In the name of Allah

Amirkabir University of Technology
(Tehran Polytechnic)
Industrial Engineering Department

Course Title:
Engineering Economics

11. Breakeven and Payback Analysis

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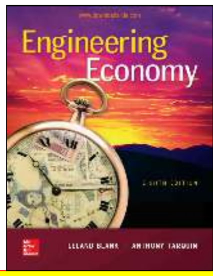
Learning Stage 3: Making Better Decisions

- Chapter 10 *not covered in this course
  - Project Financing and Noneconomic Attributes
- Chapter 11
  - Replacement and Retention Decisions
- Chapter 12 *not covered in this course
  - Independent Projects with Budget Limitation
- Chapter 13
  - Breakeven and Payback Analysis



Chapter 13 of EE (BT) book 8th edition

LEARNING OUTCOMES

- Purpose:
  - Determine the breakeven for one or two alternatives and calculate the payback period with and without a return required.

1. Breakeven point – one parameter
2. Breakeven point – two alternatives
3. Payback period analysis

Breakeven Point

- Value of a parameter that makes two elements equal
  - The parameter (variable) can be an amount of revenue, cost, supply, demand, etc. for one project or between two alternatives
- One project
  - Breakeven point is identified as Q_{BE}. Determined using linear or non-linear math relations for revenue and cost
- Between two alternatives
  - Determine one of the parameters P, A, F, i, or n with others constant
- Solution is by one of three methods:
  - Direct solution of relations
  - Trial and error
  - Spreadsheet functions or tools (Goal Seek or Solver)

Cost-Revenue Model — One Project

- Quantity, Q
  - An amount of the variable in question, e.g., units/year, hours/month
    - Breakeven value is Q_{BE}
- Fixed cost, FC
  - Costs not directly dependent on the variable, e.g., buildings, fixed overhead, insurance, minimum workforce cost
- Variable cost, VC
  - Costs that change with parameters such as production level and workforce size. These are labor, material and marketing costs.
    - Variable cost per unit is v
- Total cost, TC, Sum of fixed and variable costs, TC = FC + VC
- Revenue, R, Amount is dependent on quantity sold
  - Revenue per unit is r
- Profit, P, Amount of revenue remaining after costs $P = R - TC = R - (FC + VC)$

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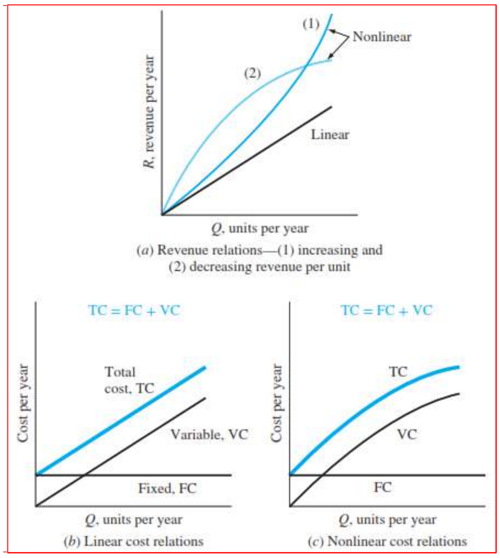
Cost-Revenue Model

- Linear and nonlinear revenue and cost relations.



(a) Revenue relations—(1) increasing and (2) decreasing revenue per unit
(b) Linear cost relations
(c) Nonlinear cost relations

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Breakeven for linear R and TC

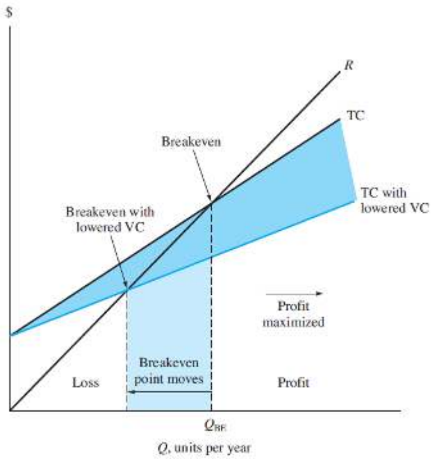
- Set R = TC & solve for Q = Q_{BE}

$$R = TC$$

$$rQ = FC + vQ$$

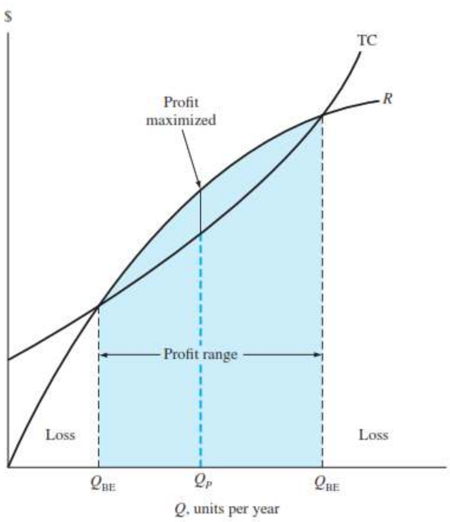
$$Q_{BE} = \frac{FC}{r - v}$$

- When variable cost, v, is lowered, Q_{BE} decreases (moves to left)
  - Effect on the breakeven point when the variable cost per unit is reduced.



Breakeven for nonlinear R and TC

- Breakeven points and maximum profit point for a nonlinear analysis.
- The maximum profit occurs at Q_P
  - between the two breakeven points where the distance between the R and TC relations is greatest.



Example: One Project Breakeven Point

- A plant produces 15,000 units/month.
  - Find breakeven level if FC = \$75,000 /month, revenue is \$8/unit and variable cost is \$2.50/unit.
  - Determine expected monthly profit or loss.

Solution: Find Q_{BE} and compare to 15,000; calculate Profit

Q_{BE} = 75,000 / (8.00 – 2.50) = 13,636 units/month

Production level is above breakeven ➡ Profit

$$\begin{aligned} \text{Profit} &= R - (FC + VC) \\ &= rQ - (FC + vQ) = (r - v)Q - FC \\ &= (8.00 - 2.50)(15{,}000) - 75{,}000 \\ &= \$\ 7500/\text{month} \end{aligned}$$

Some points

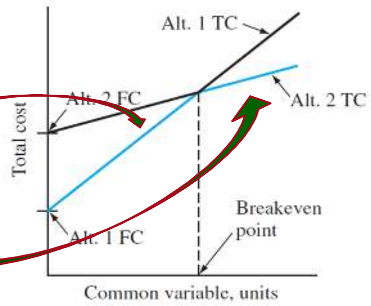
- In some circumstances,
  - breakeven analysis performed on a per unit basis is more meaningful.
  - The value of Q_{BE} is still calculated using the main Equation.
    - however, the relations for R and TC are divided by Q.
    - In the case of TC, the expression for cost per unit, also termed average cost per unit Cu, is:

$$\boxed{C_u = \frac{TC}{Q} = \frac{FC + vQ}{Q} = \frac{FC}{Q} + v}$$

- It may be necessary to do some dimensional analysis initially
  - to obtain the correct revenue and total cost relations in order to use the same dimension for both relations,
    - for example, \$ per unit, miles per month, or units per year.

Breakeven Between Two Alternatives

- To determine value of common variable between 2 alternatives, do the following:
  1. Define the common variable
  2. Develop equivalence PW, AW or FW relations as function of common variable for each alternative
  3. Equate the relations; solve for variable. This is breakeven value
- Selection of alternative is based on anticipated value of common variable:
  - Value BELOW breakeven; select higher variable cost
  - Value ABOVE breakeven; select lower variable cost



Example: Two Alternative Breakeven Analysis

- Perform a make/buy analysis where the common variable is X, the number of units produced each year. AW relations are:

$AW_{make} = -18{,}000(A/P, 15\%, 6) + 2{,}000(A/F, 15\%, 6) - 0.4X$

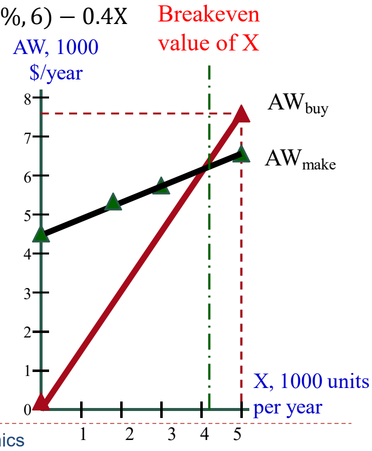
$AW_{buy} = -1.5X$

Solution: Equate AW relations, solve for X

$-1.5X = -4528 - 0.4X$

X = 4116 per year

If anticipated production > 4116, select make alternative (lower variable cost)



Breakeven Analysis Using Goal Seek Tool (1)

- Spreadsheet tool Goal Seek finds breakeven value for the common variable between two alternatives

Problem: Two machines (1 & 2) have following estimates.
a) Use spreadsheet and AW analysis to select one at MARR = 10%.
b) Use Goal Seek to find the breakeven first cost.

Machine	1	2
P, $	−80,000	−110,000
NCF, $/year	25,000	22,000
S, $	2,000	3,000
n, years	4	6

	A	B	C	D
1	MARR =	10%		
2		Net cash flows, $/year		
3	Year	Machine 1	Machine 2	
4	0	-80,000	-110,000	
5	1	25,000	22,000	
6	2	25,000	22,000	
7	3	25,000	22,000	
8	4	27,000	22,000	
9	5		22,000	
10	6		25,000	
11	AW @ MARR	193	-2,868	
12				
13				
14				

= -PMT(B1,4,NPV($B1,B5:B8)+B4)

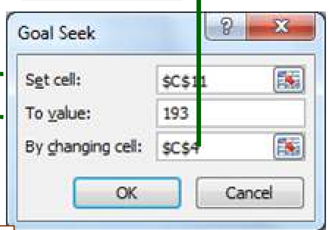
Solution: a) Select machine 1 with $AW_1 = \$193$

Breakeven Analysis Using Goal Seek Tool (2)

Solution: b) Goal Seek finds a first-cost breakeven of $96,669 to make machine 2 economically equivalent to 1

	A	B	C
1	MARR =	10%	
2		Net cash flows, $/year	
3	Year	Machine 1	Machine 2
4	0	-80,000	-96,669
5	1	25,000	22,000
6	2	25,000	22,000
7	3	25,000	22,000
8	4	27,000	22,000
9	5		22,000
10	6		25,000
11	AW @ MARR	193	193

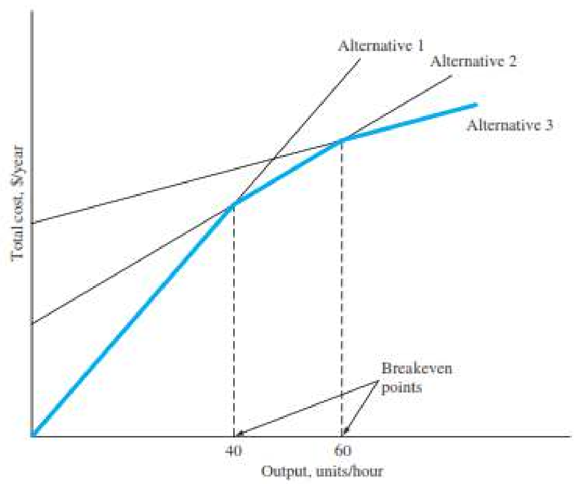
Changing cell



Spreadsheet after Goal Seek is applied

Target cell

Breakeven points for three alternatives.



Payback Period Analysis

- Payback period:
  - Estimated amount of time (n_p) for cash inflows to recover an initial investment (P) plus a stated return of return (i%)
- Types of payback analysis: No-return and discounted payback
  - No-return payback means rate of return is ZERO (i = 0%)
  - Discounted payback considers time value of money (i > 0%)
- Caution:
  - Payback period analysis is a good initial screening tool,
    - rather than the primary method to justify a project or select an alternative (Discussed later)

Payback Period Computation

- Formula to determine payback period (n_p) varies with type of analysis.
  - NCF_t: Net Cash Flow per period t
  - n_p: payback period P: initial investment

No return, $i = 0\%$; NCF_t varies annually:	$0 = -P + \sum_{t=1}^{t=n_p} \text{NCF}_t$	**Eqn. 1**
No return, $i = 0\%$; annual uniform NCF:	$n_p = \frac{P}{\text{NCF}}$	**Eqn. 2**
Discounted, $i > 0\%$; NCF_t varies annually:	$0 = -P + \sum_{t=1}^{t=n_p} \text{NCF}_t(P/F,i,t)$	**Eqn. 3**
Discounted, $i > 0\%$; annual uniform NCF:	$0 = -P + \text{NCF}(P/A,i,n_p)$	**Eqn. 4**

Points to Remember About Payback Analysis

- No-return payback neglects time value of money,
  - so no return is expected for the investment made
- No cash flows after the payback period are considered in the analysis.
  - Return may be higher if these cash flows are expected to be positive.
- Approach of payback analysis is different from PW, AW, ROR and B/C analysis.
  - A different alternative may be selected using payback.
- Rely on payback as a supplemental tool;
  - use PW or AW at the MARR for a reliable decision
- Discounted payback (i > 0%) gives a good sense of the risk involved.

Example: Payback Analysis (1)

- Problem: Use (a) no-return payback, (b) discounted payback at 15%, and (c) PW analysis at 15% to select a system. Comment on the results.

	System 1	System 2
First cost, $	12,000	8,000
NCF, $ per year	3,000	1,000 (year 1-5) 3,000 (year 6-14)
Maximum life, years	7	14

- Solution: (a) Use Eqns. 1 and 2

$n_{p1} = 12{,}000/3{,}000 = 4\ years$

$\mathrm{n_{p2}} = -8{,}000 + 5(1{,}000) + 1(3{,}000) = 6$ years

So Select system 1

Example: Payback Analysis (2)

	System 1	System 2
First cost, $	12,000	8,000
NCF, $ per year	3,000	1,000 (year 1-5) 3,000 (year 6-14)
Maximum life, years	7	14

- Solution: (b) Use Eqns. 3 and 4

System 1: $0 = -12{,}000 + 3{,}000(P/A, 15\%, np_1) \rightarrow \ n_{p1} = 6.6$ years

System 2: $0 = -8{,}000 + 1{,}000(P/A, 15\%, 5) + 3{,}000(P/A, 15\%, np_2 - 5)(P/F, 15\%, 5)$

$n_{p1} = 9.5$ years

Select system 1

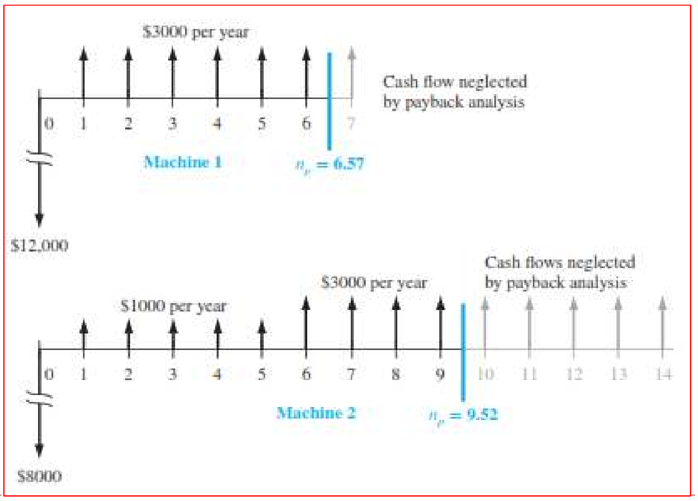
(c) Find PW over LCM of 14 years; $PW_1 = \$663$; $PW_2 = \$2470$

Select system 2

- Comment: PW method considers cash flows after payback period. Therefore, selection changes from system 1 to 2

Example: Payback Analysis (3)

- Illustration of payback periods and neglected net cash flows



Summary of Important Points

- Breakeven amount is a point of indifference to accept or reject a project
- One project breakeven: accept if quantity is > Q_{BE}
- Two alternative breakeven: if level > breakeven,
  - select lower variable cost alternative (smaller slope)
- Payback estimates time to recover investment.
  - Return can be i = 0% or i > 0%
- Use payback as supplemental to PW or other analyses,
  - because n_p neglects cash flows after payback, and if i = 0%, it neglects time value of money
- Payback is useful to sense the economic risk in a project