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CERTIFICATION COURSES

Business Analytics for Management Decision

Decision Analytics [56]

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Course Contents

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Week 5	:	Inferential Analytics 2
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Week 8	:	Predictive Analytics 3
Week 9	:	Prescriptive Analytics 1
Week 10	:	Prescriptive Analytics 2
Week 11	:	Prescriptive Analytics 3
Week 12	:	Decision Analytics

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Learning Objectives

- Making decisions with uncertain information
- Understanding foundations of decision trees.
- The value of information
- Utility and decision making
- Knowing the steps of the decision-making process and describe the different types of decision-making environments.
- Knowing the use of Excel to set up and solve problems involving decision tables.
- Develop accurate and useful decision trees.
- Understanding the importance and use of utility theory in decision making

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Highlights

- Decision Strategies for a Minimum Objective
- Decision Strategies for a Maximum Objective
- Decision Trees & Risk
- Value of Information
- Perfect Information
- Bayes' Rule
- Utility Theory

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Decision Analytics: An Overview

- An analytic and systematic approach to the study of decision making
  - Based on logic
  - Considers all possible alternatives
  - Examines all available information about the future
  - Applies the decision modeling approach

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DA: Five Step Process

1. Define the problem
2. List *all* possible alternatives
3. Identify all possible outcomes for each alternative
4. Identify the payoff for each alternative and outcome combination
5. Use a decision modeling technique to choose an alternative

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Example: Thompson Lumber

1. Decision: Should he make and sell storage sheds
2. Alternatives:
    1. Build a large plant
    2. Build a small plant
    3. Do nothing
3. Outcomes: Demand for sheds will be
    1. High
    2. Moderate
    3. Low

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Example: Thompson Lumber

4. Payoff table

ALTERNATIVES	OUTCOMES		
	HIGH DEMAND	MODERATE DEMAND	LOW DEMAND
Build large plant	$200,000	$100,000	–$120,000
Build small plant	$ 90,000	$ 50,000	–$ 20,000
No plant	$ 0	$ 0	$ 0

5. Select and apply decision analysis model

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Decision-Making Environments

Type 1: Decision making under certainty

Type 2: Decision making under uncertainty

Type 3: Decision making under risk

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Three Variables in Decision Analytics Problems

- Decision Alternatives are *the various choices or options available to the decision maker in any given problem situation.*
- States of Nature are *the occurrences of nature that can effect the outcome of the decision.* They are beyond the decision maker's control.
- Payoffs are the *benefits or rewards that result from selecting a particular decision alternative.* They are often expressed in dollars, but may be stated in other units, such as market share.

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Decision Table

Decision Alternatives

States of Nature

	s_1	s_2	s_3	$\cdots$	s_n
d_1	$P_{1,1}$	$P_{1,2}$	$P_{1,3}$	$\cdots$	$P_{1,n}$
d_2	$P_{2,1}$	$P_{2,2}$	$P_{2,3}$	$\cdots$	$P_{2,n}$
d_3	$P_{3,1}$	$P_{3,2}$	$P_{3,3}$	$\cdots$	$P_{3,n}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
d_m	$P_{m,1}$	$P_{m,2}$	$P_{m,3}$	$\cdots$	$P_{m,n}$

where: s_j = state of nature
d_j = decision alternative
$P_{i,j}$ = payoff for decision i under state j

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Case for Certainty

- Consequence of every alternative is known
- Usually only one outcome for each alternative
- Occasionally occurs in reality

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Case for Uncertainty

- Probabilities of possible outcomes not known
- Decision making methods:
  1. Maximax
  2. Maximin
  3. Criterion of realism
  4. Equally likely
  5. Minimax regret

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Making Decisions with Uncertain Information

- The purpose of business analytic models is to provide decision-makers with information needed to make decisions.
- There are often trade-offs to consider when making decisions.
- Making decisions requires human assessment of factors not included in analytic models.
- Understanding the philosophy of decision making and how to deal with uncertainty and risk is vitally important to being a good manager.

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Making Decisions with Uncertain Information

- Many decisions involve making a choice between a small set of decisions with uncertain consequences.
- Such decisions involve:
  1. a number of decision alternatives
  2. outcomes that may occur (events)
  3. payoffs associated with the events (often summarized in a payoff table)

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Making Decisions with Uncertain Information

Example 1: Selecting a Mortgage Instrument

- A family is considering purchasing a new home and wants to finance $150,000.
- Three mortgage options are available and the payoff table for the outcomes is shown below.
- The payoffs represent total interest paid under three future interest rate situations.

	Outcome		
Decision	Rates Rise	Rates Stable	Rates Fall
1-year ARM	$61,134	$46,443	$40,161
3-year ARM	$56,901	$51,075	$46,721
30-year fixed	$54,658	$54,658	$54,658

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Making Decisions with Uncertain Information

Decision Strategies for a MINIMUM Objective

Average Payoff Strategy

- Choose the decision with the smallest average payoff.

Aggressive Strategy - Minimin

- Choose the strategy with minimum of the smallest possible payoffs for each decision.

Conservative Strategy - Minimax

- Choose strategy with minimum of the largest possible payoffs for each decision.

Opportunity Loss Strategy - Minimax Regret

- Choose the strategy with the minimum opportunity-loss: its payoff – best payoff for that outcome

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Making Decisions with Uncertain Information

Case 1: Mortgage Decision with the Average Payoff Strategy

- Suppose the family decides to use the average payoff strategy.
- Compute the *average* interest cost for each type of mortgage and choose the minimum.

	Outcome			
Decision	Rates Rise	Rates Stable	Rates Fall	Average Payoff
1-year ARM	$61,134	$46,443	$40,161	$49,246
3-year ARM	$56,901	$51,075	$46,721	$51,566
30-year fixed	$54,658	$54,658	$54,658	$54,658

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Making Decisions with Uncertain Information

Case 2: Mortgage Decision with the Aggressive Strategy

- Suppose the family decides to use the aggressive *minimin* payoff strategy.
- Determine the lowest interest cost for each type of mortgage and choose the minimum.

	Outcome			
Decision	Rates Rise	Rates Stable	Rates Fall	Best Payoff
1-year ARM	$61,134	$46,443	$40,161	$40,161
3-year ARM	$56,901	$51,075	$46,721	$46,721
30-year fixed	$54,658	$54,658	$54,658	$54,658

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Making Decisions with Uncertain Information

Case 3: Mortgage Decision with the Conservative Strategy

- Suppose the family decides to use the conservative *minimax* payoff strategy.
- Determine the highest interest cost for each type of mortgage and choose the minimum.

	Outcome			
Decision	Rates Rise	Rates Stable	Rates Fall	Worst Payoff
1-year ARM	$61,134	$46,443	$40,161	$61,134
3-year ARM	$56,901	$51,075	$46,721	$56,901
30-year fixed	$54,658	$54,658	$54,658	$54,658

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Making Decisions with Uncertain Information

Case 4: Mortgage Decision with the Opportunity-Loss Strategy

- Suppose the family decides to minimize their opportunity loss (*minimax regret* strategy).
- For each outcome, compute the opportunity loss as follows:

Step 1:
Find the minimum of each column.

Decision	Outcome		
	Rates Rise	Rates Stable	Rates Fall
1-year ARM	$61,134	$46,443	$40,161
3-year ARM	$56,901	$51,075	$46,721
30-year fixed	$54,658	$54,658	$54,658

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Making Decisions with Uncertain Information

Case 4 (Cont.): Mortgage Decision with the Opportunity-Loss Strategy

	Outcome		
Decision	Rates Rise	Rates Stable	Rates Fall
1-year ARM	$61,134	$46,443	$40,161
3-year ARM	$56,901	$51,075	$46,721
30-year fixed	$54,658	$54,658	$54,658

Step 2: Subtract the minimum column value from each value.

Step 3: Determine the maximum opportunity loss (maximum row value) and choose the minimum.

	Outcome			
Decision	Rates Rise	Rates Stable	Rates Fall	Max Opportunity Loss
1-year ARM	$6,476	$—	$—	$6,476
3-year ARM	$2,243	$4,632	$6,560	$6,560
30-year fixed	$—	$8,215	$14,497	$14,497

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Making Decisions with Uncertain Information

Decision Strategies for a MAXIMUM Objective

→ same basic approaches as for minimum objectives

Average Payoff Strategy

- Choose the decision with the largest average payoff.

Aggressive Strategy - Maximax

- Choose the strategy with maximum of the largest possible payoffs for each decision.

Conservative Strategy - Maximin

- Choose the strategy with minimum of the largest possible payoffs for each decision.

Opportunity Loss Strategy – Minimax Regret

- Choose the strategy with the minimum opportunity loss: best payoff for that outcome – its payoff

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Making Decisions with Uncertain Information

Case 5: Evaluating Risk in the Mortgage Decision

- Suppose the family has obtained the standard deviations of the interest costs associated with each loan type.

Decision	Standard Deviation
1-year ARM	$10,763.80
3-year ARM	$5,107.71
30-year fixed	$—

- While none of the previous payoff strategies chose the 3-year ARM, it may be attractive to the family due to its moderate risk level and potential upside at stable and falling interest rates.

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Making Decisions with Uncertain Information

Case 6: Mortgage Decision with the Expected Value Strategy

- Suppose the family has obtained probability information concerning future interest rates.
- For each loan type, compute the expected value of the interest cost and choose the minimum.

	Outcome			
	0.6	0.3	0.1	
Decision	Rates Rise	Rates Stable	Rates Fall	Expected Payoff
1-year ARM	$61,134	$46,443	$40,161	$54,629.40
3-year ARM	$56,901	$51,075	$46,721	$54,135.20
30-year fixed	$54,658	$54,658	$54,658	$54,658.00

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Decision Making Criteria Under Uncertainty

- Average Payoff: Choose the best with largest average payoff.
- Maximax payoff: Choose the best of the best
- Maximin payoff: Choose the best of the worst
- Hurwicz payoff: Use a weighted average of the extremes
- Minimax regret: Minimize the maximum opportunity loss

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Example: Decision Table for an Investor

	Stagnant	Slow Growth	Rapid Growth
Stocks	$ (500)	$ 700	$ 2,200
Bonds	$ (100)	$ 600	$ 900
CDs	$ 300	$ 500	$ 750
Mixture	$ (200)	$ 650	$ 1,300

Annual payoffs for an investment of $10,000

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Decision-Making Under Certainty

The states of nature are known.

	Stagnant	Slow Growth	Rapid Growth
Stocks	$ 500)	$ 00	$ 2,200
Bonds	$ 100)	$ 00	$ 00
CDs	$ 00	$ 00	$ 50
Mixture	$ 200)	$ 50	$,300

Annual payoffs for an investment of $10,000

The economy will grow rapidly. Invest in stocks.

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Maximax Criterion

1. Identify the maximum payoff for each alternative.
2. Choose the alternative with the largest maximum.

	Stagnant	Slow Growth	Rapid Growth	Maximum
Stocks	$ (500)	$ 700	$ 2,200	$ 2,200
Bonds	$ (100)	$ 600	$ 900	$ 900
CDs	$ 300	$ 500	$ 750	$ 750
Mixture	$ (200)	$ 650	$ 1,300	$ 1,300

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Maximin Criterion

1. Identify the minimum payoff for each alternative.
2. Choose the alternative with the largest minimum.

	Stagnant	Slow Growth	Rapid Growth	Minimum
Stocks	$ (500)	$ 700	$ 2,200	$ (500)
Bonds	$ (100)	$ 600	$ 900	$ (100)
CDs	$ 300	$ 500	$ 750	$ 300
Mixture	$ (200)	$ 650	$ 1,300	$ (200)

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Hurwicz Criterion

1. Identify the maximum payoff for each alternative.
2. Identify the minimum payoff for each alternative.
3. Calculate a weighted average of the maximum and the minimum using α and $(1 - \alpha)$ for weights.
4. Choose the alternative with the largest weighted average.

	Stagnant	Slow Growth	Rapid Growth	Maximum (α =.7)	Minimum ($1-\alpha$ =.3)	Weighted Average
Stocks	$ (500)	$ 700	$ 2,200	$ 2,200	$ (500)	$ 1,390
Bonds	$ (100)	$ 600	$ 900	$ 900	$ (100)	$ 600
CDs	$ 300	$ 500	$ 750	$ 750	$ 300	$ 615
Mixture	$ (200)	$ 650	$ 1,300	$ 1,300	$ (200)	$ 850

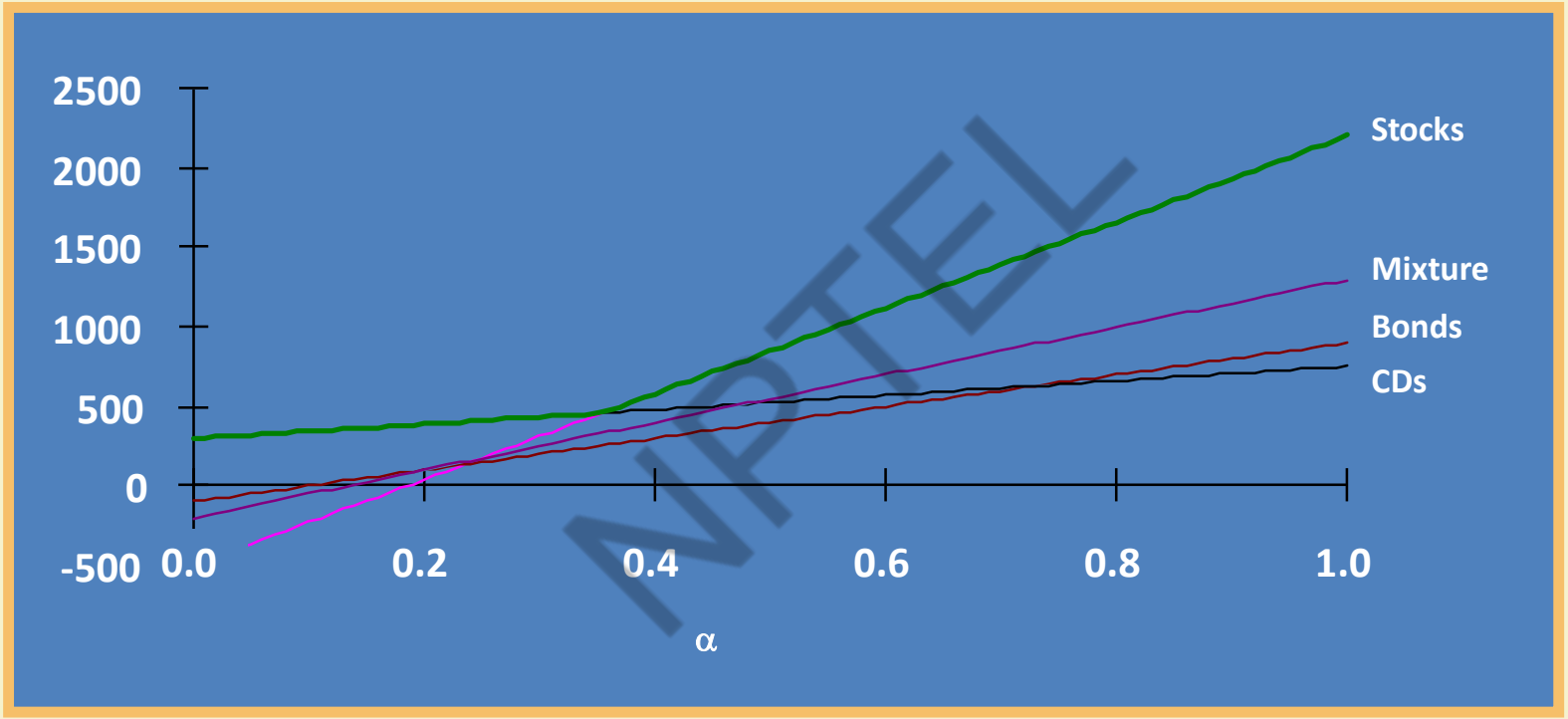
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Decision Alternatives for Various Values of α

		Stocks		Bonds		CDs		Mixture	
		Max	Min	Max	Min	Max	Min	Max	Min
α	1-α	2,200	-500	900	-100	750	300	1,300	-200
0.0	1.0	-500		-100		300		-200	
0.1	0.9	-230		0		345		-50	
0.2	0.8	40		100		390		100	
0.3	0.7	310		200		435		250	
0.4	0.6	580		300		480		400	
0.5	0.5	850		400		525		550	
0.6	0.4	1120		500		570		700	
0.7	0.3	1390		600		615		850	
0.8	0.2	1660		700		660		1000	
0.9	0.1	1930		800		705		1150	
1.0	0.0	2200		900		750		1300	

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Hurwicz Criterion Selections for Various Values of α



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Investment Example: Selected Regrets

	Stagnant	Slow Growth	Rapid Growth
Stocks	$ (500)	$ 700	$ 2,200
Bonds	$ (100)	$ 600	$ 900
CDs	$ 300	$ 500	$ 750
Mixture	$ (200)	$ 650	$ 1,300

I invested in stocks, and the economy grew slowly. I have no regrets.

I invested in stocks. Then the economy stagnated. I regret not investing in CDs. I am $800 down from where I could have been.

I invested in CDs. Then the economy grew rapidly. I am out $1,450.

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Investment Example: Opportunity Loss Table

	Stagnant	Slow Growth	Rapid Growth
Stocks	800	0	0
Bonds	400	100	1,300
CDs	0	200	1,450
Mixture	500	50	900

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Investment Example: Calculating Opportunity Loss

Payoff Table

	Stagnant	Slow Growth	Rapid Growth
Stocks	$ (500)	$ 700	$ 2,200
Bonds	$ (100)	$ 600	$ 900
CDs	$ 300	$ 500	$ 750
Mixture	$ (200)	$ 650	$ 1,300

Opportunity Loss Table

	Stagnant	Slow Growth	Rapid Growth
Stocks	800	0	0
Bonds	400	100	1,300
CDs	0	200	1,450
Mixture	500	50	900

$$OL_{i,j} = \text{Max(column j)} - P_{i,j}$$

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Minimax Regret

1. Identify the maximum regret for each alternative.
2. Choose the alternative with the least maximum regret.

	Stagnant	Slow Growth	Rapid Growth	Maximum
Stocks	800	0	0	**800**
Bonds	400	100	1,300	1,300
CDs	0	200	1,450	1,450
Mixture	500	50	900	900

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Making Decisions with Uncertain Information

Summary of Decision Strategies Under Uncertainty

Strategy/ Objective	Average Payoff Strategy	Aggressive Strategy	Conservative Strategy	Opportunity-Loss Strategy
Minimize objective	Choose the decision with the smallest average payoff.	Find the smallest payoff for each decision among all outcomes, and choose the decision with the smallest of these (*minimum*).	Find the largest payoff for each decision among all outcomes, and choose the decision with the smallest of these (*minimax*).	For each outcome, compute the opportunity loss for each decision as the difference between its payoff and the *smallest* payoff for that outcome. Find the maximum opportunity loss for each decision, and choose the decision with the smallest opportunity loss (*minimax regret*).
Maximize objective	Choose the decision with the largest average payoff.	Find the largest payoff for each decision among all outcomes, and choose the decision with the largest of these (*maximax*).	Find the smallest payoff for each decision among all outcomes, and choose the decision with the largest of these (*maximin*).	For each outcome, compute the opportunity loss for each decision as the difference between its payoff and the *largest* payoff for that outcome. Find the maximum opportunity loss for each decision, and choose the decision with the smallest opportunity loss (*minimax regret*).

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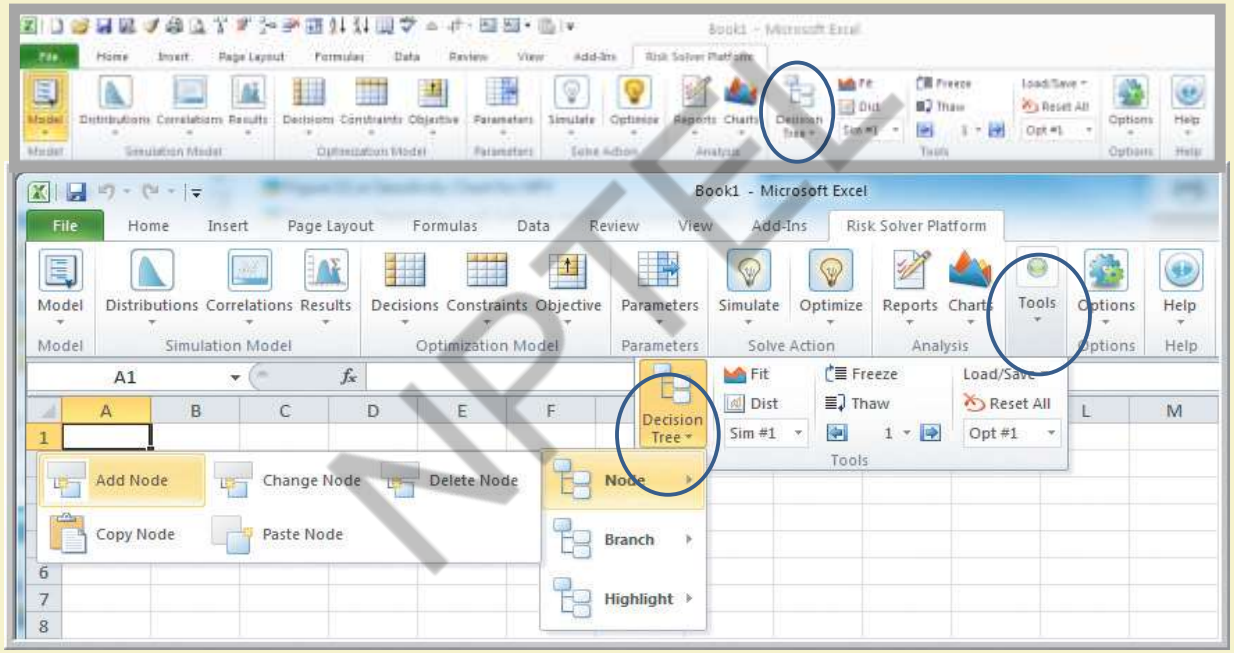
Decision Trees

- Decision trees, which consist of nodes and branches, are a useful approach to structuring decision problems involving uncertainty.
- Nodes are points in time at which events take place.
- Decision nodes are nodes in which a decision takes place by choosing among several alternatives (typically denoted as squares).
- Event nodes are nodes in which an event occurs not controlled by the decision-maker (typically denoted as circles).

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Decision Trees

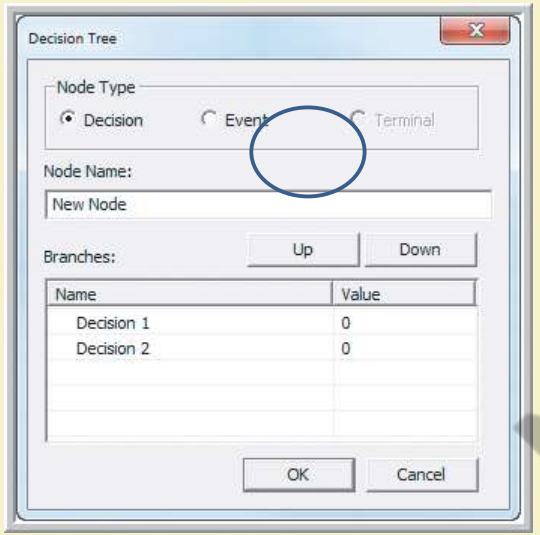
Decision Tree Menu in *Risk Solver Platforms*

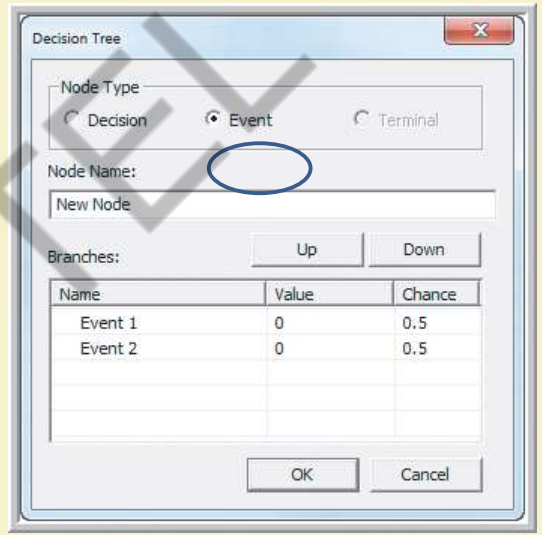


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Decision Trees

Decision Tree Node Dialogs in *Risk Solver Platform*





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Decision Trees

Example: Creating a Decision Tree

- For the mortgage selection problem, create a decision tree using *Risk Solver.*
- To start the decision tree, add a node for selection of the loan type.
- Then, for each type of loan, add a node for selection of the uncertain interest rate conditions.

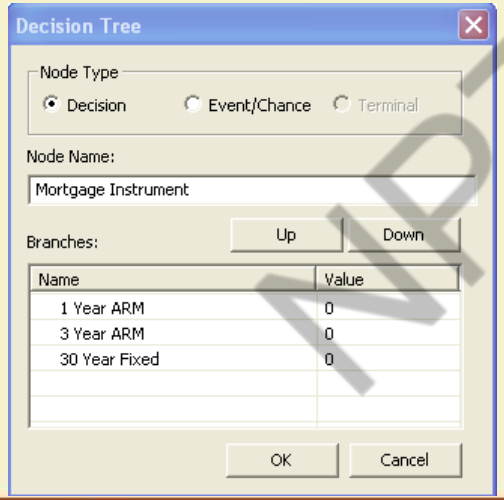
	Outcome		
	0.6	0.3	0.1
Decision	Rates Rise	Rates Stable	Rates Fall
1-year ARM	$61,134	$46,443	$40,161
3-year ARM	$56,901	$51,075	$46,721
30-year fixed	$54,658	$54,658	$54,658

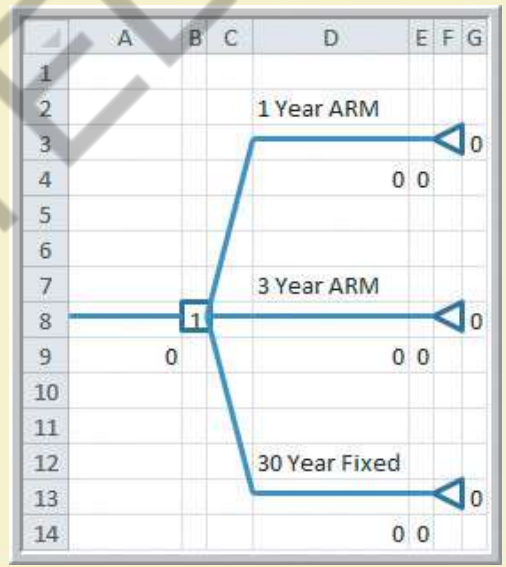
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Decision Trees

Example (contd.): Creating a Decision Tree

Decision Tree > Node > Add Node



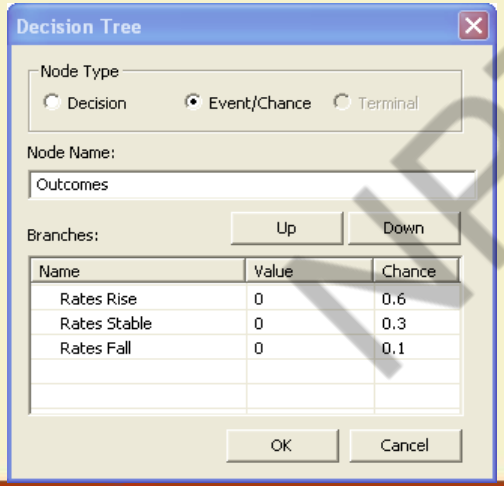


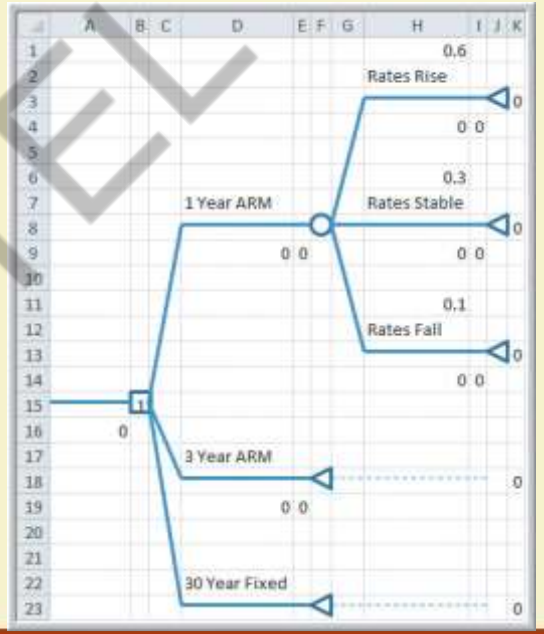
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Decision Trees

Example (contd.): Creating a Decision Tree

Select the 1 Year ARM end node.
Decision Tree > Node > Add Node





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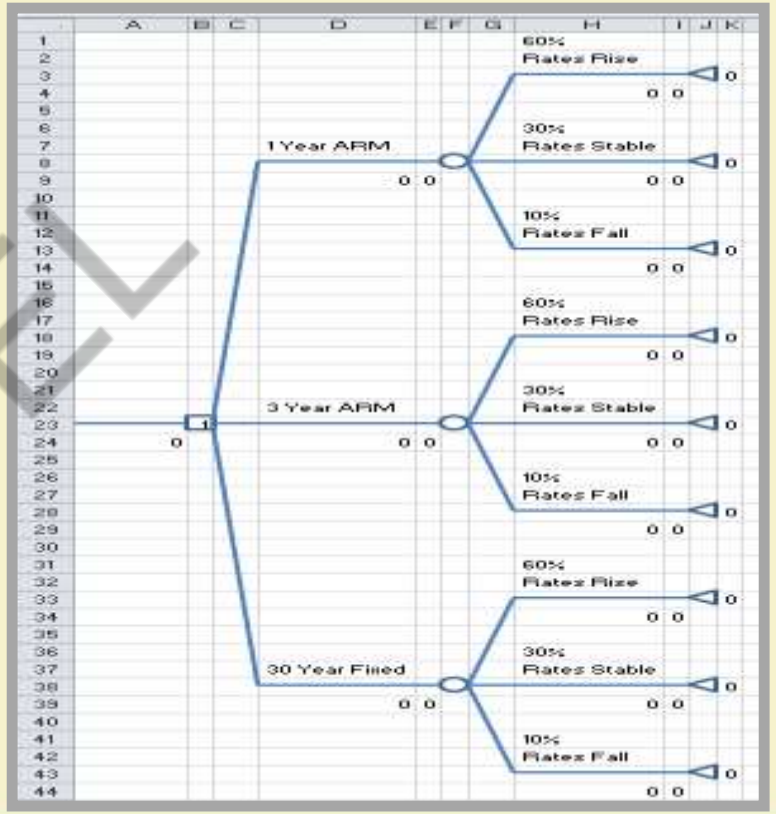
Decision Trees

Example (contd.): Creating a Decision Tree

Select 1 Year ARM end node.
Decision Tree > Node > Copy Node

Select 3 Year ARM end node.
Paste Node

Select 30 Year Fixed end node.
Paste Node



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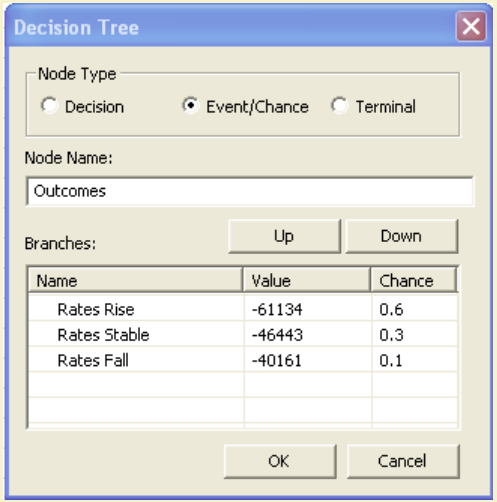
Decision Trees

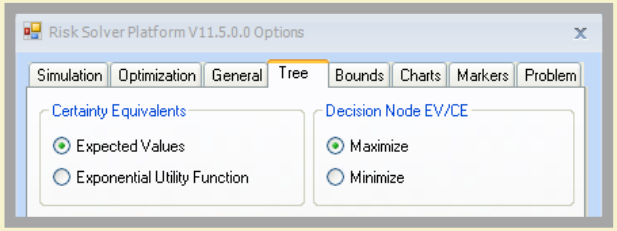
Example (contd.): Creating a Decision Tree

Select the top right branch of the tree.
Decision Tree > Branch > Change Branch
Enter the interest costs as negative values (or simply enter the values in column H).

Repeat for the other two mortgage types.

Optional:
Change the objective to minimize.
Remove the negative signs from costs.
Options > All Options > Tree > Minimize





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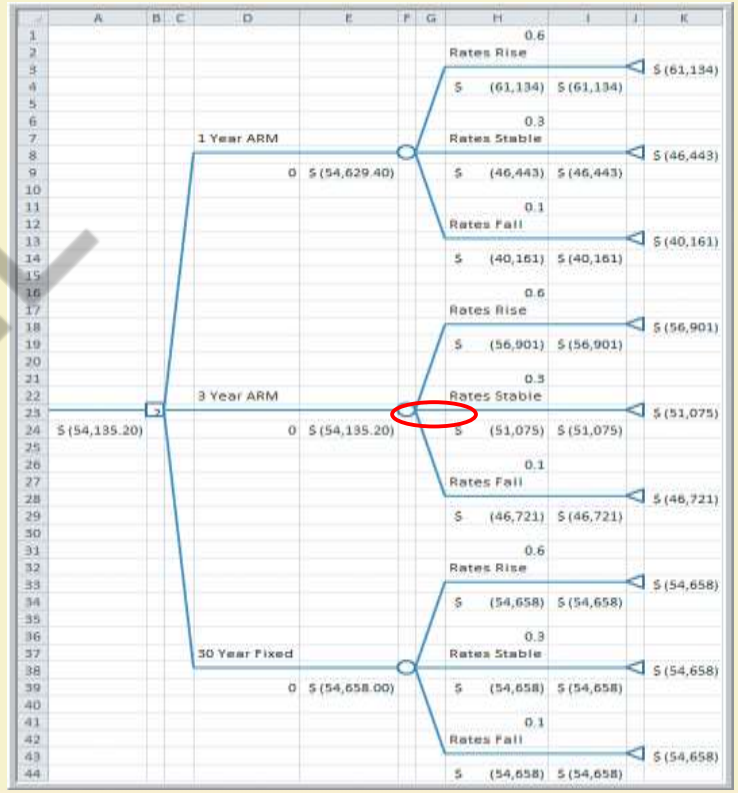
Decision Trees

Example (contd.): Creating a Decision Tree

Expected values are computed automatically for the 3 mortgage types.

The maximum expected value is provided at the start of the decision tree.

The 3 Year ARM has the minimum expected interest cost at $54,135.20.



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Decision Trees

Example (contd.): Creating a Decision Tree

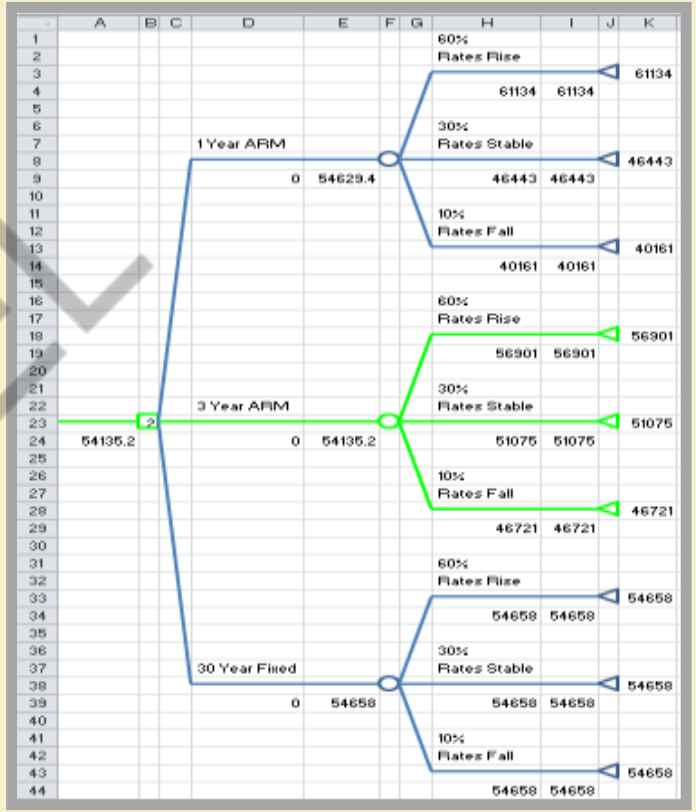
Solved as a Minimization Problem

Best decision can be highlighted

Decision Tree

Highlight

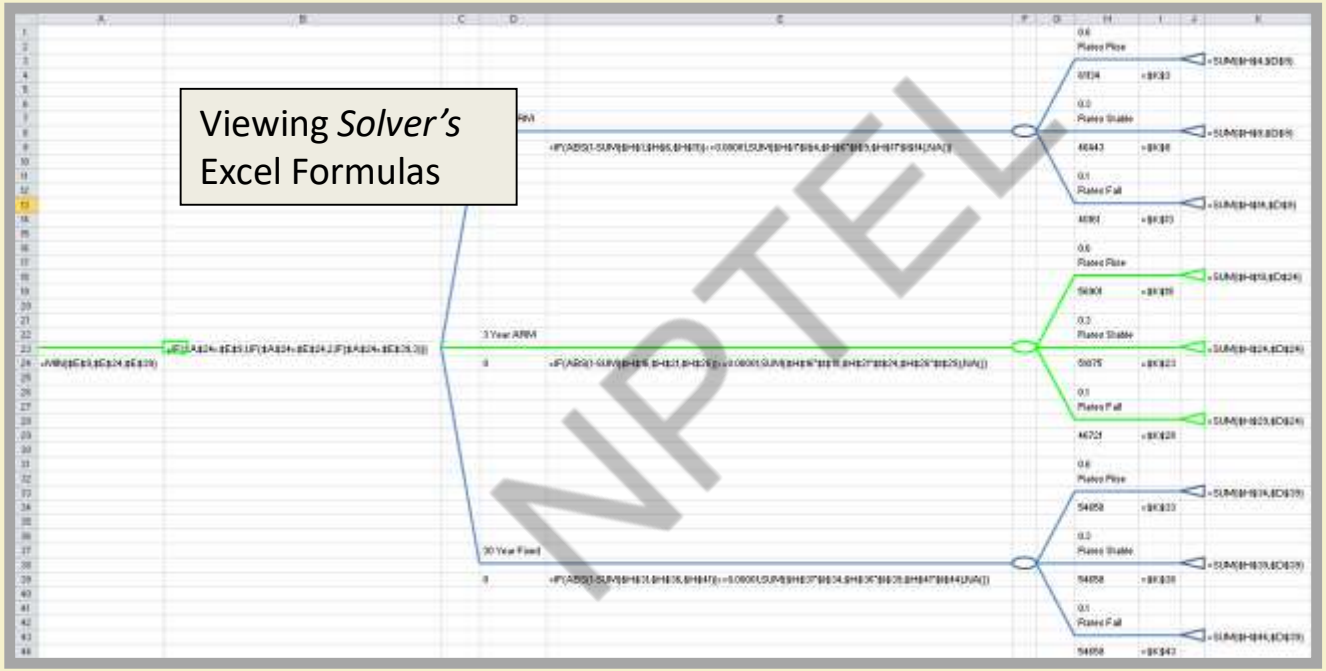
Highlight Best



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Decision Trees

Example (contd.): Creating a Decision Tree



Decision Trees

Example: A Pharmaceutical R&D Model

- *Moore Pharmaceuticals* needs to decide whether to conduct clinical trials and seek FDA approval for a newly developed drug.
- $300 million has already been spent on research.
- The next decision is whether to conduct clinical trials at a cost of $250 million.
- 30% is the likelihood of success following trials.
- If the trials are successful, the next decision is whether to seek FDA approval, costing $25 million.
- 60% is likelihood of FDA approval.

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Decision Trees

Example (contd.): A Pharmaceutical R&D Model

- If the FDA approves the drug, it will be marketed
- Market response is uncertain as shown below.

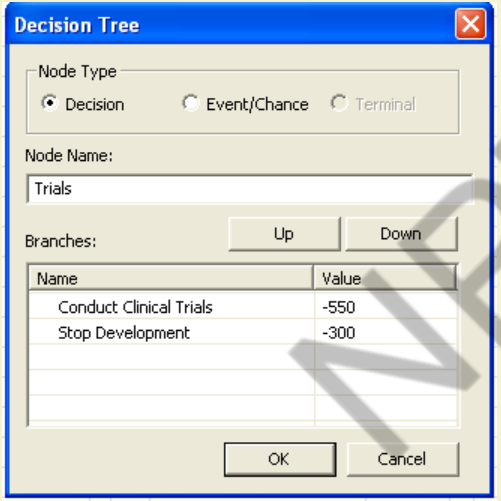
	Market Potential Expected Revenues (millions of $)	Probability
Large	$4,500	0.6
Medium	$2,200	0.3
Small	$1,500	0.1

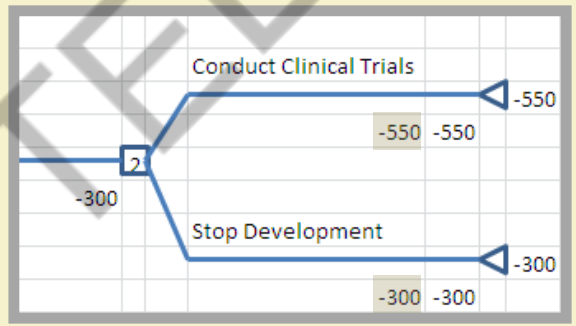
- A decision tree can be developed for this scenario.

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Decision Trees

Example (contd.): A Pharmaceutical R&D Model

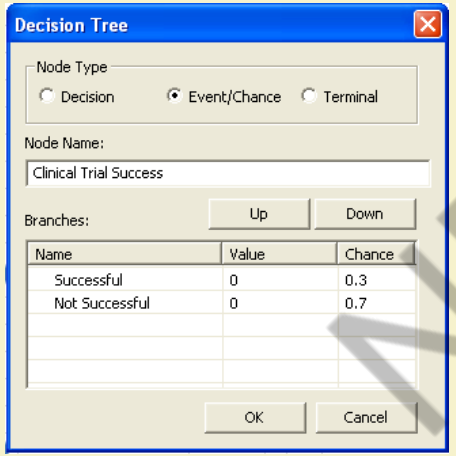


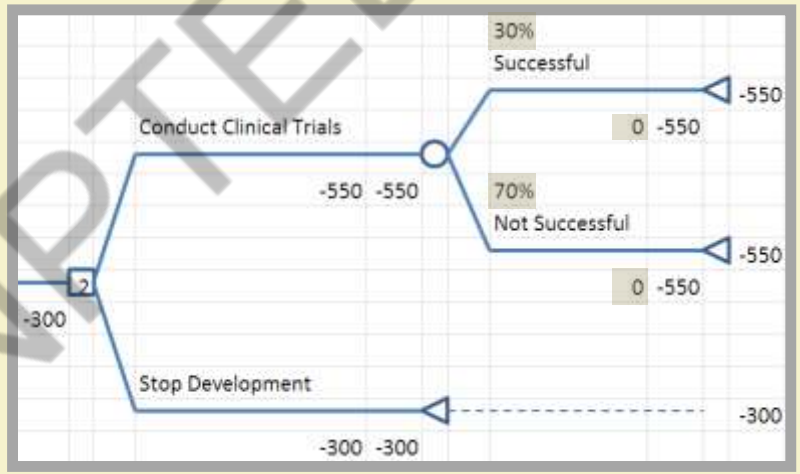


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Decision Trees

Example (contd.): A Pharmaceutical R&D Model

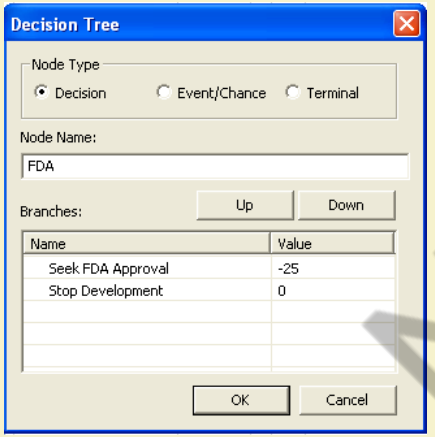


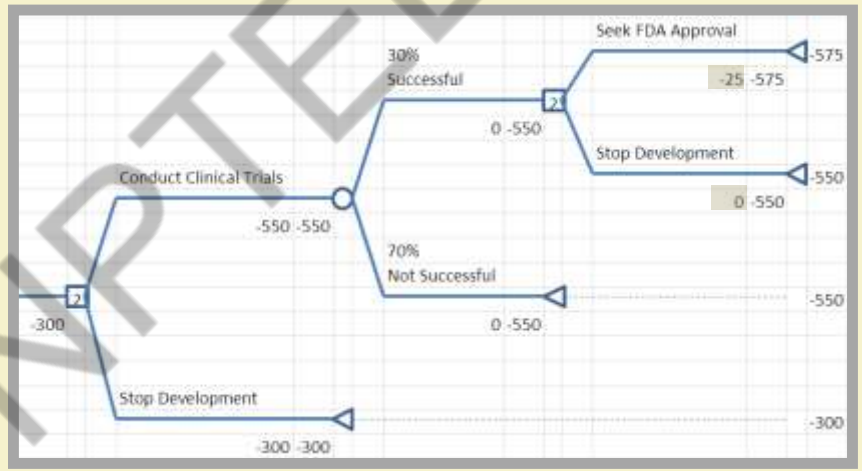


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Decision Trees

Example (contd.): A Pharmaceutical R&D Model

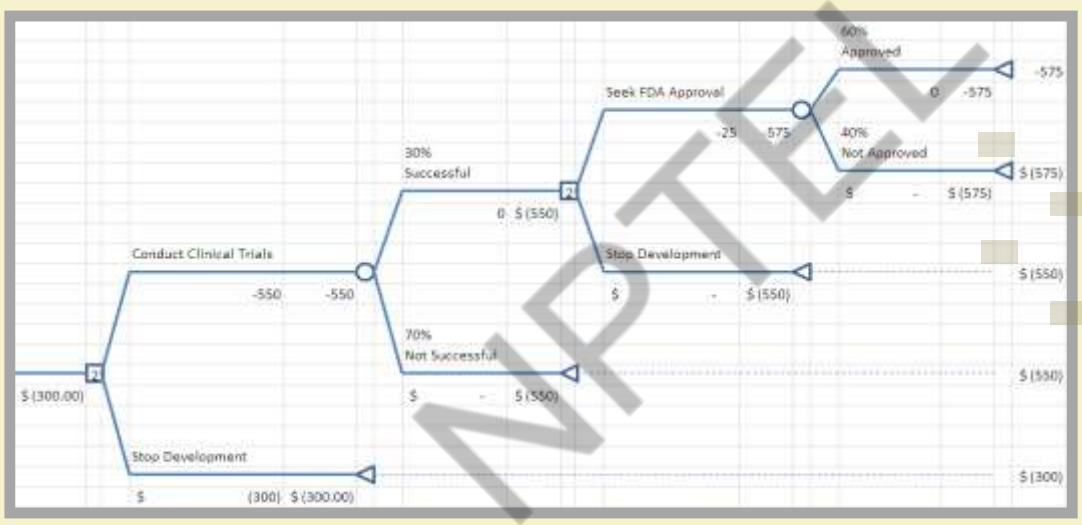


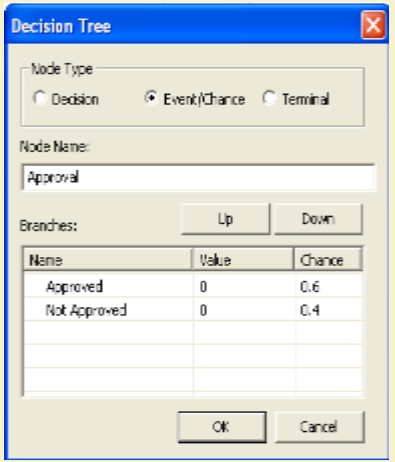


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Decision Trees

Example (contd.): A Pharmaceutical R&D Model

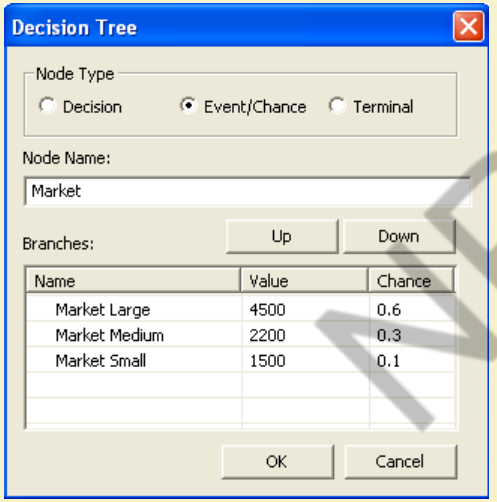




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Decision Trees

Example (contd.): A Pharmaceutical R&D Model



Partial Decision Tree

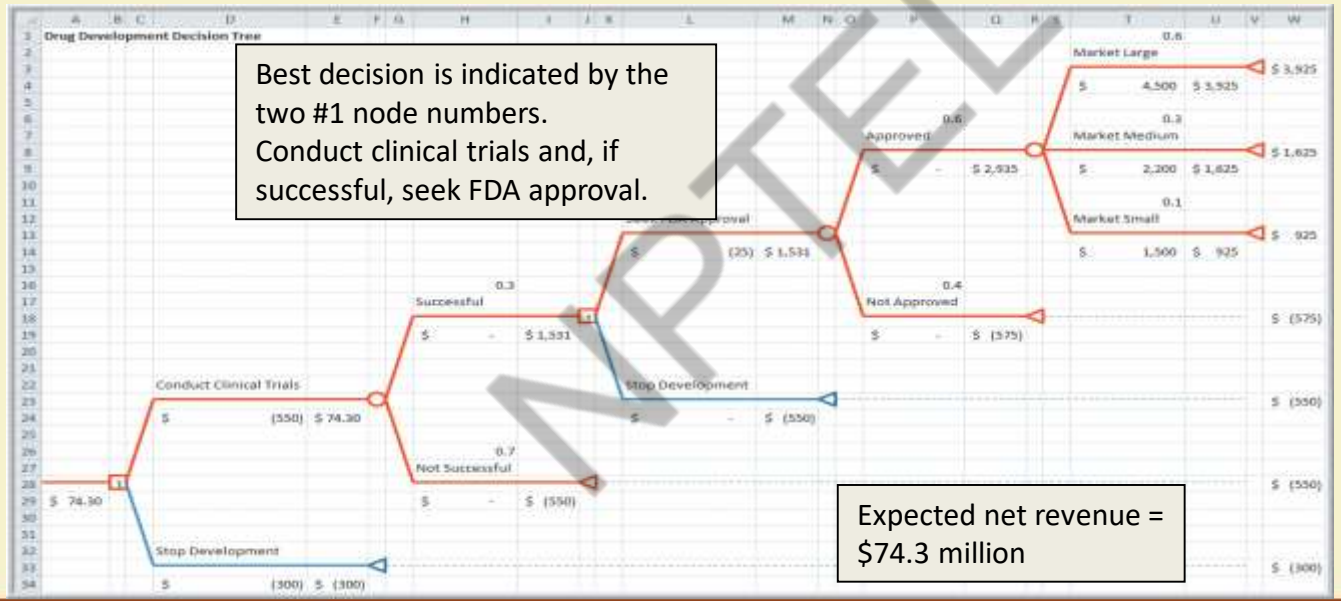


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Decision Trees

Example (contd.): A Pharmaceutical R&D Model

Completed Decision Tree



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Decision Trees

Example: Simulating the Drug-Development Decision Tree Model

- Suppose there are uncertainties we need to incorporate into the *Moore Pharmaceuticals* drug development decision tree.

Market payoffs:

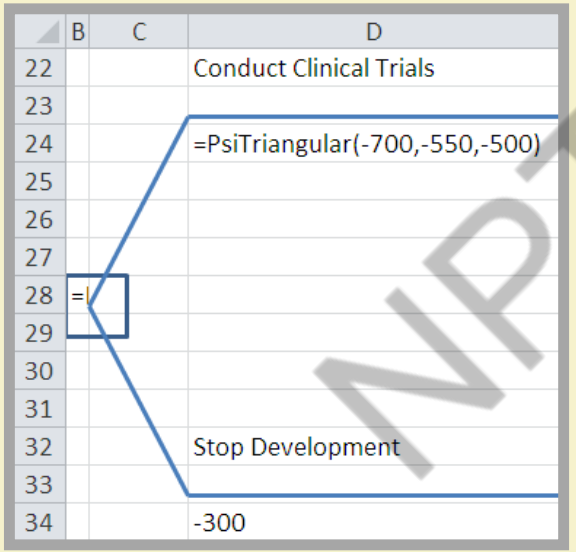
- Large response: =PsiLogNormal(4500, 1000)
- Medium response: =PsiLogNormal(2200, 500)
- Small response: =PsiNormal(1500, 200)

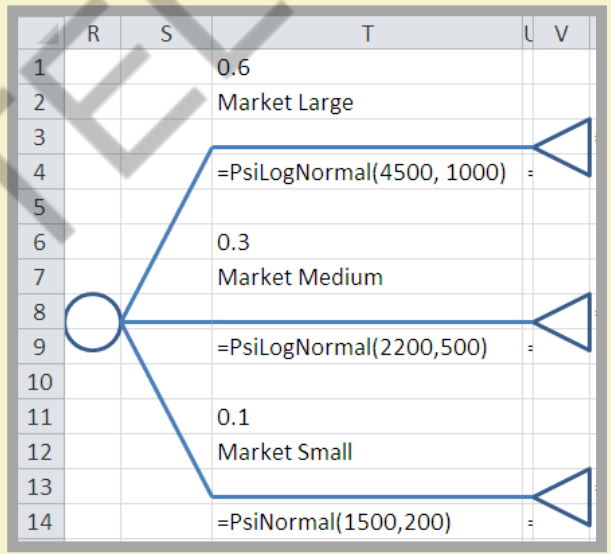
Clinical Trial Cost: =PsiTriangular(-700, -550, -500)

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Decision Trees

Example (contd.) Simulating the Drug-Development Decision Tree Model



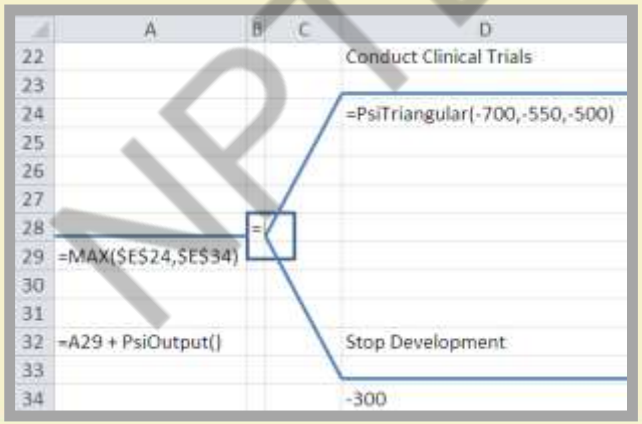


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Decision Trees

Example (contd.) Simulating the Drug-Development Decision Tree Model

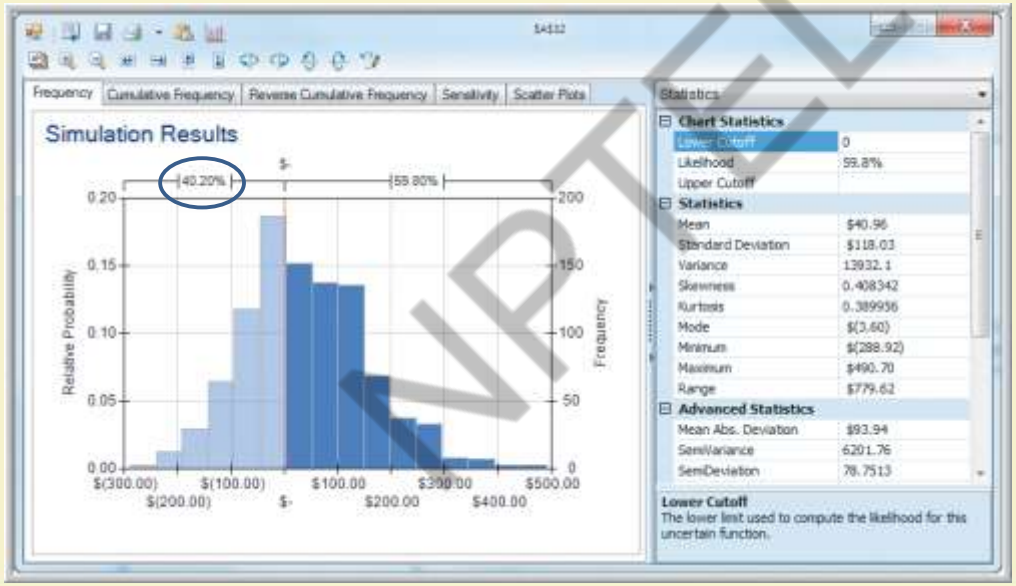
- To define the changing output cell, we cannot use the decision tree's net revenue cell (A29).
- So, in any empty cell enter, =A29 + PsiOutput()



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Decision Trees

Example (contd.) Simulating the Drug-Development Decision Tree Model



Expected net revenue = $47 million

40% chance of losing more money.

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Decision Trees

Decision Trees and Risk

- Decision trees are an example of expected value decision making and do not explicitly consider risk.
- For *Moore Pharmaceutical's* decision tree, we can form a classical decision table.

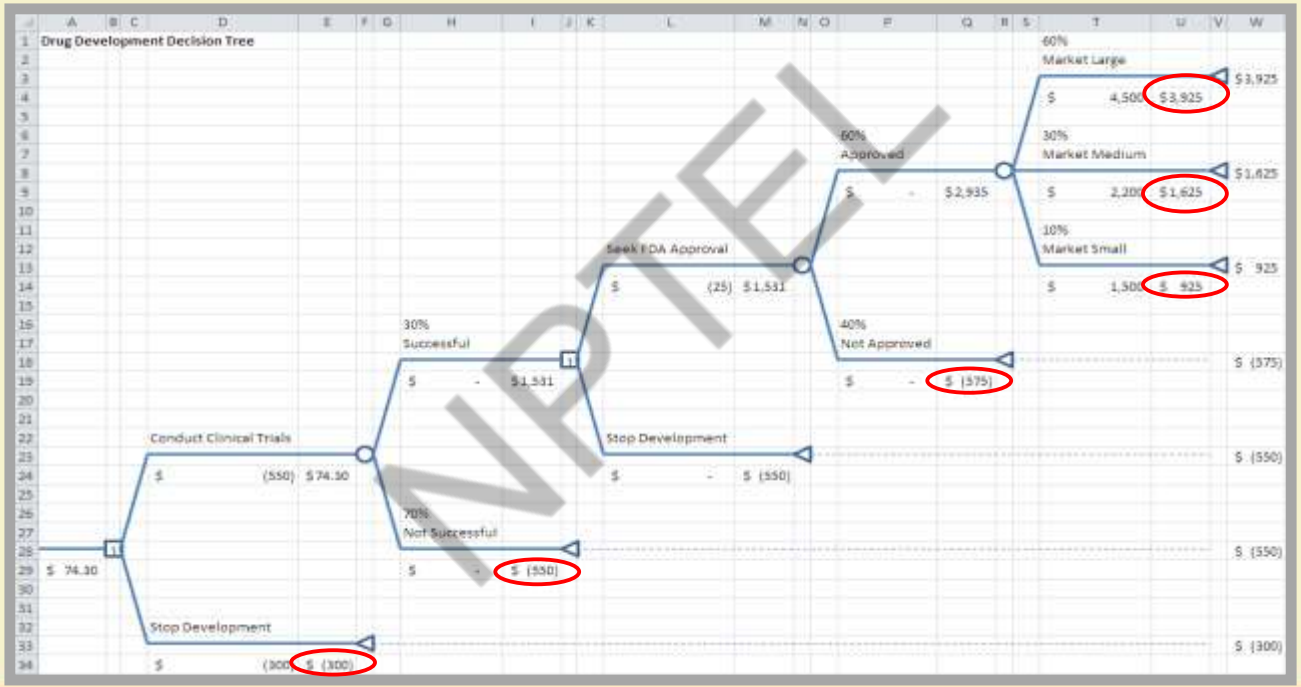
	Unsuccessful Clinical Trials	Successful Clinical Trials; No FDA Approval	Successful Trials and Approval; Large Market	Successful Trials and Approval; Medium Market	Successful Trials and Approval; Small Market
Develop drug	($550)	($575)	$3,925	$1,625	$925
Stop development	($300)	($300)	($300)	($300)	($300)

- We can then apply aggressive, conservative, and opportunity loss decision strategies.

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Decision Trees

Decision Trees and Risk (continued)



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Decision Trees

Decision Trees and Risk (continued)

- Applying the Aggressive Maximax Strategy

	Unsuccessful Clinical Trials	Successful Clinical Trials; No FDA Approval	Successful Trials and Approval; Large Market	Successful Trials and Approval; Medium Market	Successful Trials and Approval; Small Market
Develop drug	($550)	($575)	$3,925	$1,625	$925
Stop development	($300)	($300)	($300)	($300)	($300)

	Maximum
Develop drug	$3,925
Stop development	($300)

- Developing the new drug maximizes the maximum payoff.

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Decision Trees

Decision Trees and Risk (continued)

- Applying the Conservative Maximin Strategy

	Unsuccessful Clinical Trials	Successful Clinical Trials; No FDA Approval	Successful Trials and Approval; Large Market	Successful Trials and Approval; Medium Market	Successful Trials and Approval; Small Market
Develop drug	($550)	($575)	$3,925	$1,625	$925
Stop development	($300)	($300)	($300)	($300)	($300)

	Minimum
Develop drug	($575)
Stop development	($300)

- Stopping development of the new drug maximizes the minimum payoff.

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Decision Trees

Decision Trees and Risk (continued)

- Applying the Opportunity-Loss Strategy

	Unsuccessful Clinical Trials	Successful Clinical Trials; No FDA Approval	Successful Trials and Approval; Large Market	Successful Trials and Approval; Medium Market	Successful Trials and Approval; Small Market
Develop drug	($550)	($575)	$3,925	$1,625	$925
Stop development	($300)	($300)	($300)	($300)	($300)

Opportunity Losses

	Unsuccessful Clinical Trials	Successful Clinical Trials; No FDA Approval	Successful Trials and Approval; Large Market	Successful Trials and Approval; Medium Market	Successful Trials and Approval; Small Market	Maximum
Develop drug	$250	$275	$–	$–	$–	$275
Stop development	$–	$–	$4,225	$1,925	$1,225	$4,225

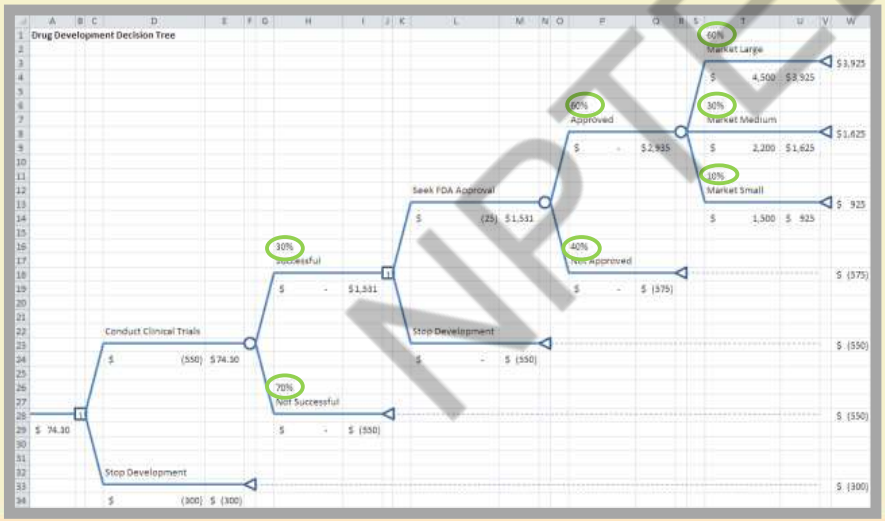
- Developing the new drug minimizes the maximum opportunity loss.

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Decision Trees

Example: Constructing a Risk Profile

- For *Moore Pharmaceutical's* drug-development decision, we can easily construct a risk profile using the decision tree probabilities.



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Decision Trees

Example (contd.): Constructing a Risk Profile

Compute the probability of each terminal outcome.

- *P*(Large market) = (.3)(.6)(.6) = 0.108
- *P*(Medium market) = (.3)(.6)(.3) = 0.054
- *P*(Small market) = (.3)(.6)(.1) = 0.018
- *P*(FDA not approved) = (.3)(.4) = 0.120
- *P*(Clinical trials not successful) = 0.700
- SUM 1.000

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Decision Trees

Example (contd.): Constructing a Risk Profile

Terminal Outcome	Net Revenue	Probability
Market large	$3,925	0.108
Market medium	$1,625	0.054
Market small	$925	0.018
FDA not approved	($575)	0.120
Clinical trials not successful	($550)	0.700

- *P*(never to market) = 1 – 0.108 – 0.054 – 0.018
  = 82%
- Should they stop now and lose $300 million or continue on and have an 82% chance of losing an additional $550-$575 million?

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Decision Trees

Example: Sensitivity Analysis for Airline Revenue Management Decisions

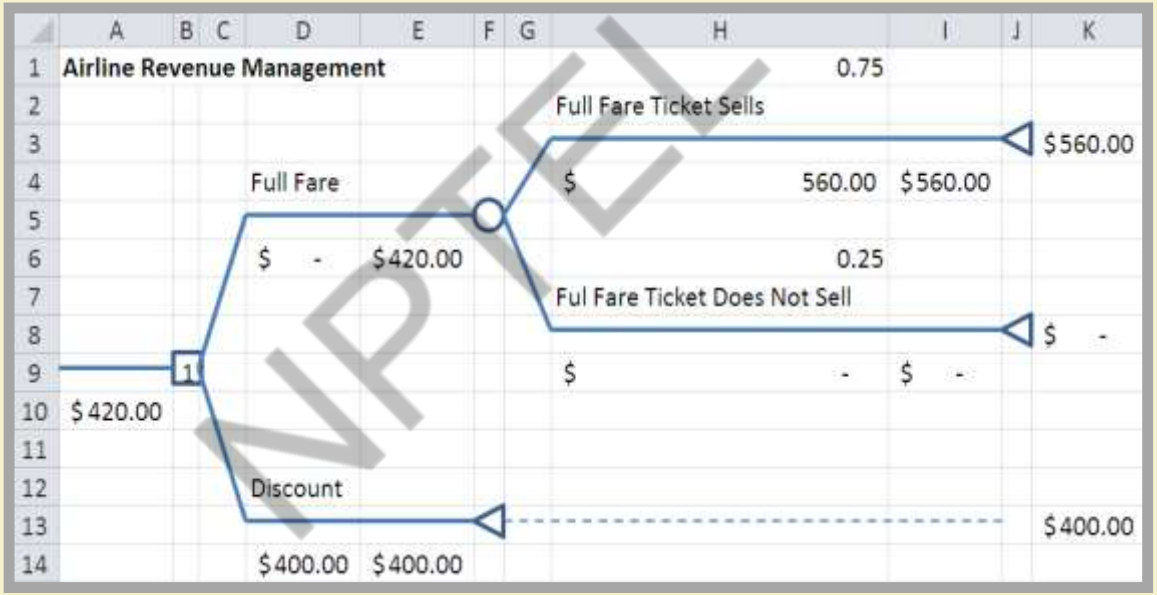
Recall Example 5.21- *Airline Revenue Management*

- Full and discount airfares are available for a flight.
- Full-fare ticket costs $560
- Discount ticket costs $400
- X = selling price of a ticket
- p = 0.75 (the probability of selling a full-fare ticket)
- $E[X]$ = 0.75($560) + 0.25(0) = $420
- Breakeven point: $400 = p($560) or p = 0.714

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Decision Trees

Example (contd.): Sensitivity Analysis for Airline Revenue Management Decisions



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Decision Trees

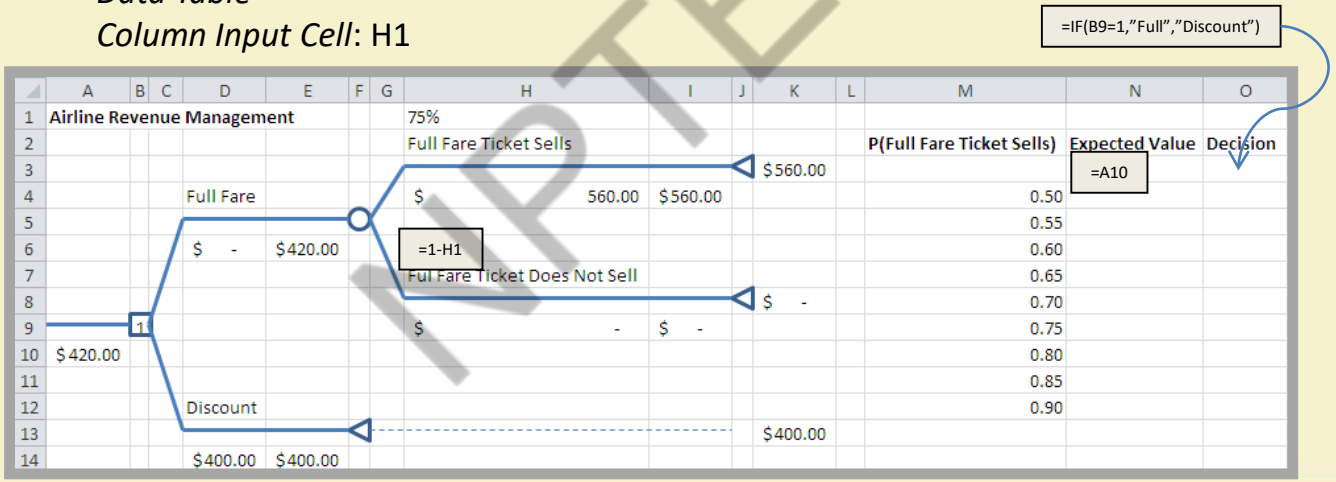
Example (contd.): Sensitivity Analysis for Airline Revenue Management Decisions

Create a Data Table that varies full fare probabilities.

Select M3:O12

Data Table

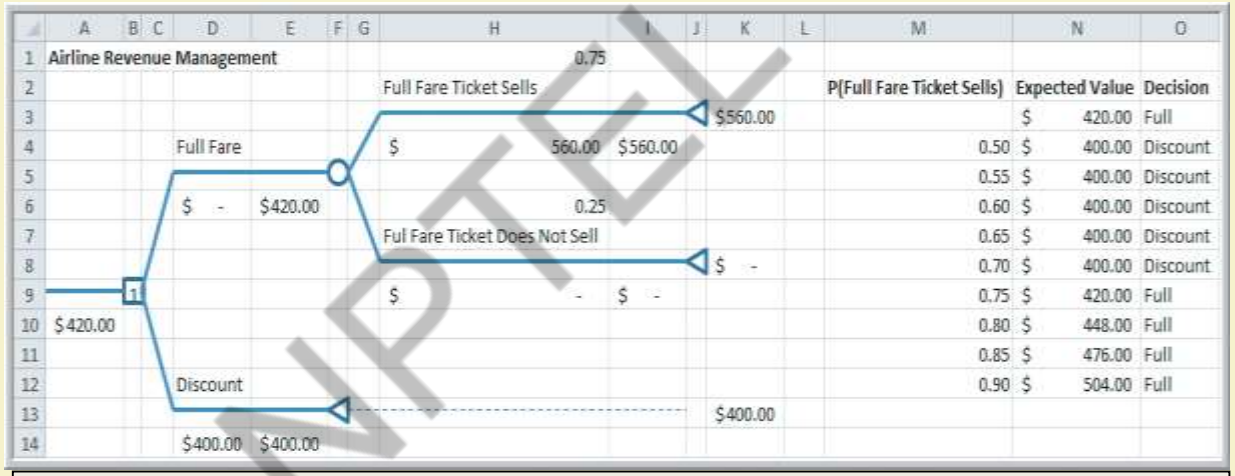
Column Input Cell: H1



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Decision Trees

Example (contd.): Sensitivity Analysis for Airline Revenue Management Decisions



	P(Full Fare Ticket Sells)	Expected Value	Decision
		$ 420.00	Full
	0.50	$ 400.00	Discount
	0.55	$ 400.00	Discount
	0.60	$ 400.00	Discount
	0.65	$ 400.00	Discount
	0.70	$ 400.00	Discount
	0.75	$ 420.00	Full
	0.80	$ 448.00	Full
	0.85	$ 476.00	Full
	0.90	$ 504.00	Full

Discount the price if the probability of selling a full fare ticket is 70% or less.

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Business Analytics for Management Decision

Decision Analytics [59]

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Course Contents

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Week 1	:	Introduction to Business Analytics
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Week 7	:	Predictive Analytics 2
Week 8	:	Predictive Analytics 3
Week 9	:	Prescriptive Analytics 1
Week 10	:	Prescriptive Analytics 2
Week 11	:	Prescriptive Analytics 3
Week 12	:	Decision Analytics

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The Value of Information

Expected Value of Perfect Information (EVPI)

- The value of information is the improvement in return if additional information is acquired.
- Perfect information tell us, with certainty, which outcome will occur.
- EVPI is expected monetary value (EMV) with perfect information minus the EMV without it.
- Expected opportunity loss is the average additional amount the investor would have achieved if the correct decision had been made.
- *Minimizing expected opportunity loss always results in the same decision as maximizing expected value.*

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The Value of Information

Example: Finding EVPI for the Mortgage-Selection Decision

Decision	Outcome		
	Rates Rise	Rates Stable	Rates Fall
1-year ARM	$61,134	$46,443	$40,161
3-year ARM	$56,901	$51,075	$46,721
30-year fixed	$54,658	$54,658	$54,658

Opportunity Losses

	0.6	0.3	0.1	
Decision	Rates Rise	Rates Stable	Rates Fall	Expected Opportunity Loss
1-year ARM	$6,476	$—	$—	$3,885.60
3-year ARM	$2,243	$4,632	$6,560	$3,391.40 = EVPI
30-year fixed	$—	$8,215	$14,497	$3,914.20

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The Value of Information

Example (contd.): Finding EVPI for the Mortgage-Selection Decision

	Outcome			
	0.6	0.3	0.1	
Decision	Rates Rise	Rates Stable	Rates Fall	Expected Payoff
1-year ARM	$61,134	$46,443	$40,161	$54,629.40
3-year ARM	$56,901	$51,075	$46,721	$54,135.20
30-year fixed	$54,658	$54,658	$54,658	$54,658.00
Best decision	$54,658	$46,443	$40,161	$50.743.80
Difference = EVPI				$3391.40

The family should not pay more than $3391.40 for any information about future interest rates, no matter how good.

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The Value of Information

Decisions with Sample Information

- Sample information is the result of conducting some type of experiment.
- Examples include marketing research studies or interviewing experts.
- Sample information is always imperfect and often comes at a cost.
- The expected value of sample information (EVSI) is the EMV of the outcome with sample information minus the EMV without it.

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The Value of Information

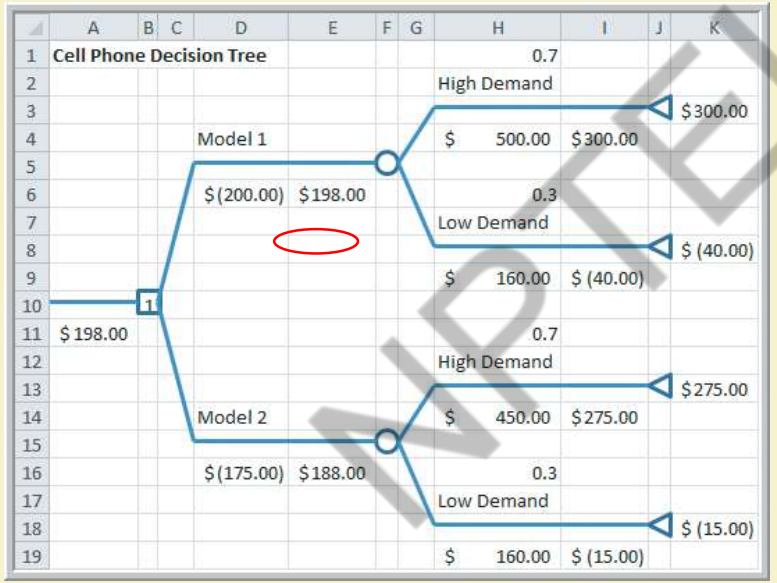
Example: Decisions with Sample Information

- A company is developing a new cell phone and currently has two models under consideration.
- 70% of their new phones have high consumer demand and 30% have low consumer demand.
- Model 1 requires $200,000 investment.
  If demand is high, revenue = $500,000
  If demand is low, revenue = $160,000
- Model 2 requires $175,000 investment.
  If demand is high, revenue = $450,000
  If demand is low, revenue = $160,000

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The Value of Information

Example (contd.): Decisions with Sample Information



Decision tree units are $000.

Choose Model 1
Expected profit
= $198,000

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The Value of Information

Example (contd.): Decisions with Sample Information

- Suppose a market research study is conducted.
- It is known that market research is not completely accurate since, in the past:
- 90% of all products that had high consumer demand received high market survey responses.
- 20% of all products that had low consumer demand received high market survey responses.
- We can update the decision tree using Bayes's rule.

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The Value of Information

Bayes's Rule for Computing Conditional Probabilities

- Bayes's rule allows revising historical probabilities based on new sample information.

$$P(A_i|B) = \frac{P(B|A_i)\,P(A_i)}{P(B|A_1)\,P(A_1) + P(B|A_2)\,P(A_2) + \ldots + P(B|A_k)\,P(A_k)}$$

For the cell phone example:

- D_L = low demand
- D_H = high demand
- M_L = low market survey response
- M_H = high market survey response

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The Value of Information

Example: Applying Bayes's Rule to Compute Conditional Probabilities

- $P(D_H) = 0.70$ $P(D_L) = 0.30$
- $P(M_H \mid D_H) = 0.90$ $P(M_L \mid D_H) = 1 - 0.90 = 0.10$
- $P(M_H \mid D_L) = 0.20$ $P(M_L \mid D_L) = 1 - 0.20 = 0.80$
- $P(D_H \mid M_H) = (.9)(.7)/[(.9)(.7)+(.2)(.3)] = 0.913$
- $P(D_L \mid M_H) = 1 - 0.913 = 0.087$
- $P(D_H \mid M_L) = (.1)(.7)/[(.1)(.7)+(.8)(.3)] = 0.226$
- $P(D_L \mid M_L) = 1 - 0.226 = 0.774$

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The Value of Information

Example (contd.): Applying Bayes's Rule to Compute Conditional Probabilities

- $P(M_H) = P(M_H \mid D_H)*P(D_H) + P(M_H \mid D_L)*P(D_L)$

  $= \quad (.9)(.7) \quad + \quad (.2)(.3)$

  $= 0.69$

- $P(M_L) = P(M_L \mid D_H)*P(D_H) + P(M_L \mid D_L)*P(D_L)$

  $= \quad (.1)(.7) \quad + \quad (.8)(.3)$

  $= 0.31$

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The Value of Information

Example (contd.): Applying Bayes's Rule to Compute Conditional Probabilities

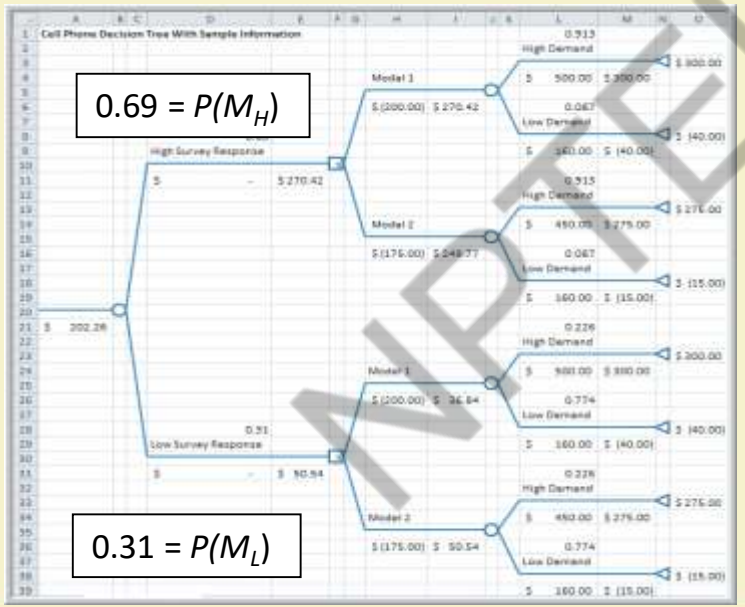
Joint probability table for the cell phone example.

	High Survey Response M_H	Low Survey Response M_L	
High Demand D_H	0.63	0.07	0.70
Low Demand D_L	0.06	0.24	0.30
	0.69	0.31	1.00

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The Value of Information

Example (contd.): Applying Bayes's Rule to Compute Conditional Probabilities



$0.913 = P(D_H \mid M_H)$

$0.087 = P(D_L \mid M_H)$

Expected profit =$202,260

$0.226 = P(D_H \mid M_L)$

$0.774 = P(D_L \mid M_L)$

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The Value of Information

Example (contd.): Applying Bayes's Rule to Compute Conditional Probabilities

- The expected profit in Example 18.14 (without additional information) is $198,000.
- The expected profit in Example 18.15 (with additional information) is $202,260.
- The EVSI = $4260.
- The company should not pay more than $4260 for a market research survey.

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Figure 18.10

Business Analytics for Management Decision

Decision Analytics [60]

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Utility and Decision Making

- Utility theory is an approach for assessing risk attitudes quantitatively.
- An individual's utility function reflects their preference toward risk.
- The risk premium is the payoff amount that an individual is willing to forgo to avoid risk.
- The break-even probability is the point at which an individual is indifferent between a guaranteed payoff and taking a gamble for a higher payoff.
- The certainty equivalent is the amount an individual feels is equivalent to the payoff from an uncertain gamble.

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Utility and Decision Making

Example: A Personal Investment Decision

- Suppose you have $10,000 to invest short-term.
- You are considering 3 options:
  - Bank CD paying 4% return
  - Bond fund with uncertain return
  - Stock fund with uncertain return

Decision/Event	Rates Rise	Rates Stable	Rates Fall
Bank CD	$400	$400	$400
Bond fund	–$500	$840	$1,000
Stock fund	–$900	$600	$1,700

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Utility and Decision Making

Example: Constructing a Utility Function for the Personal Investment Decision

- Sort the payoff amounts from highest to lowest.
- Assign a utility to the highest payoff of U(*X*) = 1.
- Assign a utility to the lowest payoff of U(*X*) = 0.

Payoff, *X*	Utility, *U*(*X*)
$1,700	1.0
$1,000	
$840	
$600	
$400	
−$500	
−$900	0.0

U(1700) = 1

U(1000) = the probability you would give up a certain $1000 to possibly win a $1700 payoff.

U(−900) = 0

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Utility and Decision Making

Example: Constructing a Utility Function for the Personal Investment Decision

- After deciding U(1000) = 0.90, continue choosing U(*X*) preferences for the remaining four payoffs.

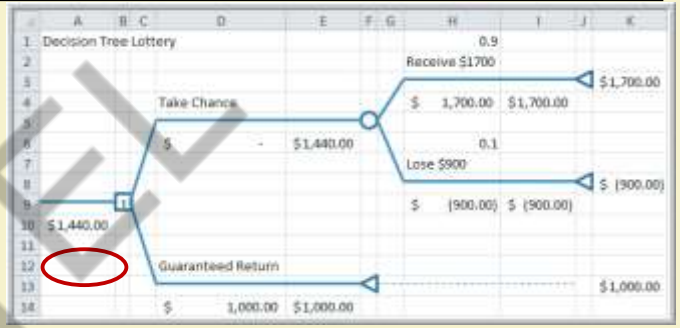
Payoff, *X*	Utility, *U*(*X*)
$1,700	1.0
$1,000	0.90
$840	0.85
$600	0.80
$400	0.75
−$500	0.35
−$900	0.0

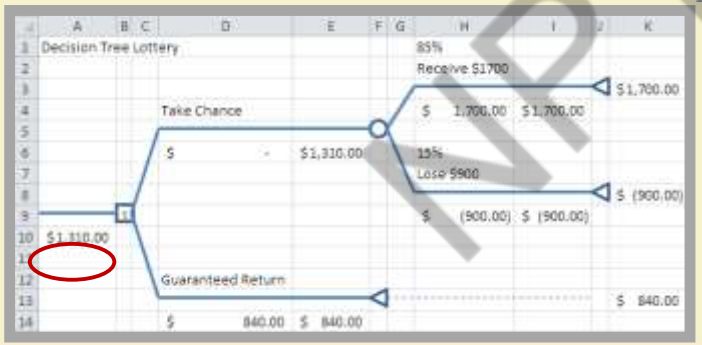
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Utility and Decision Making

Example (contd.): Utility Function for the Personal Investment Decision

For the $1000 payoff with
U(1000) = 0.90
Expected payoff = $1440
Risk premium = $440





For the $840 payoff with
U(840) = 0.85
Expected payoff = $1310
Risk premium = $470

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Utility and Decision Making

Example (contd.): Constructing a Utility Function for the Personal Investment Decision

- We can find the breakeven probability for each payoff by solving

  Payoff = $\$1700p - \$900(1-p)$

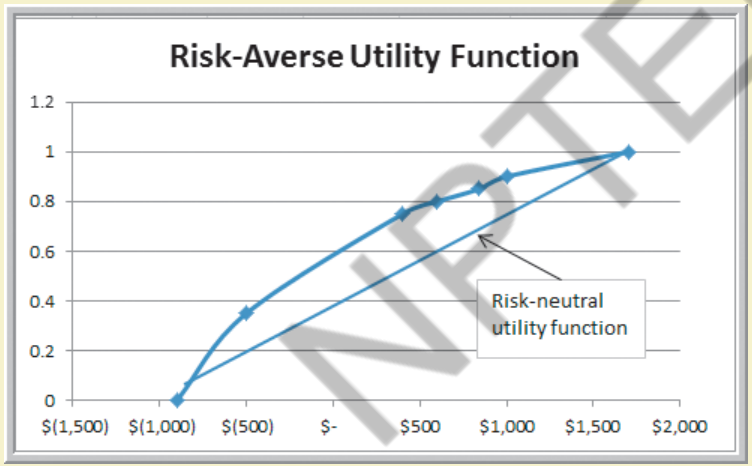
  p = (Payoff + 900)/2600

Payoff, X	Utility, U(X)	Expected Payoff	Risk Premium	Break-even Probability
$1,700	1.00			
$1,000	0.90	$1,440	$440	0.73
$840	0.85	$1,310	$470	0.67
$600	0.80	$1,180	$580	0.58
$400	0.75	$1,050	$650	0.50
-$500	0.35	$10	$510	0.15
-$900	0.00			

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Utility and Decision Making

Example (contd.): Constructing a Utility Function for the Personal Investment Decision



Risk Aversion
Risk premiums > 0
U(*X*) > Risk neutral
Concave downward

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Utility and Decision Making

Example of a Risk Taking Utility Function

Payoff, X	Utility, $U(X)$
\$1,700	1.0
\$1,000	0.6
\$840	0.55
\$600	0.45
\$400	0.40
−\$500	0.1
−\$900	0.0

Payoff, X	Utility, $U(X)$	Expected Payoff	Risk Premium	Break-even Probability
\$1,700	1.00			
\$1,000	0.60	\$660	-\$340	0.73
\$840	0.55	\$530	-\$310	0.67
\$600	0.45	\$270	-\$330	0.58
\$400	0.40	\$140	-\$260	0.50
-\$500	0.10	-\$640	-\$140	0.15
-\$900	0.00			

Risk Taker
Risk premiums < 0
$U(X)$ < Break-even Probability
Concave upward utility function

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Utility and Decision Making

Using a Utility Function Instead of Payoffs

- Expected values of the risk averse utilities

Decision/Event	Rates Rise	Rates Stable	Rates Fall	Average Utility
Bank CD	0.75	0.75	0.75	0.75
Bond fund	0.35	0.85	0.9	0.70
Stock fund	0	0.80	1.0	0.60

- Expected values of the payoffs for each decision

Decision/Event	Rates Rise	Rates Stable	Rates Fall	Average Payoff
Bank CD	$400	$400	$400	$400
Bond fund	–$500	$840	$1,000	$447
Stock fund	–$900	$600	$1,700	$467

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Utility and Decision Making

Using a Utility Function Instead of Payoffs (contd.)

- Expected values of the risk taker utilities

Decision/Event	Rates Rise	Rates Stable	Rates Fall	Average Utility
Bank CD	0.40	0.40	0.40	0.40
Bond fund	0.10	0.55	0.60	0.42
Stock fund	0.00	0.45	1.00	0.48

- Expected values of the payoffs for each decision

Decision/Event	Rates Rise	Rates Stable	Rates Fall	Average Payoff
Bank CD	$400	$400	$400	$400
Bond fund	–$500	$840	$1,000	$447
Stock fund	–$900	$600	$1,700	$467

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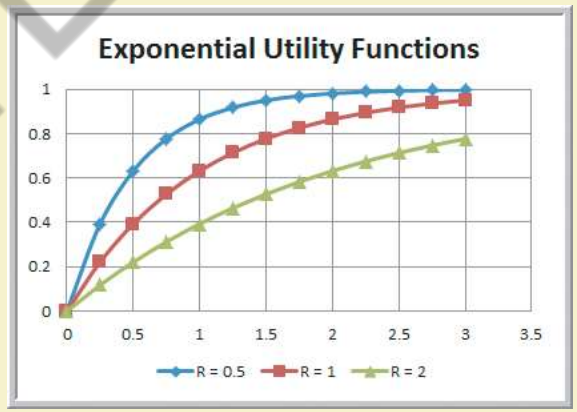
Utility and Decision Making

Exponential Utility Function

- Rather than asking the decision-maker to specify their utility for each payoff possibility, an exponential utility function might be used.

$$U(x) = 1 - e^{-x/R}$$

- *R* is a shape parameter indicative of risk tolerance.
- Smaller values of *R* have a more concave U(*X*) and are more risk averse.



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Utility and Decision Making

Exponential Utility Function (continued)

One approach to estimating an appropriate value of *R* for the decision maker is to:

- Find the maximum payoff $*R* for which the decision maker believes that taking a chance to win $*R* is equivalent to losing $*R*/2.
- Would you take on a bet of possibly winning $10 versus losing $5?
- How about risking $50 to win $100?
- How about risking $500 to win $1000?
- *R* measures one's maximum risk comfort level.

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Utility and Decision Making

Example: Using an Exponential Utility Function

- In the $10,000 *Personal Investment Decision* example, suppose you use an exponential utility function with R = $400.

- $U(X) = 1 - e^{-X/400}$

You are willing to risk $200 to win $400.

Payoff, X	Utility, $U(X)$
$1,700	0.9857
$1,000	0.9179
$840	0.8775
$600	0.7769
$400	0.6321
– $500	– 2.4903
– $900	– 8.4877

Decision/Event	Rates Rise	Rates Stable	Rates Fall	Average Utility
Bank CD	0.6321	0.6321	0.6321	0.6321
Bond fund	– 2.4903	0.8775	0.9179	– 0.2316
Stock fund	– 8.4877	0.7769	0.9857	– 2.2417

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Utility and Decision Making

Analytics in Practice: Using Decision Analysis in Drug Development

- Pharma, a business unit of Bayer Pharmaceuticals, developed a new blood-clot-busting drug.
- They used a structured decision analysis approach to evaluate market potential of the drug.
- A decision tree with 6 decision points delivered to senior managers the expected net present value, the likelihood of success, and the risks involved.
- This decision tree approach set new standards for subsequent new drug developments at Pharma.

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Summary

- Decision-Making under Uncertainty
- Average Payoff, Aggressive, Conservative & Opportunity Loss Strategies
- Decision Tree Creation
- Construction of Risk Profile
- Expected Value of Perfect Information
- Expected Opportunity Loss
- Expected Value of Sample Information
- Conditional Probabilities
- Construction of Utility Function

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Highlights

- Decision Strategies for a Minimum Objective
- Decision Strategies for a Maximum Objective
- Decision Trees & Risk
- Perfect Information
- Bayes' Rule
- Utility Theory
- Risk Taker & Risk Averse

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Key Terms

- Branches
- Certainty equivalent
- Decision node
- Decision strategy
- Decision tree
- Event
- Event node
- Expected opportunity loss
- Expected value of perfect information
- Expected value of sample information
- Laplace, or average, payoff strategy
- Maximax strategy
- Maximin strategy

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Key Terms

- Minimax regret strategy
- Minimax strategy
- Minimin strategy
- Nodes
- Payoff table
- Perfect information
- Risk averse
- Risk premium
- Risk profile
- Sample information
- Utility theory
- Value of information

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Thank You!!

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