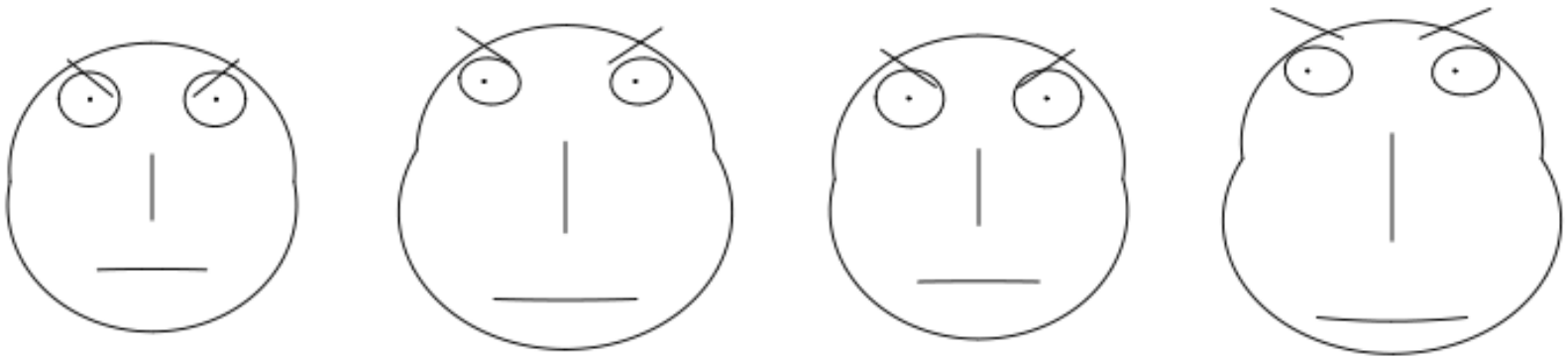
Week 7
Alternatives to MAUT
SYS 660



Steven Hoffenson, Assistant Professor

Fall 2016

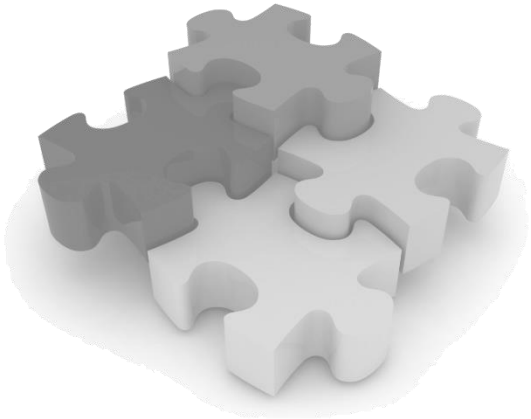
Where are we in the course?

Theme	Week	Topic	Assigned
Modeling decisions	1	Introduction to Decision and Risk Analysis in SE	
	2	Structuring a Decision	HW1
	3	Tradeoffs under Certainty	HW2
Uncertainty	4	Probability Refresher	HW3
	5	Subjective Probability and the Value of Information	HW4
Utility	6	Multi-Attribute Utility Theory	HW5
	7	**Alternatives to MAUT**	**Midterm**
	8	**Midterm Exam – Q & A Session**	**(Midterm)**
Risk	9	Cognitive Bias and Perceptions of Risk	HW6
	10	Introduction to Risk Management	Projects
	11	Project Risk Management	
	12	Incorporating Financial Risk into Project Decisions	
	13	Risk of Extreme Events & Model Risk	
	14	~~Model Risk~~ Project Presentations	
	15	~~Project Presentations~~	

Grading	
Homework	30 %
Mid-term	35 %
Team project	35 %

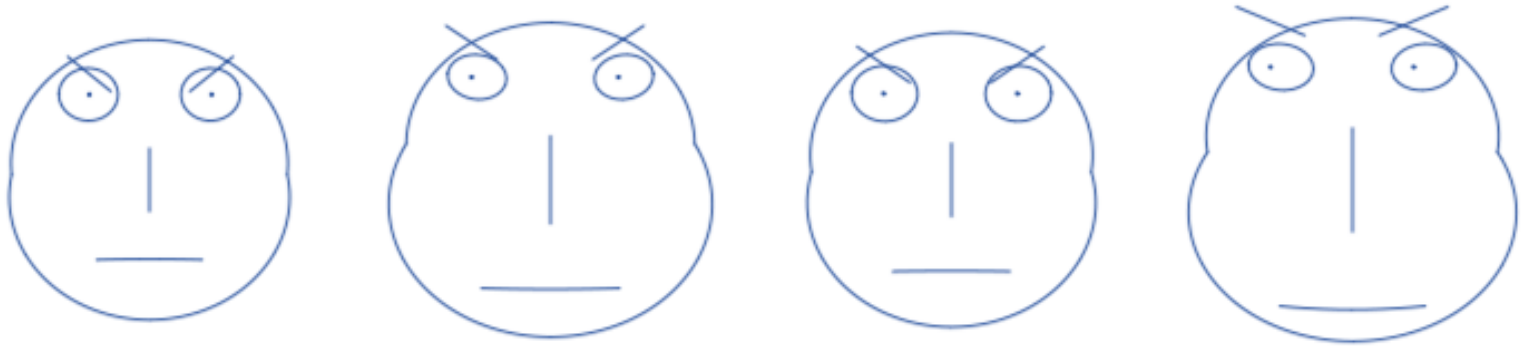
Challenges to MAUT

- While multi-attribute utility theory is the most common approach to decision analysis, there is a degree of **skepticism** about its application
- Many question the stability of utility functions assessed from real decision makers
  (We have discussed some biases in the assessment process)
- Researchers have developed **many alternative techniques** to aid decision makers in exploring tradeoffs without assessing formal utility functions
- These approaches are categorized as **Multi-Criteria Decision Making (MCDM)** methods



Alternatives to MAUT

- Multi-Criteria Decision-Making (MCDM) methods
- Holism vs Reductionism
- Visualization for decision making
- Decision Support Systems
- Prospect Theory



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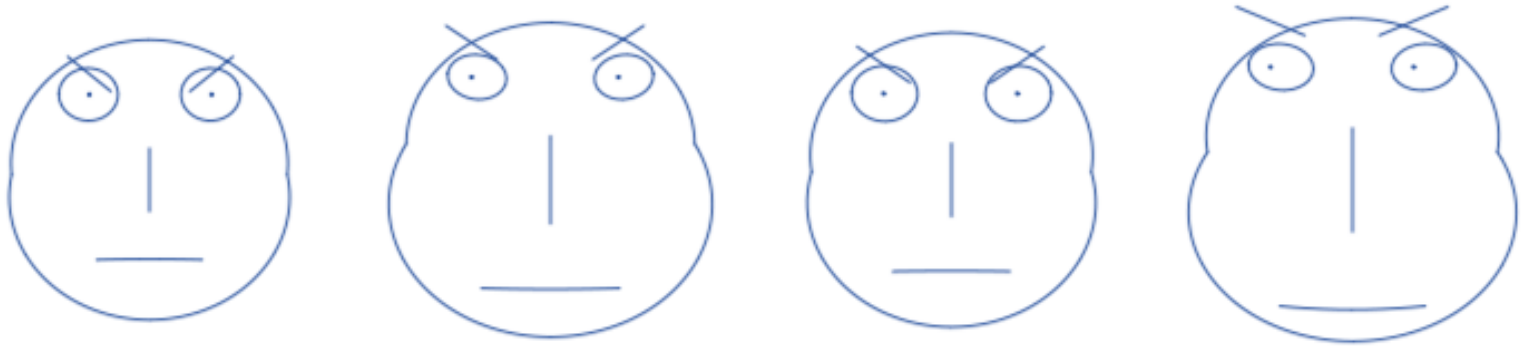


Survey of Multi-Criteria Decision Making (MCDM) methods

- Simple Additive Weighting (SAW)
- Weighted Sum Methods (WSM)
- Weighted Product Model (WPM)
- Analytic Hierarchy Process (AHP)
- Analytic Network Process (ANP)
- Multi-Attribute Utility Theory (MAUT)
- Multiple Attribute Group Decision Making (MAGDM)
- Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
- Elimination and Choice Expressing Reality (ELECTRE)
- Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE)
- Geometrical Analysis for Interactive Aid (GAIA)
- Superiority and Inferiority Ranking Method (SIR Method)
- Potentially All Pairwise RanKings of all possible Alternatives (PAPRIKA)
- Aggregated Indices Randomization Method (AIRM)
- Decision Making Trial and Evaluation Laboratory (DEMATEL)
- Data Envelopment Analysis (DEA)
- Complex Proportional Assessment of Alternatives (COPRAS)
- Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA)
- Dominance Based Rough Set Approach (DRSA)
- The Evidential Reasoning Approach (ER)
- Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH)
- Goal programming
- Grey Relational Analysis (GRA)
- Step Method (STEM)
- CODASID
- New Approach to Appraisal (NATA)
- Value Analysis (VA)
- Value Engineering (VE)
- The VIKOR Method
- Group Decision Support System (GDSS)
- Interpretive Structural Modeling (ISM)
- Game Theory Methods
- Policy Goal Percentaging Analysis
- UTA (Utilitiés Additives) method

Georgiadis, D.R., T.A. Mazzuchi, and S. Sarkani, 2013, Using Multi Criteria Decision Making in Analysis of Alternatives for Selection of Enabling Technology, *Systems Engineering*, 16(3), 287-303.

Example: Conjoint approach to Random Utility Theory (RUT)

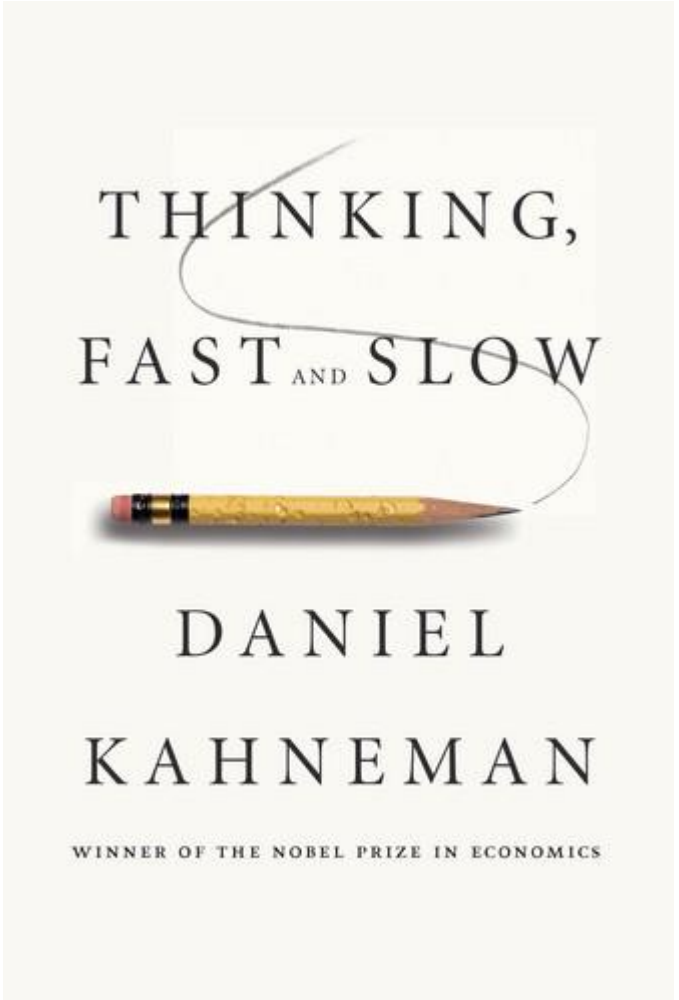
Conjoint analysis, in particular ***Choice-Based Conjoint*** (CBC), is a widely-used approach to assess utility from survey questions that mimic real shopping behavior

Brand		SONY	LG
Price	$500	$300	$400
Resolution	480x720	720x480	1280x800
Size			

A CBC study would ask each respondent to choose from many permutations (randomly changing the combinations of attributes) of the above question; there are a number of ways to analyze the results to derive utility functions

A Few Observations

- The previous list of 34 is not even complete, and this range of competing techniques shows how the field has not converged on a robust set of tools and methods
- *Thinking Fast and Slow* (Kahneman book) gives insights on this
- The main challenge is in humans making consistent tradeoffs over many conflicting objectives
- No decision analysis technique has convincingly overcome this



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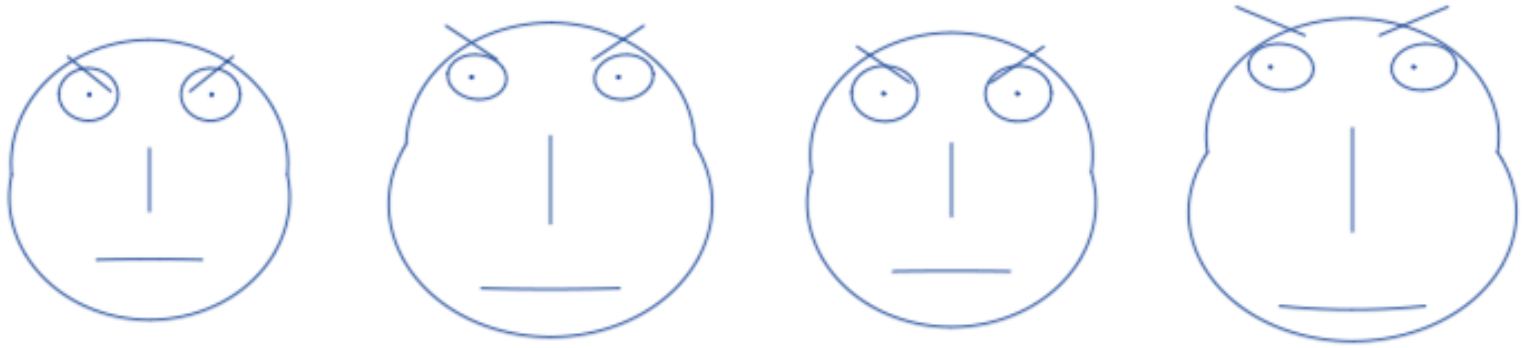


Holism vs. Reductionism

In systems science & engineering, there is a perennial discussion on holism vs. reductionism

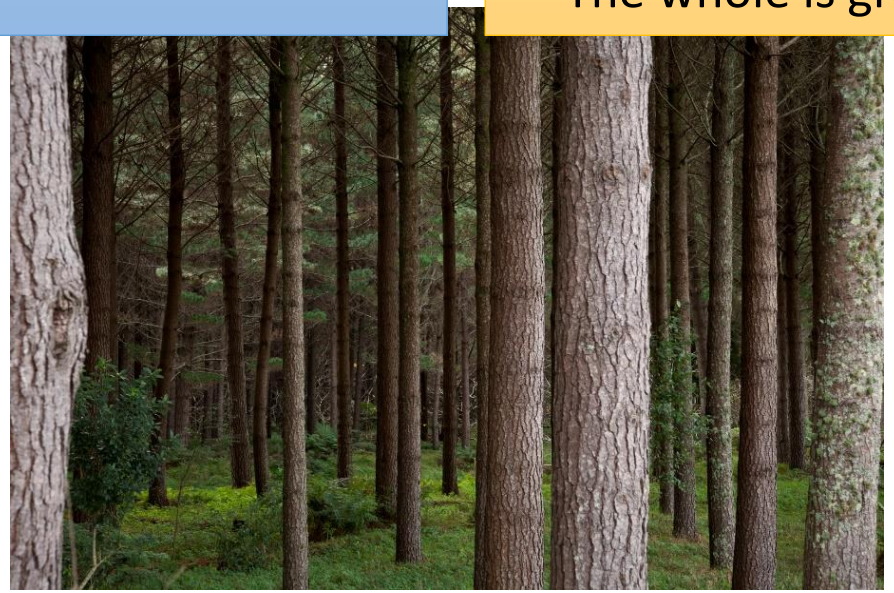
Reductionism guides most science and engineering

- A system can be broken up into its constituent **parts**
- The parts can be studied and understood individually
- By understanding the parts we can understand the system as whole

Holism postulates that certain properties of a system can only be understood when the system is viewed as a **whole**

- Systems have emergent behaviors that cannot be predicted by studying the constituent parts
- The whole is greater than the sum of its parts

Trees



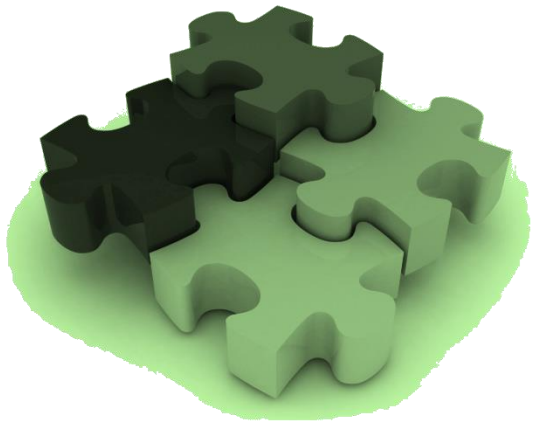
Forest

Holism vs. Reductionism

- There is still some tension between holism and reductionism approaches
- Practically, both viewpoints are relevant
  - Most systems that we care about do have emergent properties that are difficult to predict via reductionist approaches
  - Emergent behaviors are why we build systems!
  - E.g., An engine, a transmission, an electrical system, etc. are not particularly useful by themselves, but when we put them all together as a car, the system has a lot of useful emergent properties
- So, we need to take a holistic perspective to understand why we value a given system
- However, when we are actually designing and building a system, we really have to take a reductionist perspective

Holism vs. Reductionism

- Decision analysis is subject to this dilemma
- MAUT is essentially a ***reductionist*** approach, decomposing an individual's preferences into manageable pieces and assessing those pieces individually
  - The hope is that when the pieces are put back together they bear some semblance to the decision maker's preferences
  - Unfortunately, this is not always the case
- Those taking a more ***holistic*** perspective toward decision analysis often advocate using visualizations over MAUT



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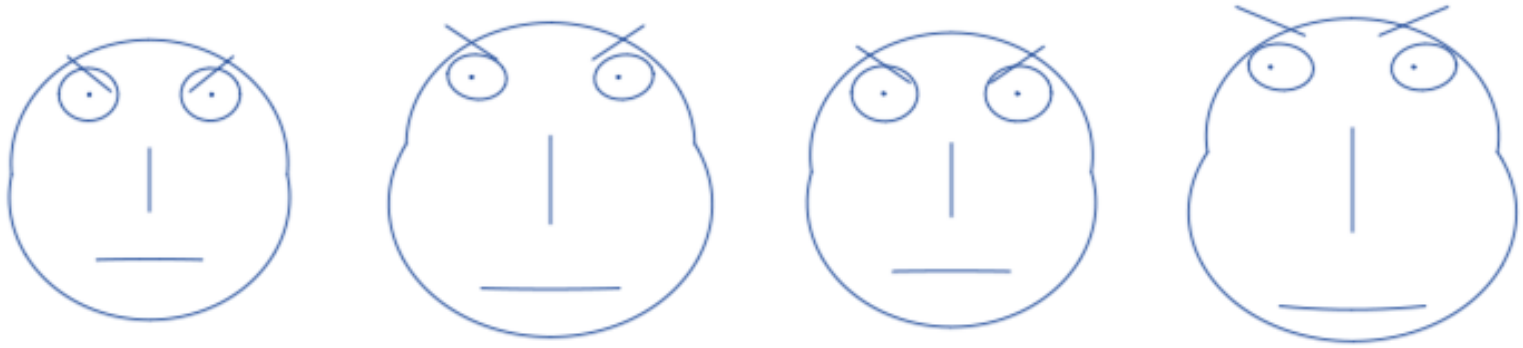
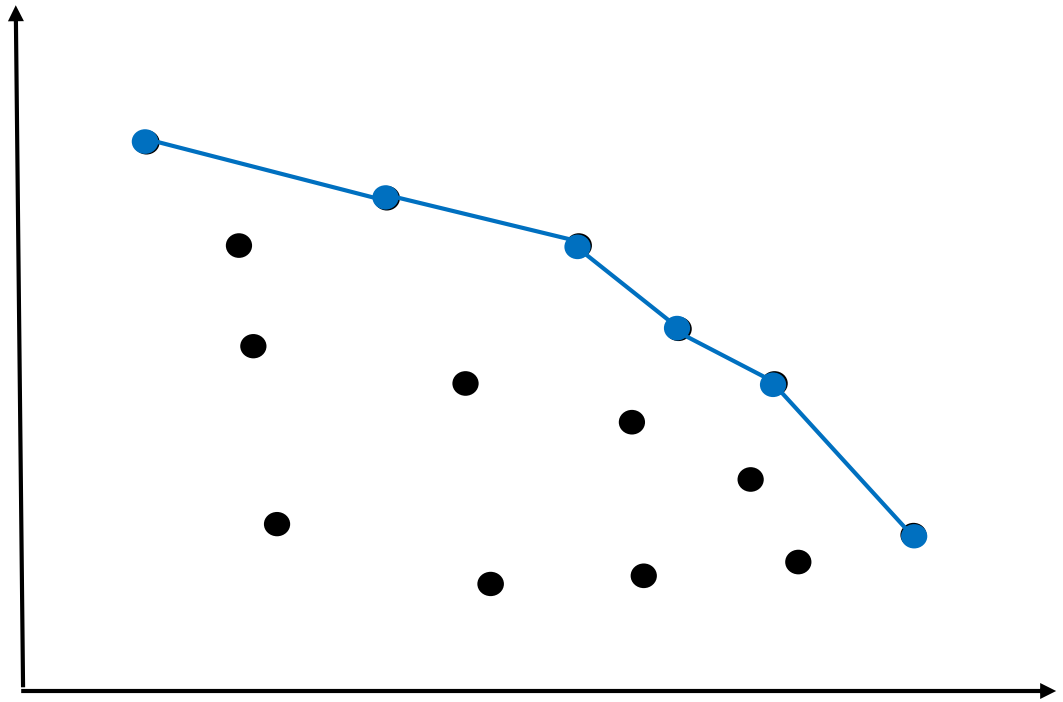


Visualization

- Visualization techniques let a decision-maker view the whole problem and simultaneously consider all relevant attributes
- This requires portraying the Pareto frontier over all attributes so the decision maker can explore the trade offs among alternatives
- This is straightforward for two attributes, but becomes increasingly difficult as the number of attributes increases
- We will discuss some visualization techniques that show increasing numbers of attributes

Two Attributes

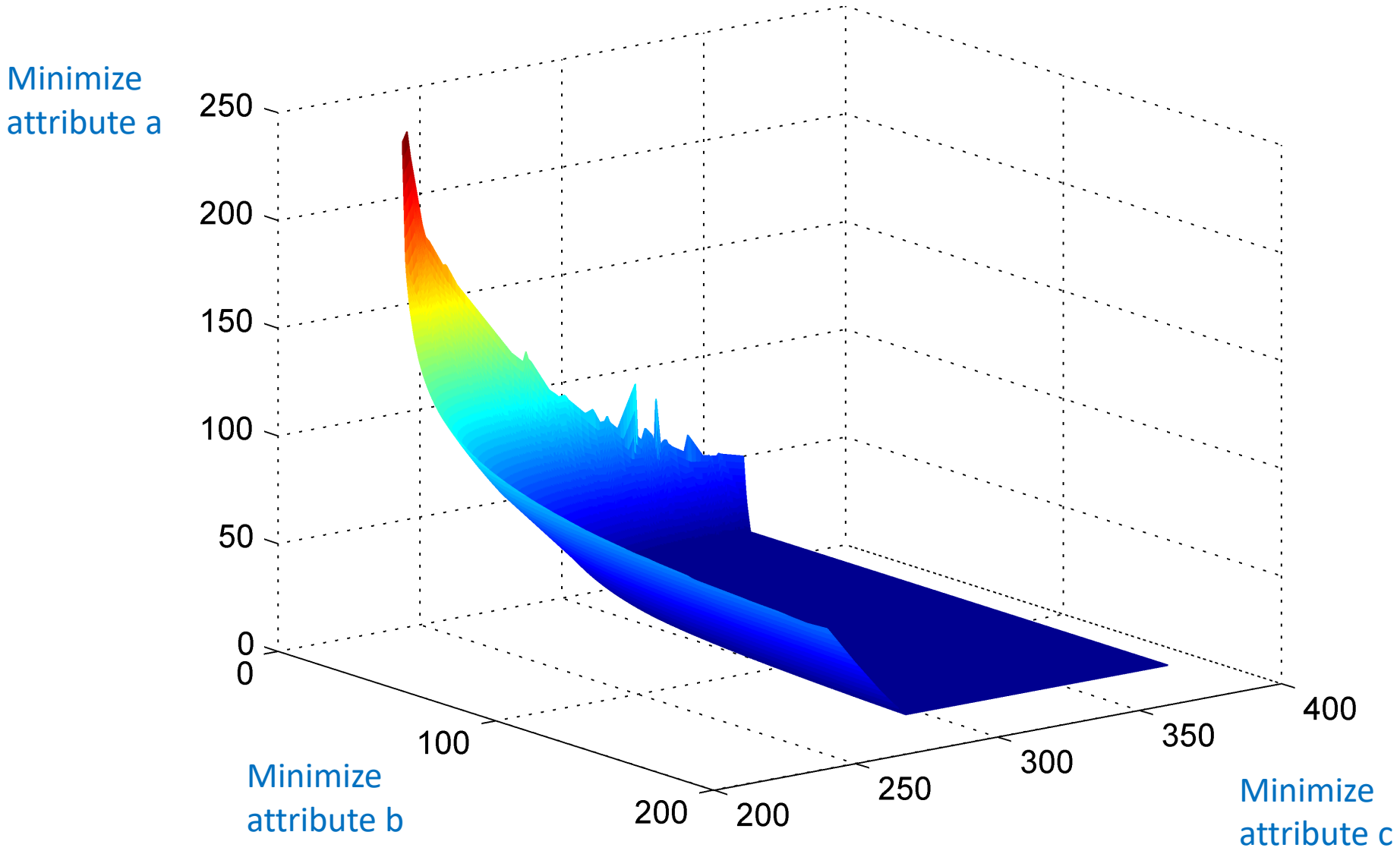
Maximize
Top Speed



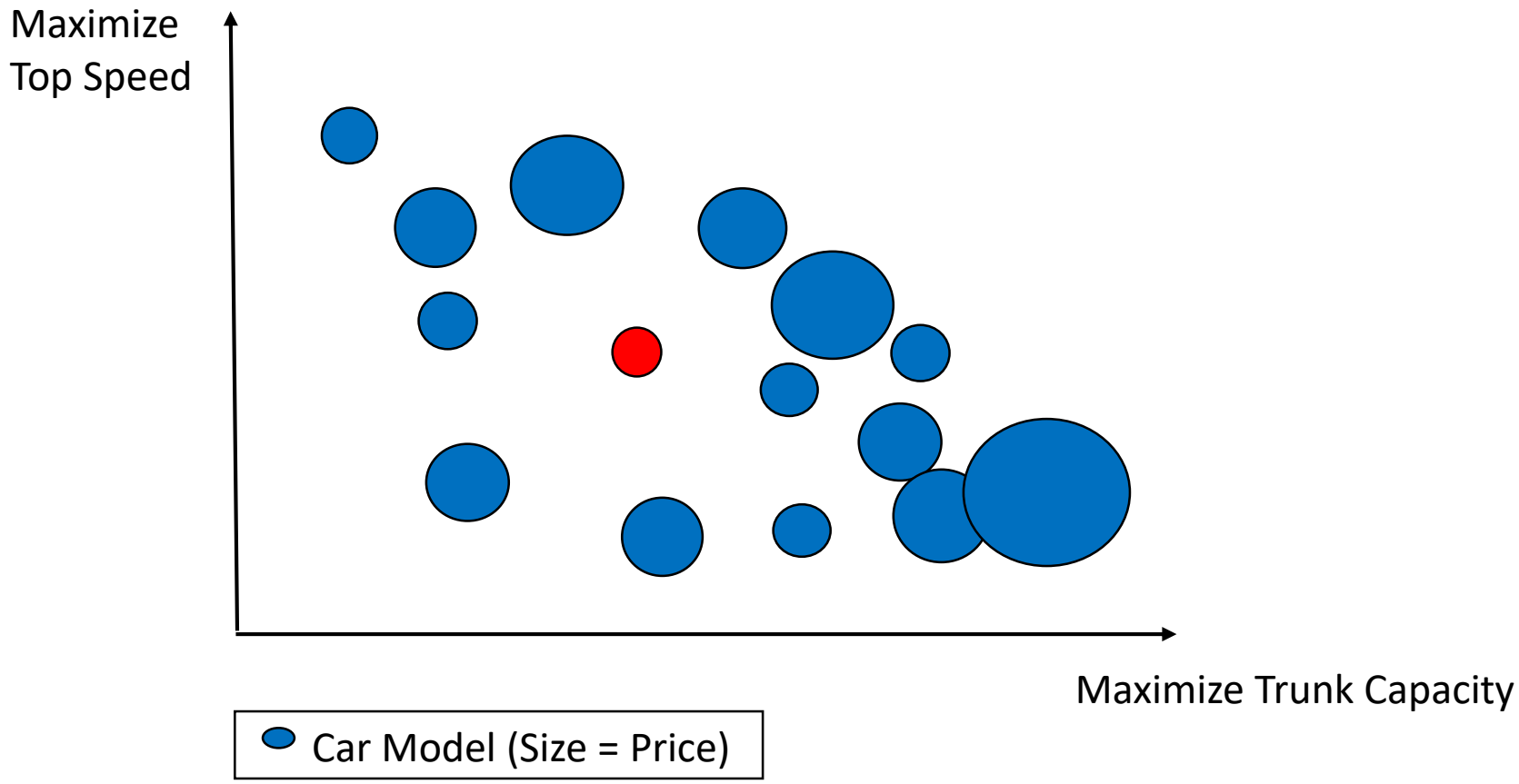
Maximize Trunk Capacity

Car Model

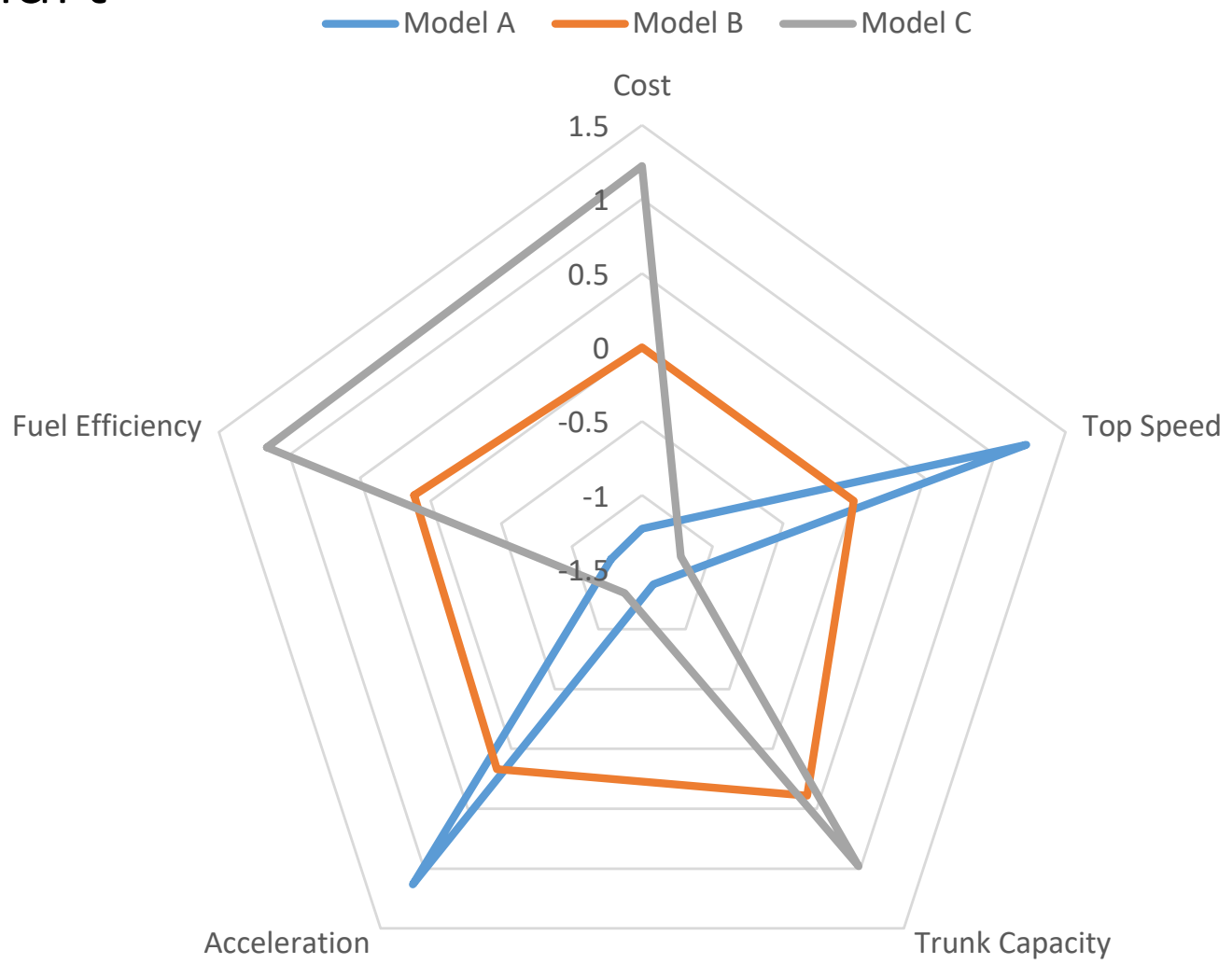
Three-dimensional Pareto frontier



Bubble Chart



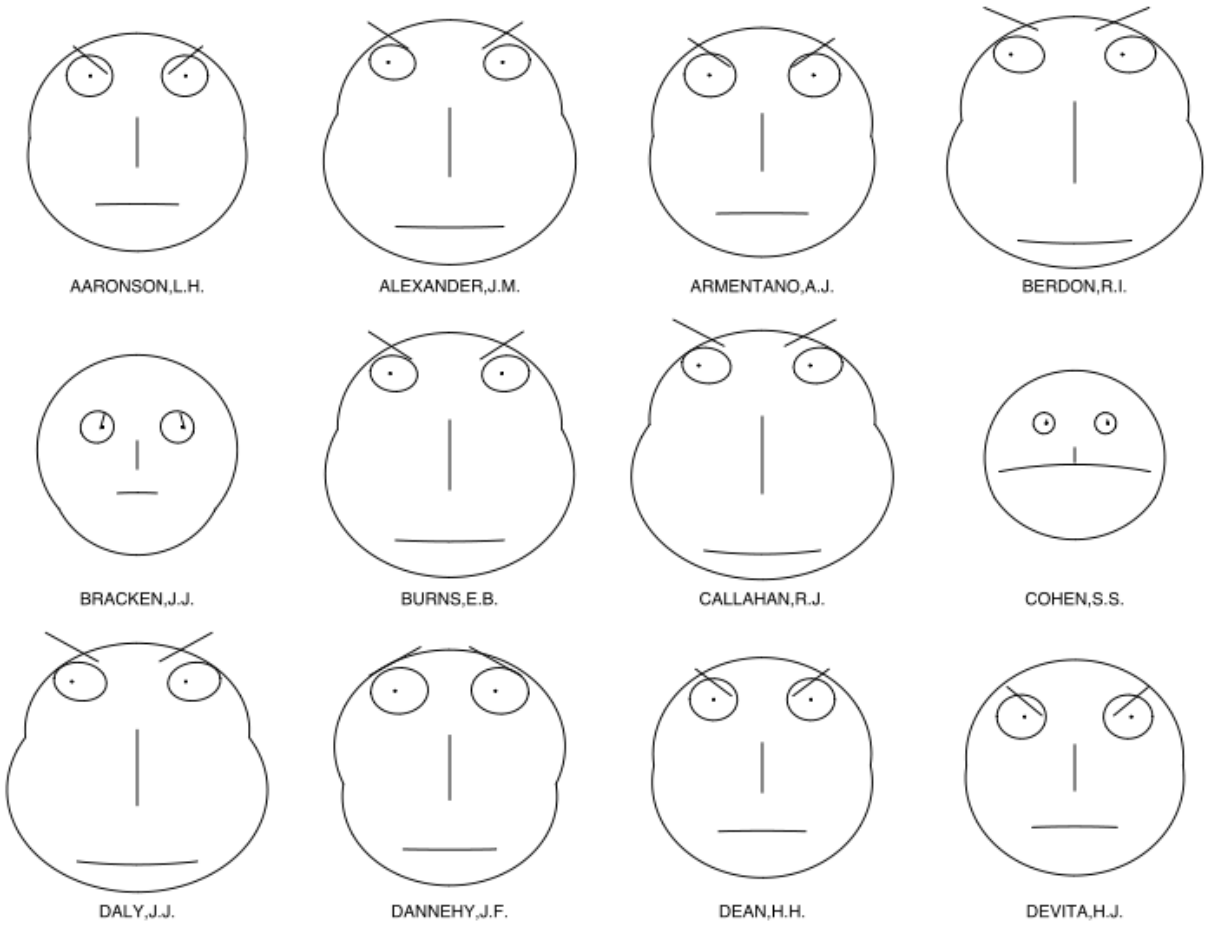
Spider Chart



Note: Values have been scaled by the mean and standard deviation to facilitate comparisons. All axes have been set so that more is better.

Chernoff Faces

Example: Lawyers' ratings of 12 judges

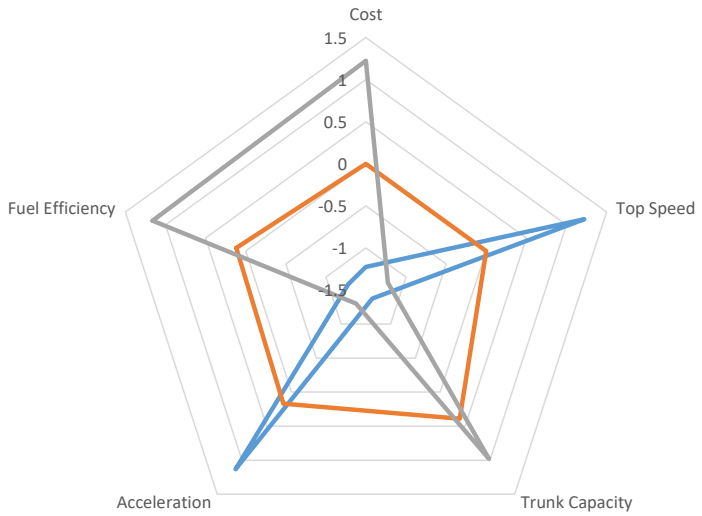


Source: Wikipedia (http://en.wikipedia.org/wiki/Chernoff_face), last accessed 3-2-14.

Limitations

- Difficult to depict large numbers of attributes in an interpretable way
- Generally speaking, you can handle a large number of options over a small number of attributes, or a small number of options over a large number of attributes
- It is difficult to perform a sensitivity analysis or assess consistency when using visualizations for decision-making
- Scales must be carefully chosen to avoid distortions
- Risk can only be incorporated with additional attributes

  E.g., if cost is uncertain, we need to add an attribute to the visualization that captures that uncertainty

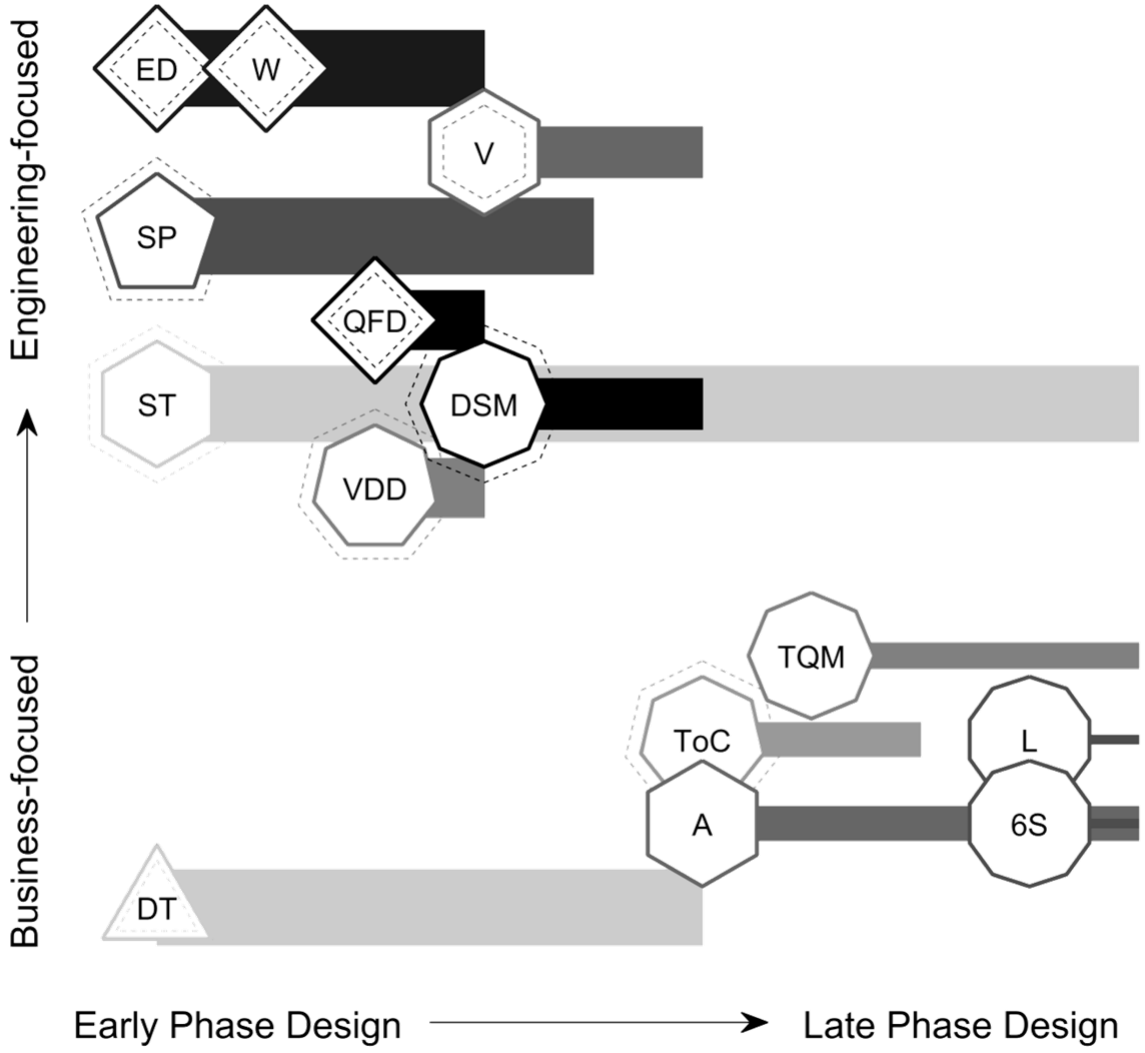


Example: Design Methodologies

This plot shows some key characteristics of 15 design methodologies in engineering and business disciplines

(*Note: This is still a work in progress*)

- X-axis: Placement says where in the design process (early vs. late phase) it applies to
- Tail: Shows span of design process phases
- Y-axis: Placement shows whether approach is more business- or engineering-focused
- Shape: Polygon with more sides = greater complexity of the products it is geared toward
- Shading: Darker indicates a more highly structured approach
- Dashed in/outline: If present, shows whether it focuses inside the details of the product itself or on factors outside of the product

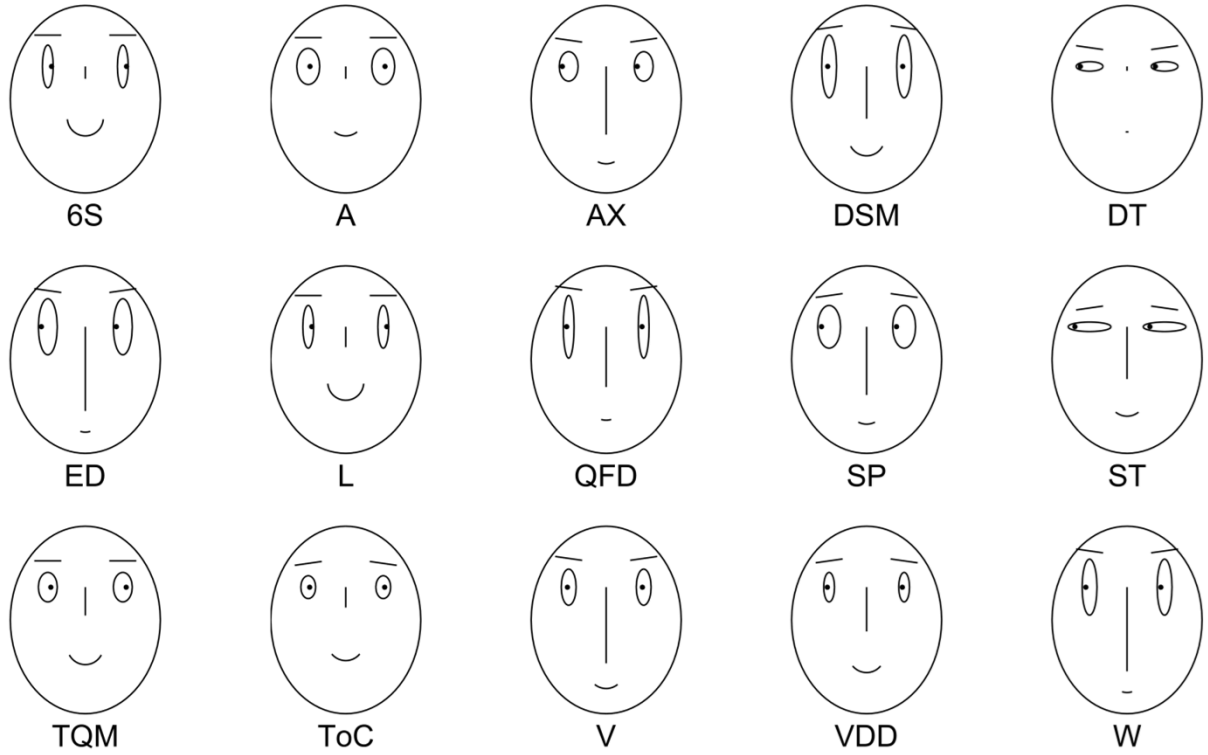


Example: Design Methodologies (Chernoff)

These Chernoff faces show the same key characteristics of those 15 design methodologies

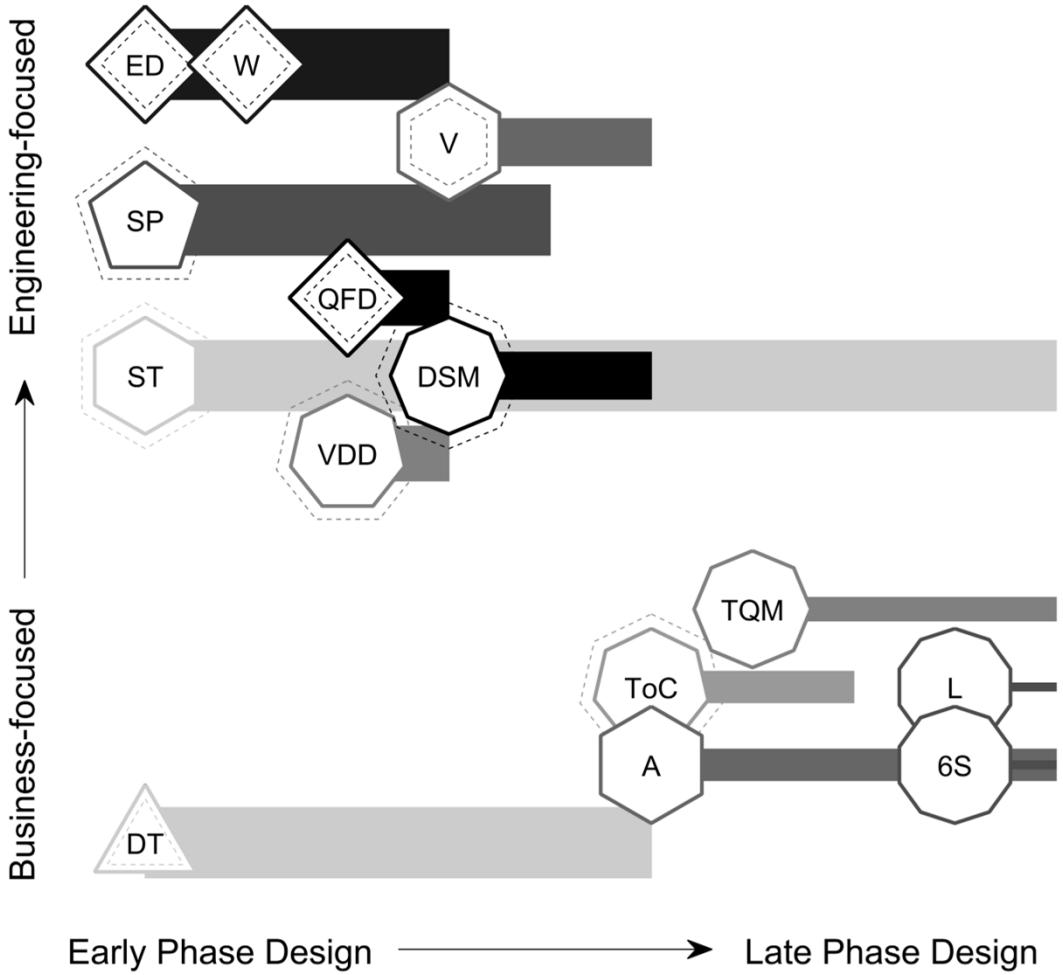
(*Note: This is still a work in progress*)

- Eye direction: Where in the design process (early to left, late to right) it begins
- Eye width: Span of design process phases
- Nose: Shorter is more business-focused; longer is more engineering-focused
- Mouth arc: Larger = greater complexity of the products it is geared toward
- Eye height: Amount of structure in approach
- Eyebrows: Angled in = focus inside the details of the product itself; angled out = focus on factors outside of the product

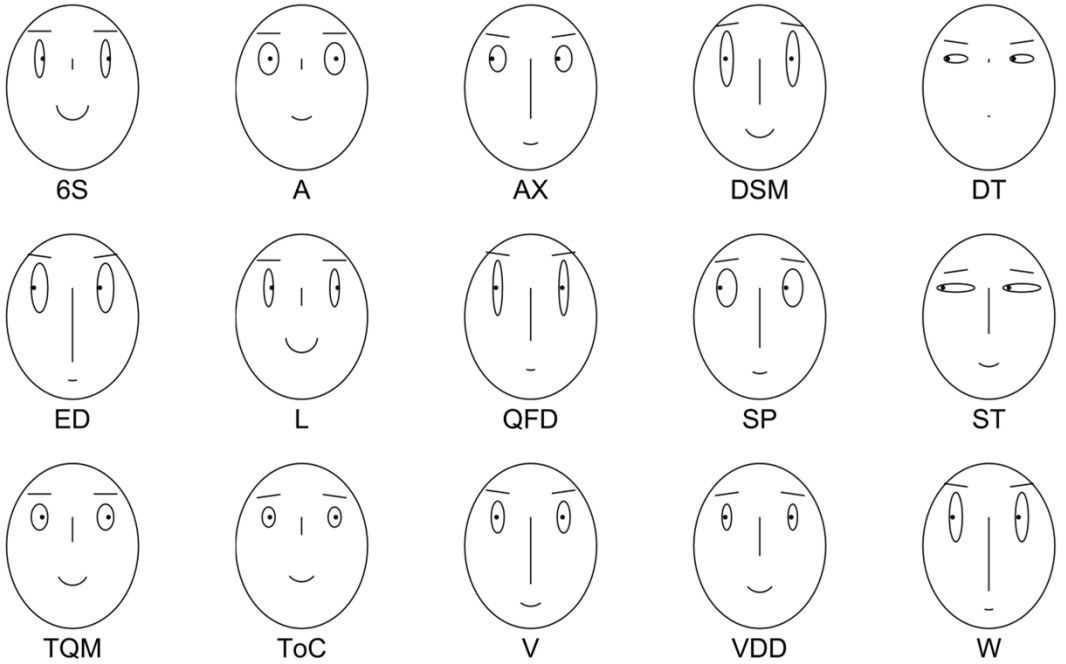


Which do you prefer?

(what I call a) **Modified bubble chart**



Chernoff Faces



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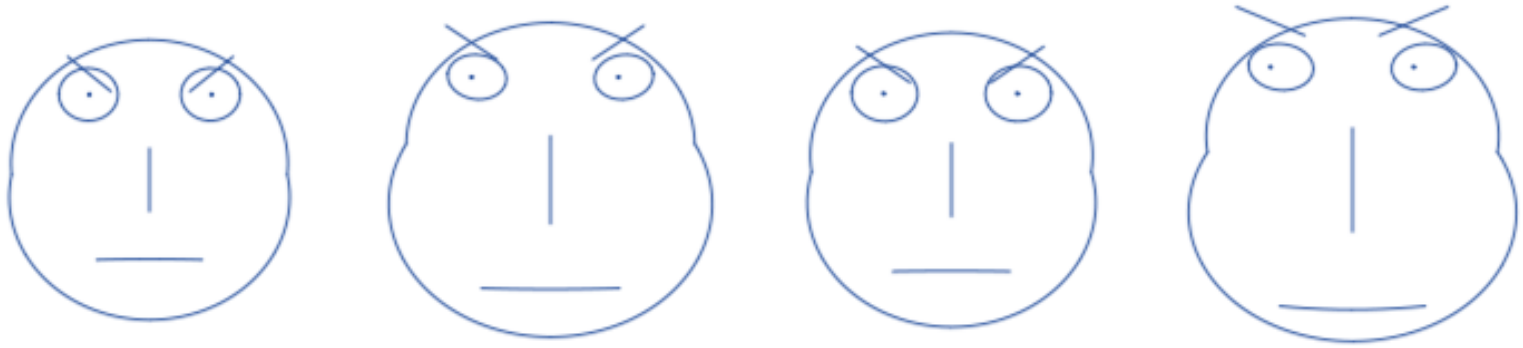
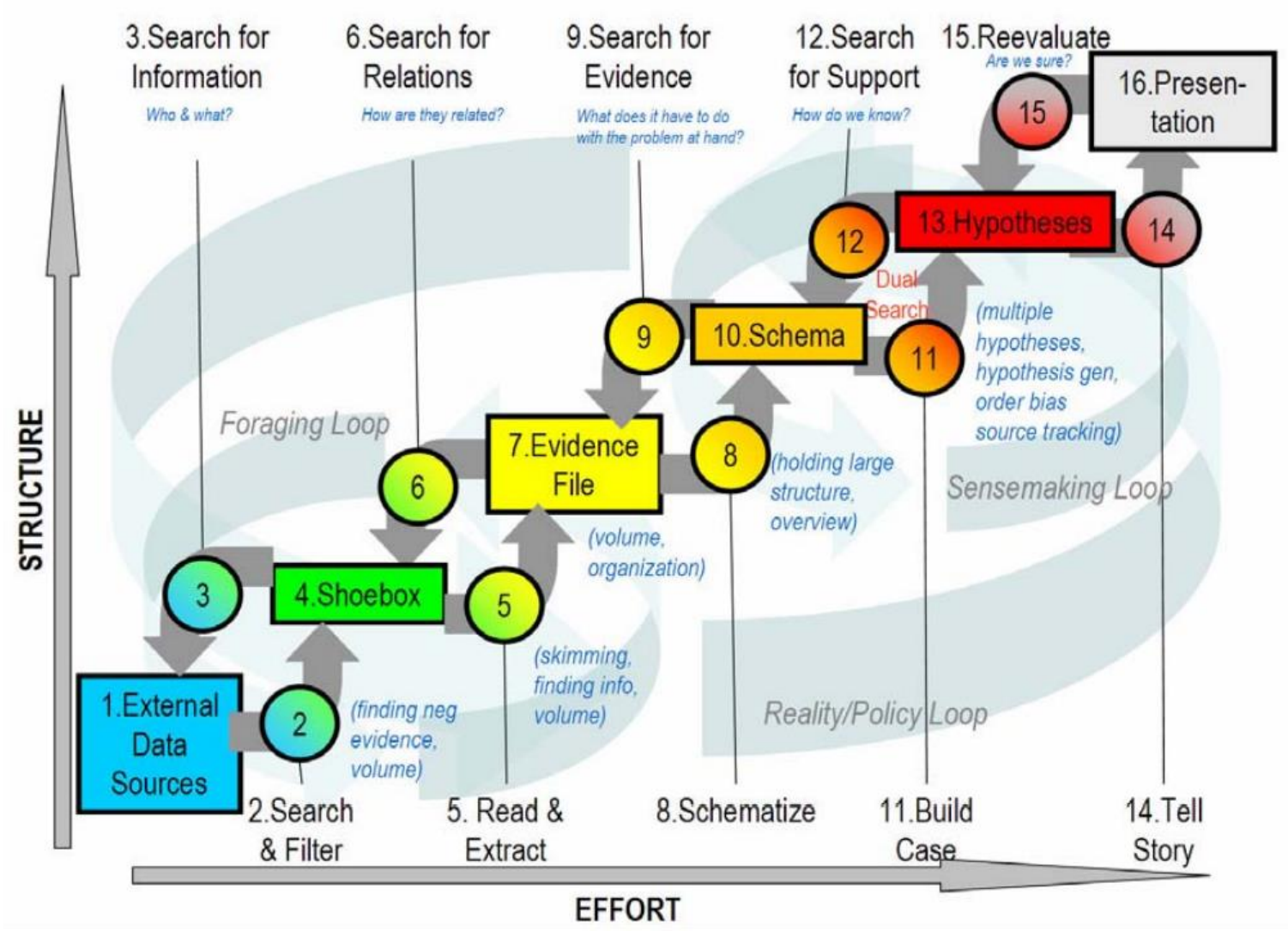


Decision Support Systems

- An interactive approach can mitigate some of the challenges of both numerical and visualization methods
- A decision support system (DSS) models key aspects of the system of interest and allows a user to interact with it via software
  - This is not only for engineered systems—e.g., it could work for a business, an economy, or an ecosystem
  - You will create a new DSS in your project during the second half of this course!
- A DSS allows users to see how changing decisions and assumptions affects outcomes
- Visualizations are often key parts of the interface
- Numerical methods for modeling preferences (e.g., MAUT) can be integrated into a DSS

The SenseMaking Process



The SenseMaking process is a descriptive model of how humans analyze and organize data.

This is something to keep in mind when developing a DSS!

Source: Pirolli, P., and S. Card (2005), The Sensemaking Process and Leverage Points for Analyst Technology as Identifies Through Cognitive Task Analysis, *Proceedings of International Conference on Intelligence Analysis*, 5: 2-4, McLean, VA: Mitre.

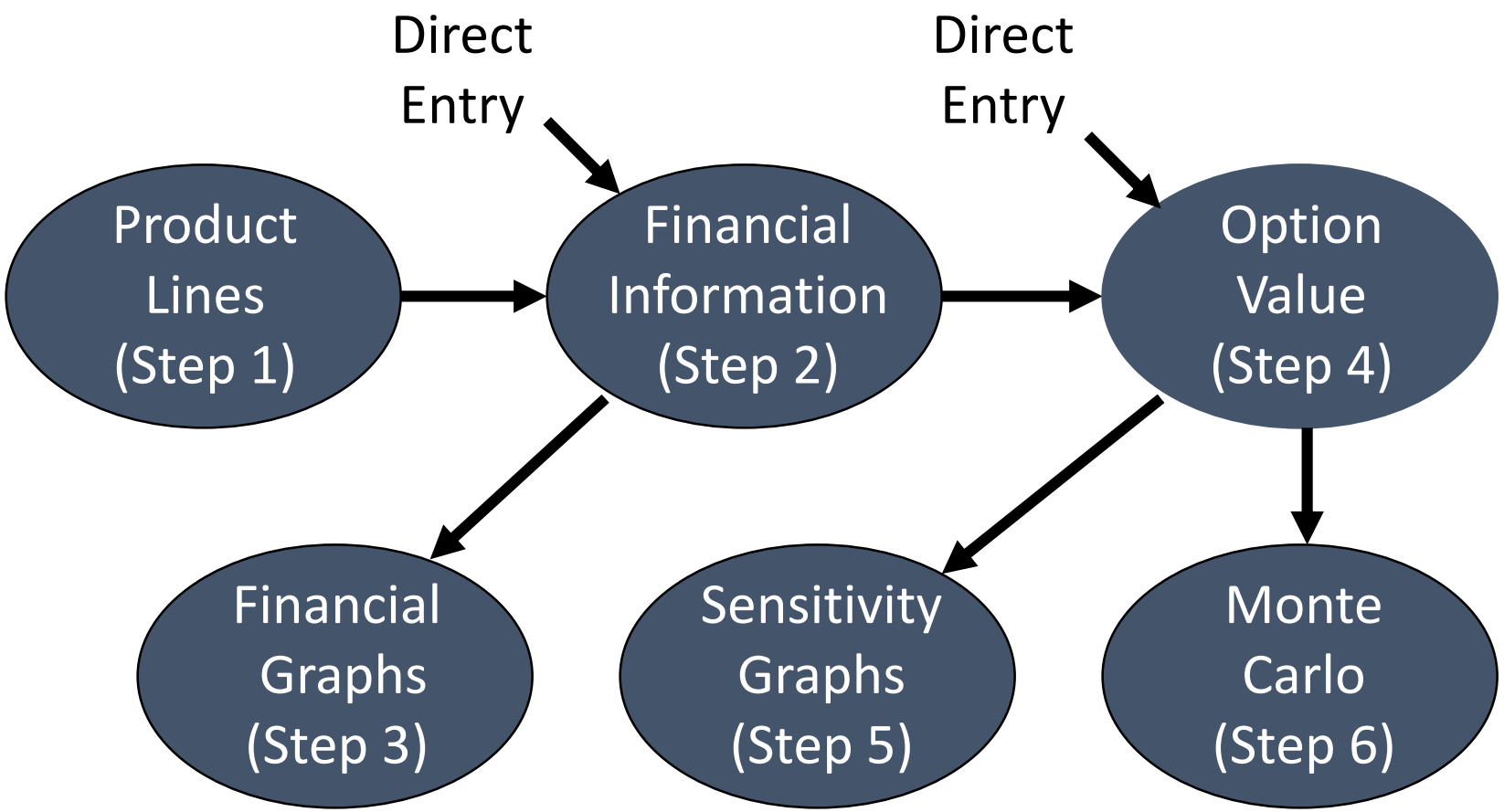
DSS Example: Technology Investment Advisor (TIA)

Technology Investment Advisor (TIA) is an actual DSS developed by a Stevens professor to help companies decide in which technologies to invest

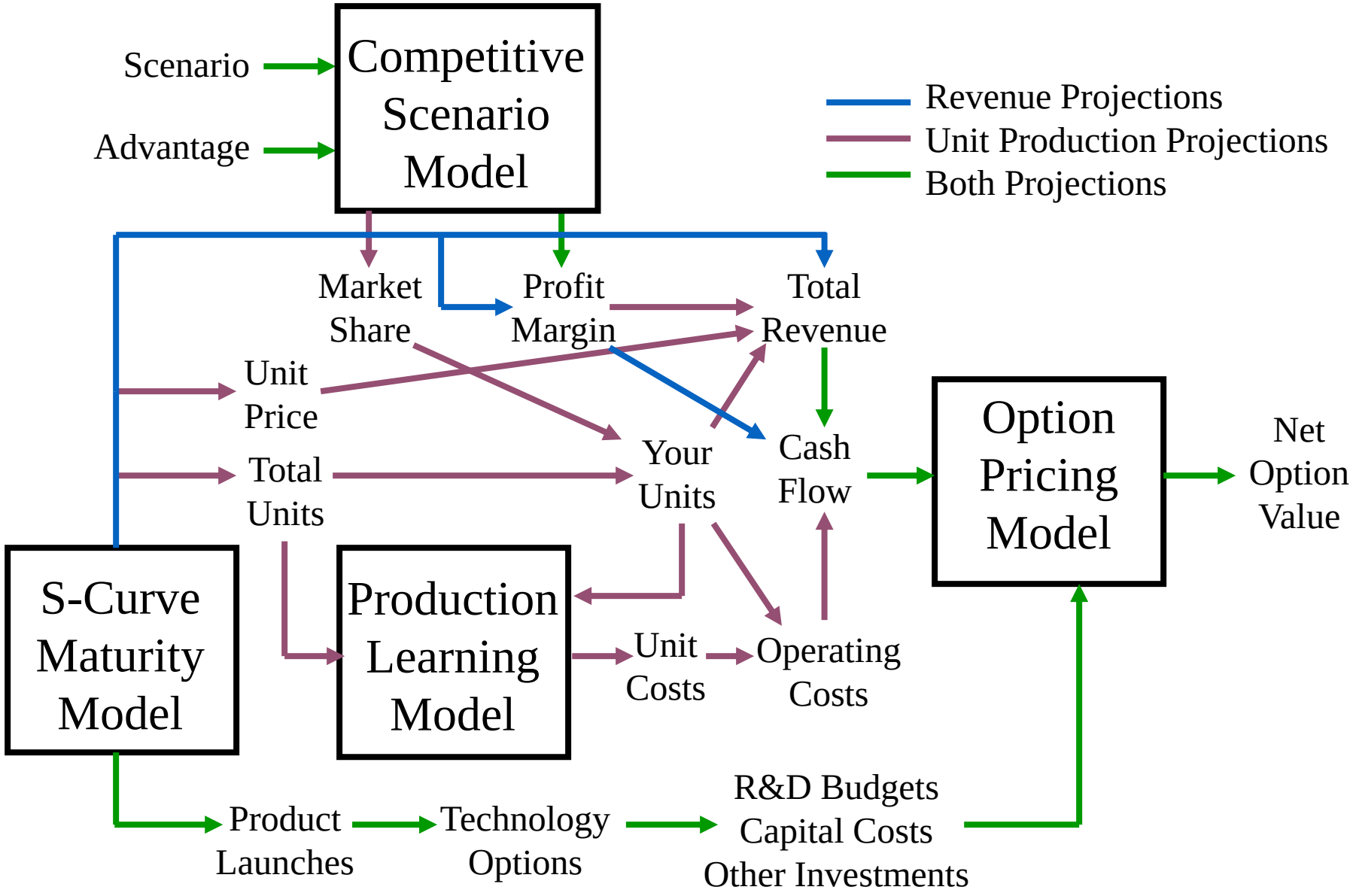
Step 1: Product Lines
Step 2: Financial Information
Step 3: Financial Graphs
Step 4: Option Pricing Model
Step 5: Sensitivity Graphs
Step 6: Monte Carlo Analysis

Source: Rouse, W.B., Howard, C.W., Carns, W.E., & Prendergast, E.J. (2000). Technology investment advisor: An options-based approach to technology strategy. *Information • Knowledge • Systems Management*, 2 (1), 63-81.

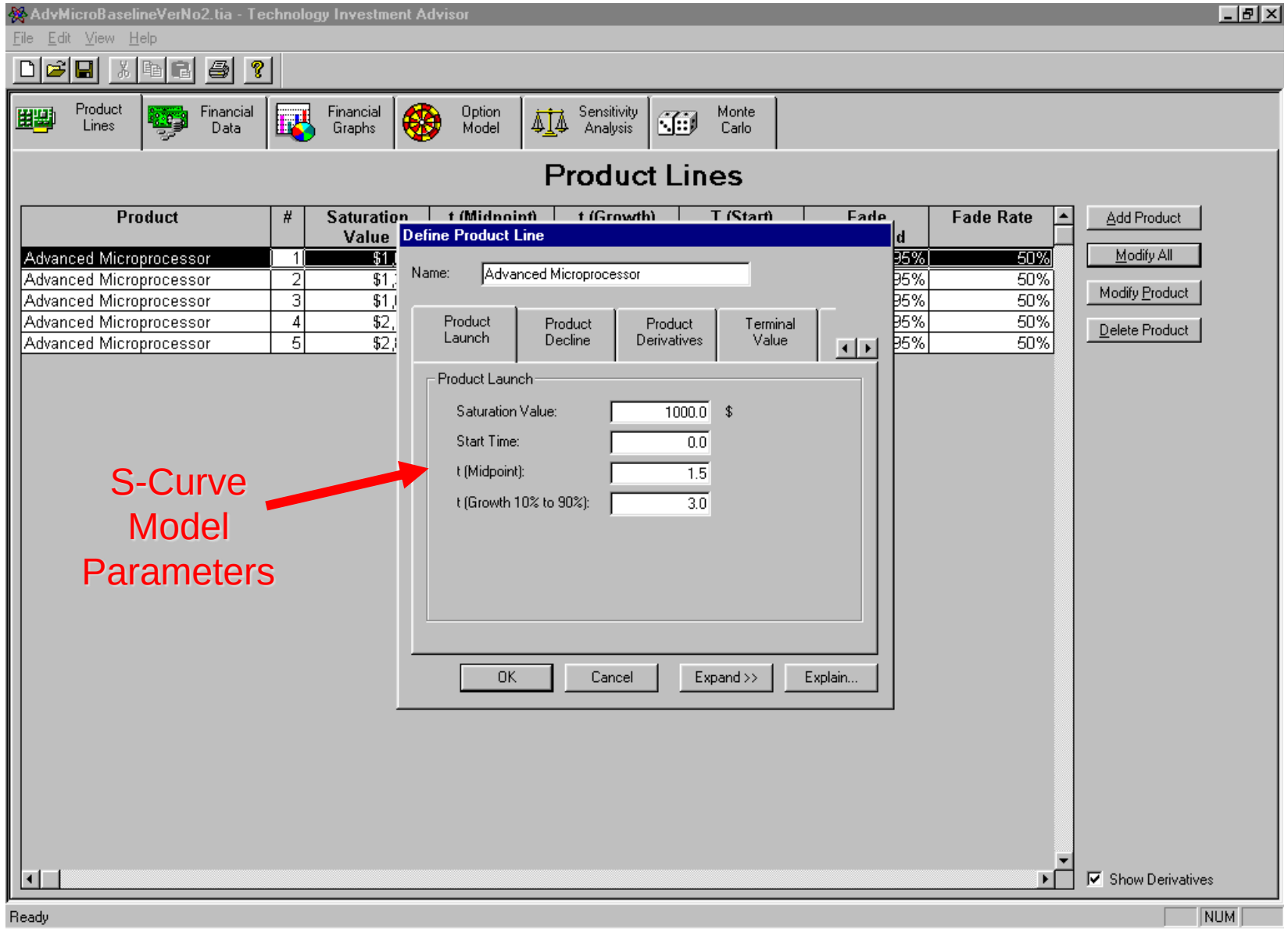
TIA Concept of Use



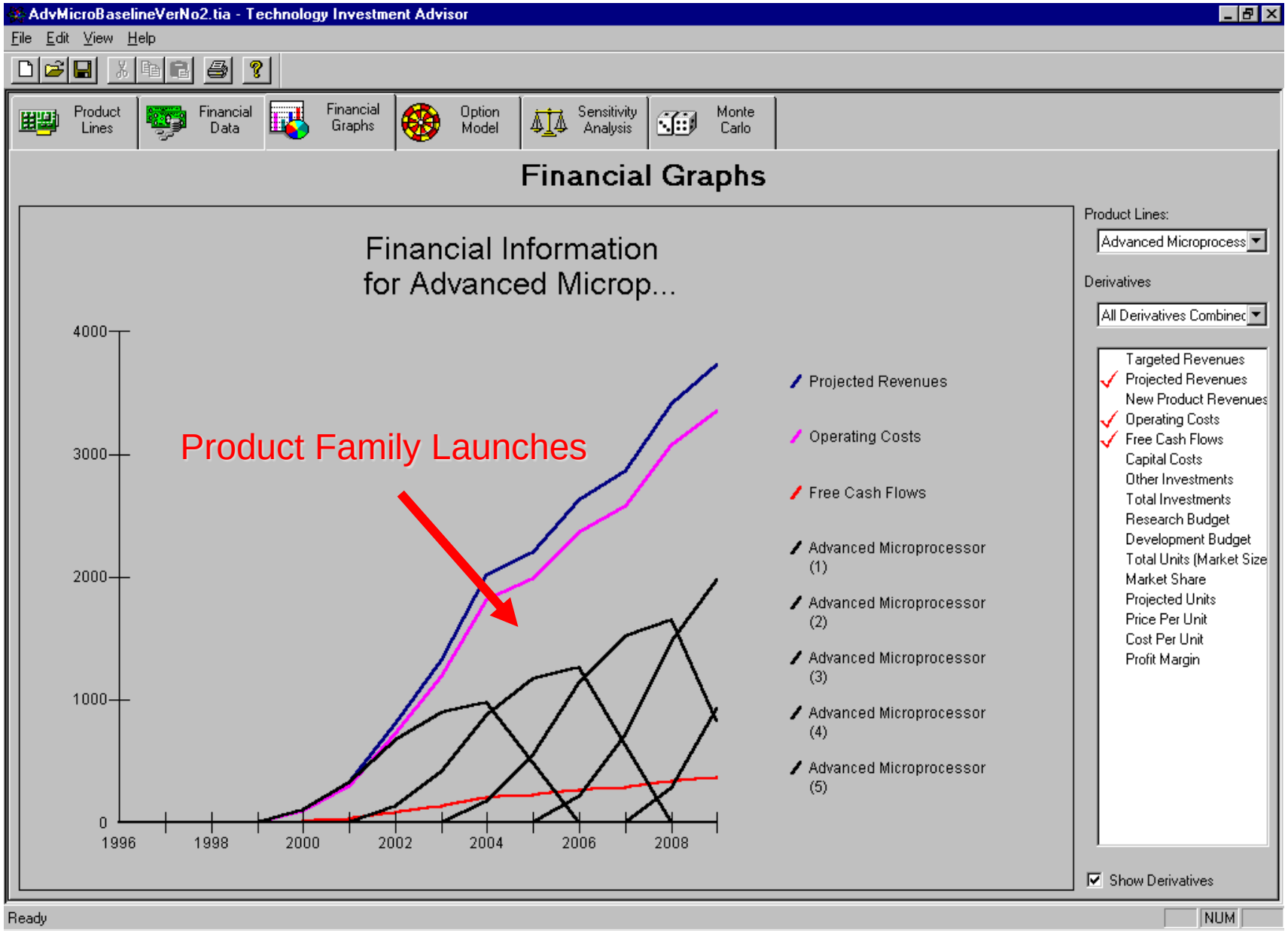
UNDERLYING RELATIONSHIPS



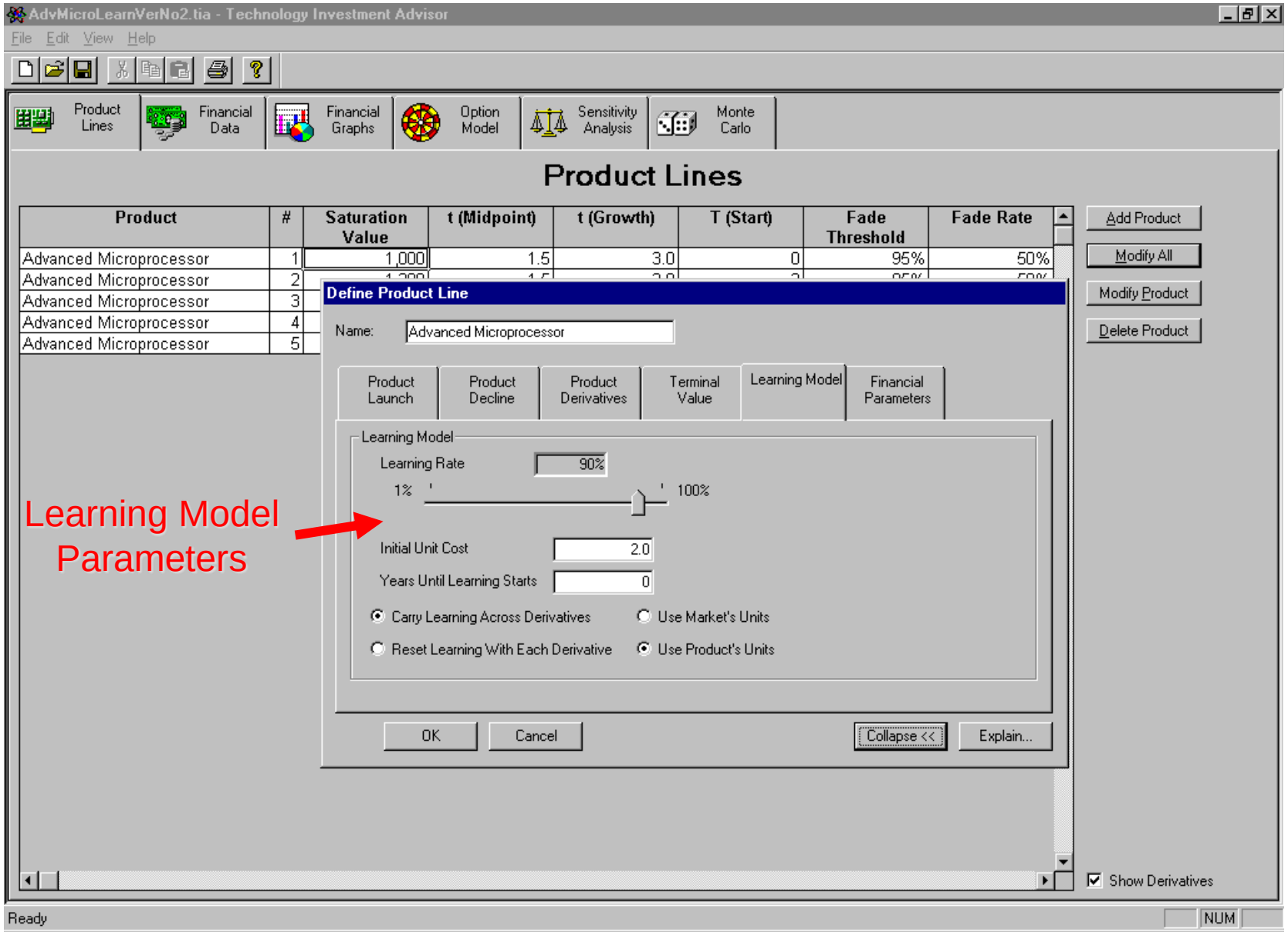
Market Maturity Model



Financial Projections

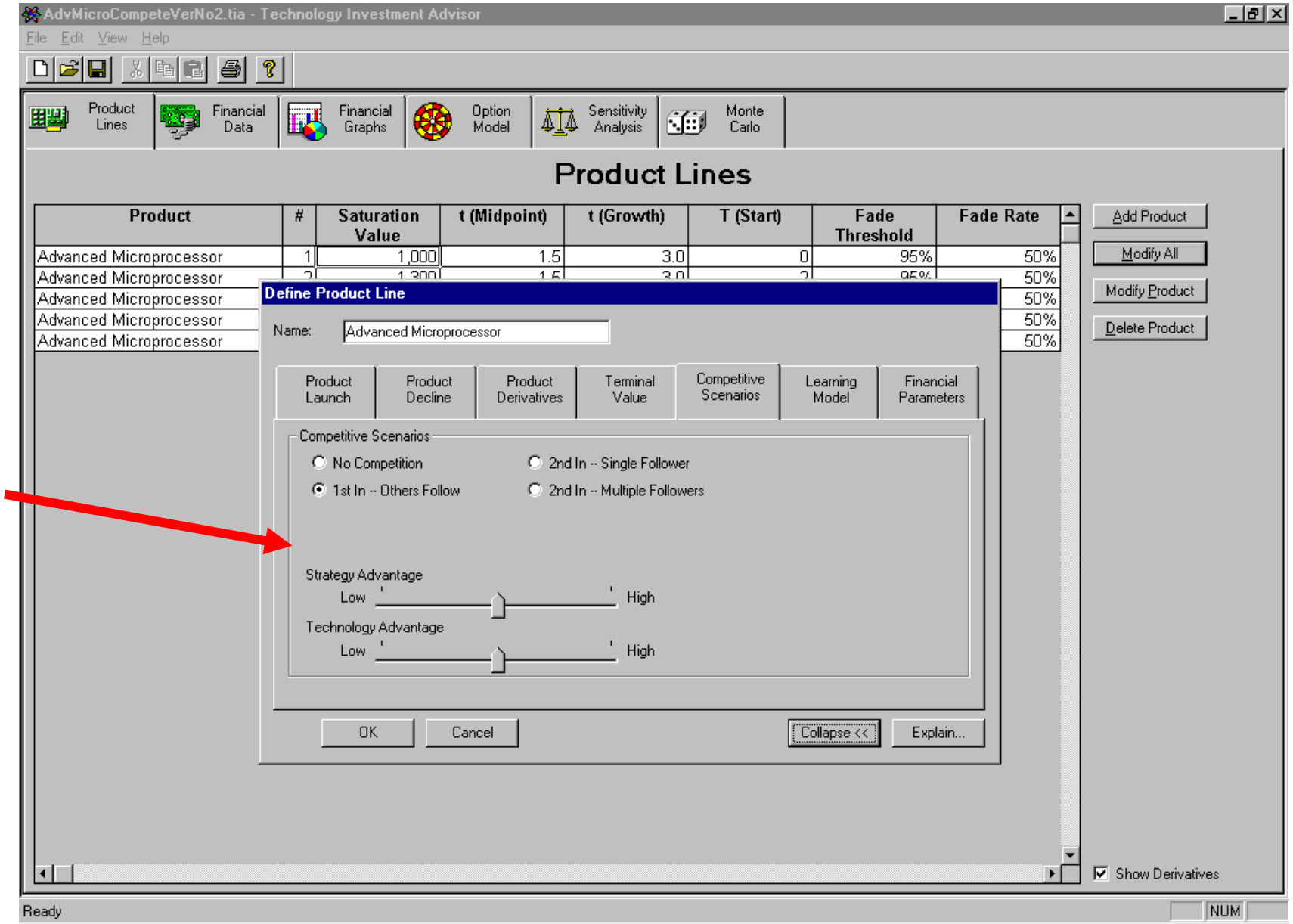


Production Learning Model

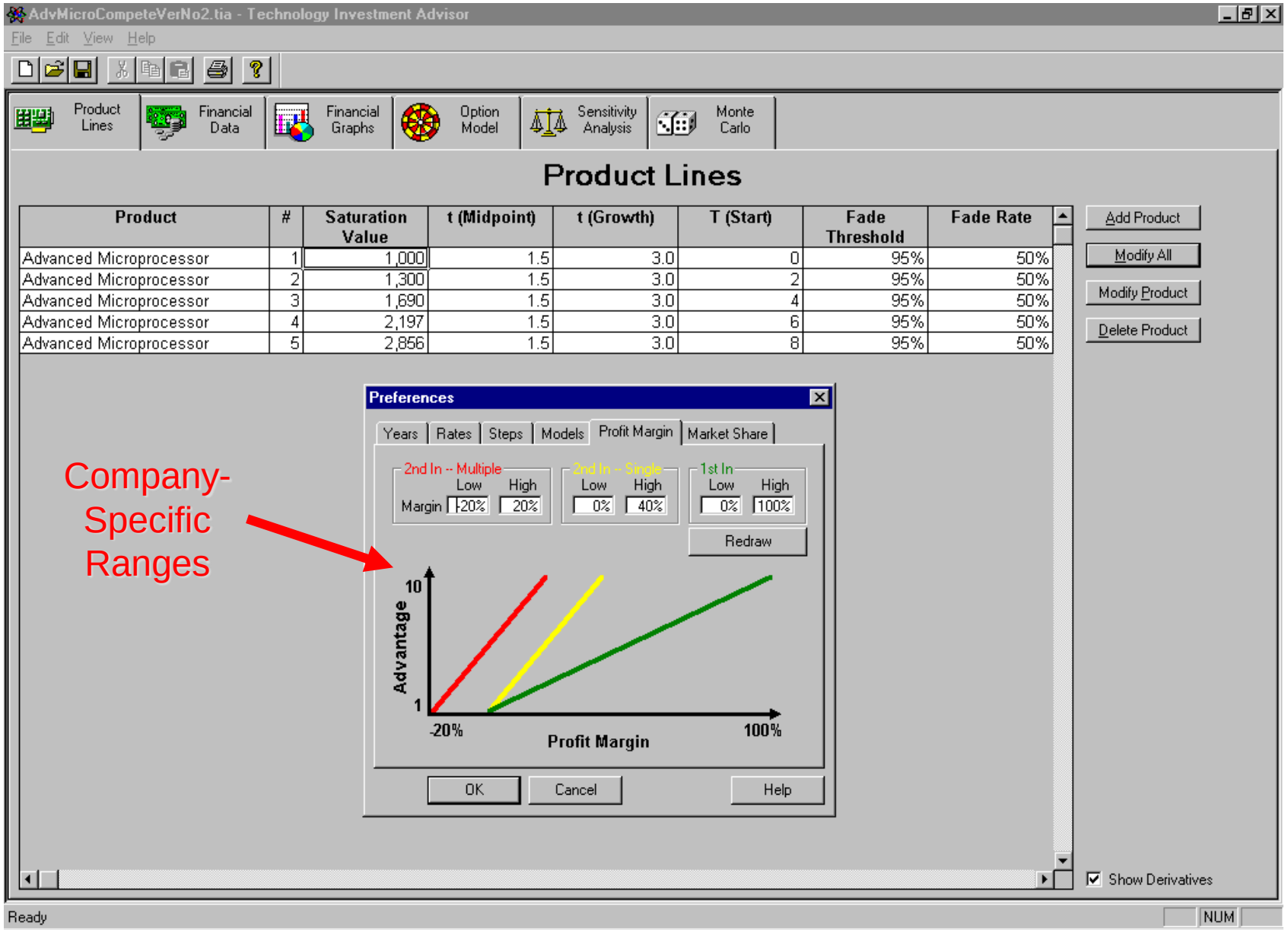


Competitive Scenarios

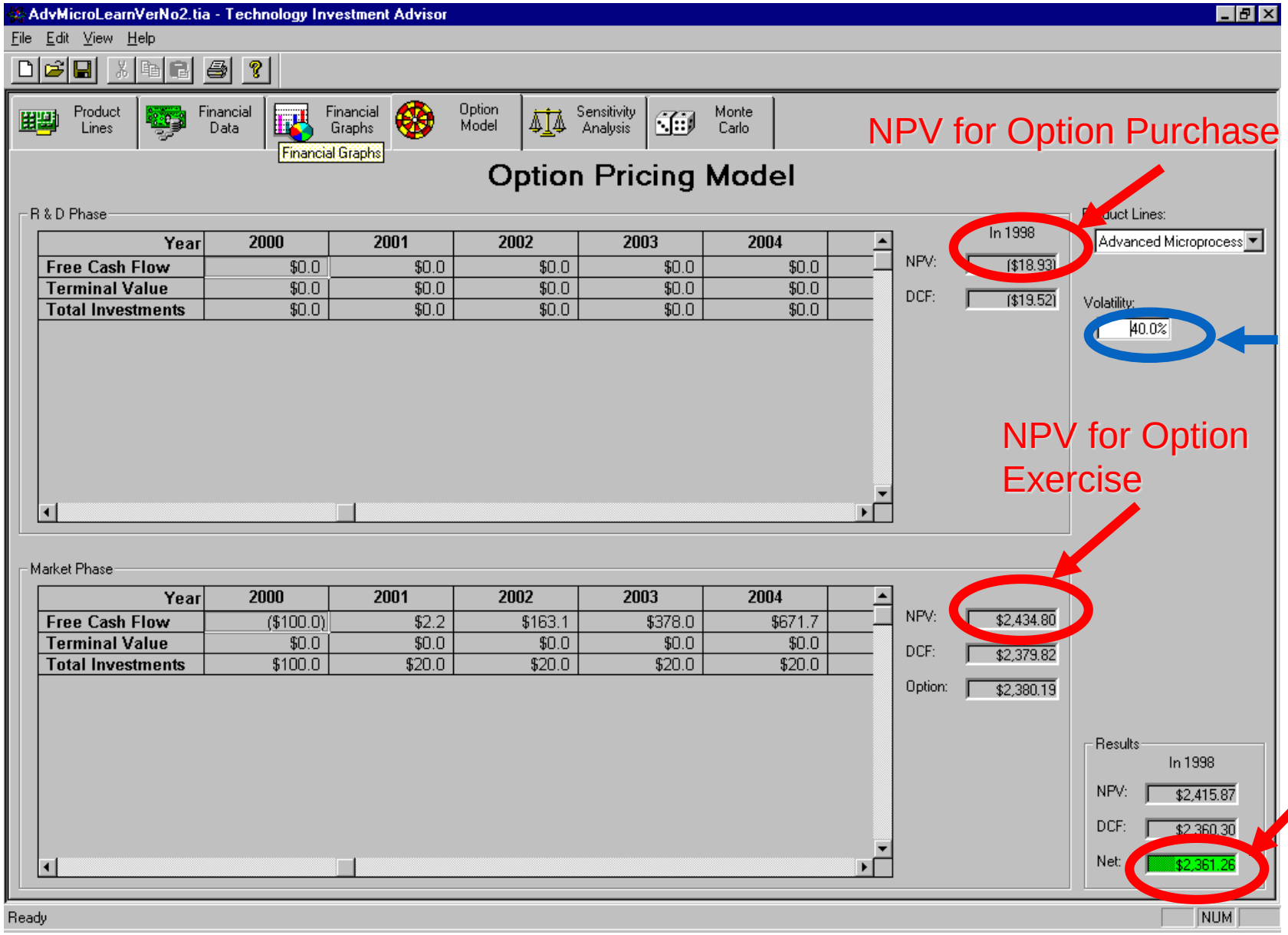
Competitive Scenario Parameters



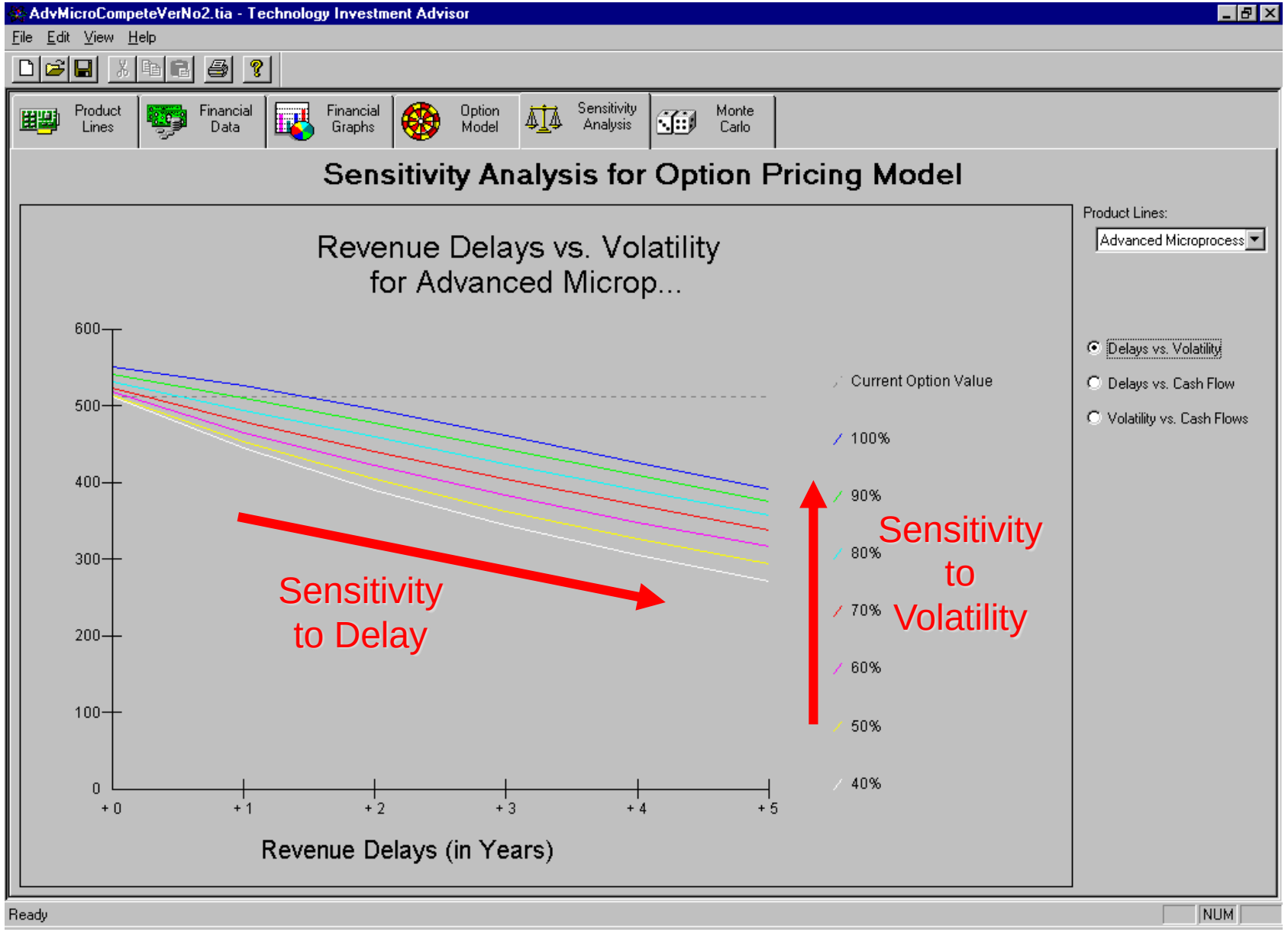
Margin/Share Impacts



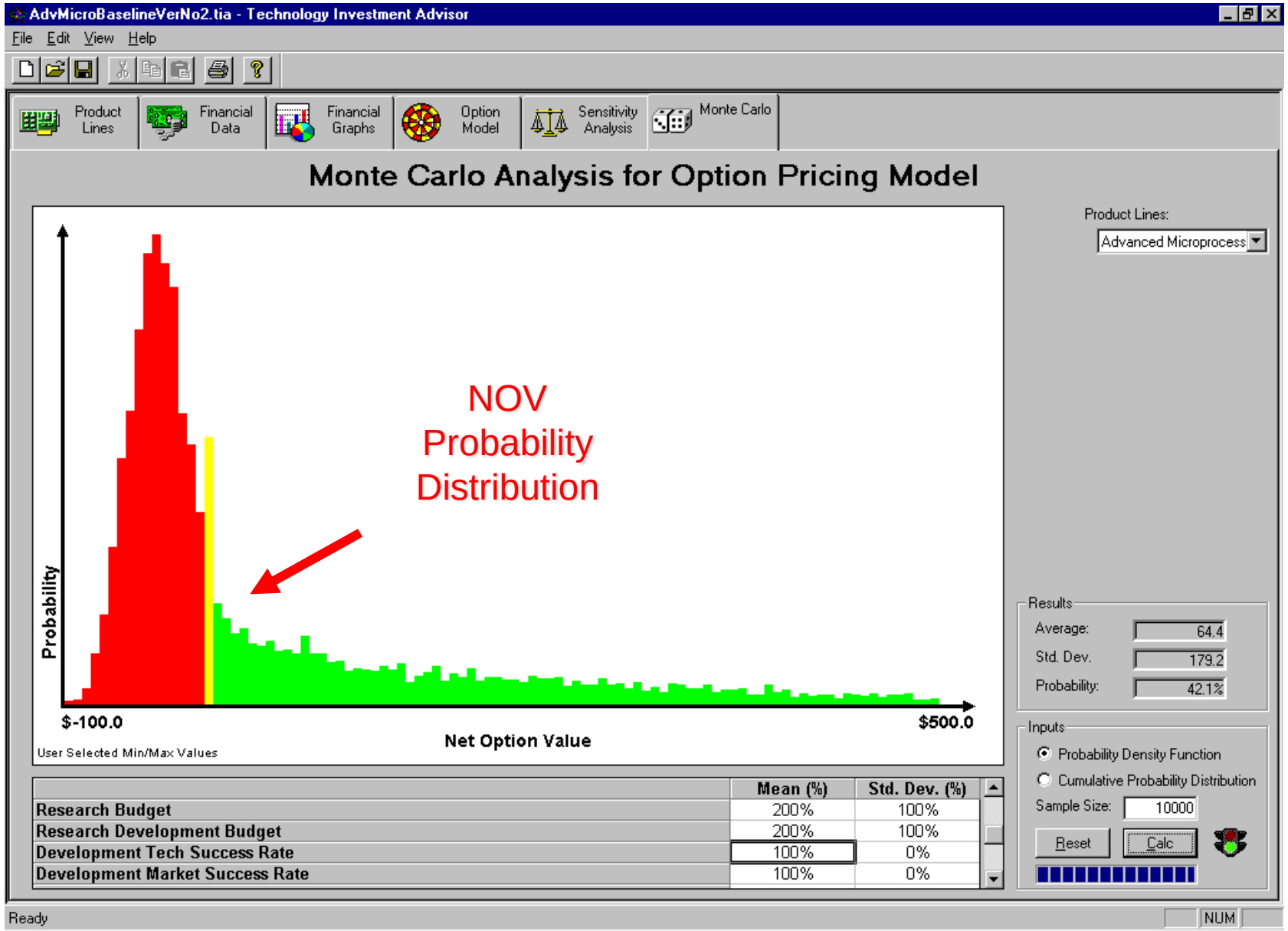
Option Pricing Model



Sensitivity Analysis

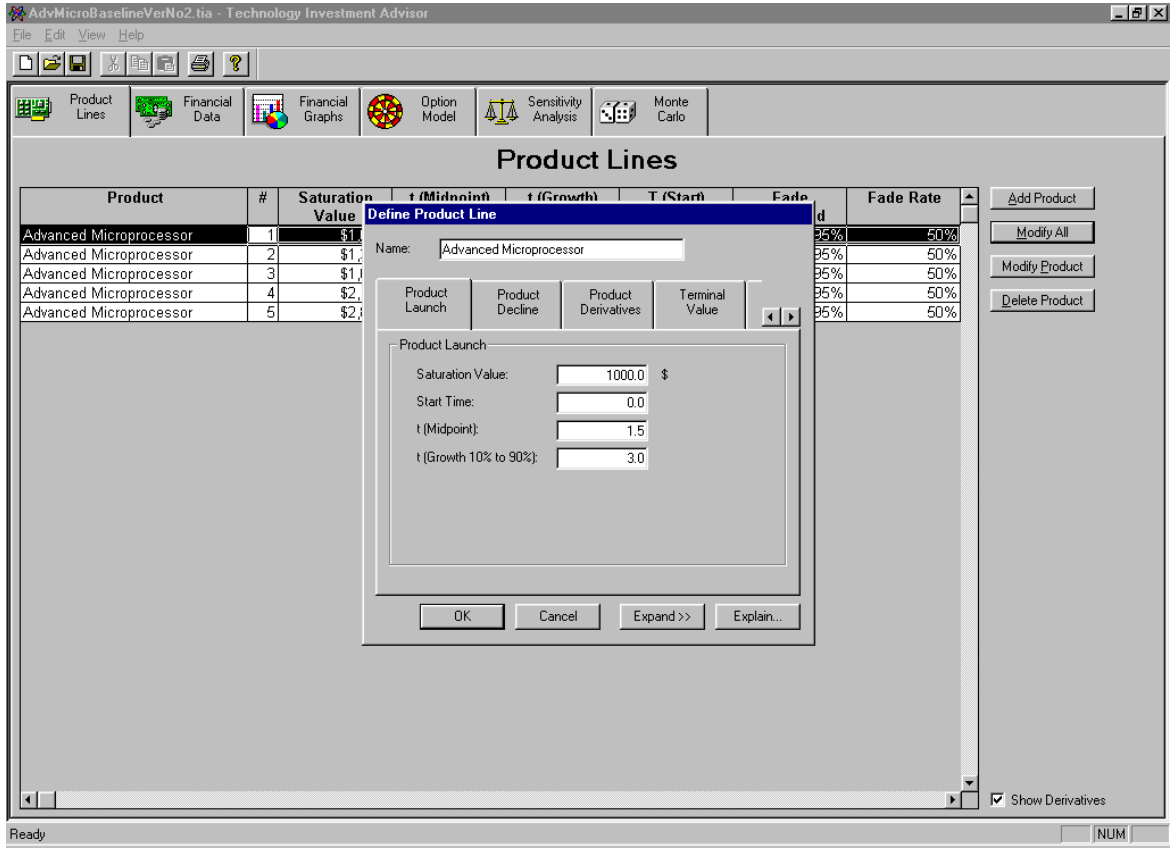


Monte Carlo Analysis



TIA Summary

- Integrates Strategy Best Practices
  - Options Pricing Models
  - Maturity Models
  - Learning Models
  - Competitive Scenarios
- Supports Multiple Levels of Use
  - Use of All or Any Models
  - Use of All or Any Steps



Decision Support System (DSS)

A DSS is an interactive, model-integrated, software-based, visualization-rich tool for a user to see how changing decisions and assumptions affects outcomes.

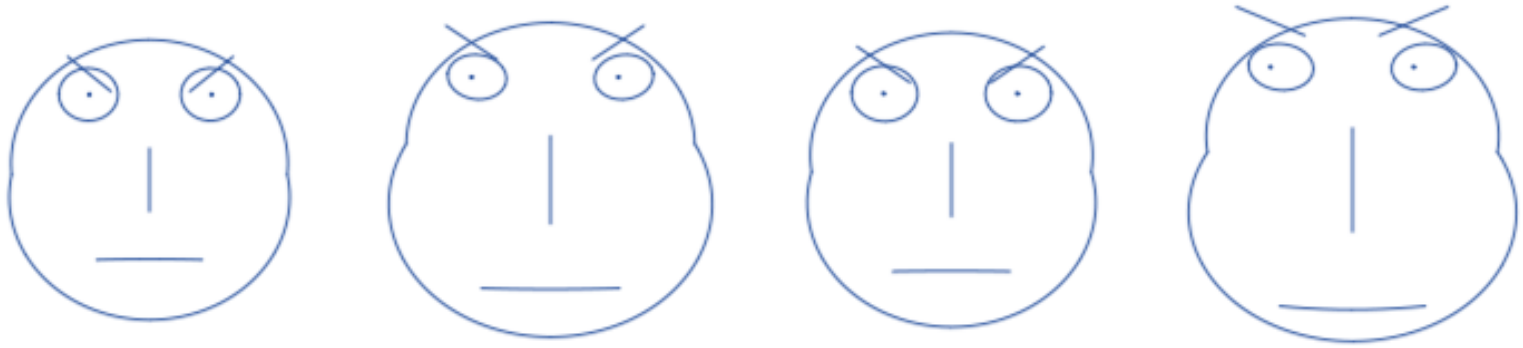
Take 5 minutes. Think of some uses/applications of a DSS and discuss them with your classmates

DSS ideas

- Prediction of sales
- Dynamic pricing
- Decisions on whether to upgrade software on a corporate scale
- Healthcare policy implementation
- Emergency support systems
- Contractor hiring
- Adapting new enterprise management systems
- Diversity policies for hiring/admissions
- Repair scheduling/prioritization for damaged parts in manufacturing
- Doctors prescribing treatments for patients
- Picking stocks
- Designing pipes
- Forecasting and managing inventory in manufacturing
- Health tracking (step trackers/Fitbit)

Alternatives to MAUT

- Multi-Criteria Decision-Making (MCDM) methods
- Holism vs Reductionism
- Visualization for decision making
- Decision Support Systems
- **Prospect Theory**



Mid-semester evaluation and break

Please do the quick survey here:

https://goo.gl/forms/oXOr7WtHvppIxR3W2

We will re-convene in 15 minutes.

Prescriptive vs. descriptive methods

So far, we have discussed ***prescriptive*** approaches for modeling decisions, but there are also ***descriptive*** approaches.

Prescriptive

Utility theory can be thought of as how people ***should*** make decisions.

In ***classical economics***, "Econs" are assumed to behave as rational utility maximizers.

However, people generally do not behave this way.

Descriptive

Sometimes we want to know how people ***actually*** behave/make decisions.

Examples: How will customers react to a new product? How will the public react to a new policy?

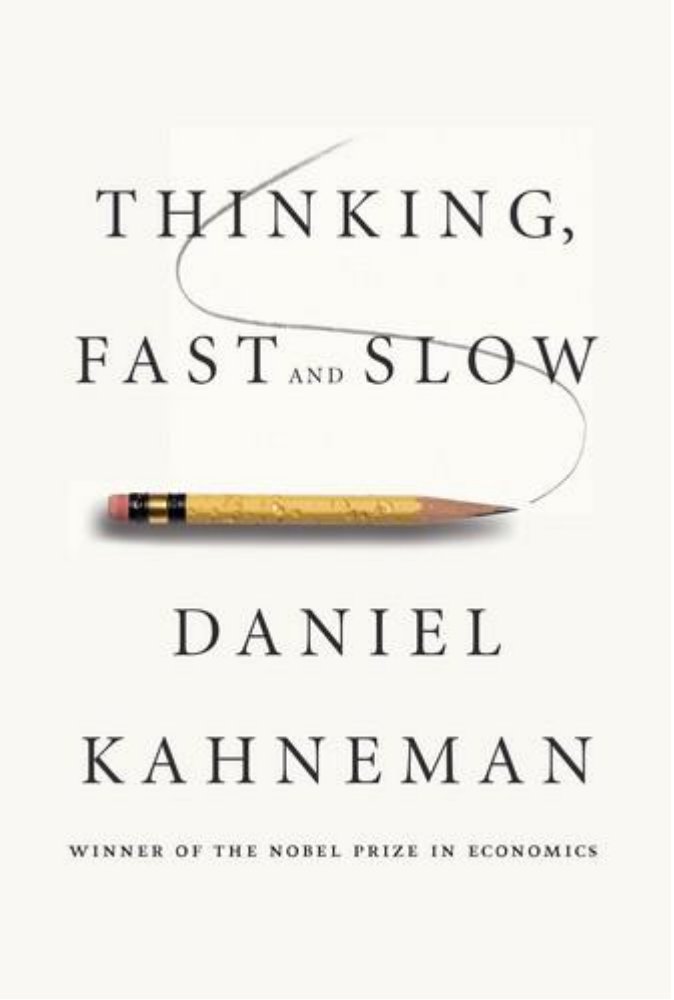
Prospect theory offers a descriptive approach.

Prospect Theory

Daniel Kahneman received the Nobel prize in Economics for developing ***Prospect Theory*** as an alternative to utility theory.

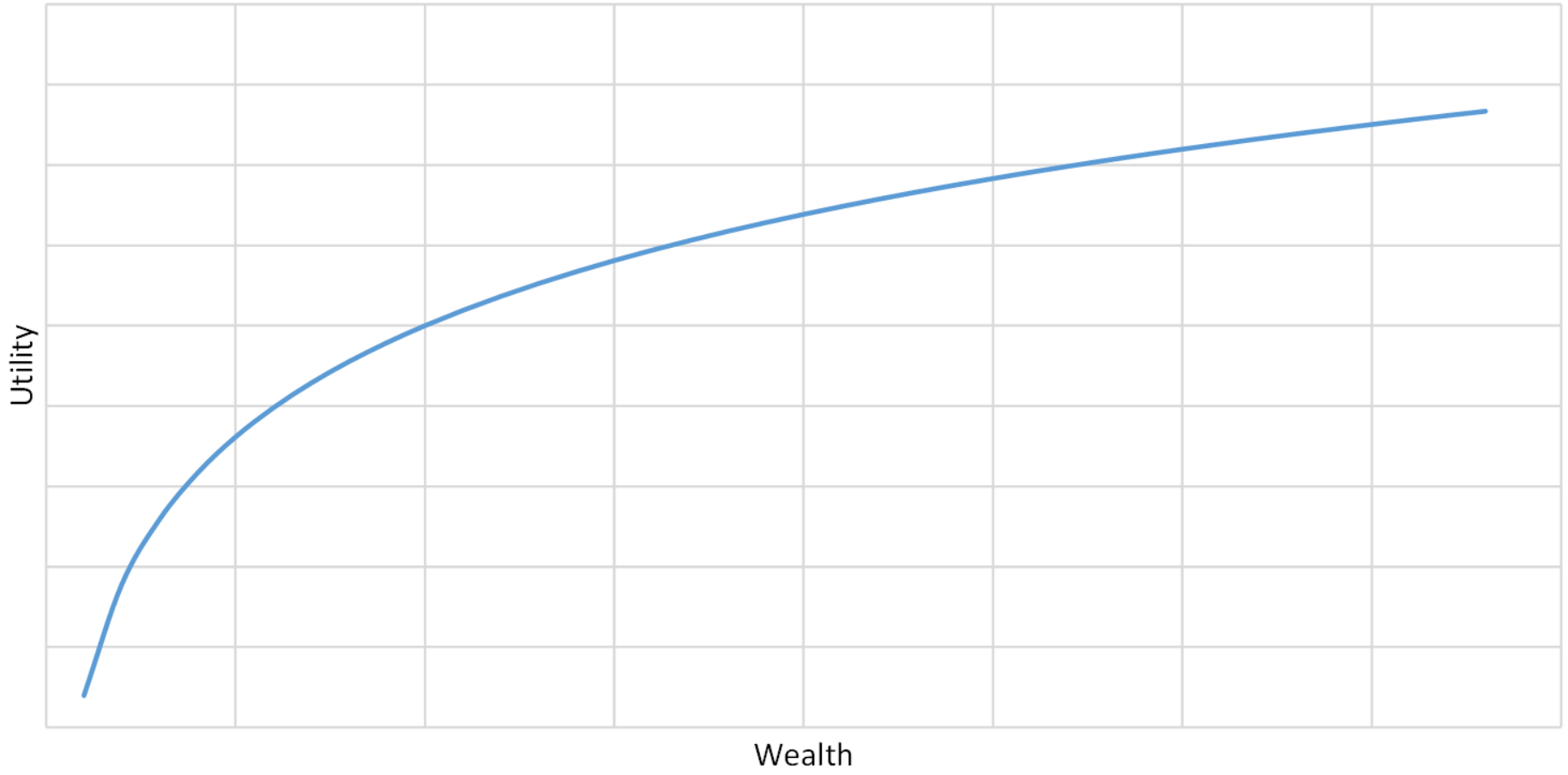
Prospect Theory more accurately describes how human preferences change in response to risk

- The key insight: Utility theory ignores reference points
- Perceptions of risk depend on whether the outcomes are viewed as losses or gains (we tend to weigh losses more heavily than gains)



Decreasing risk aversion

Recall from utility theory: Many decision makers exhibit decreasing risk aversion as a function of their current level of wealth



Prospect Theory

Question: How many people do you think know their current state of wealth with a high level of accuracy?

(It gets harder as you get older and accumulate credit cards, loans, retirement accounts, etc.)

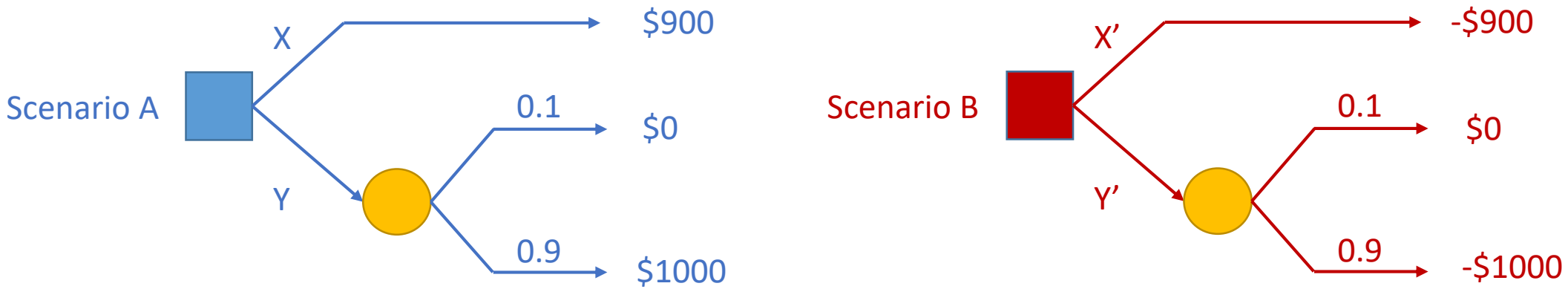
If people are not sure what their current level of wealth is, how can it factor into their decision making with a high level of precision?

This questions assessing utility functions with lotteries over small quantities

In ***prospect theory***, we assess a decision maker's risk attitudes with respect to changes in wealth rather than the end state of wealth

Differences from Utility Theory

Which would you choose?



Most people would choose the sure gain (X) for scenario A and the gamble (Y') for scenario B

This implies ***risk averse*** behavior for the "gain" scenario and ***risk seeking*** behavior for the "loss" scenario—but if your risk preferences are a function of your current wealth, then why would you be risk averse in one scenario and risk seeking in another?

Source: Kahneman, D., 2011, *Thinking Fast and Slow*, New York: Farrar, Strauss and Grioux.

Differences From Utility Theory

- In real life, psychological factors can dominate “rational” behavior
- Humans weigh losses more heavily than gains

Every Olympics year, there are news stories about how bronze medalists (3rd place) tend to be happier than silver medalists (2nd place)!

- How a choice/outcome is framed changes the psychological reference point from which gains and losses are measured
- For example, many would view getting a smaller raise than his or her coworkers as a loss even though it is technically a gain

Contrasting Predictions

What would you do in these scenarios?

(Half of the classroom should close their eyes)

Scenario A

1. In addition to whatever you own, you have been given $1000
2. You are now asked to choose one of these options:
   A. A 50% chance to win $1000
   B. A certain $500

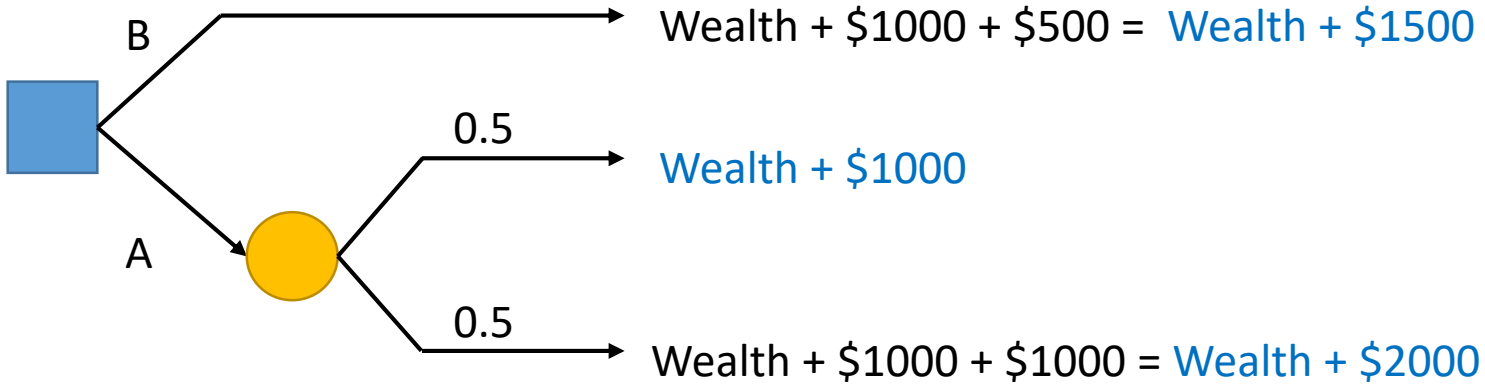
Scenario B

1. In addition to whatever you own, you have been given $2000
2. You are now asked to choose one of these options:
   C. A 50% chance to lose $1000
   D. A certain $500 loss

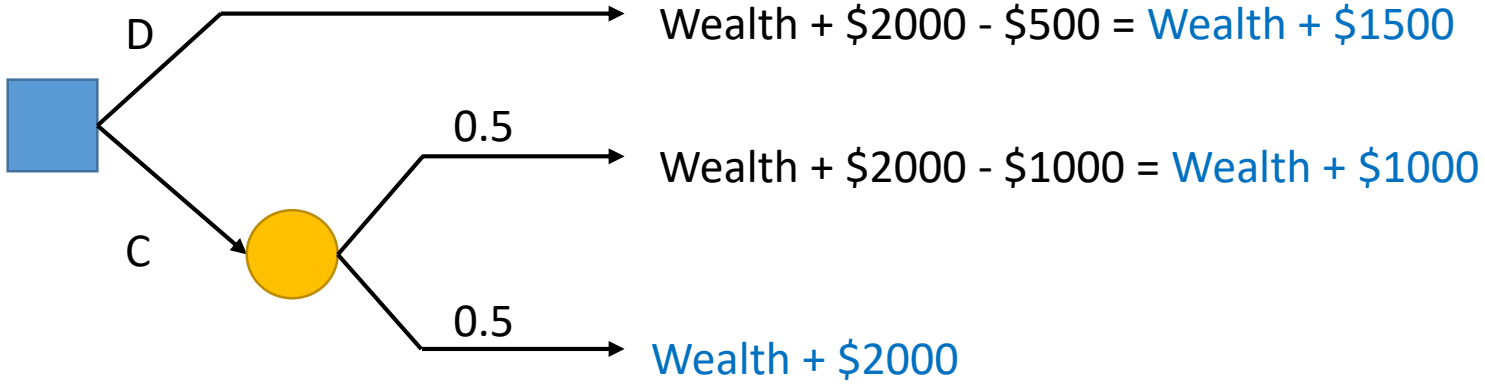
Source: Kahneman, D., 2011, *Thinking Fast and Slow*, New York: Farrar, Strauss and Grioux.

Contrasting Predictions

Scenario A:



Scenario B:



According to utility theory, these two scenarios are identical!

Contrasting Predictions

Utility theory predicts that the decision maker should have the ***same preference*** between the certain outcome and the gamble in both scenarios.

What do real people choose?

A. In scenario A, most people would take the certain outcome
B. In scenario B, most people would take the gamble

Why does this occur?

- Providing the decision maker with different endowments changes the reference point
- In scenario A, moving from $1000 to $1500 is gain
- In scenario B, moving from $2000 to $1500 is a loss
- The endowment is immediately added to the reference point and then the reference point is ignored in favor of focusing on a gain vs. a loss

Source: Kahneman, D., 2011, *Thinking Fast and Slow*, New York: Farrar, Strauss and Grioux.

Psychological Principles

1. Evaluation of choices is relative to a reference point called the ***adaptation level***
   - After a cold winter, a daytime high of 50°F feels warm
   - After a hot summer, a daytime high of 50°F feels cold
2. There is a diminishing sensitivity in the evaluation in changes of wealth
   - An increase from $10,000 to $11,000 would feel larger than from $100,000 to $101,000
   - Think about it as a 10% raise versus a 1% raise
3. Humans exhibit loss aversion
   - All things being equal, a loss is weighted more heavily than a gain
   - Kahneman suggests that loss aversion is a result of evolutionary pressures

Prospect Theory Model

Decision making occurs in two phases: editing and evaluation

1. During ***editing***
   - Outcomes are ordered
   - Equivalent outcomes are identified
   - A reference point is set
   - Lesser outcomes are viewed as losses, and better outcomes are viewed as gains
2. During ***evaluation***
   - People act as if they are choosing the option with the highest expected utility
   - However, the utility function is modified to:
     a) Value gains differently than losses
     b) Better handle very large and very small probabilities

Prospect as modified Utility

Under ***utility theory***, the expected utility of discrete outcomes is computed as

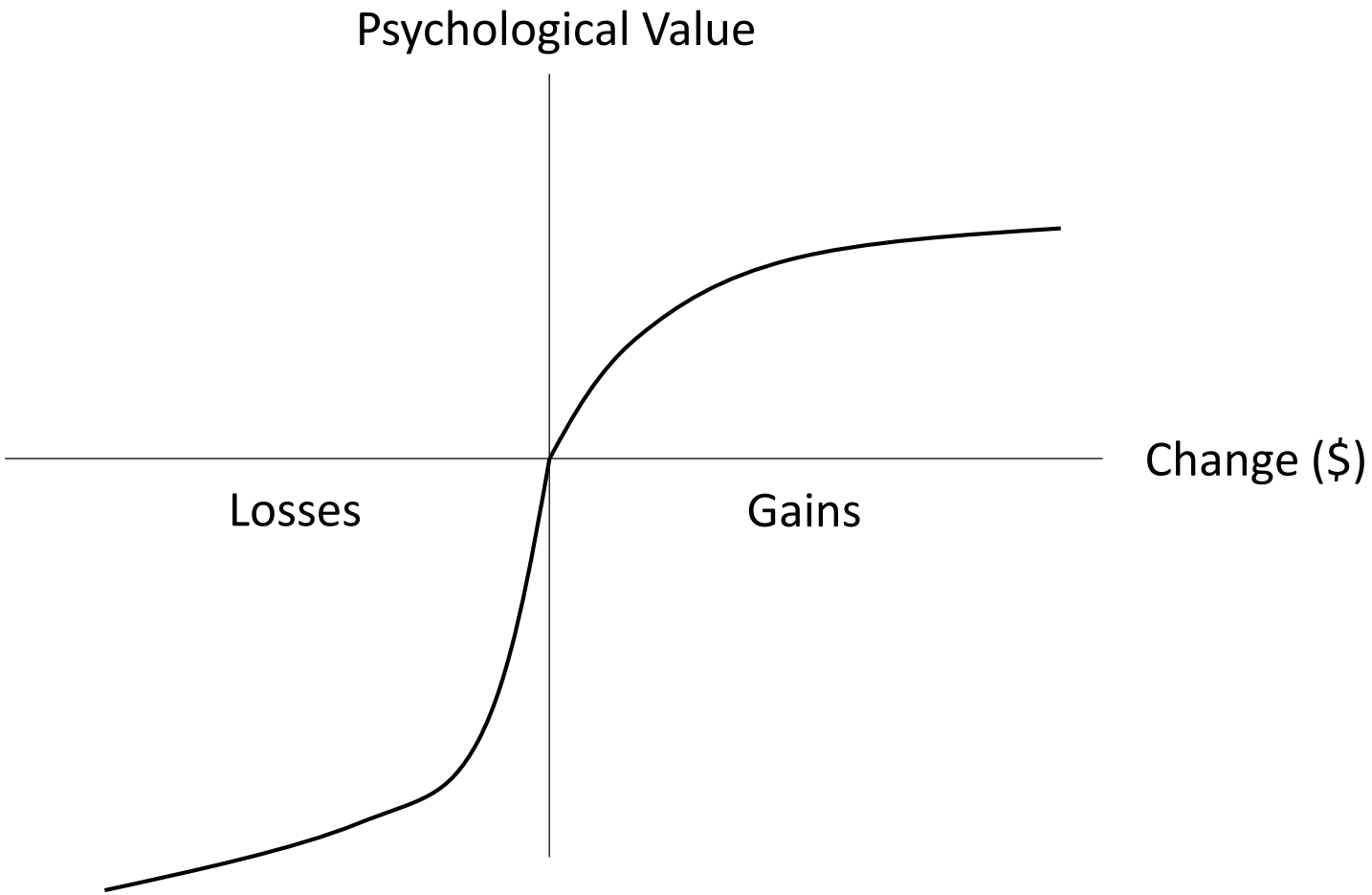
$$E[U(X)] = \sum_{i=1}^{n} p_i \, U(x_i)$$

Under ***prospect theory***, the expected utility of discrete outcomes is computed as

$$V(X) = \sum_{i=1}^{n} \pi(p_i) \, v(x_i)$$

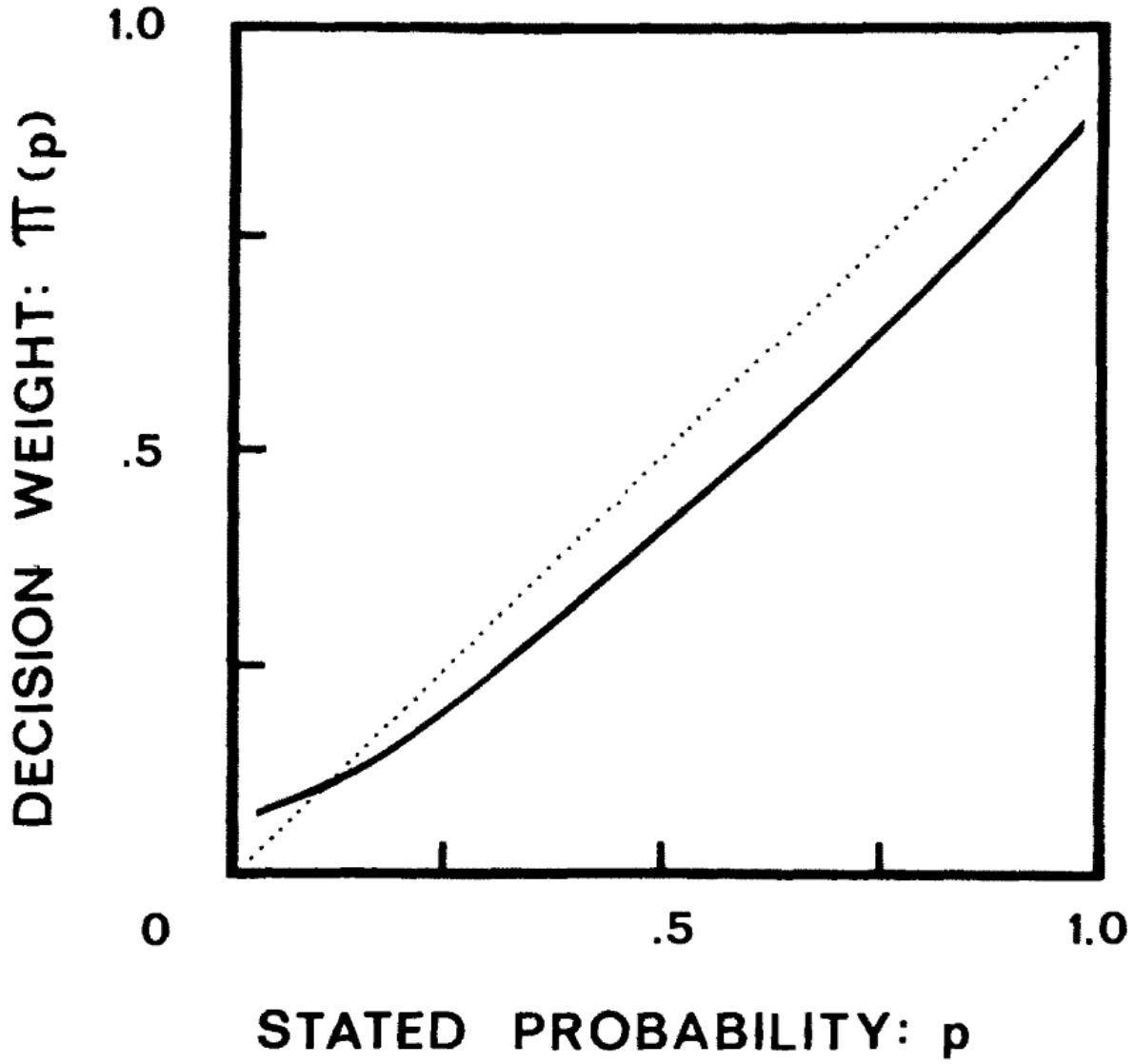
where $v(x)$ is the value function, and $\pi(p)$ is the weighting function

Value Function, $v(x)$



Adapted from: Kahneman, D., 2011, *Thinking Fast and Slow*, New York: Farrar, Strauss and Grioux.

Weighting Function, $\pi(p_i)$

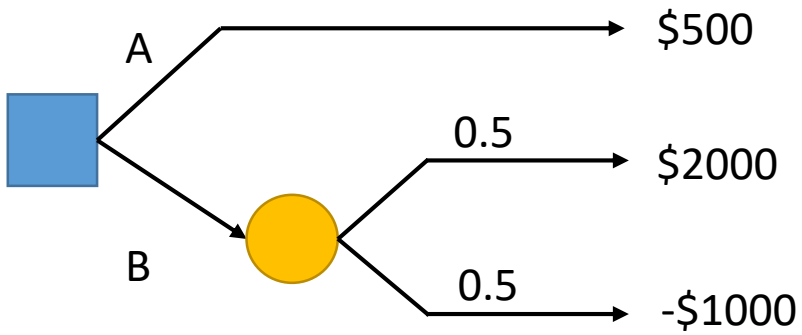


Source: Kahneman, D., & Tversky, A. (1979). Prospect theory: An analysis of decision under risk. *Econometrica: Journal of the Econometric Society*, 263-291.

Implications

In a mixed gamble, decision makers exhibit extreme risk aversion because the risk of loss weighs heavily

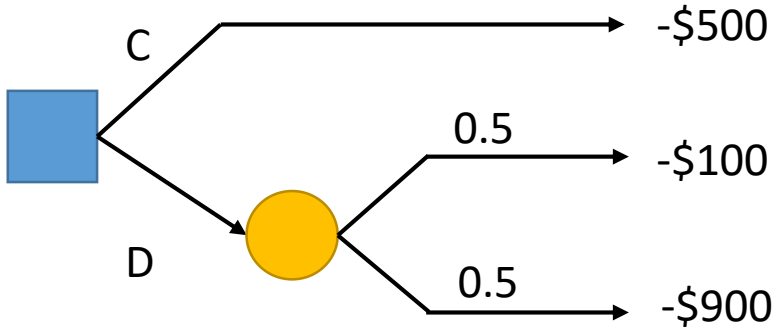
E.g.,



Many decision makers would choose A

When all options are bad, decision makers become risk seeking

E.g.,



Many of the same decision makers would choose D

The net result is that real decision makers may turn down favorable opportunities because of fear of loss and take risky gambles when they feel they are backed into a corner

Implications

	Gains	Losses
High Probability	Risk Averse	Risk Seeking
Low Probability	Risk Seeking	Risk Averse

Summary

- As a ***prescriptive decision model, utility theory*** remains the standard of comparison, and it should serve as the ideal for "rational" decision-making
- However, applying utility theory in real decision problems is not always practical
- A number of ***MCDM alternatives*** have been proposed over the years, but none have supplanted utility theory as the theoretical standard
- Some have taken a holistic approach and employ ***visualization*** as an aid to decision makers to simultaneously assess decisions over all attributes
- ***Decision support systems*** can leverage the best of each approach by allowing decision makers to dynamically interact with the decision model
- As a ***descriptive model, Prospect Theory*** is often more representative of real human decision-making behavior, in that it accounts for certain psychological factors

The next slide shows a video review of *Thinking Fast and Slow*, from:
https://www.youtube.com/watch?v=uqXVAo7dVRU

Where are we in the course?

Theme	Week	Topic	Assigned
Modeling decisions	1	Introduction to Decision and Risk Analysis in SE	
	2	Structuring a Decision	HW1
	3	Tradeoffs under Certainty	HW2
Uncertainty	4	Probability Refresher	HW3
	5	Subjective Probability and the Value of Information	HW4
Utility	6	Multi-Attribute Utility Theory	HW5
	7	**Alternatives to MAUT**	**Midterm**
	8	**Midterm Exam – Q & A Session**	**(Midterm)**
Risk	9	Cognitive Bias and Perceptions of Risk	HW6
	10	Introduction to Risk Management	Projects
	11	Project Risk Management	
	12	Incorporating Financial Risk into Project Decisions	
	13	~~Risk of~~ Extreme Event and Model Risk	
	14	~~Model Risk~~ Project Presentations	
	15	~~Project Presentations~~	

Grading	
Homework	30 %
Mid-term	35 %
Team project	35 %

Mid-term

Due Oct 31 by 6:15pm