9. Global Supply Chains and Decision Analysis

STEVENS INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY®

BIA 674 - Supply Chain Analytics

Intro to Decision Analysis

Some introductory probability concepts

- Decision Making under Uncertainty

- Simple examples of probabilities

    ⇨ prior probabilities … of external events

    ⇨ conditional probabilities … of experimental results on external events

    ⇨ unconditional probabilities of experimental results

    ⇨ Bayes' rule for calculating probabilities

$$P(A|B) \cdot P(B) = P(B|A) \cdot P(A)$$

Calculating Probabilities & Expected Returns

- Launching of a new product
- Market demand could be High or Low
  - High demand with probability 40%
  - Low demand with probability 60%
- If Demand is High, Revenues amount to $300M
- If Demand is Low, Revenues amount to $200M
- Prior probabilities: $P(H) = 0.4$, $P(L) = 0.6$
- Expected Return
  - $ER(H) \cdot P(H) + ER(L) \cdot P(L) = 300 \cdot 0.4 + 200 \cdot 0.6 = 240M$

Introduce market research

- A market research could be conducted before launching the product
- The results of the test could be:
  - Positive
  - Negative
  - Uncertain-Balanced

The market research experience

- Experience has shown that in case demand turns out to be:
  - **High** the test results had turned out to be
    - 50% of the time Positive
    - 25% of the time Negative
    - 25% of the time Uncertain
  - **Low** the test results had turned out to be
    - 20% of the time Positive
    - 55% of the time Negative
    - 25% of the time Uncertain

Calculating New Probabilities

P(positive)$=P(pos|H) \cdot P(H) + P(pos|L) \cdot P(L)$

$= 0.5 \cdot 0.4 + 0.2 \cdot 0.6 = 0.32$

P(H|pos) $= P(pos|H) \cdot P(H) / P(pos) =$

$0.5 \cdot 0.4 / 0,32 = 0.625$

P(L|pos) $= P(pos|L) \cdot P(L) / P(pos)$

$0.2 \cdot 0.6 / 0.32 = 0.375$

Calculating New Expected Returns if Test is Positive

Therefore, if test is positive,

$$ER = ER(H|pos) \cdot P(H|pos) + ER(L|pos) \cdot P(L|pos) =$$

$$= 300 \cdot 0.625 + 200 \cdot 0.375 = \$262.5M$$

Decision Trees

Easy way to represent a probabilistic sequential problem when some probabilities are known.

□	=	**decision node**
○	=	**chance node**
——	=	**arc (decision or alternative outcome)**

Build a TREE with decision and chance nodes, where along each arc we indicate the expected return (or cost) of the corresponding decision / chance, and the probability that it will occur.

Decision Trees

Attention to the correct tree representation

- ⇨ correct decision nodes
- ⇨ correct chance nodes
- ⇨ correct time sequence
- ⇨ correct estimation/validation of probabilities
- ⇨ correct estimation/validation of costs & returns for each decision

Production Capacity Selection Problem

- We are introducing a new product in an existing market
- We face 2 alternative immediate decisions:
  - We can either build a small production unit now (cost = $100 M) with the possibility to expand in 2 years (NPV cost expansion = $220 M), or
  - We can immediately build a big plant (cost = $300 M)

Production Capacity Selection Problem

- Demand for the product is uncertain. From Market studies we know that initial (first 2yrs) demand could be High (with Probability 70%) or Low (with Probability 30%)
  - If demand is initially H, it will stay H with probability 85%, or it could drop to L with probability 15%
  - If demand is initially L, it will stay so.

Expected NPV’s of alternative investments and market situations

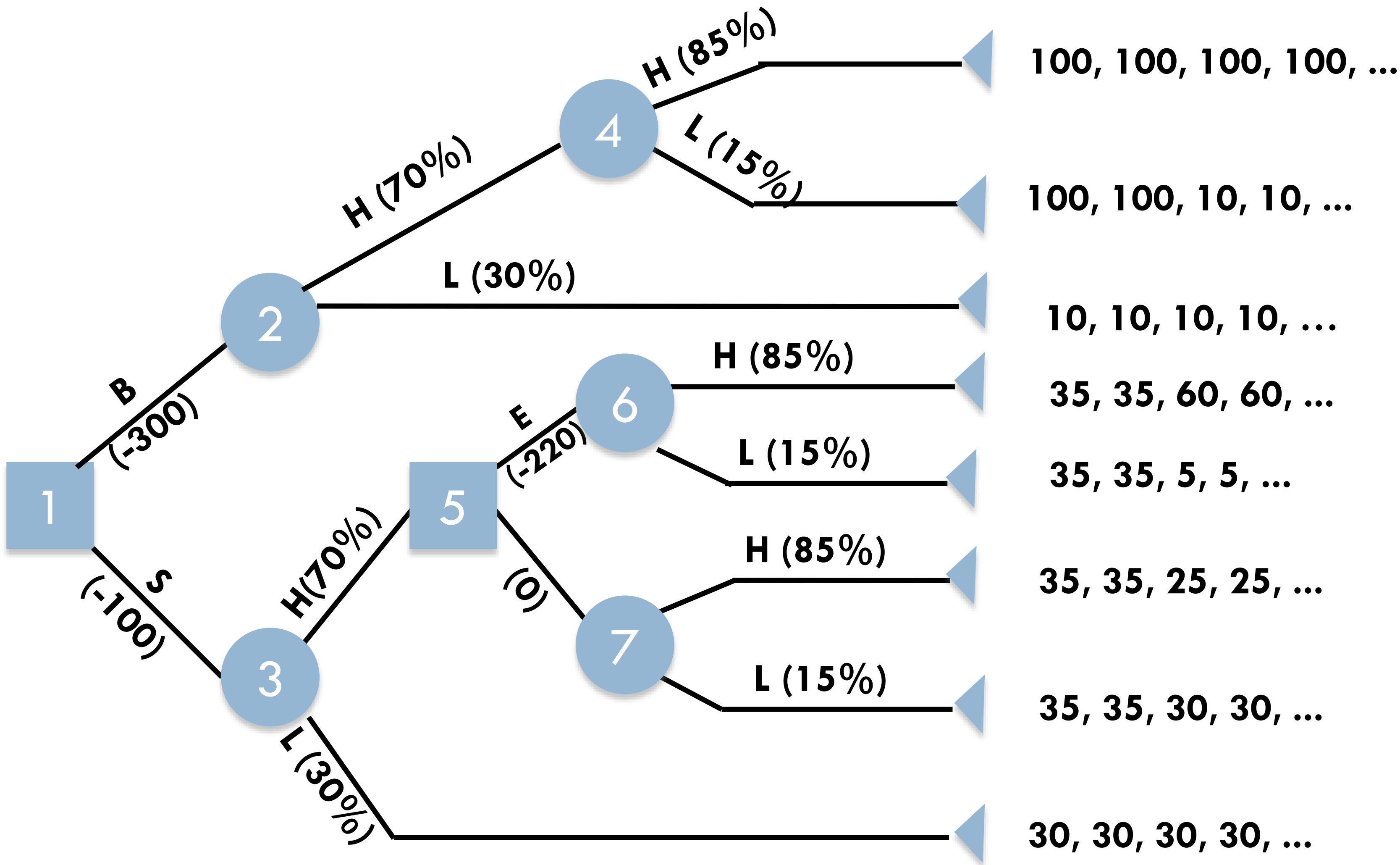
a) First 2 years:

	High Demand	Low Demand
Big Plant	100	10
Small Plant	35	30

b) Remaining 8 years:

	High Demand	Low Demand
Big Plant	100	10
Expansion	60	5
Small Plant	25	30

The Decision Tree



Using the Expected Return Criteria

ER(4) = (1000)(85%) + (280)(15%) = 892

ER(2) = (892)(70%) + (100)(30%) = 654.40

ER(Big plant) = (654.40-300) = **354.40**

ER(6) = (550)(85%) + (110)(15%) = 484

ER(7) = (270)(85%) + (310)(15%) = 276

ER(5) = max [484-220, 276] = max [264, 276] = 276

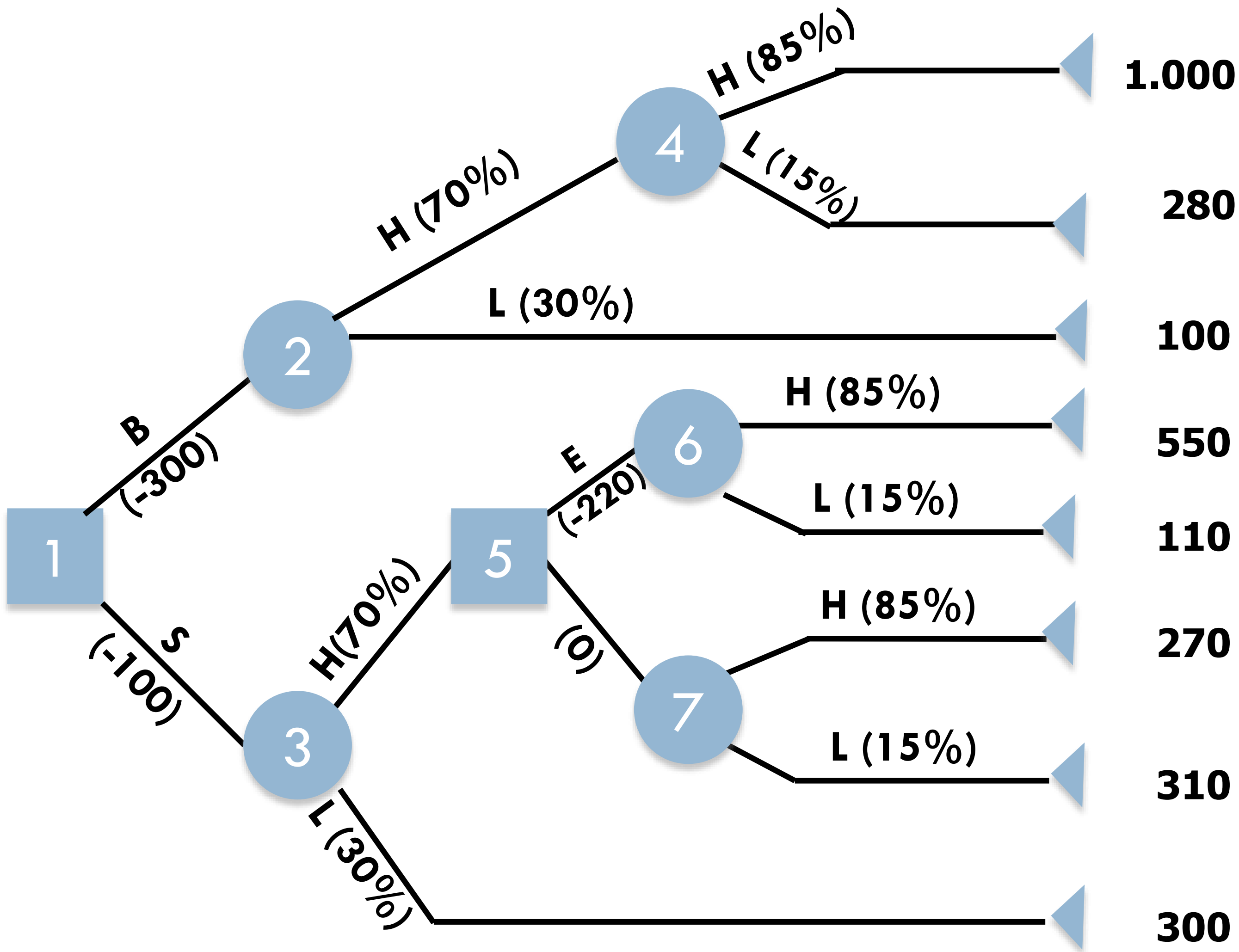
→ No Expansion!

ER(3) = (276)(70%) + (300)(30%) = 283.20

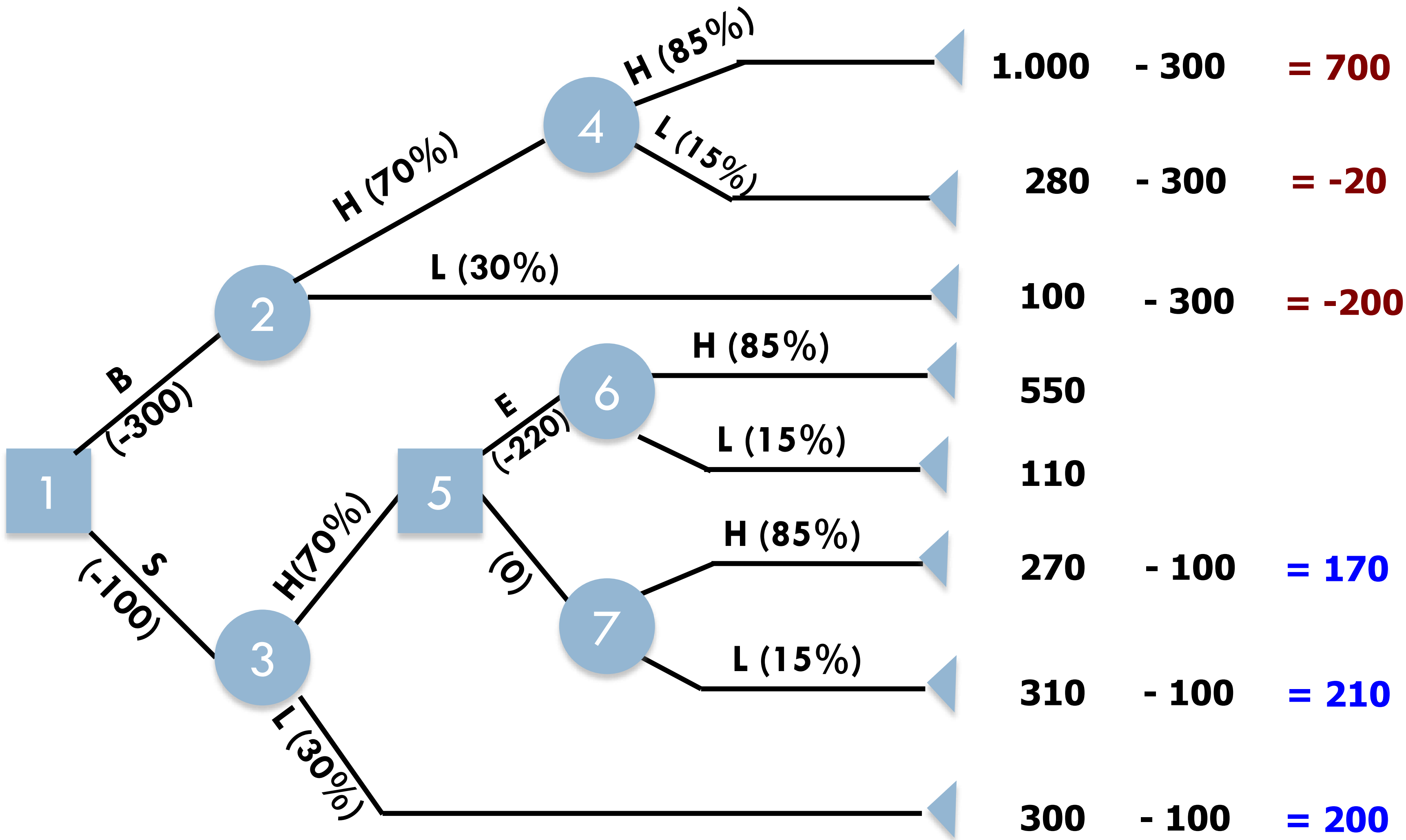
ER(small plant) = 283,20 - 100 = **183.20**

BASED ON THE CRITERION OF EXPECTED RETURN
IT IS PREFERRED TO BUILD A BIG PLANT NOW!

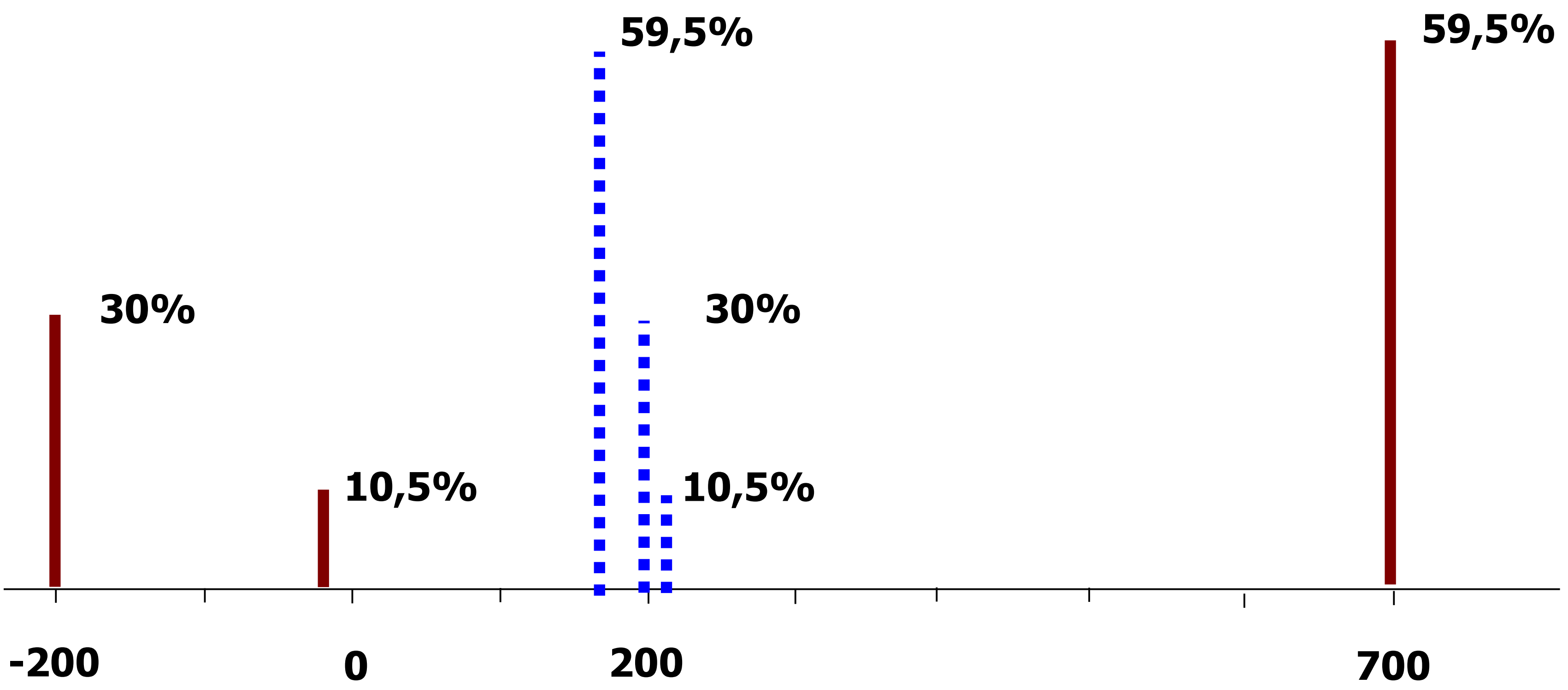
The Decision Tree



The Decision Tree



Risk Profiles



Now, would you follow the “BIG” decision ?

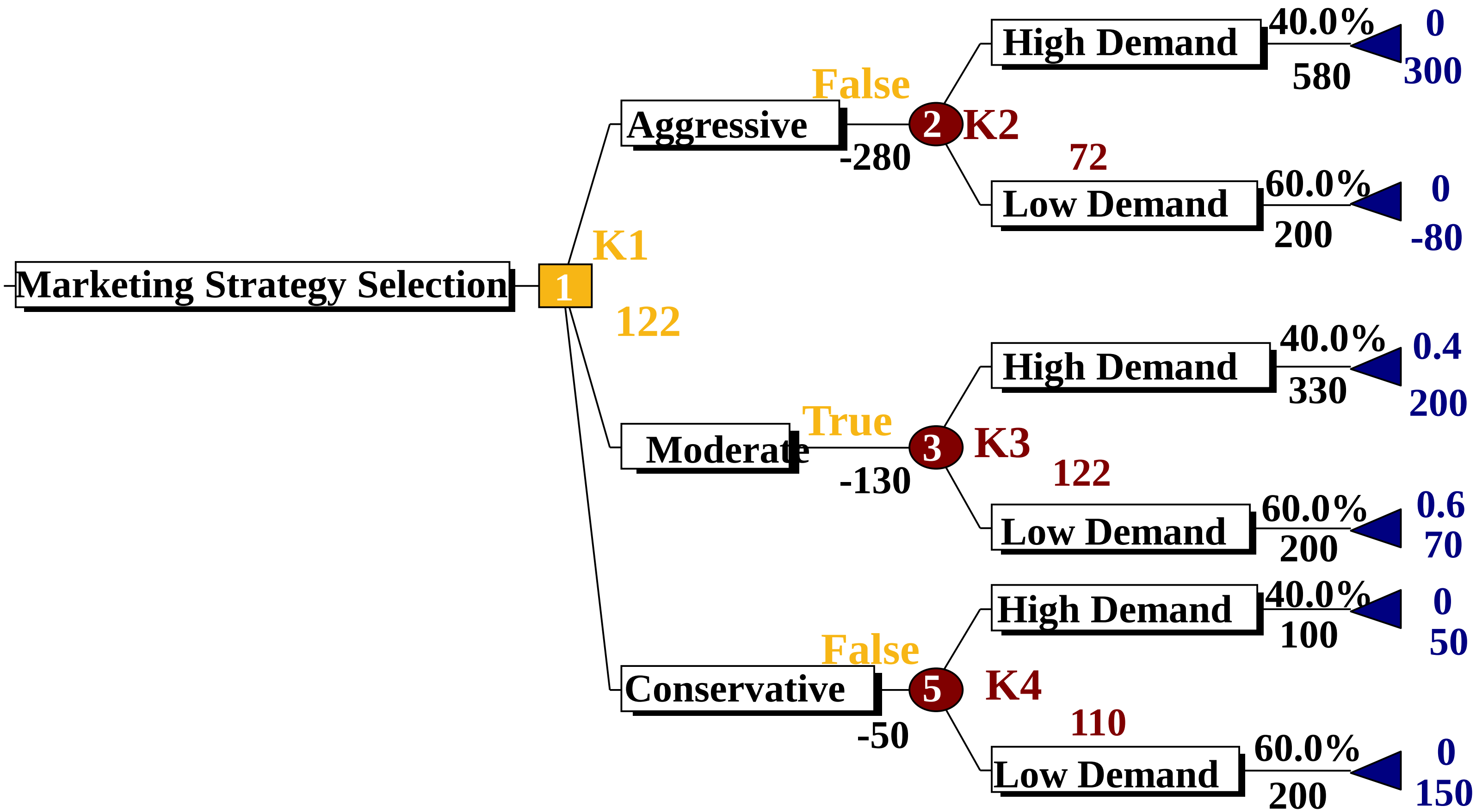
- Applies to Risk-Neutral investors
- Other Criteria / other investors
  - ☞ Minimax (min max possible loss)
  - ☞ Maximin (max min possible return)
  - ☞ Cash Availability
- Another approach: Risk Profile
  - ☞ Shows the actual returns to occur, with corresponding probabilities.

Another Example: Marketing Strategy

- Launching of a new product
- P (High demand) = 40%, P (low demand) = 60%
- 3 different marketing strategies:
  - Aggressive (High Inventory at all outlets)
  - Moderate (Inventory at outlets only for popular products)
  - Conservative (Almost no inventory at outlets)
- Table indicates revenues & costs ('000 $) for each strategy corresponding to each market condition

Marketing Strategy	Demand High (H)	Demand Low (L)	Cost of Strategy
Aggressive, A	580	200	280
Moderate, M	330	200	130
Conservative, C	100	200	50

The Decision Tree



Calculating Expected Returns

- Assume P(H) = 0.4 and P(L) = 0.6

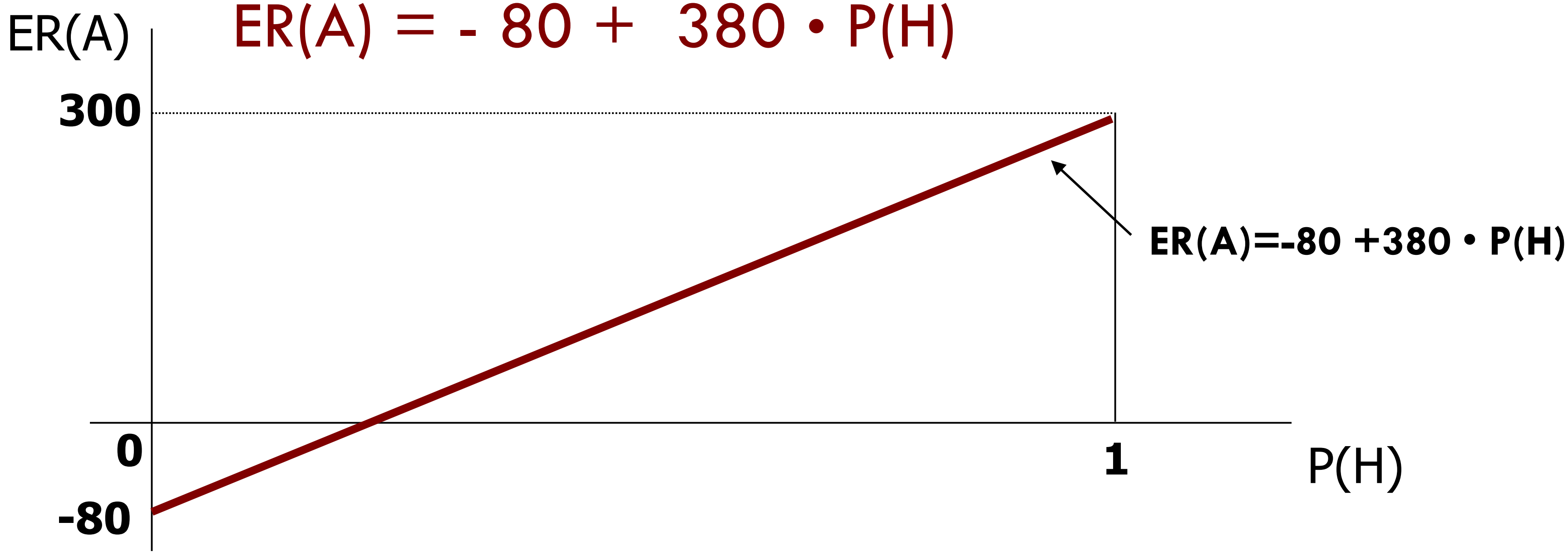
- ER(2) = ER(A) = (580)(0,40)+(200)(0,60)-280 = $72 K
- ER(3) = ER(M) = (330)(0,40)+(200)(0,60)-130 = $122 K
- ER(4) = ER(C) = (100)(0,40)+(200)(0,60) - 50 = $110 K

The best strategy is the Moderate (M)

Sensitivity Analysis on P(H): start with the A strategy

- Remember: P(H) = 0.40 and P(L) = 0.60
- Generally, P(H) + P(L) = 1 ➡ P(L) = 1 - P(H)
- So, ER(A) = 580 P(H) + 200 (1-P(H)) – 280 ⇨

ER(A) = - 80 + 380 • P(H)



Sensitivity Analysis on P(H): continue with the M and C strategies

- **Similarly for Moderate Strategy**

$$ER(M) = 330\ P(H) + 200\ (1\text{-}P(H)) - 130$$

$$ER(M) = 70 + 130 \cdot P(H)$$

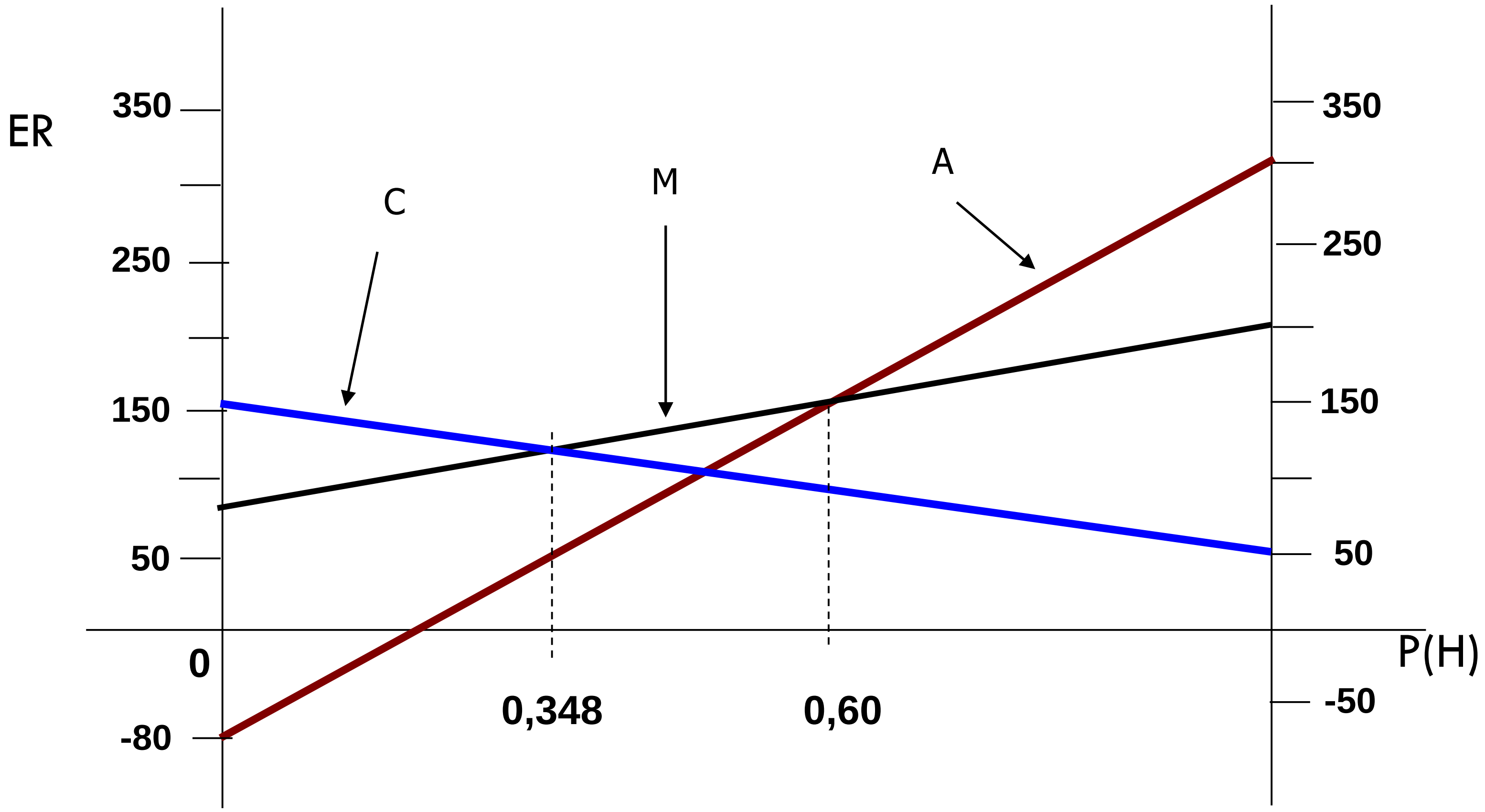
- **and for Conservative Strategy**

$$ER(C) = 100\ P(H) + 200\ (1\text{-}P(H) - 50$$

$$ER(C) = 150 - 100 \cdot P(H)$$

Sensitivity Analysis

Similar analysis with Moderate and Conservative Strategies



Sensitivity Analysis

- Since the criterion is the highest expected Net Return we can see that:

If	P(H) <= 0,348	then	Conservative!
If	P(H) in (0,348 ↔ 0,60]	then	Moderate!
If	P(H) > 0,60	then	Aggressive!

Note that ranges are quite large, therefore, fairly small changes in the probabilities do NOT affect the strategies

Design of Global Supply Chains

Many opportunities, but also many risks

Impact of Globalization on Supply Chain Networks

Risk Factors	Percentage of Supply Chains Impacted
Natural disasters	35
Shortage of skilled resources	24
Geopolitical uncertainty	20
Terrorist infiltration of cargo	13
Volatility of fuel prices	37
Currency fluctuation	29
Port operations/custom delays	23
Customer/consumer preference shifts	23
Performance of supply chain partners	38
Logistics capacity/complexity	33
Forecasting/planning accuracy	30
Supplier planning/communication issues	27
Inflexible supply chain technology	21

Accenture Survey of sources of Supply Chain Risk

The Offshoring Decision: Total Cost

- Comparative advantage in global supply chains
- Quantify the benefits of offshore production along with the reasons
- Two reasons offshoring fails
  1. Focusing exclusively on unit cost rather than total cost
  2. Ignoring critical risk factors

Impact of Offshoring on Supply Chain Performance

Performance Dimension	Activity Impacting Performance	Impact of Offshoring
Order communication	Order placement	More difficult communication
Supply chain visibility	Scheduling and expediting	Poorer visibility
Raw material costs	Sourcing of raw material	Could go either way depending on raw material sourcing
Unit cost	Production, quality (production and transportation)	Labor/fixed costs decrease; quality may suffer
Freight costs	Transportation modes and quantity	Higher freight costs
Taxes and tariffs	Border crossing	Could go either way
Supply lead time	Order communication, supplier production scheduling, production time, customs, transportation, receiving	Lead time increase results in poorer forecasts and higher inventories

Impact of Offshoring on Supply Chain Performance

Performance Dimension	Activity Impacting Performance	Impact of Offshoring
On-time delivery/lead time uncertainty	Production, quality, customs, transportation, receiving	Poorer on-time delivery and increased uncertainty resulting in higher inventory and lower product availability
Minimum order quantity	Production, transportation	Larger minimum quantities increase inventory
Product returns	Quality	Increased returns likely
Inventories	Lead times, inventory in transit and production	Increase
Working capital	Inventories and financial reconciliation	Increase
Hidden costs	Order communication, invoicing errors, managing exchange rate risk	Higher hidden costs
Stock-outs	Ordering, production, transportation with poorer visibility	Increase

The Offshoring Decision: Total Cost

- A global supply chain with offshoring increases the length and duration of information, product, and cash flows
- The complexity and cost of managing the supply chain can be significantly higher than anticipated
- Quantify factors and track them over time
- Big challenges with offshoring is increased risk and its potential impact on cost

Key Elements of Total Cost

1. Supplier price: direct materials, labor, incl. management, overhead, taxes, local regulations
2. Terms: net payment terms, volume discounts
3. Delivery costs
4. Inventory and warehousing: inventory, handling, w/h, sc inv.
5. Cost of quality: validation, cost of drop of quality, cost of remedies, etc
6. Customer duties, value added-taxes, local tax incentives
7. Cost of risk, procurement staff, broker fees, infrastructure, and tooling and mold costs
8. Exchange rate trends and their impact on cost

Risk Management In Global Supply Chains

- Risks include supply disruption, supply delays, demand fluctuations, price fluctuations, and exchange-rate fluctuations
- Critical for global supply chains to be aware of the relevant risk factors and build in suitable mitigation strategies

- Important: evaluate in terms of Total Cost!

Supply Chain Risks to be considered in Network design

Category	Risk Drivers
Disruptions	Natural disaster, war, terrorism Labor disputes Supplier bankruptcy
Delays	High capacity utilization at supply source Inflexibility of supply source Poor quality or yield at supply source
Systems risk	Information infrastructure breakdown System integration or extent of systems being networked
Forecast risk	Inaccurate forecasts due to long lead times, seasonality, product variety, short life cycles, small customer base Information distortion

Supply Chain Risks to be considered in Network design

Category	Risk Drivers
Intellectual property risk	Vertical integration of supply chain Global outsourcing and markets
Procurement risk	Exchange-rate risk Price of inputs Fraction purchased from a single source Industry-wide capacity utilization
Receivables risk	Number of customers Financial strength of customers
Inventory risk	Rate of product obsolescence Inventory holding cost Product value Demand and supply uncertainty
Capacity risk	Cost of capacity Capacity flexibility

Risk Management In Global Supply Chains

- Good network design can play a significant role in mitigating supply chain risk
- Every mitigation strategy comes at a price and may increase other risks
- Global supply chains should generally use a combination of rigorously evaluated mitigation strategies along with financial strategies to hedge uncovered risks

Risk Mitigation Strategies during Network design

Risk Mitigation Strategy	Tailored Strategies
Increase capacity	Focus on low-cost, decentralized capacity for predictable demand. Build centralized capacity for unpredictable demand. Increase decentralization as cost of capacity drops.
Get redundant suppliers	More redundant supply for high-volume products, less redundancy for low-volume products. Centralize redundancy for low-volume products in a few flexible suppliers.
Increase responsiveness	Favor cost over responsiveness for commodity products. Favor responsiveness over cost for short–life cycle products.

Risk Mitigation Strategies during Network design

Risk Mitigation Strategy	Tailored Strategies
Increase inventory	Decentralize inventory of predictable, lower value products. Centralize inventory of less predictable, higher value products.
Increase flexibility	Favor cost over flexibility for predictable, high-volume products. Favor flexibility for unpredictable, low-volume products. Centralize flexibility in a few locations if it is expensive.
Pool or aggregate demand	Increase aggregation as unpredictability grows.
Increase source capability	Prefer capability over cost for high-value, high-risk products. Favor cost over capability for low-value commodity products. Centralize high capability in flexible source if possible.

Risk Mitigation Strategies during Network design

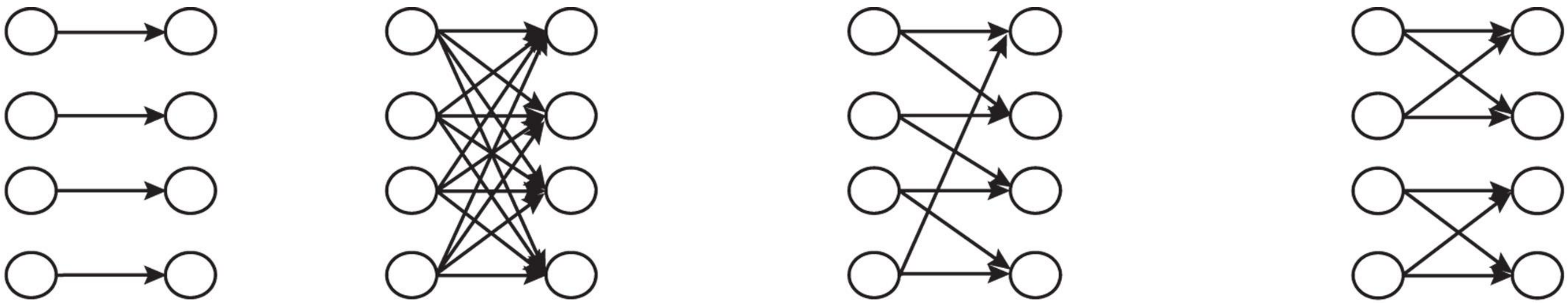
Risk Mitigation Strategy	Tailored Strategies
Increase inventory	Decentralize inventory of predictabl[illegible]er value products. Centralize inventory [illegible]table, higher value products.
Increase flexibility	Favor cost over fl[illegible]able, high-volume prod[illegible]y for unpred[illegible]e products. Centralize fl[illegible]ocations if it is expensive.
Pool or aggregate demand	[illegible]ggregation as unpredictability grows.
Increase source capab[illegible]	[illegible]er capability over cost for high-value, high-risk products. Favor cost over capability for low-value commodity products. Centralize high capability in flexible source if possible.

Flexibility plays an important role in mitigating risks and uncertainties in supply chains

Flexibility, Chaining, and Containment

- Three broad categories of flexibility
  - New product flexibility
    - Ability to introduce new products into the market at a rapid rate
  - Mix flexibility
    - Ability to produce a variety of products within a short period of time
  - Volume flexibility
    - Ability to operate profitably at different levels of output

Flexibility, Chaining, and Containment



Dedicated Network

Fully Flexible Network

Chained Network with One Long Chain

Chained Network with Two Short Chains

Highly inflexible!
Not able to meet excess demand!

Very costly!

Can pool available capacity!
Can be almost as effective in mitigating risk as a fully flexible supply chain, but coordination is more difficult!

Flexibility, Chaining, and Containment

- As flexibility is increased, the marginal benefit derived from the increased flexibility decreases
  - With demand uncertainty, longer chains pool available capacity
  - Long chains may have higher fixed cost than multiple smaller chains
  - Coordination more difficult across with a single long chain
- Flexibility and chaining are effective when dealing with demand fluctuation, but less effective when dealing with supply disruption. Here, smaller chains are more effective.

Discounted Cash Flow Analysis

- Supply chain decisions should be evaluated as a sequence of cash flows over time
- Discounted cash flow (DCF) analysis evaluates the present value of any stream of future cash flows and allows managers to compare different cash flow streams in terms of their financial value
- Based on the time value of money – a dollar today is worth more than a dollar tomorrow

Discounted Cash Flow Analysis

$$\text{discount factor} = \frac{1}{1+k}$$

$$\text{NPV} = C_0 + \sum_{t=1}^{T} \left(\frac{1}{1+k} \right)^t C_t$$

where

$C_0, C_1, \ldots, C_T$ is stream of cash flows over T periods

NPV = net present value of this stream

k = rate of return

- Compare NPV of different supply chain design options
- The option with the highest NPV will provide the greatest financial return

Trips Logistics Example

- Forecasted Demand = 100,000 units / year for each of the next 3 years
- 1,000 sq. ft. of space for every 1,000 units of demand
- Revenue = $1.22 per unit of demand
- Decision: Sign a three-year lease, OR, obtain warehousing space on the spot market?
- Three-year lease cost = $1 per sq. ft. per year
- Spot market cost = $1.20 per sq. ft. per year
- $k = 0.1$
- Evaluate the two strategies using DCF!

Spot market strategy

- Expected annual profit if warehouse space is obtained from the spot market = 100,000 x $1.22 – 100,000 x $1.20 = $2,000

$$\text{NPV(No lease)} = C_0 + \frac{C_1}{1+k} + \frac{C_2}{(1+k)^2}$$

$$= 2{,}000 + \frac{2{,}000}{1.1} + \frac{2{,}000}{1.1^2} = \$5{,}471$$

3 year lease strategy

- Expected annual profit with three year lease = 100,000 x \$1.22 – 100,000 x \$1.00 = \$22,000

$$\text{NPV(Lease)} = C_0 + \frac{C_1}{1+k} + \frac{C_2}{(1+k)^2}$$

$$= 22{,}000 + \frac{22{,}000}{1.1} + \frac{22{,}000}{1.1^2} = \$60{,}182$$

- NPV of signing lease is \$60,182 – \$5,471 = \$54,711 higher than spot market
- However, how about the uncertainty in the spot prices?

Evaluating Network Designs

- Many different decisions
  - Should the firm sign a long-term contract for warehousing space or get space from the spot market as needed?
  - What should the firm's mix of long-term and spot market be in the portfolio of transportation capacity?
  - How much capacity should various facilities have? What fraction of this capacity should be flexible?

Evaluating Network Designs

- During network design, managers need a methodology that allows them to estimate the uncertainty in demand and price forecast and incorporate this in the decision-making process
- Most important for network design decisions because they are hard to change in the short term

Basics of Decision Tree Analysis

- A *decision tree* is a graphic device used to evaluate decisions under uncertainty
  - Identify the number and duration of time periods that will be considered
  - Identify factors that will affect the value of the decision and are likely to fluctuate over the time periods
  - Evaluate decision using a decision tree

Decision Tree Methodology

1. Identify the duration of each period (month, quarter, etc.) and the number of periods T over which the decision is to be evaluated
2. Identify factors whose fluctuation will be considered
3. Identify representations of uncertainty for each factor
4. Identify the periodic discount rate k for each period
5. Represent the decision tree with defined states in each period as well as the transition probabilities between states in successive periods
6. Starting at period T, work back to Period 0, identifying the optimal decision and the expected cash flows at each step

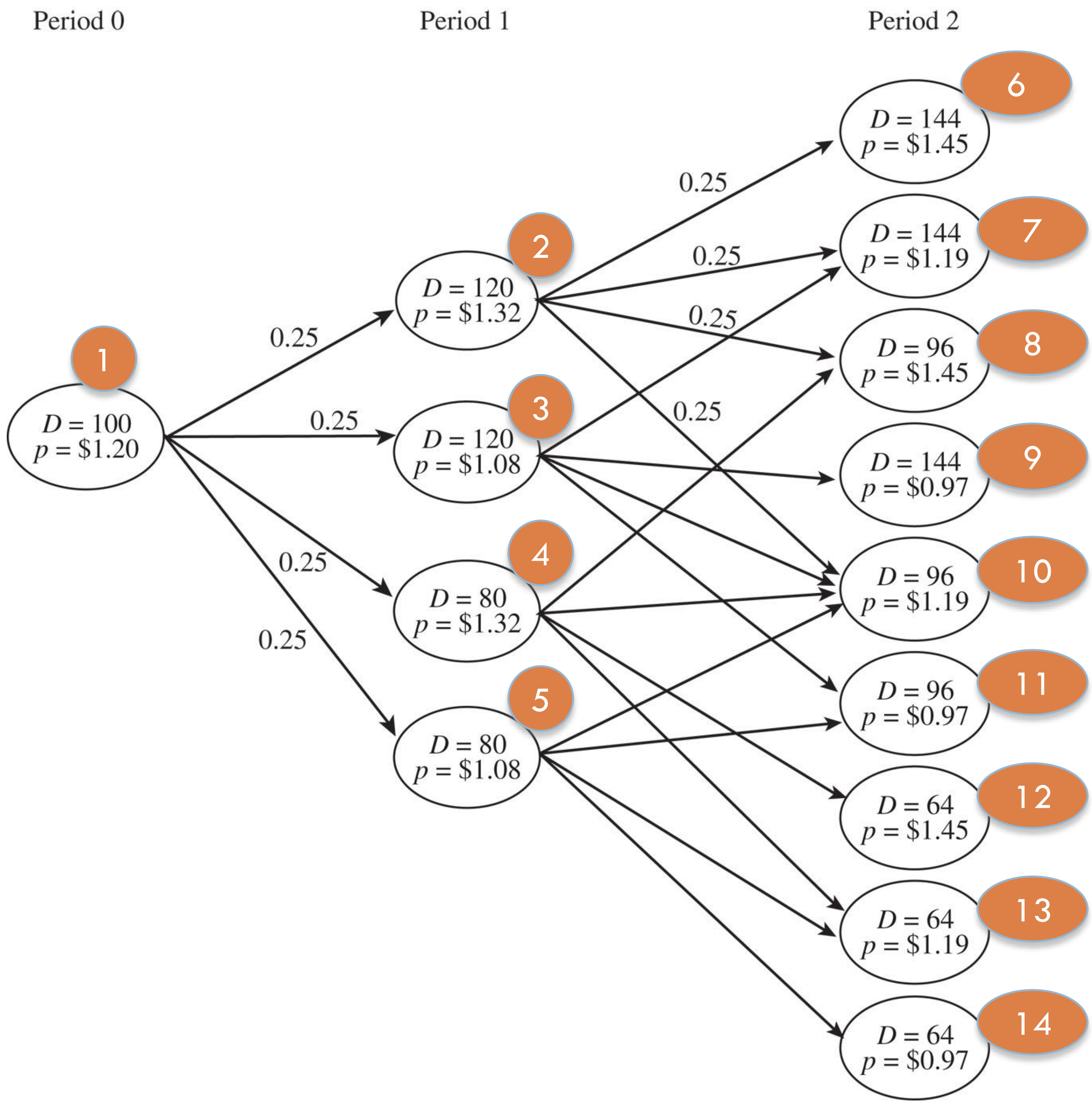
Decision Tree – Trips Logistics

- Three warehouse lease options
  1. Get all warehousing space from the spot market as needed
  2. Sign a three-year lease for a fixed amount of warehouse space and get additional requirements from the spot market
  3. Sign a flexible lease with a minimum charge that allows variable usage of warehouse space up to a limit with additional requirement from the spot market

Decision Tree – Trips Logistics

- 1000 sq. ft. of warehouse space needed for 1000 units of demand
- Current demand = 100,000 units per year
- Binomial uncertainty: Demand can go up by 20% with $p = 0.5$ or down by 20% with $1 - p = 0.5$
- Lease price = \$1.00 per sq. ft. per year
- Spot market price = \$1.20 per sq. ft. per year
- Spot prices can go up by 10% with $p = 0.5$ or down by 10% with $1 - p = 0.5$
- Revenue = \$1.22 per unit of demand
- $k = 0.1$

Decision Tree for the spot market option



Calculating Net at Period 2

- Analyze the option of not signing a lease and using the spot market
- Start with Period 2 and calculate the profit at each node.
- Begin with Node 6:

For Node 6 ($D = 144$, $p = \$1.45$) in Period 2:

$$C(\text{node } 6) = 144{,}000 \times 1.45 = \$208{,}800$$

$$P(\text{node } 6) = 144{,}000 \times 1.22 - C(\text{node } 6)$$

$$= 175{,}680 - 208{,}800 = -\$33{,}120$$

- Continue with the other nodes of period 2.

Calculating Profit at all nodes of period 2

		Revenue	Cost $C(D =, p =, 2)$	Profit $P(D =, p =, 2)$
6	$D = 144, p = 1.45$	144,000 × 1.22	144,000 × 1.45	–$33,120
7	$D = 144, p = 1.19$	144,000 × 1.22	144,000 × 1.19	$4,320
8	$D = 96, p = 1.45$	96,000 × 1.22	96,000 × 1.45	-$22,080
9	$D = 144, p = 0.97$	144,000 × 1.22	144,000 × 0.97	$36,000
10	$D = 96, p = 1.19$	96,000 × 1.22	96,000 × 1.19	$2,880
11	$D = 96, p = 0.97$	96,000 × 1.22	96,000 × 0.97	$24,000
12	$D = 64, p = 1.45$	64,000 × 1.22	64,000 × 1.45	–$14,720
13	$D = 64, p = 1.19$	64,000 × 1.22	64,000 × 1.19	$1,920
14	$D = 64, p = 0.97$	64,000 × 1.22	64,000 × 0.97	$16,000

Calculating Expected Profit at Nodes in Period 1

- Expected profit at each node in Period 1 is the profit during Period 1 plus the present value of the expected profit in Period 2
- Expected profit $\mathrm{EP}(D =, p =, 1)$ at a node is the expected profit over all four nodes in Period 2 that may result from this node
- $\mathrm{PVEP}(D =, p =, 1)$ is the present value of this expected profit and $\mathrm{P}(D =, p =, 1)$, and the total expected profit, is the sum of the profit in Period 1 and the present value of the expected profit in Period 2

Calculating Expected Profit at Nodes in Period 1

- From node 2 (D = 120, p = \$1.32 in Period 1), there are four possible states in Period 2
- Therefore, the expected profit in Period 2 from node 2 is
  EP(node 2) = 0.25 x [P(node 6) + … + P(node 10)] =

  = 0.25 x [–33,120 + 4,320 – 22,080 + 2,880 = –\$12,000
- The present value of this expected value in Period 1 is

  PVEP(node 2) = EP(node 2) / (1 + k) = –\$12,000 / (1.1) = –\$10,909
- The total expected profit P(node 2) at node 2 in Period 1 is the sum of the profit in Period 1 at this node, plus the present value of future expected profits possible from this node

  P(node 2) = 120,000 x 1.22 – 120,000 x 1.32 + PVEP(node 2) =

  = –\$12,000 – \$10,909 = –\$22,909
- Continue with all nodes in period 1

Calculating Expected Profit in Period 0

- For Period 0, the total profit P(node 1) is the sum of the profit in Period 0 and the present value of the expected profit over the four nodes in Period 1

EP(node 1) = 0.25 x [P(node 2) + P(node 3) + P(node 4) +P(node 5)] =

= 0.25 x [–22,909 + 32,073 – 15,273) + 21,382] = \$3,818

$PVEP$(node 1) = EP(node 1) / (1 + k) = \$3,818 / (1.1) = \$3,471

P(node 1) = 100,000 x 1.22 – 100,000 x 1.20 + $PVEP$(node 1)

= \$2,000 + \$3,471 = \$5,471

- Therefore, the expected NPV of not signing the lease and obtaining all warehouse space from the spot market is given by NPV(Spot Market) = \$5,471

Evaluating the Fixed Lease option

	Node	Leased Space	Warehouse Space at Spot Price (S)	Profit $P(D =, p =, 2)$ $= D$ x 1.22 – (100,000 x 1 + S x p)
6	$D = 144, p = 1.45$	100,000 sq. ft.	44,000 sq. ft.	\$11,880
7	$D = 144, p = 1.19$	100,000 sq. ft.	44,000 sq. ft.	\$23,320
8	$D = 96, p = 1.45$	100,000 sq. ft.	0 sq. ft.	\$17,120
9	$D = 144, p = 0.97$	100,000 sq. ft.	44,000 sq. ft.	\$33,000
10	$D = 96, p = 1.19$	100,000 sq. ft.	0 sq. ft.	\$17,120
11	$D = 96, p = 0.97$	100,000 sq. ft.	0 sq. ft.	\$17,120
12	$D = 64, p = 1.45$	100,000 sq. ft.	0 sq. ft.	–\$21,920
13	$D = 64, p = 1.19$	100,000 sq. ft.	0 sq. ft.	–\$21,920
14	$D = 64, p = 0.97$	100,000 sq. ft.	0 sq. ft.	–\$21,920

Moving to period 1

Node	$EP(D =, p =, 1)$	Warehouse Space at Spot Price (S)	$P(D =, p =, 1) = D \times 1.22 - (100{,}000 \times 1 + S \times p) + EP(D =, p = ,1)(1 + k)$
2 $D = 120$, $p = 1.32$	0.25 x [P(node 6) + P(node 7) + P(node 8) + P(node 10)] = 0.25 x (11,880 + 23,320 + 17,120 + 17,120) = \$17,360	20,000	\$35,782
3 $D = 120$, $p = 1.08$	0.25 x (23,320 + 33,000 + 17,120 + 17,120) = \$22,640	20,000	\$45,382
4 $D = 80$, $p = 1.32$	0.25 x (17,120 + 17,120 – 21,920 – 21,920) = –\$2,400	0	–\$4,582
5 $D = 80$, $p = 1.08$	0.25 x (17,120 + 17,120 – 21,920 – 21,920) = –\$2,400	0	–\$4,582

Decision Tree – Trips Logistics

- Using the same approach for the lease option, NPV(Lease) = $38,364
- Recall that when uncertainty was ignored, the NPV for the lease option was $60,182
- However, the manager would probably still prefer to sign the three-year lease for 100,000 sq. ft. because this option has the higher expected profit

Evaluating the flexible lease option

	Node	Warehouse Space at \$1 (W)	Warehouse Space at Spot Price (S)	Profit $P(D =, p =, 2)$ $= D \times 1.22 - (W \times 1 + S \times p)$
6	$D = 144, p = 1.45$	100,000 sq. ft.	44,000 sq. ft.	\$11,880
7	$D = 144, p = 1.19$	100,000 sq. ft.	44,000 sq. ft.	\$23,320
8	$D = 96, p = 1.45$	100,000 sq. ft.	0 sq. ft.	\$17,120
9	$D = 144, p = 0.97$	100,000 sq. ft.	44,000 sq. ft.	\$33,000
10	$D = 96, p = 1.19$	96,000 sq. ft.	0 sq. ft.	\$21,120
11	$D = 96, p = 0.97$	96,000 sq. ft.	0 sq. ft.	\$21,120
12	$D = 64, p = 1.45$	64,000 sq. ft.	0 sq. ft.	\$14,080
13	$D = 64, p = 1.19$	64,000 sq. ft.	0 sq. ft.	\$14,080
14	$D = 64, p = 0.97$	64,000 sq. ft.	0 sq. ft.	\$14,080

Decision Tree – Trips Logistics

Node	$EP(D =, p =, 1)$	Warehouse Space at $1 ($W$)	Warehouse Space at Spot Price (S)	$P(D =, p =, 1) = D \times 1.22 - (W \times 1 + S \times p) + EP(D =, p = ,1)(1 + k)$
$D = 120$, $p = 1.32$	0.25 x (11,880 + 23,320 + 21,120 + 21,120) = $19,360	100,000	20,000	$37,600
$D = 120$, $p = 1.08$	0.25 x (23,320 + 33,000 + 21,120 + 21,120) = $24,640	100,000	20,000	$47,200
$D = 80$, $p = 1.32$	0.25 x (21,120 + 21,120 + 14,080 + 14,080) = $17,600	80,000	0	$33,600
$D = 80$, $p = 1.08$	0.25 x (21,920 + 21,920 + 14,080 + 14,080) = $17,600	80,000	0	$33,600

Comparison of all options

Option	**Value**
All warehouse space from the spot market	$5,471
Lease 100,000 sq. ft. for three years	$38,364
Flexible lease to use between 60,000 and 100,000 sq. ft.	$46,545

Flexibility is worth $46,545 - $38,364 = $8,181

Onshore or Offshore

- D-Solar demand in Europe = 100,000 panels per year
- Each panel sells for €70
- Annual demand may increase by 20 percent with probability 0.8 or decrease by 20 percent with probability 0.2
- Build a plant in Europe or China with a rated capacity of 120,000 panels

D-Solar Decision

European Plant		Chinese Plant	
Fixed Cost (euro)	Variable Cost (euro)	Fixed Cost (yuan)	Variable Cost (yuan)
1 million/year	40/panel	8 million/year	340/panel

Period 1		Period 2	
Demand	**Exchange Rate**	**Demand**	**Exchange Rate**
112,000	8.64 yuan/euro	125,440	8.2944 yuan/euro

D-Solar Decision

- European plant has greater volume flexibility
- Increase or decrease production between 60,000 to 150,000 panels
- Chinese plant has limited volume flexibility
- Can produce between 100,000 and 130,000 panels
- Chinese plant will have a variable cost for 100,000 panels and will lose sales if demand increases above 130,000 panels
- Yuan, currently 9 yuan/euro, expected to rise 10%, probability of 0.7 or drop 10%, probability of 0.3
- Sourcing decision over the next three years
- Discount rate $k = 0.1$

D-Solar Decision

Period 0 profits = 100,000 x 70 – 1,000,000 – 100,000 x 40 = €2,000,000

Period 1 profits = 112,000 x 70 – 1,000,000 – 112,000 x 40 = €2,360,000

Period 2 profits = 125,440 x 70 – 1,000,000 – 125,440 x 40 = €2,763,200

Expected profit from onshoring = 2,000,000 + 2,360,000/1.1 + 2,763,200/1.21

= €6,429,091

Period 0 profits = 100,000 x 70 – 8,000,000/9 – 100,000 x 340/9 = €2,333,333

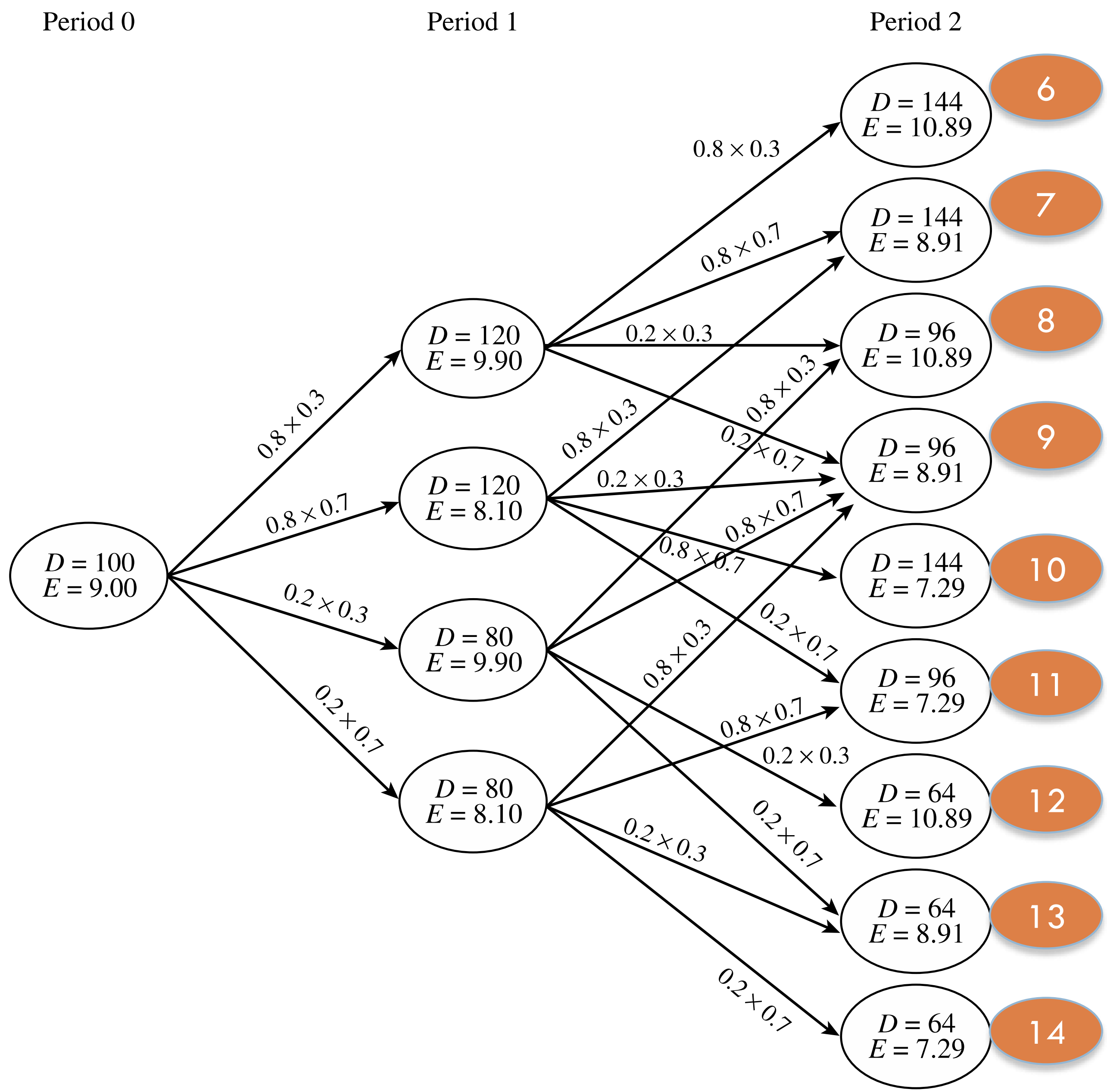
Period 1 profits = 112,000 x 70 – 8,000,000/8.64 – 112,000 x 340/8.64 = €2,506,667

Period 2 profits = 125,440 x 70 – 8,000,000/8.2944 – 125,440 x 340/8.2944 = €2,674,319

Expected profit from off-shoring = 2,333,333 + 2,506,667/1.1 + 2,674,319/1.21

= €6,822,302

Decision Tree



D-Solar Decision at node 6:

- Period 2 evaluation – onshore – can produce all!

Revenue from the manufacture
and sale of 144,000 panels = 144,000 x 70
= €10,080,000

Fixed + variable cost
of onshore plant = 1,000,000 + 144,000 x 40
= €6,760,000

$P(D = 144, E = 10.89,2)$ = 10,080,000 – 6,760,000
= €3,320,000

D-Solar Decision (onshore)

	D	*E*	Sales	Production Cost Quantity	Revenue (euro)	Cost (euro)	Profit (euro)
6	144	10.89	144,000	144,000	10,080,000	6,760,000	3,320,000
7	144	8.91	144,000	144,000	10,080,000	6,760,000	3,320,000
8	96	10.89	96,000	96,000	6,720,000	4,840,000	1,880,000
9	96	8.91	96,000	96,000	6,720,000	4,840,000	1,880,000
10	144	7.29	144,000	144,000	10,080,000	6,760,000	3,320,000
11	96	7.29	96,000	96,000	6,720,000	4,840,000	1,880,000
12	64	10.89	64,000	64,000	4,480,000	3,560,000	920,000
13	64	8.91	64,000	64,000	4,480,000	3,560,000	920,000
14	64	7.29	64,000	64,000	4,480,000	3,560,000	920,000

D-Solar Decision

- Period 1 evaluation – onshore

$EP(D = 120, E = 9.90, 1) = 0.24 \times P(D = 144, E = 10.89, 2) +$
$0.56 \times P(D = 144, E = 8.91, 2) +$
$0.06 \times P(D = 96, E = 10.89, 2) +$
$0.14 \times P(D = 96, E = 8.91, 2)$
$= 0.24 \times 3{,}320{,}000 + 0.56 \times 3{,}320{,}000 +$
$0.06 \times 1{,}880{,}000 + 0.14 \times 1{,}880{,}000$
$= €3{,}032{,}000$

$PVEP(D = 120, E = 9.90, 1) = EP(D = 120, E = 9.90, 1)/(1 + k)$
$= 3{,}032{,}000/1.1 = €2{,}756{,}364$

D-Solar Decision

- Period 1 evaluation – onshore

Revenue from manufacture
and sale of 120,000 panels = 120,000 x 70 = €8,400,000

Fixed + variable cost of onshore plant = 1,000,000 + 120,000 x 40
= €5,800,000

$P(D = 120, E = 9.90, 1)$ = 8,400,000 – 5,800,000 +
$PVEP(D = 120, E = 9.90, 1)$
= 2,600,000 + 2,756,364
= €5,356,364

Same for all nodes of period 1 (onshore)

D	*E*	Sales	Production Cost Quantity	Revenue (euro)	Cost (euro)	Profit (euro)
120	9.90	120,000	120,000	8,400,000	5,800,000	5,356,364
120	8.10	120,000	120,000	8,400,000	5,800,000	5,356,364
80	9.90	80,000	80,000	5,600,000	4,200,000	2,934,545
80	8.10	80,000	80,000	5,600,000	4,200,000	2,934,545

Moving to period 0 (onshore)

- Period 0 evaluation – onshore

$EP(D = 100, E = 9.00, 1) = 0.24 \times P(D = 120, E = 9.90, 1) +$

$0.56 \times P(D = 120, E = 8.10, 1) +$

$0.06 \times P(D = 80, E = 9.90, 1) +$

$0.14 \times P(D = 80, E = 8.10, 1)$

$= 0.24 \times 5{,}356{,}364 + 0.56 \times 5{,}5356{,}364 +$

$0.06 \times 2{,}934{,}545 + 0.14 \times 2{,}934{,}545$

$=$ € 4,872,000

$PVEP(D = 100, E = 9.00,1) \quad = EP(D = 100, E = 9.00,1)/(1 + k)$

$= 4{,}872{,}000/1.1 =$ €4,429,091

D-Solar Decision

- Period 0 evaluation – onshore

Revenue from manufacture
and sale of 100,000 panels = 100,000 x 70 = €7,000,000

Fixed + variable cost of onshore plant = 1,000,000 + 100,000 x 40
= €5,000,000

$P(D = 100, E = 9.00, 1)$ = 8,400,000 – 5,800,000 +
$PVEP(D = 100, E = 9.00, 1)$
= 2,000,000 + 4,429,091
= €6,429,091

Evaluating the Offshore decision

- Period 2 evaluation – offshore

Revenue from the manufacture
and sale of 130,000 panels = 130,000 x 70
= €9,100,000

Fixed + variable cost
of offshore plant = 8,000,000 + 130,000 x 340
= 52,200,000 yuan

$P(D = 144, E = 10.89,2) = 9,100,000 - 52,200,000/10.89$
= €4,306,612

D-Solar Decision

	D	*E*	Sales	Production Cost Quantity	Revenue (euro)	Cost (yuan)	Profit (euro)
6	144	10.89	130,000	130,000	9,100,000	52,200,000	4,306,612
7	144	8.91	130,000	130,000	9,100,000	52,200,000	3,241,414
8	96	10.89	96,000	100,000	6,720,000	42,000,000	2,863,251
9	96	8.91	96,000	100,000	6,720,000	42,000,000	2,006,195
10	144	7.29	130,000	130,000	9,100,000	52,200,000	1,939,506
11	96	7.29	96,000	100,000	6,720,000	42,000,000	958,683
12	64	10.89	64,000	100,000	4,480,000	42,000,000	623,251
13	64	8.91	64,000	100,000	4,480,000	42,000,000	−233,805
14	64	7.29	64,000	10,000	4,480,000	3,560,000	−1,281,317

D-Solar Decision

- Period 1 evaluation – offshore

$EP(D = 120, E = 9.90, 1) = 0.24 \times P(D = 144, E = 10.89, 2) +$
$0.56 \times P(D = 144, E = 8.91, 2) +$
$0.06 \times P(D = 96, E = 10.89, 2) +$
$0.14 \times P(D = 96, E = 8.91, 2)$
$= 0.24 \times 4{,}306{,}612 + 0.56 \times 3{,}241{,}414 +$
$0.06 \times 2{,}863{,}251 + 0.14 \times 2{,}006{,}195$
$= € \; 3{,}301{,}441$

$PVEP(D = 120, E = 9.90{,}1) = EP(D = 120, E = 9.90{,}1)/(1 + k)$
$= 3{,}301{,}441/1.1 = €3{,}001{,}310$

D-Solar Decision

- Period 1 evaluation – offshore

Revenue from manufacture
and sale of 120,000 panels = 120,000 x 70 = €8,400,000

Fixed + variable cost of offshore plant = 8,000,000 + 120,000 x 340
= 48,800,000 yuan

$P(D = 120, E = 9.90, 1)$ = 8,400,000 – 48,800,000/9.90 +
$PVEP(D = 120, E = 9.90, 1)$
= 3,470,707 + 3,001,310
= €6,472,017

D-Solar Decision

D	*E*	Sales	Production Cost Quantity	Revenue (euro)	Cost (yuan)	Expected Profit (euro)
120	9.90	120,000	120,000	8,400,000	48,800,000	6,472,017
120	8.10	120,000	120,000	8,400,000	48,800,000	4,301,354
80	9.90	80,000	100,000	5,600,000	42,000,000	3,007,859
80	8.10	80,000	100,000	5,600,000	42,000,000	1,164,757

D-Solar Decision

- Period 0 evaluation – offshore

$EP(D = 100, E = 9.00, 1) = 0.24 \times P(D = 120, E = 9.90, 1) +$
$0.56 \times P(D = 120, E = 8.10, 1) +$
$0.06 \times P(D = 80, E = 9.90, 1) +$
$0.14 \times P(D = 80, E = 8.10, 1)$
$= 0.24 \times 6{,}472{,}017 + 0.56 \times 4{,}301{,}354$
$+ 0.06 \times 3{,}007{,}859 + 0.14 \times 1{,}164{,}757$
= € 4,305,580

$PVEP(D = 100, E = 9.00,1) = EP(D = 100, E = 9.00,1)/(1 + k)$
$= 4{,}305{,}580/1.1 =$ €3,914,164

D-Solar Decision

- Period 0 evaluation – offshore

Revenue from manufacture
and sale of 100,000 panels = 100,000 x 70 = €7,000,000

Fixed + variable cost of onshore plant = 8,000,000 + 100,000 x 340
= €42,000,000 yuan

$P(D = 100, E = 9.00, 1)$ = 7,000,000 – 42,000,000/9.00 +
$PVEP(D = 100, E = 9.00, 1)$
= 2,333,333 + 3,914,164
= €6,247,497

Decisions Under Uncertainty

1. Combine strategic planning and financial planning during global network design
2. Use multiple metrics to evaluate global supply chain networks
3. Use financial analysis as an input to decision making, not as the decision-making process
4. Use estimates along with sensitivity analysis