

C_t = cash flow at time t
k = nominal interest or discount rate
N = total number of year periods

Critical issue: 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 find the cost of capital for a levered firm by adding the un-levered cost of capital to the product of the debt to equity ratio times the difference between cost of equity and cost of debt times 1 minus the corporate tax rate (in countries that subsidize corporate investments through tax incentives)

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

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

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

Where:

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

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

$\sigma_m^2 =$ Variance of market portfolio

$r_m =$ Return of market portfolio

$r_f =$ Risk-free interest rate

$k_e^U =$ Un-levered rate of return for equity

$k_e^L =$ Levered required rate of return

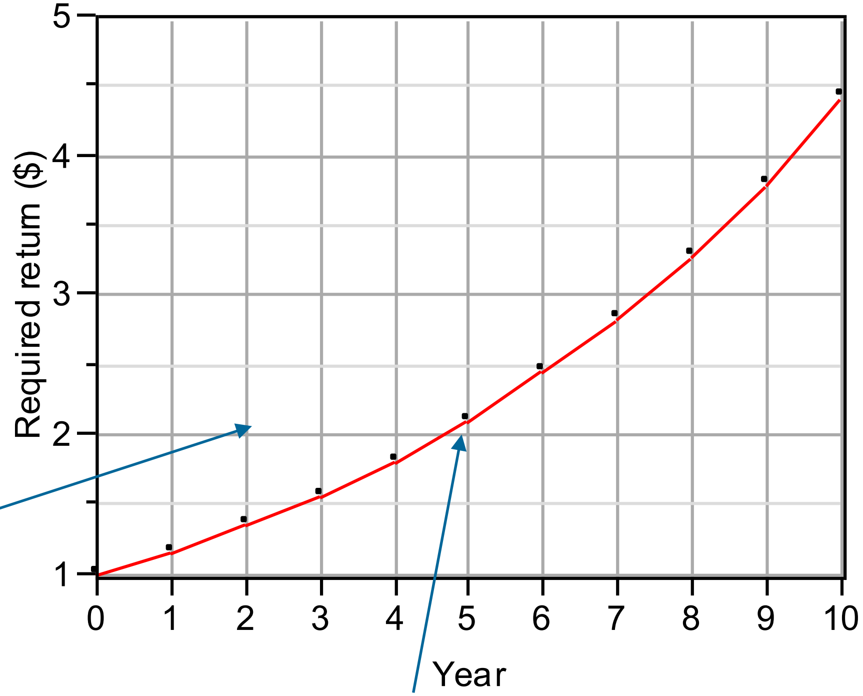
Let's look at the other way around
What is the future value of our project?

- Future value = sum of all present cash flow values times the incremental time value of money based on 1 plus the discount rate
- Future value of an R&D project can be viewed as the project's "required rate of return"

$$FV = \sum_{t=0}^{T} PV_t (1+k)^t$$

What does this mean in the real-world?
The longer the term, the more risk for your R&D project

- At 16% earning your cost of capital (k) back after 1 or 2 years is not so difficult
- The problem is that required return is exponential



Double your money in 2 years? You're a hero

Double your money in 5 years? You've lost money!

Year	0	1	2	3	4	5	6	7	8	9	10
Required return	$1.00	$1.16	$1.35	$1.56	$1.81	$2.10	$2.44	$2.83	$3.28	$3.80	$4.41

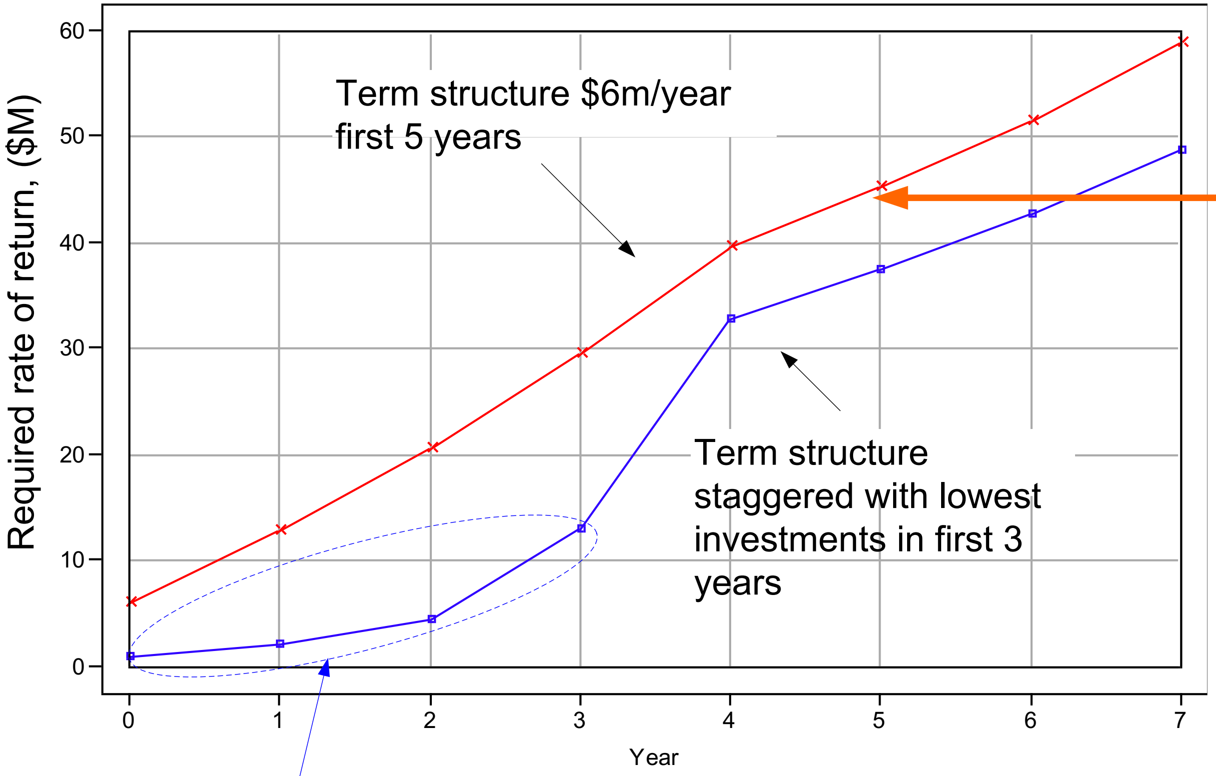
What does this mean to you?
Same $30mil investment – drastically different outcomes!

k	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



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

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

This is why we limit our exposure

And why we try to stay small – especially up-front!

- A common error in the industry is to treat research like development – too much up-front investment
  - Stay small
  - De-risk technology
  - Cancel projects once they're discovered to be infeasible
- Sometimes, research delivers new and useful technologies, but sometimes not…
- Research may fail to produce evidence to support the commercial use of a technology or method that has never been tried before
  - Research may be successful even if project fails – but only creates value if the outcome is used to guide business decisions
  - For example: Spend $0.5 mil to decide whether to invest $100 mil in future program – real options approach to R&D flexibility

Developing option scenarios

- Creating flexibility – the notion of real options

What are options?
Agreement between buyer and seller

- Options are contracts that usually have a finite expiry date – they are a concrete form of flexibility
- They give the owner the right to buy or sell an asset at a particular price at a point in the future
- They may also give the owner the right to switch from one asset to another at a particular price in the future
- Exotic financial options exist that give the owner the right to buy or sell multiple types of assets at particular prices based on one or more external conditions at a time in the future

Classes of options
Two frequently-used classes

- Call option
  - An option to purchase an underlying asset at a particular price sometime in the future
- Put option
  - An option to sell an underlying asset at a particular price sometime in the future
- Both call and put options may have restrictions on when the owner of the option can exercise, i.e. either buy or sell the underlying asset
  - Some options may be be exercised anytime before expiry date
  - Some options may only be exercised at the expiry date

How are options used?
Many ways to create flexibility

- An option to buy a particular piece of property
  - Costs much less than the purchase price of the property
  - Provides the holder the flexibility to either buy the property or not, usually within a finite period of time
  - Example: pay $20,000 for an option to buy a piece of property for $2mil in the next 2 years – if the option is not exercised, the holder loses the $20,000 but avoids carrying cost and market risk of property ownership if the property is in fact not needed in the future
- A call option to buy shares of stock
  - Allows holder to pay a small price to lock in a purchase price to reduce market risk of the stock going up in value, or for hedging
- A put option to sell shares of stock
  - Provides insurance that the owner of the stock can sell the stock at a particular price in the future
- Options may be used in many other ways – like the creation of flexibility for R&D and innovation

Developing option scenarios for R&D and innovation
Create 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

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
Reduce risk before implementation phase

- 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

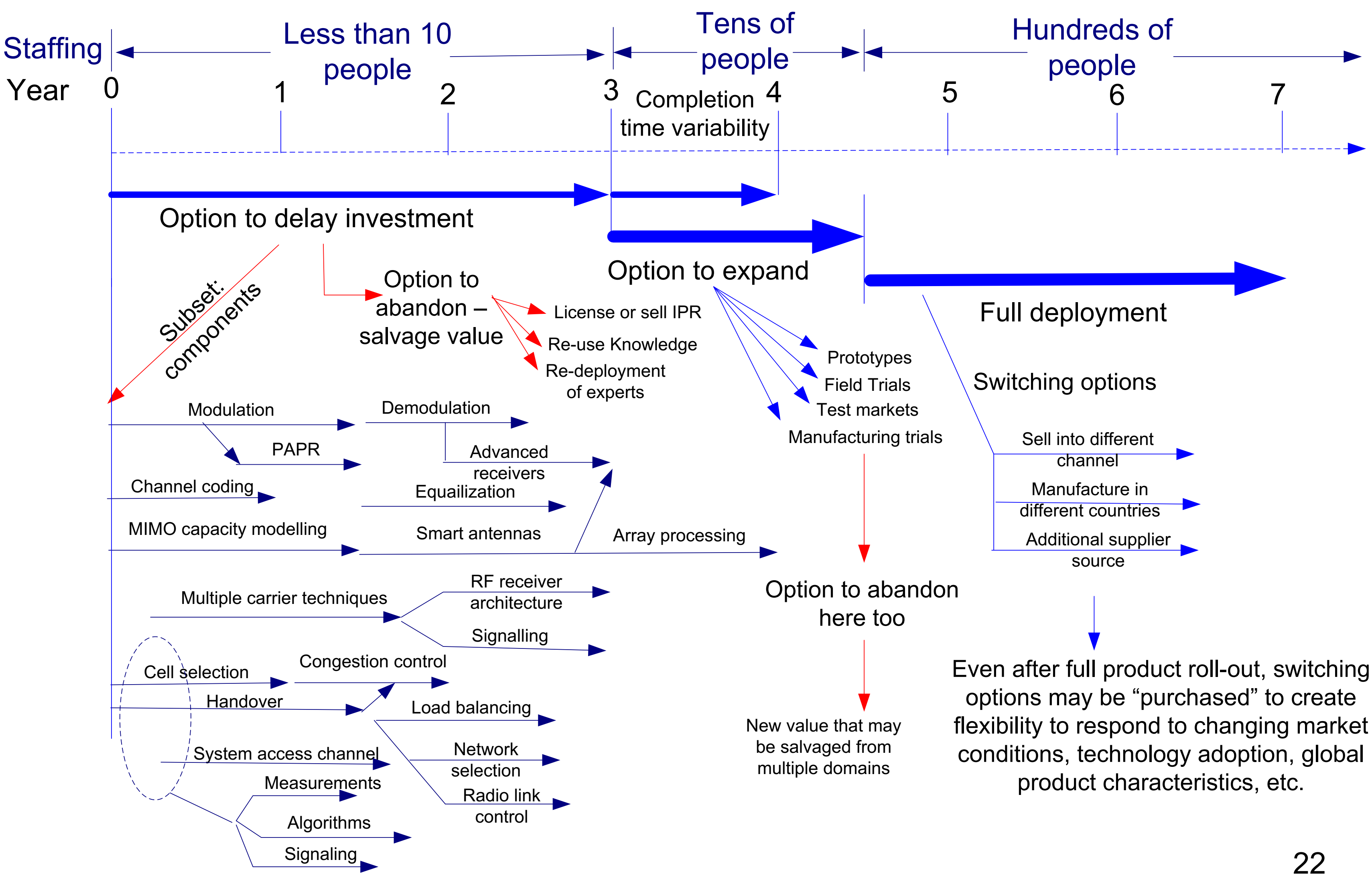
Option to abandon
Cancel project and salvage what's re-usable

- 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 put option

Option to switch
Flexibility to change 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

Structuring R&D options – example for wireless
Illustration: how we think about flexibility is key



Dialogue

- Can you think of an example in your own business where having the flexibility of options could provide an advantage?
  - What kind of options could you use and where?
  - What kind of advantage might you have and how could you quantify it?

Option valuation techniques

- Geometric Brownian motion, binomial trees, risk-neutral pricing equation, limitations to valuation methods

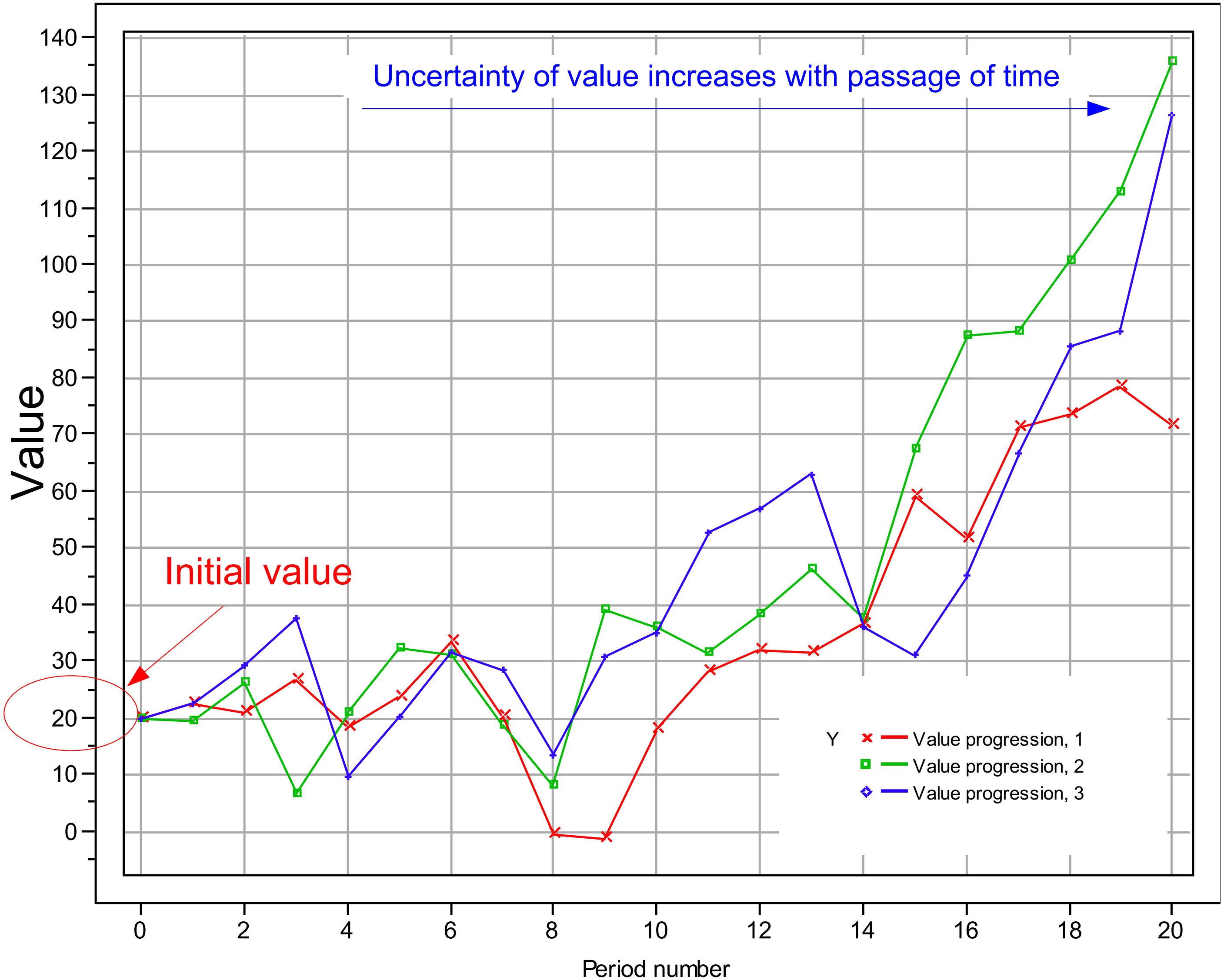
Valuation of flexibility – well known, fairly simple
As long as you can estimate certain parameters

- 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

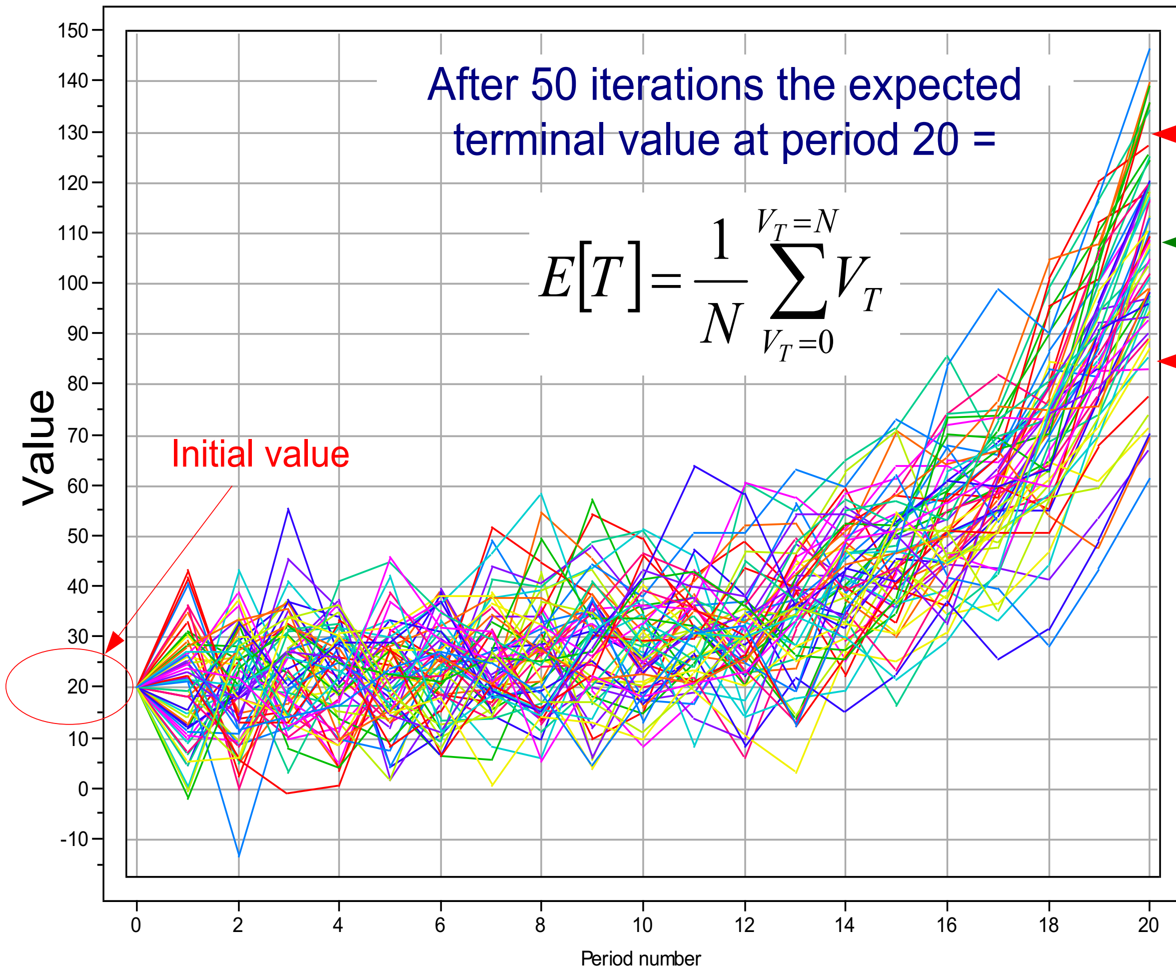
$$\frac{\delta V}{V} = g(\delta t) + \sigma V \sqrt{dt}$$

- 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

Finding the option's value
The notion of risk-neutral pricing

- *Option value is the present value of the most you would pay today to find out whether the deal (R&D investment, stock share, etc.) is worth full investment*
- Three steps
  1. Progress present value of asset forward using geometric Brownian motion
  2. Limit the terminal (ending) prices by the strike price (purchase or implementation price of the asset)
  3. Use the risk-neutral pricing equation to incrementally find the present value of the option

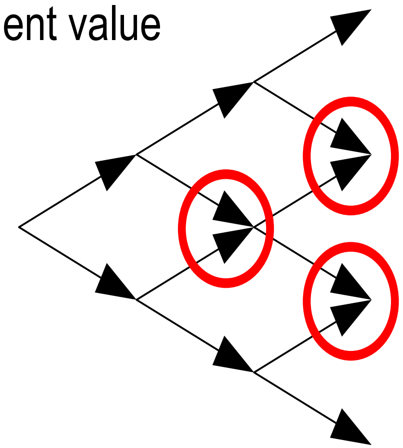
Build a binomial tree

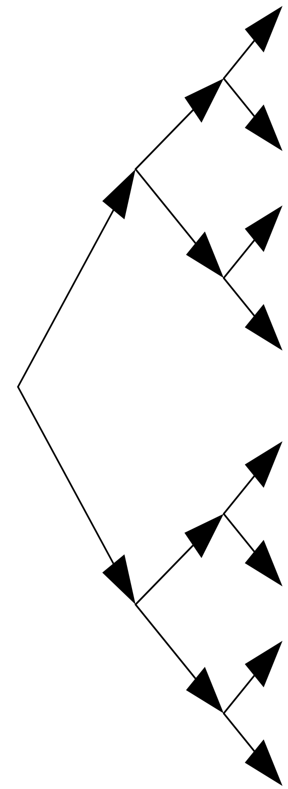
Fold the tree to reduce computational complexity

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

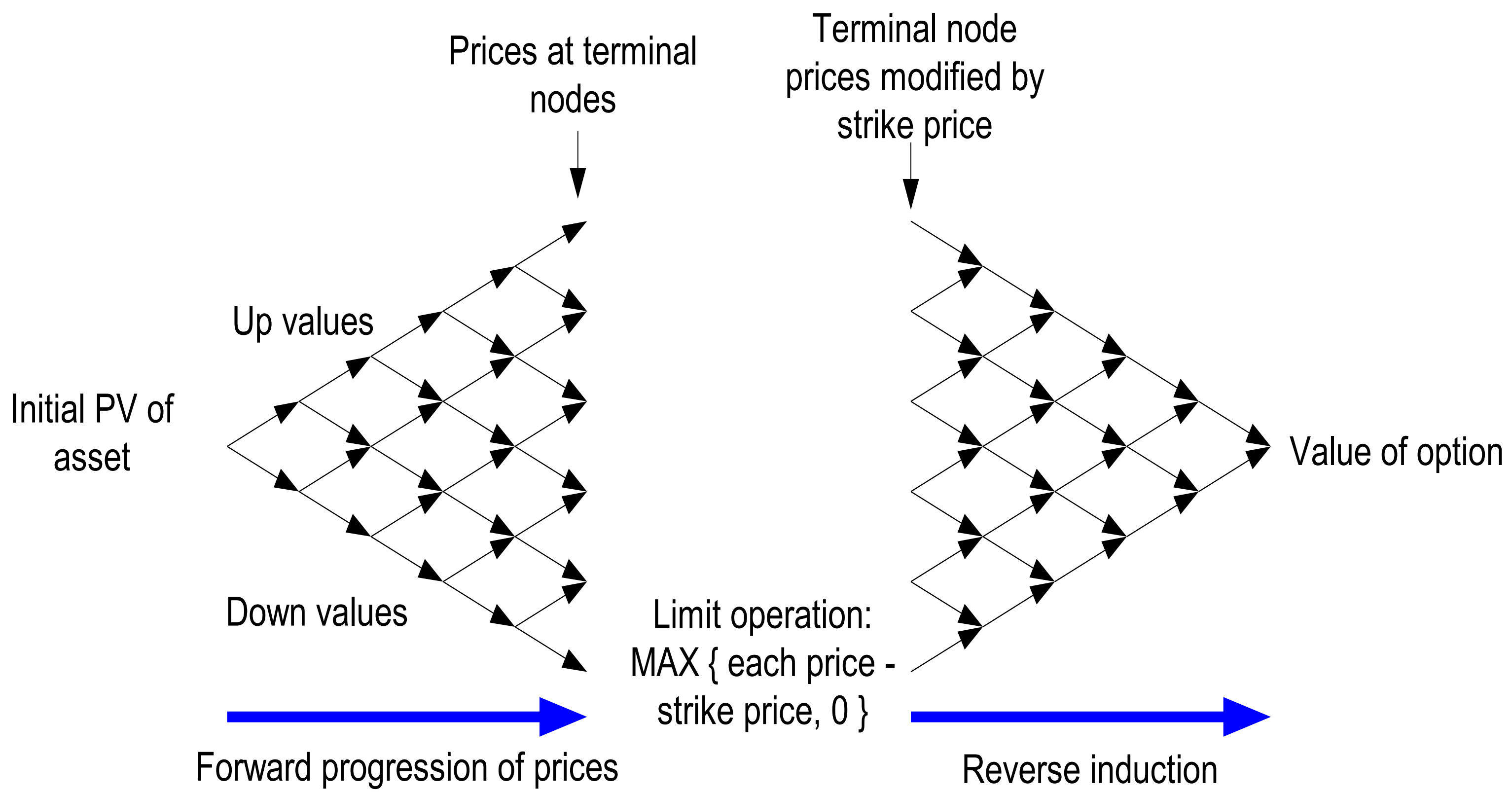
Processing complexity:

$$2^N$$

- Recombining tree not as versatile as full binary tree, but requires much fewer calculations
  - As long as up/down ratio is the same

It takes two trees to value an option

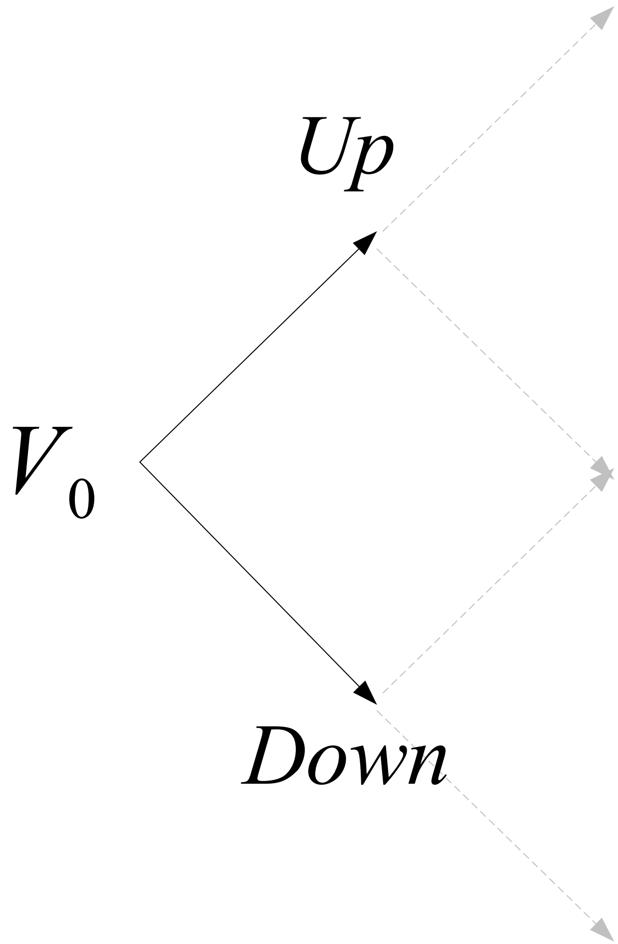
One to progress prices forward, another for backward induction of value



Three basic operations:

1. Forward progression of underlying asset using geometric Brownian motion
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

Forward progression of prices
Assumes symmetry between up/down function

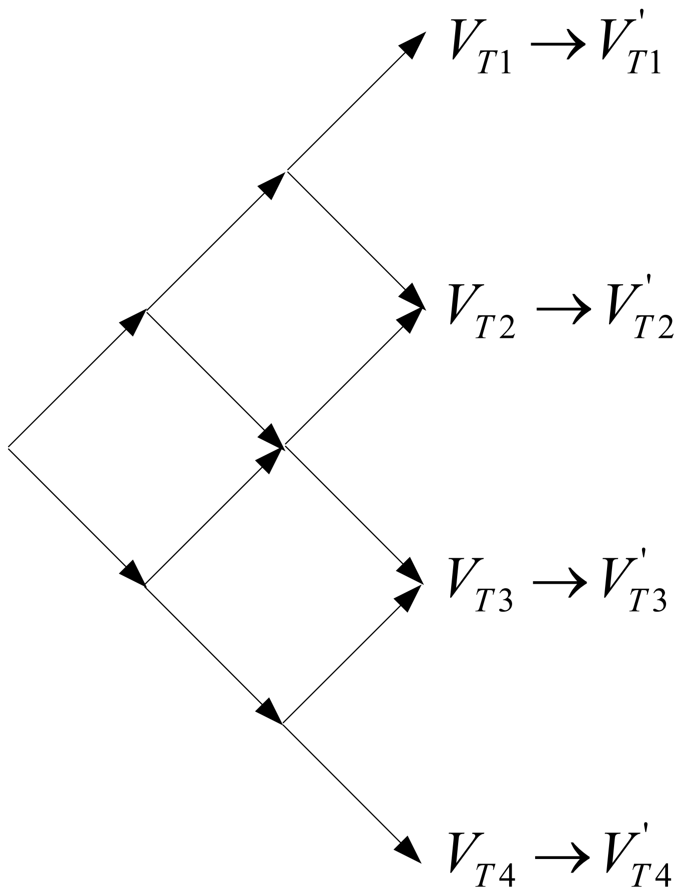


Forward value progression

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

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

Progress prices for lifetime of the option
Then limit terminal values by strike price



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

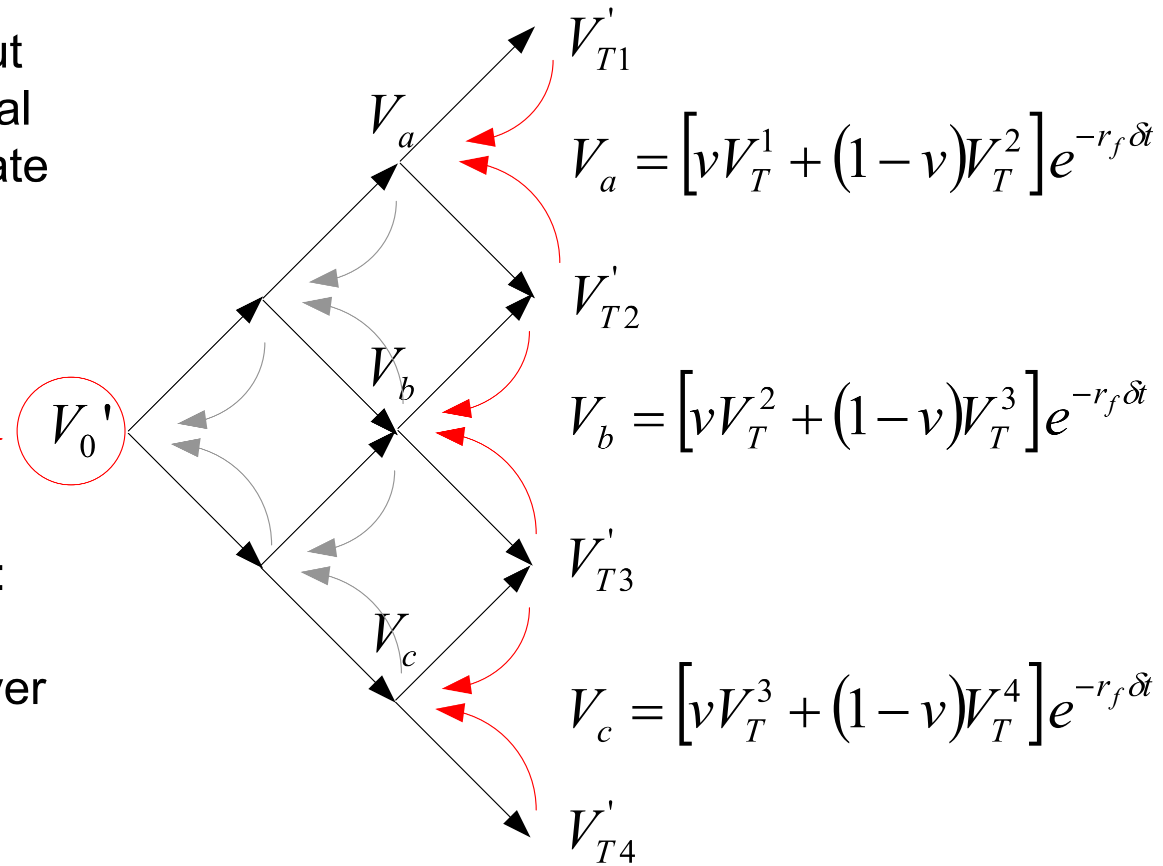
For an option to delay investment (same as a call option) the terminal values are converted as follows:

$$V_T^{'} = MAX\{V_T - X,\ 0\}$$

Then, use backward induction to find the value
Risk-neutral pricing equation

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

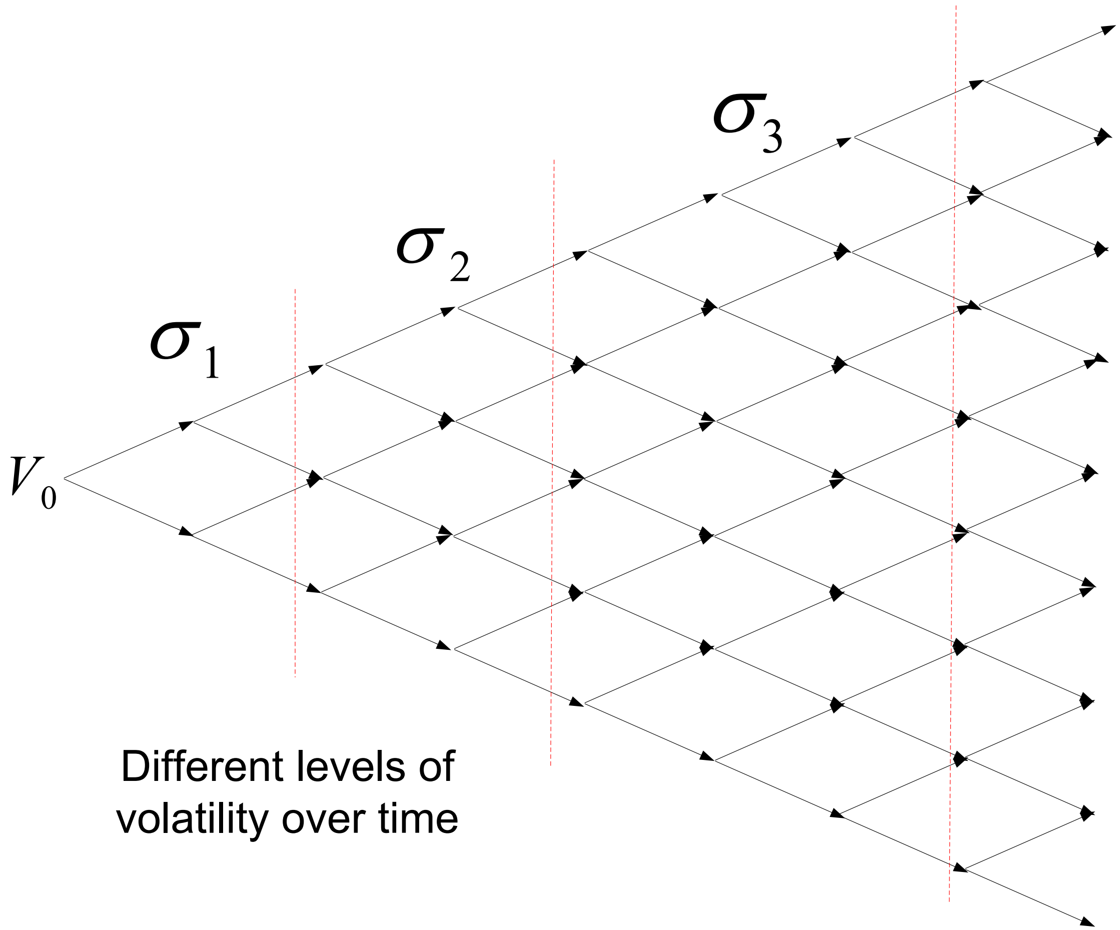
$$v = \frac{e^{-r_f \sqrt{\delta t}} - down}{up - down}$$



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



Different levels of volatility over time

- 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

Another way to value options: Black-Scholes model
Not as flexible, doesn't work over longer-term

$$C = Se^{(b-r)T}\Phi\left(\frac{\ln\left(\frac{S}{X}\right)+\left(b+\left(\frac{\sigma^2}{2}\right)T\right)}{\sigma\sqrt{T}}\right) - Xe^{-rT}\Phi\left(\frac{\ln\left(\frac{S}{X}\right)+\left(b+\left(\frac{\sigma^2}{2}\right)T\right)}{\sigma\sqrt{T}}\right)$$

Where:

C = value of call option ($)
S = present value of future cash flows = underlying stock price ($)
X = implementation cost = strike price ($)
r = risk-free interest rate (%)
T = time to expiration of option (years)
σ = volatility (%)
Φ = cumulative standard normal distribution
q = continuous representation of any dividend payout (%)
b = carrying cost (%) = r - q

Let's try some calculations

- What is flexibility worth?
- How does uncertainty affect its value?
- We'll use a mini-binomial tree and see what happens when we change parameters

A miniature binomial tree to experiment with
Embedded spreadsheet – value your own options

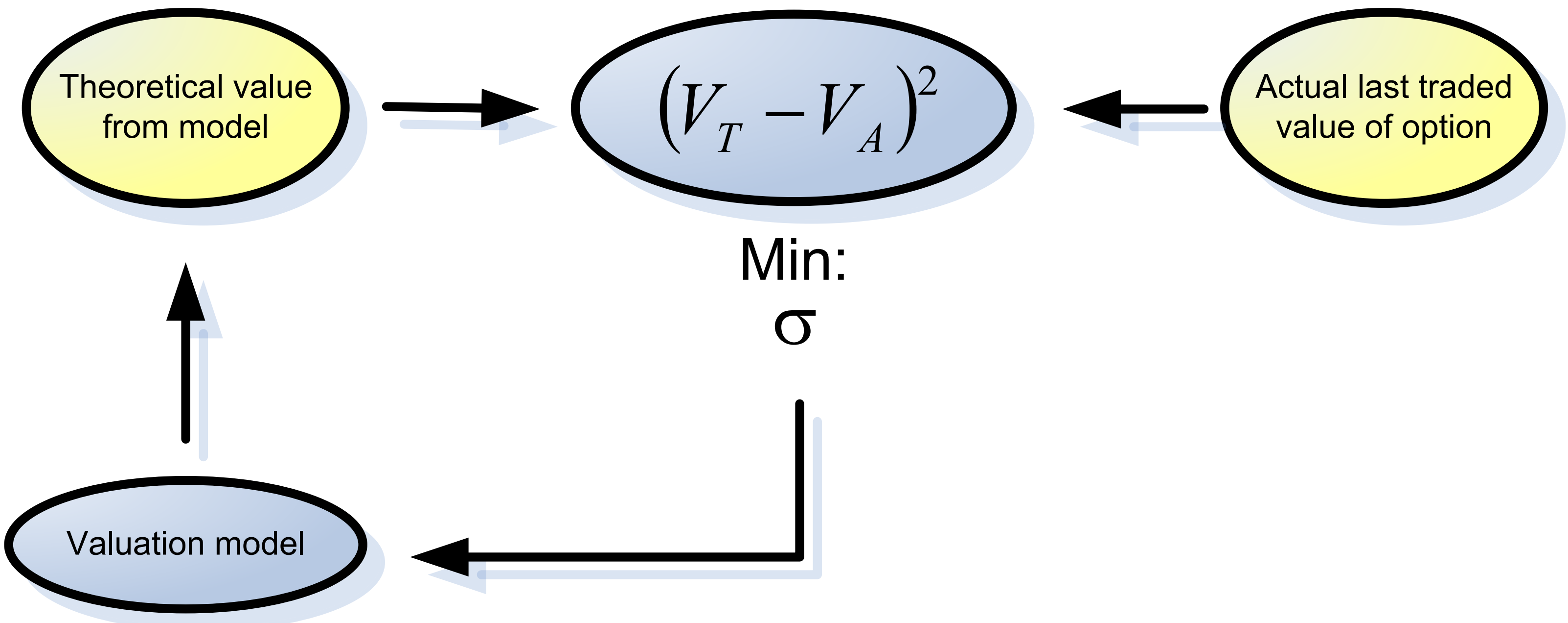
	0	**1**	**2**	**3**	**4**	**5**			
						319.6			
					253.33				
				200.8		200.8			
			159.16		159.16				
		126.16		126.16		126.16			
Start PV (S)	100		100		100			**American Call option**	
		79.265		79.265		79.265		Years to expiration	3
			62.829		62.829			PV of equity (S)	100
				49.801		49.801		Stddev (sigma)	0.3
					39.474			Num periods (T)	5
						31.289		Fraction of T per leaf (delta)	0.12
								Risk-free rate (rf)	0.05
						219.6		Strike price (X)	100
					156.28				
				106.62		100.8		u=exp(sigma*sqrt(delta t))	1.262
			70.039		62.118			d=exp(-sigma*sqrt(delta t))	0.793
		44.563		36.728		26.16		p=exp(rf*delta*t)-d/u-d	0.507
Option value	27.611		21.105		12.874				
		11.877		6.3354		0			
			3.1178		0				
				0		0			
					0				
						0			

Variability and uncertainty
The sources of value itself

- As σ increases, so does the value of flexibility
- As time to expiry (or implementation) increases, so does the value of flexibility
- If we were sure about the outcome over time, the value of the option would be zero

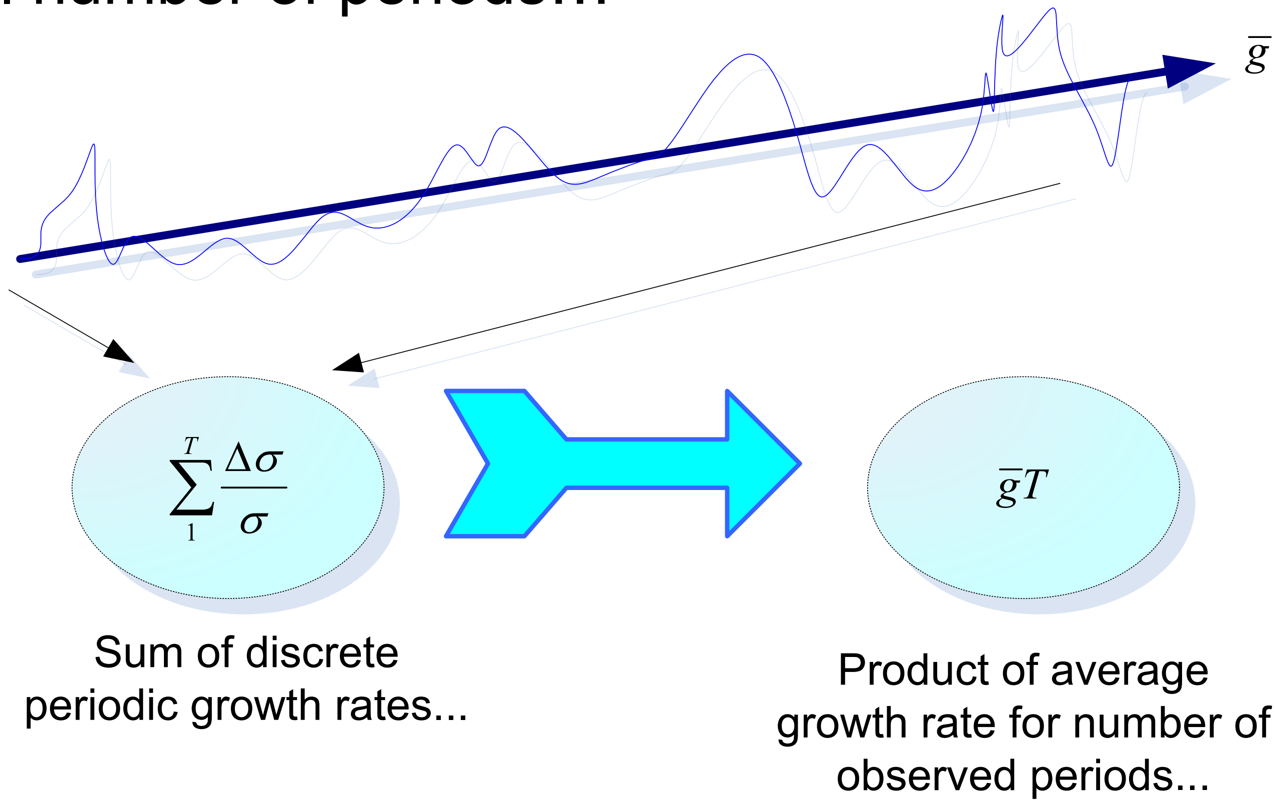
Estimating σ - large impact on value of flexibility
Not so difficult for assets with a liquid market

- For exchange-traded shares or contracts, the notion of implied volatility is used
  - Minimize the mean squared difference between traded option value and the theoretical value of the option, varying σ



Illiquid assets like R&D projects present another problem
Valuation of a real option, like an R&D project

- If the uncertainty is expected to follow an invariant growth pattern, then the sum of the periodic growth rates are replaced with the product of the average growth and the total number of periods…



The recipe requires management estimate of certainty
…and fairly restricted model definition

- Then, if a) the general form of uncertainty has been determined and b) 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?"

Just solve for σ
Convert from certainty to uncertainty

- 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

Then use your estimate of σ

- Your estimate for σ is then used to find the value of your option to delay investment or to expand using your binomial tree

But finding σ this way is not conclusive either!
Nothing is easy when you don't have a benchmark

- If underlying asset is marked to a market
  - e.g. price of oil, gold, wheat, stock shares,

  volatility estimation is fairly straightforward and accurate for a period of time

- If underlying asset is NOT marked to any liquid market, e.g. an R&D innovation project, volatility estimation ranges from difficult to almost impossible

➢ The consequence is that volatility greatly affects valuation of an option, no matter what valuation technique is used

Other lessons learned in estimating σ
No simple recipes here…

- Volatility of a project
  - Not the same as the volatility of the firm
  - Typically volatility of firm will be lower
- Try comparables – but be careful…
  - Find past projects having similar risk characteristics along with time frame structures
  - How do completed projects compare *a posteriori* to the volatility of the firm? Should be higher than firm volatility – but how much?
  - How does the proposed project differ from past comparables?
    - Problem: backward-looking – like driving forward looking in the rear-view mirror; yesterday's forces may not exist today.

Valuation of real options works better for some industries
If a very clear market segment/size is available

- Biotech/drug discovery
- Oil and gas exploration and production
- Farming
- Mining operations
- Insurance products
- Retailing operations
- Financial services

➢ The more ground-breaking and unusual the innovation level, the more difficult it is to value the option

Switching Options – evolution of a modelling approach
Example: Multiple manufacturing plants

- Assume that we have 6 manufacturing plants
- Each of the 6 make the same product
- Each of the 6 ship product to 4 geographical regions around the world
- In order to create a dynamic switching option model, the firm needs to monitor the following:
  1. Plant efficiency
  2. Plant capacity
  3. Transportation costs
  4. Import duties
  5. Currency exchange rates
  6. Demand

Development of model
Figure out: Which plants should stay open?

- To simplify the model, no attempt is made to create a revenue model, but rather to view the case in terms of a cost model having the following assumptions:
  - the same revenue in adjusted $US in all regions
  - that there are no costs to shutdown a plant.
- It is useful to view the cost of a unit of product sold to a particular region as an adjusted amount based on
  - unit cost of manufacturing plus shipping
  - import duty to each importing region (next slide)

Computing adjusted cost
Normalize value for global comparison

$$C_{adj} = C_U + C_T + (D_I C_U)$$

Where:

C_{adj} = Cost of each unit, adjusted for transportation and import duty (normalized to $US)

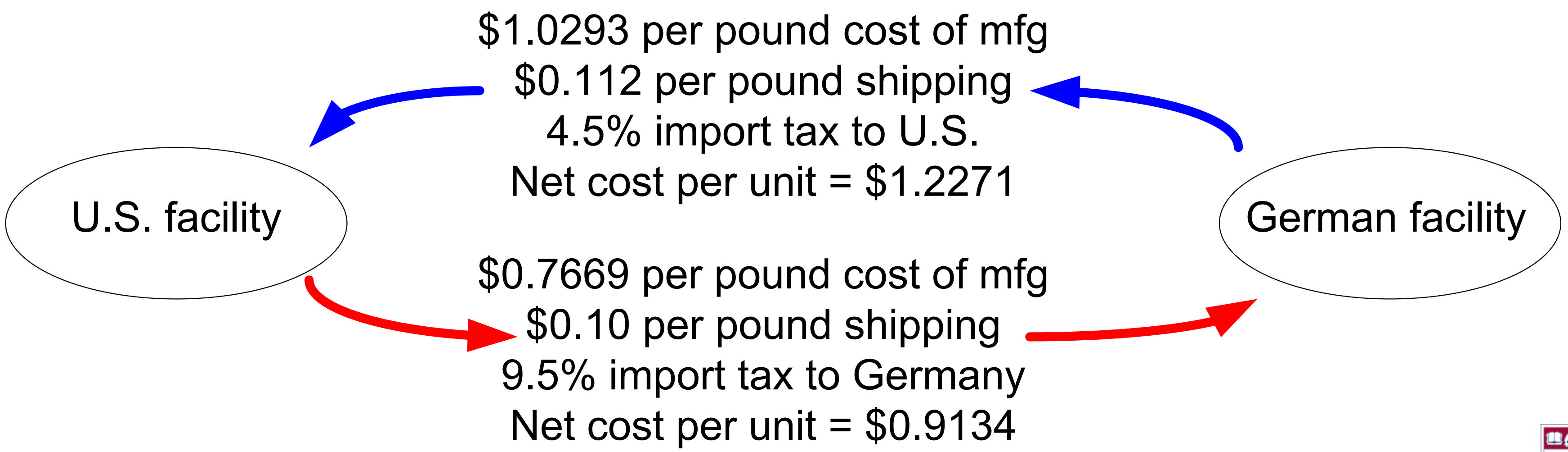
C_U = Cost to manufacture each unit ($US per pound)

C_T = Cost to transport each unit ($US per pound)

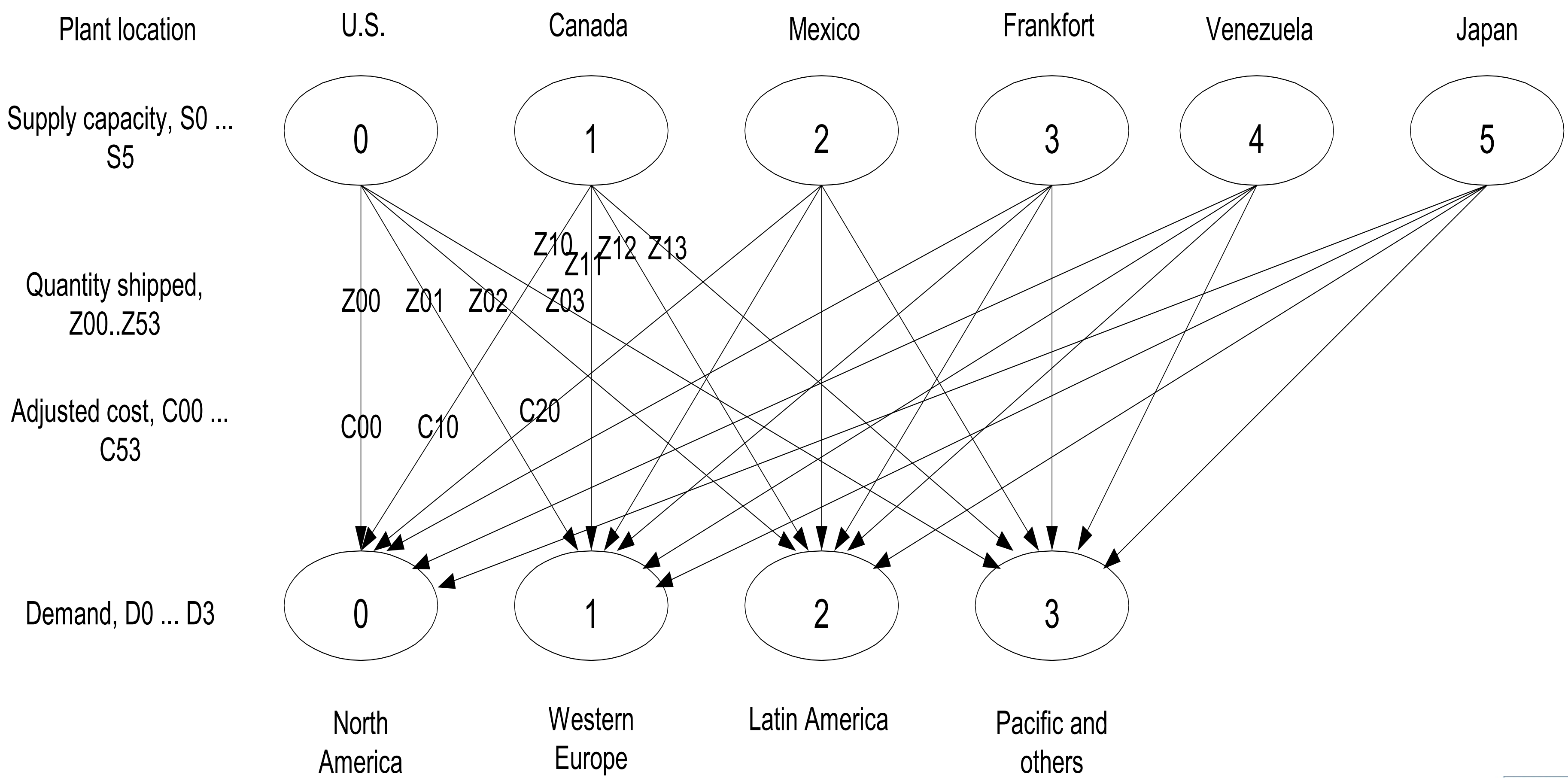
D_I = Import duty (% value of unit cost)

Then, adjust for currency exchange rate

- The criteria for switching may be asymmetric
  - For example, it costs $0.10 to ship a pound of product plus a 9.5% import duty from the U.S. facility to Germany, but $0.112 per pound to ship the same pound of product plus a 4.5% import duty from Germany to the U.S.



Basic model
Supply, plant capacity, adjusted cost, demand



Some sample parameters to create Cadj

	Mexico to U.S. (C20)	Mexico to Europe (C21)	Mexico to Mexico (C22)	Mexico to Pacific (C33)
Shipping (Ct)	$0.1100	$0.1000	$0.1000	$0.1250
Cost to manufacture (Cu)	$0.9501	$0.9501	$0.9501	$0.9501
Import duty, (Di) (%)	4.50%	9.50%	60.00%	6.00%
Cost, adjusted (Cadj)	**$1.1029**	**$1.1404**	**$1.6202**	**$1.1321**
Current exch rate (Rc)	96.5	96.5	96.5	96.5
Exch rate benchmark (Rb)	96.5	96.5	96.5	96.5
Exchange factor (F)	1	1	1	1
Exch rate adjusted cost (Cadj')	**$1.1029**	**$1.1404**	**$1.6202**	**$1.1321**

	Europe to U.S. (C30)	Europe to Europe (C31)	Europe to Mexico (C32)	Europe to Pacific (C33)
Shipping (Ct)	$0.1120	$0.0000	$0.1000	$0.1330
Cost to manufacture (Cu)	$0.7669	$0.7669	$0.7669	$0.7669
Import duty, (Di) (%)	4.50%	9.50%	60.00%	6.00%
Cost, adjusted (Cadj)	**$0.9134**	**$0.8398**	**$1.3270**	**$0.9459**
Current exch rate (Rc)	2.38	2.38	2.38	2.38
Exch rate benchmark (Rb)	2.38	2.38	2.38	2.38
Exchange factor (F)	1	1	1	1
Exch rate adjusted cost (Cadj')	**$0.9134**	**$0.8398**	**$1.3270**	**$0.9459**

Transportation and duty cost adjustment	U.S. to U.S. (C00)	U.S. to Europe (C01)	U.S. to Mexico (C02)	U.S. to Pacific (C03)
Shipping (Ct)	$0.0000	$0.1000	$0.1000	$0.1250
Cost to manufacture (Cu)	$1.0293	$1.0293	$1.0293	$1.0293
Import duty, (Di) (%)	0.00%	9.50%	60.00%	6.00%
Cost, adjusted (Cadj)	**$1.0293**	**$1.2271**	**$1.7469**	**$1.2161**
Current exch rate (Rc)	1	1	1	1
Exch rate benchmark (Rb)	1	1	1	1
Exchange factor (F)	1	1	1	1
Exch rate adjusted cost (Cadj')	**$1.0293**	**$1.2271**	**$1.7469**	**$1.2161**

	Canada to U.S. (C10)	Canada to Europe (C11)	Canada to Mexico (C12)	Canada to Pacific (C13)
Shipping (Ct)	$0.0600	$0.1150	$0.1100	$0.1300
Cost to manufacture (Cu)	$0.9735	$0.9735	$0.9735	$0.9735
Import duty, (Di) (%)	4.50%	9.50%	60.00%	6.00%
Cost, adjusted (Cadj)	**$1.0773**	**$1.1810**	**$1.6676**	**$1.1619**
Current exch rate (Rc)	1.23	1.23	1.23	1.23
Exch rate benchmark (Rb)	1.23	1.23	1.23	1.23
Exchange factor (F)	1	1	1	1
Exch rate adjusted cost (Cadj')	**$1.0773**	**$1.1810**	**$1.6676**	**$1.1619**

	Venezuela to U.S. (C40)	Venezuela to Europe (C41)	Venezuela to Mexico (C42)	Venezuela to Pacific (C43)
Shipping (Ct)	$0.1040	$0.1300	$0.0700	$0.1430
Cost to manufacture (Cu)	$1.1634	$1.1634	$1.1634	$1.1634
Import duty, (Di) (%)	4.50%	9.50%	60.00%	6.00%
Cost, adjusted (Cadj)	**$1.3198**	**$1.4039**	**$1.9314**	**$1.3762**
Current exch rate (Rc)	4.3	4.3	4.3	4.3
Exch rate benchmark (Rb)	4.3	4.3	4.3	4.3
Exchange factor (F)	1	1	1	1
Exch rate adjusted cost (Cadj')	**$1.3198**	**$1.4039**	**$1.9314**	**$1.3762**

	Japan to U.S. (C50)	Japan to Europe (C51)	Japan to Mexico (C52)	Japan to Pacific (C53)
Shipping (Ct)	$0.1300	$0.1420	$0.1400	$0.0000
Cost to manufacture (Cu)	$1.5380	$1.5380	$1.5380	$1.5380
Import duty, (Di) (%)	4.50%	9.50%	60.00%	6.00%
Cost, adjusted (Cadj)	**$1.7372**	**$1.8261**	**$2.6008**	**$1.6303**
Current exch rate (Rc)	235	235	235	235
Exch rate benchmark (Rb)	235	235	235	235
Exchange factor (F)	1	1	1	1
Exch rate adjusted cost (Cadj')	**$1.7372**	**$1.8261**	**$2.6008**	**$1.6303**

Optimizing the number of plants to remain open
Set to minimize total cost Ck over entire network

- Build a linear constraint optimization model using
  - Our cost model and switching criteria
  - Plant capacity
  - Economic demand for products in each region

$$Min : c_k = \sum_{i=0}^{5} Z_{ij} C_{ij} = \sum_{k=0}^{3} \sum_{i=0}^{5} Z_{ij} C_{ij}$$

ST:

1) The sum of all demand must be less than or equal to all available supply capacity: $\sum_{i=0}^{3} D_i \leq \sum_{i=0}^{5} S_i$

2) The sum of all quantity of product flowing into a particular demand node must be greater than or equal to the demand of that node: $\sum_{i=0}^{3} \sum_{j=0}^{5} Z_{ij} \geq D_i$ for all $D_{0...3}$

3) The sum of what each plant delivers must be less than or equal to its total capacity: $\sum_{i=0}^{3} Zij \leq S_j$

Minimize total cost Ck

OPTIMIZER SECTION

i	0	1	2	3	4	5		
	U.S.	Canada	Mexico	Frankfort	Venezuela	Japan		
Supply capacity (millions of lbs)	18.5	3.7	22	47	4.5	5		
Percent available capacity (%)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%		
Maximum capacity (mm of lbs)	18.5	3.7	22	47	4.5	5		
							Total production	
Z(src, dest) = xfer quantity	18.5	0	0	0			18.5	U.S.
Z00 through Z53	3.7	0	0	0			3.7	Canada
	0	0	0	10.7			10.7	Mexico
	9.8	20	16	1.2			47	Germany
	0	0	0	0			0	Venezuela
	0	0	0	0			0	Japan
C(src, dest) = adj cost per lb	$1.0293	$1.2271	$1.7469	$1.2161				
C00 through C53	$1.0773	$1.1810	$1.6676	$1.1619				
(Input from model above: Cadj')	$1.1029	$1.1404	$1.6202	$1.1321				
	$0.9134	$0.8398	$1.3270	$0.9459				
	$1.3198	$1.4039	$1.9314	$1.3762				
	$1.7372	$1.8261	$2.6008	$1.6303				
A(src, dest) = adj actual cost	$19.0421	$0.0000	$0.0000	$0.0000				
A00 through A53	$3.9860	$0.0000	$0.0000	$0.0000				
	$0.0000	$0.0000	$0.0000	$12.1135				
	$8.9514	$16.7951	$21.2326	$1.1351				
	$0.0000	$0.0000	$0.0000	$0.0000				
	$0.0000	$0.0000	$0.0000	$0.0000				
Total actual cost, Ck	$31.9795	$16.7951	$21.2326	$13.2486	$83.2559			
j	0	1	2	3				
	North America	Western Europe	Latin America	Pacific				
Sum of all supply (quantity)	32	20	16	11.9				
	>=	>=	>=	>=				
Actual demand (millions of lbs)	32	20	16	11.9				
Demand offset (%)	100.00%	100.00%	100.00%	100.00%				
1982 demand	32	20	16	11.9				

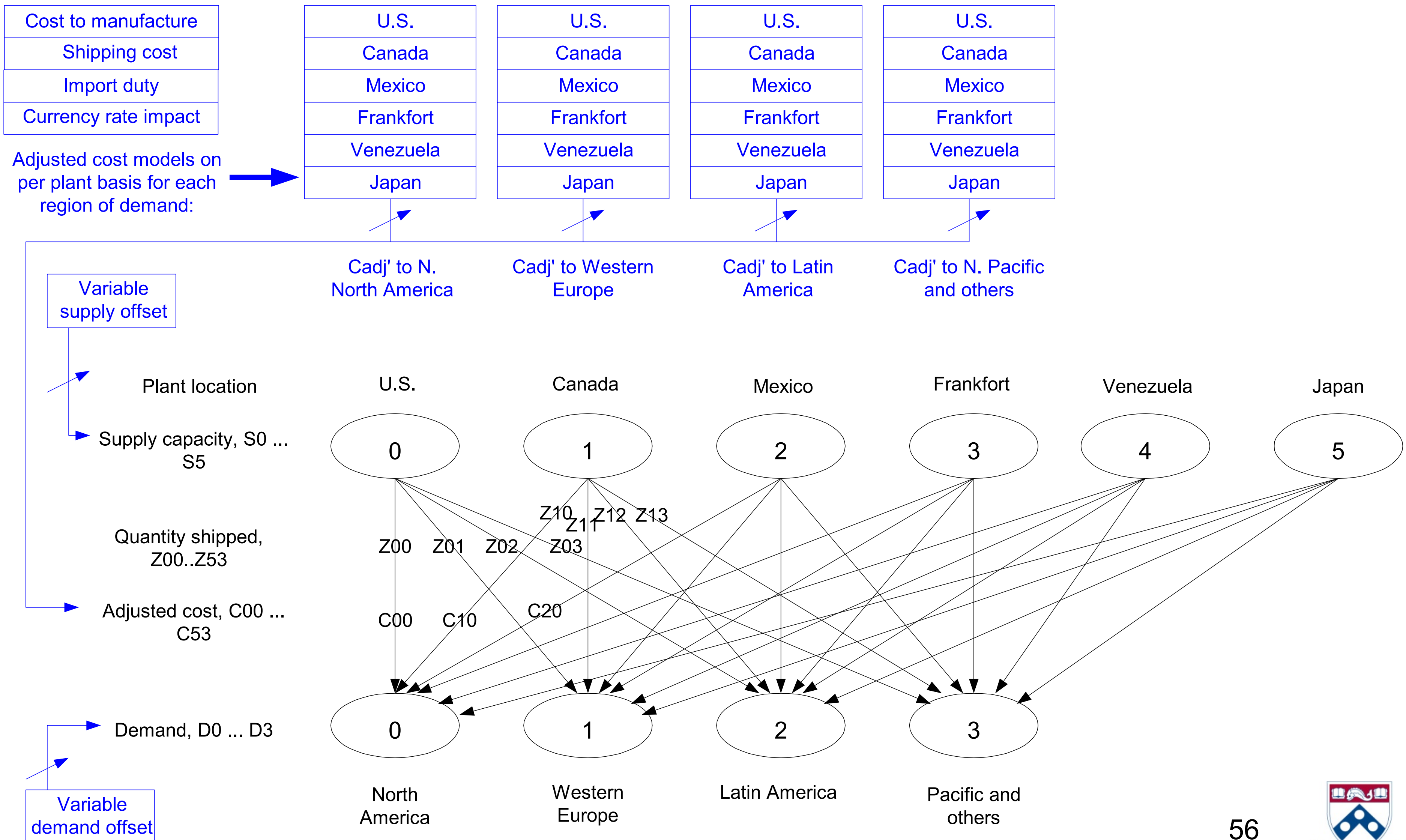
$$Min: c_k = \sum_{i=0}^{5} Z_{ij} C_{ij} = \sum_{k=0}^{3} \sum_{i=0}^{5} Z_{ij} C_{ij}$$

Minimizing total cost tells us to close two plants

- Total production for each plant:
- U.S. 18.5
- Canada 3.7
- Mexico 10.7
- Germany 47
- Venezuela 0
- Japan 0

- Our model says that minimum total cost is achieved when Venezuela and Japan are both closed
- In the real world, this would be impractical you'd have shutdown costs

A better model – keeps all plants open, adjusts supply
Allows for “what if” scenarios, parameter adjustment



Using the better model…

- Change parameters manually to model “what if” scenarios
- Collect data automatically in real time
  - Factory capacity
  - Demand forecasts
  - Currency exchange rate
  - Transportation costs
  - Import duty
- Periodically perform fine adjustments to each factory output, keeping total cost to minimum

Summary
Real options offer flexibility

- Options = flexibility, and flexibility = real value
  - To delay
  - To abandon
  - To expand
  - To switch
- The concept of real options in the context of R&D and innovation for the future is
  1. **Less** about valuation modelling
  2. **More** about understanding risk and creating flexibility

View Real Options as a decision framework

- Real option valuation is imperfect for projects that have no tie to market value of underlying asset
- But real options are a powerful framework to create flexibility – and flexibility creates value in a world of uncertainty and variability

Dialogue

- Can you think of a case where real options analysis might provide additional insight into an R&D effort, in contrast to DCF analysis?
  - Overvaluation/undervaluation tendency for DCF vs. real options approach?
  - The dangers of “risk adjusted cost of capital”?
- Can you think of an example where each of the following options may be used?
  - Switching options?
  - Option to abandon?
  - Option to delay investment?
  - Option to expand?

Mark Pecen – who am I?

MARK PECEN serves as COO of ISARA Corporation, a world leader in quantum-safe cryptographic solutions for governments and original equipment manufacturers

Chairman and founding member of the European Telecommunication Standards Institute (ETSI) Working Group for Quantum Safe Cryptography (Cyber QSC) in Sophia Antipolis, FRANCE

35+ years in ICT R&D and standardization management. Retired senior executive of BlackBerry, Ltd. and founded the Advanced Technology Research Centre - helped to develop a significant portion of BlackBerry's wireless and networking patent portfolio. Previously awarded title of Distinguished Innovator and Science Advisory Board member at Motorola for significant contributions to wireless technology and global standards

Served on over 20 governance and advisory boards for both public and private companies in Canada, Europe and the U.S. and is currently serving on Canadian university governance boards for the University of Waterloo Institute for Quantum Computing and Wilfred Laurier University Lazaridis Institute for Business and Economics

Advisor to the European Commission on ICT R&D and technology standardization and various agencies of the Canadian government

Named as inventor on more than 100 fundamental patents in wireless communication, networking and computing, and a graduate of the University of Pennsylvania, Wharton School of Business and the School of Engineering and Applied Sciences