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Lecture 8
Benefit-Cost Ratio Analysis
Payback Period Analysis
Cost Effectiveness Analysis

The Avro Arrow

The Avro Arrow, cont'd

- 1940 brought the invasion of France, the bombing of England, and a need for factories safe from enemy bombers to build planes.
- The National Steel & Car Corporation was taken over by the government, renamed Victory Aircraft Limited, and set to building British-designed Lancaster bombers and Anson light transports.
- By the end of the war, Victory's Malton factory outside Toronto had built a total of 3,634 Avro aircraft comprising 3,197 Ansons, 430 Mk X Lancasters, six Lancastrian transports, one Mk 15 Lincoln heavy bomber, and one York transport.

The Avro Arrow, cont'd

- After the war ended, the government sold Victory Aircraft to the British company Hawker Siddeley, which used it for its subsidiary A.V. Roe Canada Ltd (known as Avro Canada).
- In the early 1950s the RCAF was looking for a supersonic missile-armed replacement for the Canuck, and in response Avro engineers developed the Avro Arrow.
- The Arrow was considered to be the most advanced fighter of its day and an example of the excellence of Canadian engineering.

The Avro Arrow, cont'd

- Faced with rapidly escalating costs and a shift in military priorities, on 20 February 1959, the government cancelled the Arrow program.
- With the cancellation came a brain drain as the now unemployed engineers and designers headed south to work in the American aerospace industry. With them went 20 years of experience and development in high-speed, high-altitude flight.

Learning Objectives

- Introduce another analysis method: benefit-cost ratio
- Use an incremental benefit-cost ratio to evaluate a set of mutually exclusive projects
- Introduce one more analysis method: payback period
- Introduce yet another analysis method: cost effectiveness analysis

Key Summary: Update

- Variables and parameters (puzzle pieces):
  - Different kinds of interest rates
  - Discount rates
  - Costs and cost savings or revenues, now and in the future
  - Different expected lives of the possible project/purchases
  - Salvage value
  - Taxes and tax savings
  - How these escalate
- Analysis methods (ways to put the pieces together):
  - Present worth analysis (Net Present Value)
  - Equivalent uniform annual cost analysis
  - Rate of return analysis
  - **Benefit-cost ratio analysis**
  - **Payback period**
  - **Cost-effectiveness analysis**

Benefit-Cost Ratio Analysis

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Analysis Method: Benefit-Cost Ratio

- The purpose of **benefit-cost analysis** is to measure (or quantify) a project so that one can determine whether it causes a net increase in economic and social welfare.

$$B/C\ ratio = \frac{Equivalent\ worth\ of\ net\ benefits}{Equivalent\ worth\ of\ costs} =$$

$$= \frac{PW\ benefits}{PW\ costs} = \frac{FW\ benefits}{FW\ costs} = \frac{AW\ benefits}{AW\ costs}$$

  - Notice how the benefits and costs all need to be considered in the same time context
  - Typically, bring all costs and benefits to today, using Present Worth: B/C ratio = $\sum_n \frac{TB_n}{(1+r)^n} \Big/ \sum_n \frac{TC_n}{(1+r)^n}$

Another "Second-best" Analysis Method

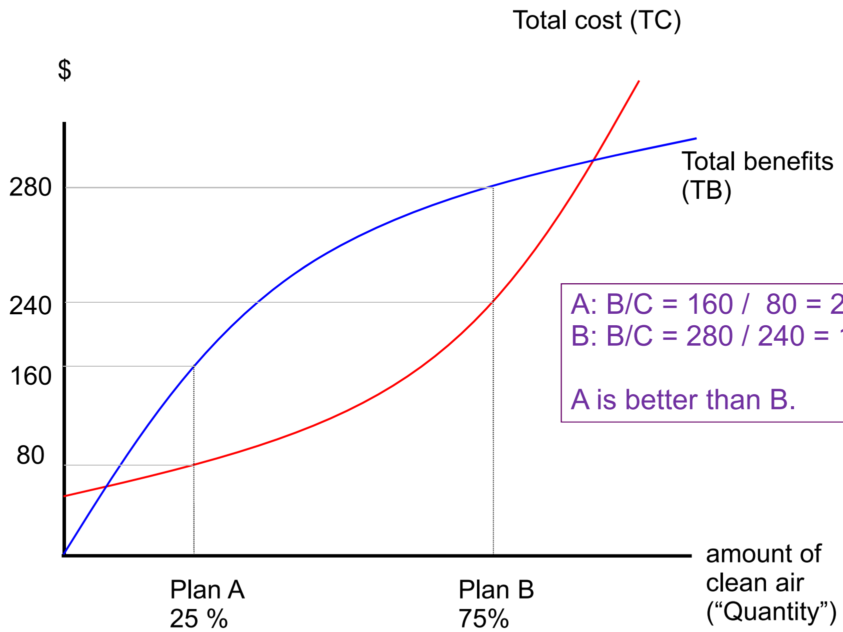
1. Ideally: Maximize discounted B/C ratio $\sum_n \frac{TB_n}{(1+r)^n} \Big/ \sum_n \frac{TC_n}{(1+r)^n}$
2. Second best approach:
   - Examine one option and decide whether to implement, OR
   - Examine several options, and choose the best among the set

- If the B/C ratio is **> 1:**

  If the ratio is very close to 1:

- If competing project options exist:

Cost–Benefit Analysis: Returning to simple example



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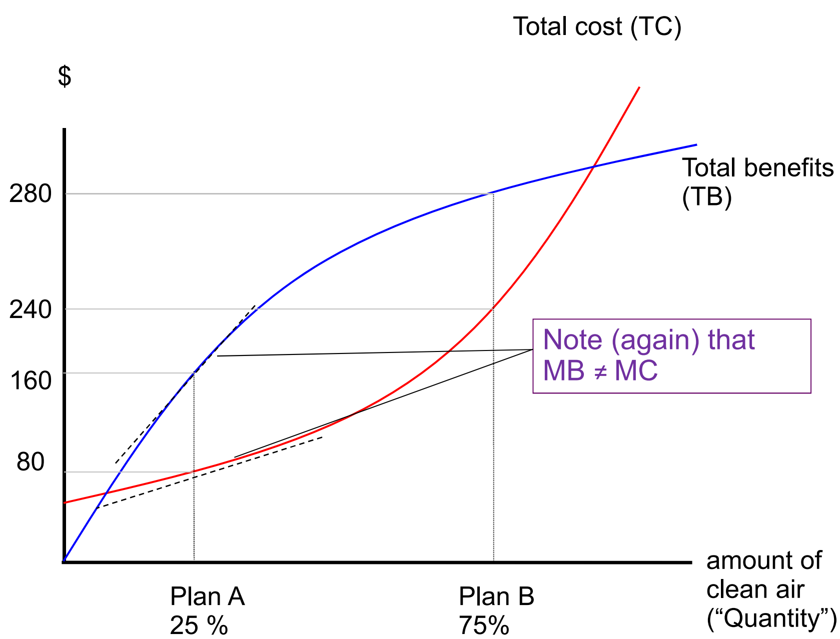

The Benefit-Cost Ratio: Problem 1

A transportation agency is considering a highway project that will cost \$1.5 million. The annual benefits are expected to be \$99,000 per year over a 20-year analysis period. Reusable material will be valued at \$300,000 at the end of the useful life. If the discount rate is 8% per annum, should the project be constructed? Use benefit–cost analysis.

The Benefit-Cost Ratio: Problem 1, cont'd

Solution

$$
\begin{aligned}
PW\ (B) &= A(P/A, i, n) + S(P/F, i, n) \\
&= 99{,}000(P/A, 8\%, 20) + 300{,}000(P/F, 8\%, 20) \\
&= 99{,}000(9.818) + 300{,}000(0.2145) \\
&= 971{,}982 + 64{,}350 \\
&= \$1{,}036{,}332
\end{aligned}
$$

PW (C) = \$1,500,000.

B/C = PW (B) / PW (C) = 1,036,332 / 1,500,000 = **0.69**

B/C is less than 1. Do not build.

(See Excel example for another way to set up of this problem.)

Analysis Method: Benefit-Cost Ratio

- Note on textbook definition - p.248 definition says conventional ratio is:

$$B/C\ ratio = \frac{EW\ of\ net\ benefits\ to\ whomsoever\ they\ may\ accrue}{EW\ of\ costs\ to\ the\ sponsors\ of\ the\ project}$$

- This doesn't match other definitions I've seen in the past. It also isn't very clear: for example, would an ongoing cost to the project sponsor be included in the numerator or denominator? It qualifies for both categories.
- My guidance: disregard definition above. Use these instead:

$$Conventional\ B/C\ ratio = \frac{PW\ of\ all\ benefits}{PW\ of\ all\ costs}$$

$$Modified\ B/C\ ratio = \frac{PW\ of\ all\ benefits, net\ of\ ongoing\ costs}{Initial\ capital\ costs\ only}$$

Analysis Method: Benefit-Cost Ratio

$$Conventional\ B/C\ ratio = \frac{PW\ of\ all\ benefits}{PW\ of\ all\ costs}$$

$$Modified\ B/C\ ratio = \frac{PW\ of\ all\ benefits, net\ of\ ongoing\ costs}{Initial\ capital\ costs\ only}$$

- Both ratios will produce the same recommendation, but the B/C ratios won't be the same.
- Net benefits to users are:
  - Expected Benefits – Disbenefits
- Disbenefits are negatives effects on individuals or groups.

Where would you put salvage value?

Note that disbenefits sound a lot like costs! They could be filed there instead. The key is to be consistent when handling a particular solution.

Either works, but you should use one of them consistently, or project recommendations won't be consistent or comparable.

Benefit–Cost Ratio: Problem 2

The cost of building a school in a neighbourhood is $525,000. The school will need to be maintained at a cost of $50,000/year. Access to the school is expected to increase property values for the neighbourhood. The increase in property value is expected to be 50%. The current average value of property is $254,000. Calculate the B/C ratio and the modified B/C ratio using an interest rate of 9% per year and a 10-year study period.

Benefit–Cost Ratio: Problem 2, cont'd

Solution

B/C

B = 254,000(0.5) = $127,000

C = 525,000 + 50,000(P/A, 9%, 10)
= 525,000 + 50,000(6.4177)
= $845,885

B/C = 127,000/845,885 = **0.15**

Modified B/C

B = 127,000 – 50,000(P/A, 9%, 10)
= 127,000 – 50,000(6.4177)
= $–193,885

C = 525,000

Modified B/C = **–0.37**

- See Excel examples for formula and Excel setup.
- Other implications:

discussion about benefits
cash flow implications

Benefit–Cost Ratio: Problem 2, cont'd

Solution

B/C

B = 254,000(0.5) = $127,000

C = 525,000 + 50,000(P/A, 9%, 10)
= 525,000 + 50,000(6.4177)
= $845,885

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Modified B/C

B = 127,000 – 50,000(P/A, 9%, 10)
= 127,000 – 50,000(6.4177)
= $–193,885

C = 525,000

Modified B/C = **–0.37**

- See Excel examples for formula and Excel setup.
- Discussion about benefits
- Cash flow implications

Incremental Benefit-Cost Analysis

- For multiple mutually exclusive projects, it is not proper to simply calculate the B/C ratio for each alternative and choose the one with the highest value.
- If you have *mutually exclusive alternatives* and want to use a B/C analysis method, you must use the **incremental B/C ratio** to compare and select.

Elements of the Incremental Benefit-Cost Ratio Method

See Excel example 8-2

1. Identify all relevant alternatives.
2. Calculate the B/C ratio of each alternative (optional).
   - **Note:** There is a case where this step *must* be skipped. If doing nothing is not an alternative and if all the alternatives have a B/C ratio less than 1, then incremental analysis will select the least-bad of the alternatives.
3. Rank-order the projects.
4. Identify the increment under consideration.
5. Calculate the B/C ratio for the incremental cash flows.
6. Use the incremental B/C ratio to decide which alternative is better.
7. Iterate to Step 4 until all increments (projects) have been considered.
8. Choose the best alternative from the set of mutually exclusive competing projects.

Elements of the Incremental Benefit-Cost Ratio Method, cont'd

See Excel example 8-2

EXAMPLE 8-2

A city may construct and operate two gas-burning power plants and a distribution network to provide electricity to several city-owned properties. The following costs and benefits have been identified:

Primary costs: Construction of the power plant facilities; cost of installing the power distribution network; life-cycle maintenance and operating costs.

Primary benefits: Elimination of payments to the current electricity provider; creation of jobs for construction, operation, and maintenance of the facilities and distribution network; revenue from selling excess power to utility companies; increased employment for city residents.

There are four possible designs for the power plants. Each has a life of 45 years. Use the B/C ratio with an interest rate of 8% to recommend a course of action.

Values (× 10^4) for Competing Design Alternatives ($ figures in tens of thousands)

	I	II	III	IV
Project costs				
Plant construction	$12,500	$11,000	$12,500	$16,800
Annual operating and maintenance	$120	$480	$325	$145
Project benefits				
Annual savings from utility payments	$580	$700	$950	$1,300
Revenue from overcapacity	$700	$550	$200	$250
Annual effect of jobs created	$400	$750	$150	$500
Other data				
Project life, in years	45	45	45	45
Discounting rate (MARR)	8%	8%	8%	8%

Elements of the Incremental Benefit-Cost Ratio Method, cont'd

SOLUTION

Alternatives I to IV and the do-nothing alternative are *mutually exclusive* choices because one and only one of them will be chosen. Therefore, an incremental B/C ratio method is used to obtain the solution.

Step 1 *Identify the alternatives.* The alternatives are do nothing, and designs I, II, III, and IV.

Step 2 *Calculate the B/C ratio for each alternative.* In this optional step we calculate the B/C ratio for each alternative based on individual cash flows. We will use the ratio of the PW of benefits to costs.

$$\text{B/C ratio (I)} = (580 + 700 + 400)(P/A, 8\%, 45)/[12{,}500 + 120(P/A, 8\%, 45)] = 1.46$$
$$\text{B/C ratio (II)} = (700 + 550 + 750)(P/A, 8\%, 45)/[11{,}000 + 480(P/A, 8\%, 45)] = 1.44$$
$$\text{B/C ratio (III)} = (200 + 950 + 150)(P/A, 8\%, 45)/[12{,}500 + 325(P/A, 8\%, 45)] = 0.96$$
$$\text{B/C ratio (IV)} = (1{,}300 + 250 + 500)(P/A, 8\%, 45)/[16{,}800 + 145(P/A, 8\%, 45)] = 1.30$$

Alternatives I, II, and IV all have B/C ratios greater than 1 and thus merit further consideration. Alternative III does not meet the acceptability criterion and could be eliminated from further consideration. However, to illustrate that Step 2 is optional, all four design alternatives will be analyzed incrementally.

Step 3 *Rank-order the projects.* Here we calculate the PW of costs for each alternative. The denominator of the B/C ratio includes first cost and annual O&M costs, so the PW of costs for the alternatives are

$$\text{PW costs (I)} = 12{,}500 + 120(P/A, 8\%, 45) = \$13{,}953$$
$$\text{PW costs (III)} = 12{,}500 + 325(P/A, 8\%, 45) = \$16{,}435$$
$$\text{PW costs (II)} = 11{,}000 + 480(P/A, 8\%, 45) = \$16{,}812$$
$$\text{PW costs (IV)} = 16{,}800 + 145(P/A, 8\%, 45) = \$18{,}556$$

The rank order from low to high value of the B/C ratio *denominator* is as follows: do nothing, I, III, II, IV. So we start off with "do nothing" as the champion.

Elements of the Incremental Benefit-Cost Ratio Method, cont'd

Step 4 *Identify the increment under consideration.*
Step 5 *Calculate the B/C ratio.*
Step 6 *Which alternative is better?*

		1st Iteration	2nd Iteration	3rd Iteration	4th Iteration
Step 4	**Increment under Consideration**	**(Do Nothing → I)**	**(I → III)**	**(I → II)**	**(II → IV)**
	ΔPlant construction cost	\$12,500	\$0	−\$1,500	\$5,800
	ΔAnnual O&M cost	120	205	360	−335
	PW of ΔCosts	13,953	2,482	2,859	1,744
	ΔAnnual utility payment savings	580	370	120	600
	ΔAnnual overcapacity revenue	700	500	−150	−300
	ΔAnnual benefits of new jobs	400	−250	350	−250
	PW of ΔBenefits	20,342	−4,601	3,875	605
Step 5	ΔB/C ratio (PW ΔB)/(PW ΔC)	1.46	−1.15	1.36	0.35
Step 6	Is increment justified?	Yes	No	Yes	No

continued

Elements of the Incremental Benefit-Cost Ratio Method, cont'd

As an example of these calculations, consider the third increment (I → II).

ΔPlant construction cost	= 11,000 − 12,500 = −$1,500
ΔAnnual O&M cost	= 480 − 120 = $360
PW of ΔCosts	= −1,500 + 360(P/A, 8%, 45) = $2,859
or	= 16,812 − 13,953 = $2,859
ΔAnnual utility payment savings	= 700 − 580 = $120
ΔAnnual overcapacity revenue	= 550 − 700 = −$150
ΔAnnual benefits of new jobs	= 750 − 400 = $350
PW of ΔBenefits	= (120 − 150 + 350)(P/A, 8%, 45)
	= $3,875
ΔB/C ratio (PW ΔB)/(PW ΔC)	= 3,875/2,850 = 1.36

The analysis in the table proceeded as follows: do nothing to Alternative I was justified (ΔB/ΔC ratio = 1.46), so Alternative I became the new champion; Alternative I to Alternative III was not justified (ΔB/ΔC ratio = −1.15), so Alternative I remained the champion; Alternative I to Alternative II was justified (ΔB/ΔC ratio = 1.36), so Alternative II became the champion; Alternative II to Alternative IV was not justified (ΔB/ΔC ratio = 0.35), so Alternative II remained as champion.

Step 8 *Select best alternative.* Alternative II is the champion at the end of the process, so we select it as best alternative.

Elements of the Incremental Benefit-Cost Ratio Method, cont'd

- Summary of value of this method:
- Let's calculate the Net Present Worth (NPW or NPV) of each alternative, and display each along with the B/C ratio:

	I	II	III	IV
B/C ratio	1.46	1.44	0.96	1.34
NPW	$6,389	$7,405	$(694)	$6,267

Conclusion:

Implications on strength/weakness of B/C ratio

Same answer with less work
Weakness of B/C ratio

Comparing B/C Ratio Analysis with NPW: Strengths and Weaknesses

- **If you are only deciding whether a project is worth doing or not:**
  .... all methods analyzed so far will give the same answer

However:

- As just seen, **if you're picking among options:**
  … different methods give different answers. Do you pick fastest horse or farthest horse: (i.e. earn most money, or most consistently)
- **If you have lots of possible projects** to invest in, analysis gets a bit more complex.
- You need to pick the best mix of projects.
- Implications on rate of return: May not pick the one with highest rate of return
- Let's look at another example (See Excel examples: Ch4 ppt example 4)

Payback Period Analysis

Another Analysis Method: Payback Period

- Payback period is the period of time required for the profit or other benefits of a project to equal the cost.

- Four important points:
  1. This is an approximate calculation.
  2. Implications on timing differences:
  3. Economic consequences beyond the payback time:
  4. Due to its approximate nature:

Payback Period: Example

EXAMPLE 8-6

A firm is trying to decide which of two scales it should install to check a package-filling operation in the plant. If both scales have a six-year life, which one should be selected? Assume an 8% interest rate.

Alternative	Cost	Uniform Annual Benefit	End-of-Useful-Life Salvage Value
Atlas scale	$2,000	$450	$100
Tom Thumb scale	3,000	600	700

SOLUTION

Atlas Scale

$$\text{Payback period} = \frac{\text{Cost}}{\text{Uniform annual benefit}}$$

$$= \frac{2{,}000}{450} = 4.4 \text{ years}$$

Tom Thumb Scale

$$\text{Payback period} = \frac{\text{Cost}}{\text{Uniform annual benefit}}$$

$$= \frac{3{,}000}{600} = 5 \text{ years}$$

Payback Period: Example

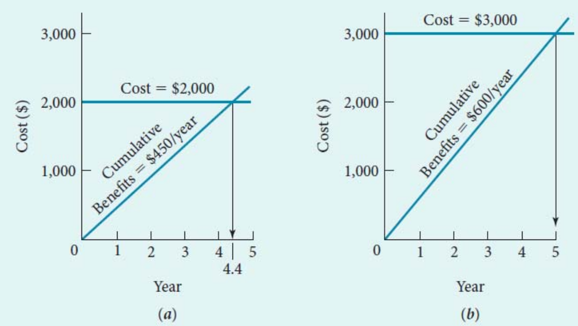


FIGURE 8-2 Payback period plots for Example 8-6: (*a*) Atlas scale and (*b*) Tom Thumb scale.

Figure 8-2 illustrates the situation. To minimize payback period, choose the Atlas scale.

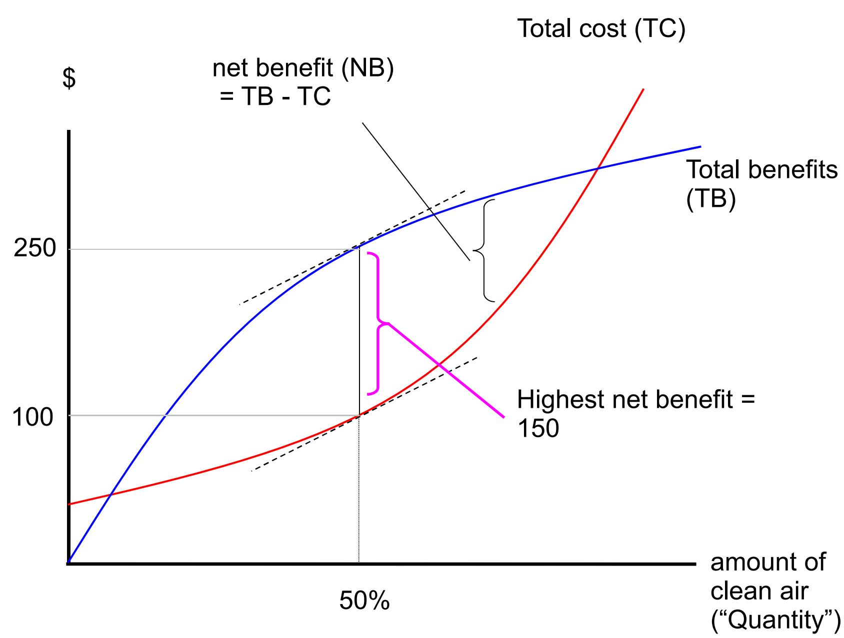
Are we sure we have the right answer? See Excel example 8-6.

Payback Period: Example 8-7

- Payback period can be used even when future costs and benefits are not uniform.
- Another payback period example: Excel example 8-7

Cost-effectiveness Analysis

Reminder: Benefits and Costs (to introduce Cost-effectiveness Analysis)



Context of Some of the Analysis Methods Explored So Far

1. Maximize discounted net benefits $\sum_n \frac{TB_n - TC_n}{(1+r)^n}$

2. Net Present Worth (Net Present Value)

   Choose option with highest positive net present value (are discounted net benefits > 0 ?)

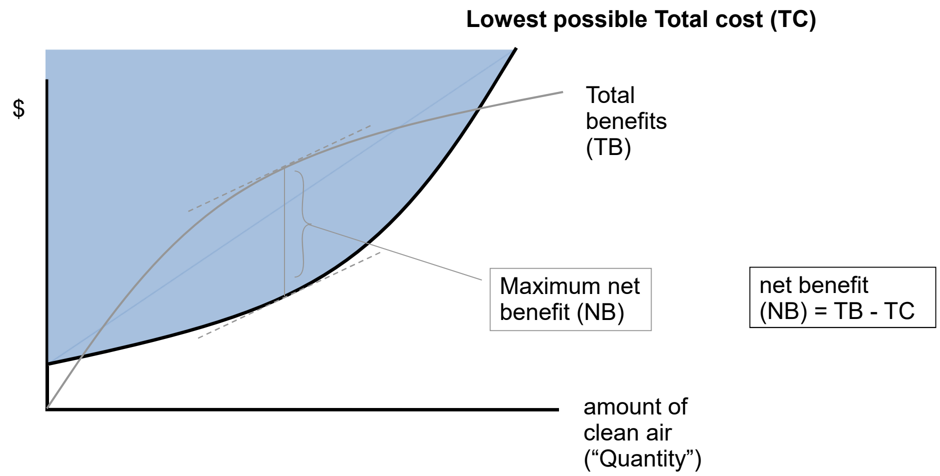
3. Benefit / Cost Ratio

   Choose option with highest benefit/cost ratio

   (is $\sum_n \frac{TB_n}{(1+r)^n} \Big/ \sum_n \frac{TC_n}{(1+r)^n} > 1$?)

Cost effectiveness analysis

require a certain level of pollution removal to be achieved, a.k.a. a "standard" to be met



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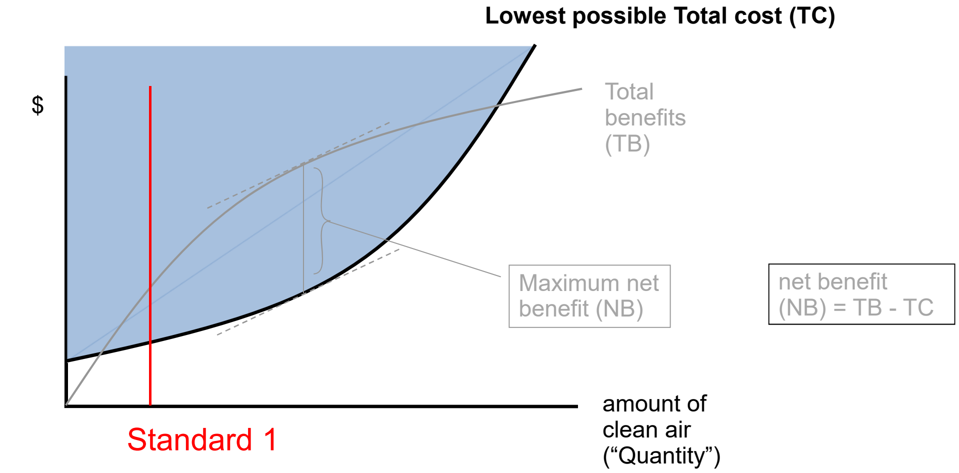

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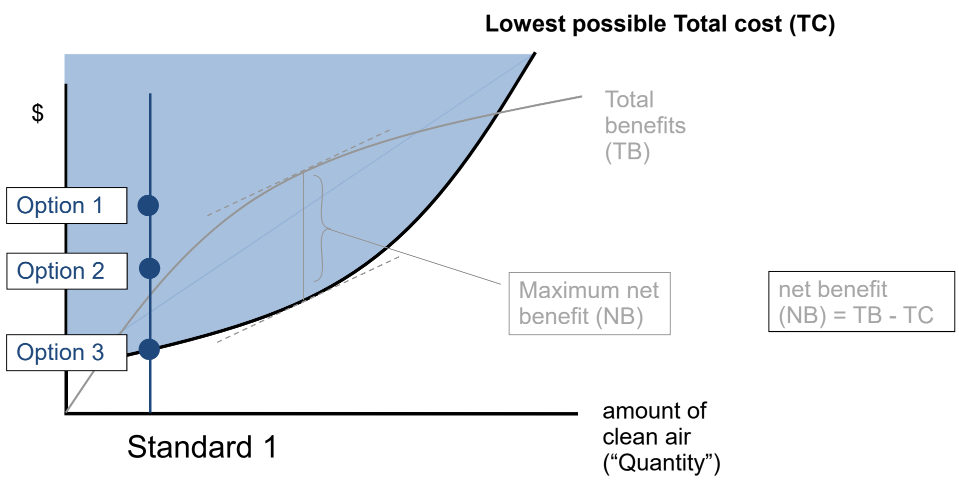
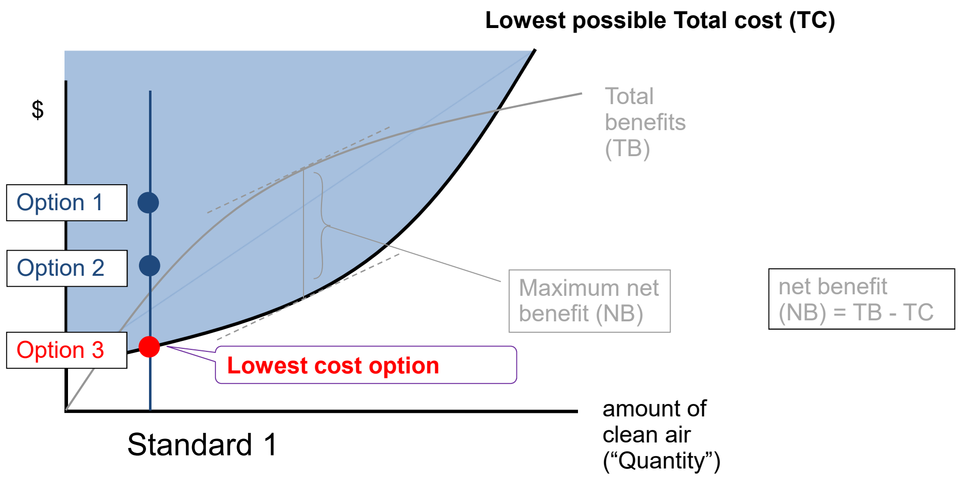


Analysis focuses on finding the least expensive option.

Cost effectiveness analysis

require a certain level of pollution removal to be achieved, a.k.a. a “standard” to be met



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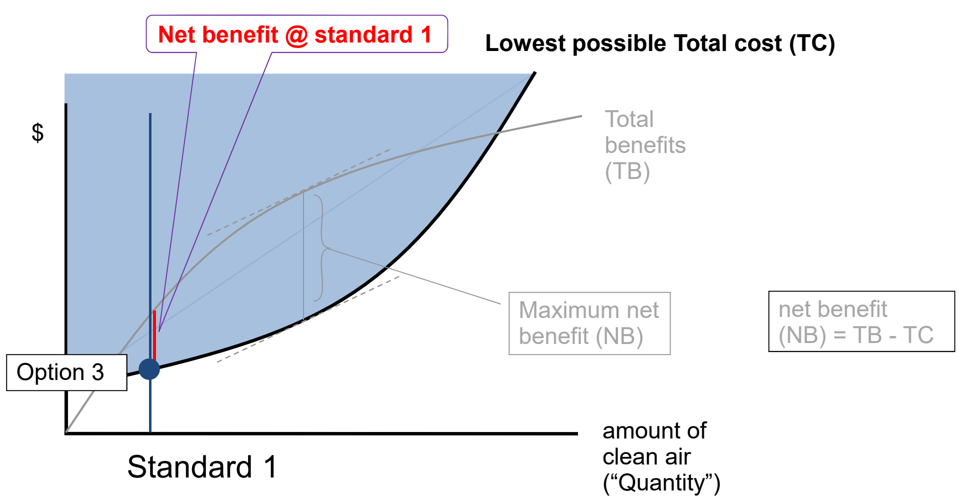

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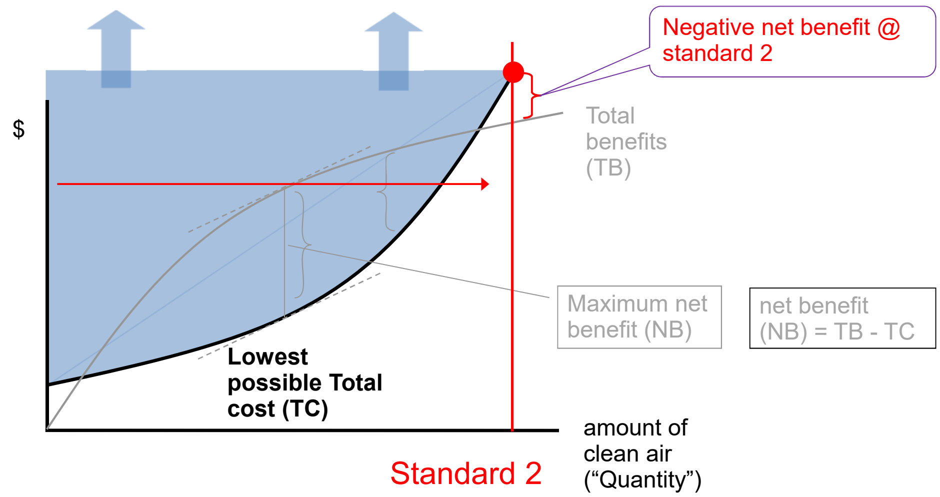

Cost-Benefit Analysis vs Cost-Effectiveness Analysis

Cost-Benefit	Cost-Effectiveness
What's the best goal (amount of pollution reduction)? Is the goal efficient?	How do we meet the predefined goal most cost effectively?