Cost Effectiveness Analysis

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TOPICS

• Decision-making and cost effectiveness
• Methodology
• Example
• Theoretical foundations
• Elaboration of methodology
• Criticisms of cost effectiveness analysis
Most decisions by government, business and households ---
--- involve allocating resources ---
-- which means deciding among alternatives ---
--- which requires considering costs and benefits

COMMON DECISION-MAKING METHODS

• Judgments by officials and professionals
  – Captures corporate memory and institutional knowledge
    \textit{But decision makers often disagree}

• Immersion in the facts
  – Stays in contact with reality
    \textit{But “what is” diverts attention from “what could be”}

• Holistic approach (“Since judgment calls are required, let the practitioner decide”)
  – People learn to do very well what they do every day
    \textit{But practitioners do not spend their days studying alternatives, costs and benefits}
ANOTHER METHOD: COST EFFECTIVENESS

• Deals with objective, alternatives, cost and benefits explicitly

• Does it quantitatively as much as possible

SOME ODDS AND ENDS

• Cost effectiveness
  – is a methodology, not a type of effectiveness
  – is sometimes called “systems analysis”
  – is related to profit maximization and cost–benefit analysis
  – in defense analysis, focuses on the peacetime cost of wartime capability
**COST EFFECTIVENESS METHODOLOGY**

- Define Objectives  
  What do we want to do?
- Structure Alternatives  
  What are the ways to do it?
- Calculate Effectiveness  
  What do we gain?
- Estimate Costs  
  What do we lose?
- Choose a Criterion  
  Which alternative is best?

**SOME CRUCIAL ISSUES**

- If at all possible, construct alternatives that hold something constant
  - Hold cost constant and maximize effectiveness
  - Hold effectiveness constant and minimize cost
- If this is impossible to bring off (i.e., cost and effectiveness both vary)
  - Identify cost-effectiveness frontier
  - Calculate cost-effectiveness ratios
- Don’t carry out the steps sequentially
OTHER IMPORTANT ISSUES

• Construct a “base case” using the most plausible inputs
• Conduct sensitivity analyses to cover uncertainties
• List omitted factors and indicate their likely effects
• Highlight critical issues requiring judgment calls
• Should the analyst make policy recommendations?

APPLICATIONS

• Government
  – Buy new C-17s or stretch B-52s?
  – Extend subway to Dulles or widen the road?
• Industrial
  – What kind of plant to build?
• Medical
  – What diagnosis tools are best?
• Consumer
  – Toyota or Lexus?
AN EXAMPLE: BUYING A NEW CAR

<table>
<thead>
<tr>
<th></th>
<th>Buy a Chevy</th>
<th>Buy a Honda</th>
<th>Buy a Chevy</th>
<th>Buy a Chevy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rent a Mercedes</td>
<td>Fly Between Cities for Inter-city Travel</td>
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</tr>
<tr>
<td>Unit Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procurement</td>
<td>$15,000</td>
<td>$20,000</td>
<td>$15,000</td>
<td>$15,000</td>
</tr>
<tr>
<td>Operating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>City</td>
<td>$0.14/mi</td>
<td>$0.12/mi</td>
<td>$0.14/mi</td>
<td>$0.14/mi</td>
</tr>
<tr>
<td>Country</td>
<td>$0.10/mi</td>
<td>$0.08/mi</td>
<td>$0.14/mi</td>
<td>$0.14/mi</td>
</tr>
<tr>
<td>Rental</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airlines</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salvage value</td>
<td>$5,000</td>
<td>$10,000</td>
<td>$6,000</td>
<td>$6,000</td>
</tr>
</tbody>
</table>

Unit Effectiveness

<table>
<thead>
<tr>
<th></th>
<th>Miles in city</th>
<th>Miles in country</th>
<th>Miles in city</th>
<th>Miles in country</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10,000 mi/yr</td>
<td>5,000 mi/yr</td>
<td>10,000 mi/yr</td>
<td>5,000 mi/yr</td>
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</tbody>
</table>

Total 10-year cost

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<tr>
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<th>City</th>
<th>Country</th>
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<tbody>
<tr>
<td></td>
<td>100,000 mi</td>
<td>50,000 mi</td>
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</table>

Total 10-year effectiveness

<table>
<thead>
<tr>
<th></th>
<th>City</th>
<th>Country</th>
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<tbody>
<tr>
<td></td>
<td>100,000 mi</td>
<td>50,000 mi</td>
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</tbody>
</table>

WHY SHOULD COST ANALYSTS UNDERSTAND COST EFFECTIVENESS

- We do cost analyses to support decision making
- The decision affects the structure of the cost analysis
  - Which costs are relevant
  - What discount rate to use
  - How much accuracy is necessary?
THEORETICAL FOUNDATIONS

Cost Effectiveness is a branch of microeconomics

<table>
<thead>
<tr>
<th></th>
<th>Benefit ($)</th>
<th>Cost ($)</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Sector</td>
<td>Revenue ($)</td>
<td>Cost ($)</td>
<td>Maximize profit ($)</td>
</tr>
<tr>
<td>Public Sector, Marketable Output</td>
<td>Benefit ($)</td>
<td>Cost ($)</td>
<td>Maximize the ratio</td>
</tr>
<tr>
<td>Public Sector, Non-marketable Output</td>
<td>Effectiveness</td>
<td>Cost ($)</td>
<td>Hold one constant, optimize the other</td>
</tr>
</tbody>
</table>

**Cost effectiveness analysis**

• More on foundations of cost effectiveness in “Economics in Cost Analysis” on February 10.
INSTITUTIONAL REQUIREMENTS

• Cost effectiveness analysis is
  – Required in the Department of Defense for large programs (COEA or AOA)
  – Recommended by OMB for non-defense programs

FALLACIES AND ISSUES IN COST EFFECTIVENESS

• Objectives
• Alternatives
• Cost
• Effectiveness
• Criterion
• “Determine the system that has the highest effectiveness and the lowest cost”
  
  How can you do both?

• “Determine the least costly system for meeting the requirements”
  
  Requirements don’t exist, except institutionally --
  The more we buy, the higher the effectiveness and the higher the cost

OBJECTIVES

(Continued)

• “You can’t analyze all resource questions — some are really intractable”
  
  A polar position!

• “You can’t analyze new technology options (basic research, exploratory development)”
  
  Make the alternatives menus of possibilities, rather than systems
ALTERNATIVES

• “We should include all alternatives”
  – We can’t
    
    *Scenarios are uncertain*
    *Data are incomplete*
    *Models are imperfect*

• One way to cope with these problems
  – Compare polar cases
    • E.g., a sophisticated costly aircraft with a simpler but less costly one

COST

• Analyze historical data using statistical regression techniques to develop a Cost Estimating Relationship

• Results of regression
  
  \[ \text{Cost} = \alpha + \beta_1 \text{ (input 1)} + \beta_2 \text{ (input 2)} + \ldots \]

• Criteria of validity
  – Intuitive signs (“+” for resource variables)
  – Statistical significance (high t-statistics for all variables)
  – High predictability (high value of R^2)
TYPES OF COST

• Acquisition (non-recurring)
  – Development
  – Procurement
    • Land
    • Facilities
    • Equipment (depends on number of systems)
  – Salvage
• Operations and Support (recurring)
  – Operations and Maintenance
  – Personnel

SUMMARY MEASURES

• 10-year system cost
  Development (~ no. of prototypes)
  + Procurement (unit proc. \(\times\) no. of systems)
  + O&S (unit O&S \(\times\) no. of systems \(\times\) 10)
    – Salvage value (unit salvage \(\times\) no. of systems)

• Life-cycle cost
  30 years of O&S

• Time-phased cost
  Total expenditures over next 10 (or 30) years
• More specifics on cost models in the remaining lectures.

ACCOUNTING FOR TIME

• A problem: $1 commands different resources in different years

• Why?
  – Inflation (general increase in prices)
  – Discount rate *(return on investment)
  – Sunk costs

• Therefore, we must adjust!

* Same as interest rate
ADJUSTMENTS

• For inflation
  – Deflate future costs to constant (current) dollars

• For interest
  – Translate future costs to present values

• For sunk costs
  – Forget them!

Calculating Constant Dollars and Present Values

• Assume 4% inflation and 6% real interest rate
  – Cost of widget purchased in 2001 = $100
  – Cost in 2000 dollars = $100/(1.04) = $96.15
  – Present value in 2000 dollars = $96.15/(1.06) = $90.71

• One step, using a nominal discount rate
  \[ 1 + \text{nominal } r = (1 + .06) \times (1 + .04) \]
  \[ = 1 + .06 + .04 + (.06)(.04) \]
  \[ \equiv 1 + .10 \]
  \[
  \text{Present value in 2000 dollars} = \frac{100}{1.10} = 90.91
  \]

WARNING!

• OMB appropriation-specific deflators include real cost increases, in addition to inflation

• Therefore:
  – Use them for budgeting
  – But not for calculating costs in constant dollars

SUNK COSTS

• Quiz for the student:
  – Why ignore sunk costs?
• Answer:
  – They are not costs!

FALLACIES

• “They’re only 14 to 16 months away from coming up with a system. It would be a shame to throw away the investment in the program.”

• “We’re interested in how much money to put in the budget, so we should use the inflated costs for our cost effectiveness studies.”

• “The DoD budget is relatively constant year-to-year, so there are no time tradeoffs, and costs should not be discounted.”
ACCOUNTING FOR LEARNING IN ESTIMATING PRODUCTION COSTS

People

Average cost = First unit cost x Slope $^{\log(Quantity)}$

Example for 90% learning curve (0.90 slope)

<table>
<thead>
<tr>
<th>Number of Systems Purchased</th>
<th>Average Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>$100.0</td>
<td>$10,000</td>
</tr>
<tr>
<td>200</td>
<td>90.0</td>
<td>18,000</td>
</tr>
<tr>
<td>300</td>
<td>84.6</td>
<td>25,400</td>
</tr>
<tr>
<td>400</td>
<td>81.0</td>
<td>32,400</td>
</tr>
</tbody>
</table>

• More on learning curves in “Cost Progress Curves” on March 9.

Slide 31

Slide 32
INDIRECT COSTS

- Reduction in reenlistment rates due to family separation
- Costs of Army defenses of deployed Air Force bases
- Reduction in mobilization base due to procurement cuts
- Imputed land cost of military bases
- Costs of environmental cleanup

IF YOU CANNOT ESTIMATE ALL COSTS

- Estimate what you can. Something is better than nothing!

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Cost of Cadillac</td>
<td>$31,000</td>
</tr>
<tr>
<td>Cost of Honda</td>
<td>$19,000</td>
</tr>
<tr>
<td>What you are paying</td>
<td>$12,000</td>
</tr>
<tr>
<td>for improved comfort</td>
<td></td>
</tr>
</tbody>
</table>

- The question becomes, “Is the softer ride worth $12,000?”
THE COST ANALYST MUST INTERACT WITH OTHER TEAM MEMBERS

• Cost effectiveness analysis is an iterative process

• The cost analyst must ensure that:
  – The alternatives are cost-able
  – The effectiveness analysis focuses on what is costed
  – The criteria reflect cost as well as effectiveness

EFFECTIVENESS MODELS

<table>
<thead>
<tr>
<th>Type of Model</th>
<th>Inputs</th>
<th>Cost of Development</th>
<th>Accuracy of Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom-up engineering</td>
<td>Detailed theory</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Engineering data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simulation (Combat model)</td>
<td>Operations analysis</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Operational data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top-down regression</td>
<td>Major variables</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Historical data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expert systems</td>
<td>Personal experience</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Back-of-the-envelope</td>
<td>General theory</td>
<td>Lowest</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Casual empiricism</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
LEVEL OF DETAIL

• Including too much detail
  – Increases the cost of doing the analysis
  – Risks “losing the bubble”

• Including too little detail
  – Loses the ability to discriminate among alternatives
  – Risks credibility

LEVEL OF DETAIL (Continued)

• Mount Everest approach to effectiveness modeling
  – “If it’s there, put it in the model”
• “If the model does anything, it will do everything”
• Objections
  – “It will do nothing!”
  – “Roughly right” beats “precisely wrong”
    -- and costs less, besides
SENSIBLE APPROACH TO MODELING

- Start with a back-of-the-envelope analysis
- Refine the model only where needed to discriminate among the alternatives

“THE ANALYSIS IS NOT REALISTIC”

- We’re analyzing alternatives, not making movies!
- All analysis involves abstraction from the real world
- The trick is to capture the effects that discriminate among the alternatives
“DON’T COMPARE APPLES AND ORANGES”

• Cost Estimating Relationship for the Base Operating Support costs of 150 Navy facilities (1981 CNA Study)
  – Naval bases, hospitals, schools, labs, shipyards, etc.

• BOS cost = \(0.041\text{ (Mil)}^{0.034}\text{(Civ)}^{0.248}\text{(Area)}^{0.249}\text{(Acre)}^{0.061}\text{(BTU)}^{1.155}\)

• \(R^2 = 0.90\)
  t-statistics: statistical significance better than 1%

CRITERION

• Hold cost or effectiveness constant

• Keep ultimate goals in mind
  – In WW II convoying, reduce ships lost, not subs sunk
  – In setting speed limits, reduce lives lost, not number of accidents
UNAMBIGUOUS CHOICES

Effectiveness

Cost

Unambiguous choices
A > B
B > C
A > C

Ambiguous choice
D ~ B

WHICH TO HOLD CONSTANT, COST OR EFFECTIVENESS?

• Theory doesn’t care
• The sponsor may have preferences
• Consider analytical convenience
HOLDING SOMETHING CONSTANT MAKES DECISION-MAKING EASIER

Which choice is easier?
$18,000 Honda vs $30,000 Cadillac

$18,000 Honda and new $12,000 kitchen vs $30,000 Cadillac

IF YOU CANNOT HOLD SOMETHING CONSTANT

Effectiveness

 Frontier

Cost
Effectiveness

BEWARE OF COST EFFECTIVENESS RATIOS

Option D’ has a better C/E ratio than option B

But B > D and B’>D’
(B technology dominates D technology)

THE KNEE OF THE CURVE:
FORGET THE KNEE, USE THE HEAD!

Spending the last $2M on parts buys $100M of ship availability
(93% – 73%) x $500M = $100M
WHAT SHOULD YOU GIVE THE SPONSOR?

• Alternatives
  – What he *asks* for?
  – What he *really* wants?
  – What you think he *should* want?

• Strategic Basing Study, Late 1950s
  – Air Force question: Where in Europe should we station the strategic bombers?
  – RAND response: Station them in the U.S. and buy tankers!

HANDLING RISK AND UNCERTAINTY

• Risk (probabilities are known)
  – Calculate expected value and variance of cost and effectiveness

• Uncertainty (probabilities are not known)
  – Give the decision maker information so he can apply his own intuition

• Show cross-over points
  – “Radar A > radar B if target range is over 100 miles”

• Show results for ranges of inputs
CRITICISMS OF CURRENT C-E PRACTICE

• Does not identify who is helped, who is hurt

• Reduces comparisons to a single dimension, generally dollars and cents

• Conceals uncertainty of estimates

C-E ANALYSIS CAN COMPLEMENT OTHER WAYS OF MAKING DECISIONS

• Helps to structure the problem
  – Offers a framework for analysis
  – Makes assumptions explicit
  – Identifies biases

• Helps advocates understand the strengths and weaknesses of their own positions

• Offers a neutral position for adjudicating disputes (elevating the quality of the debate)

• Incidentally, decision makers are free to reject our advice!!
SUMMARY

- What is cost effectiveness?
- What does it apply to?
- What are its strong points?
- What are its failings?
- Even with its failings, can it help decision makers?