



Department of Mechanical Engineering
Bangladesh University of Engineering and Technology

ME 310

Thermo-Fluid System Design

1.5 Credit Hours

ECONOMIC CONSIDERATION

Among the most important indicators of the success of an engineering enterprise are the **profit achieved** and **the return on investment**. Therefore, **economic considerations play a very important role in the decision-making processes that govern the design of a system.**

Because of the crucial importance of economic considerations in most engineering decisions, it is necessary to understand the basic principles of economics and to apply these to the evaluation of investments, in terms of costs, returns, and profits.

Basic Concepts

Time Value of Money

An important concept that is fundamental to economic analysis is the effect of time on the worth of money. The value of money increases as time elapses due to interest added on to the principal amount.

✓ **If we assume**

- That money can always be invested in the bank (or some other reliable source) now to gain a return with interest later
- That as rational actors, we never make an investment which we know to offer less money than we could get in the bank

✓ **Then**

- Money in the present can be thought as of “equal worth” to a larger amount of money in the future
- Money in the future can be thought of as having an equal worth to a lesser “present value” of money

SIMPLE INTEREST

The rate of interest i is the amount added or charged per year to a monetary unit.

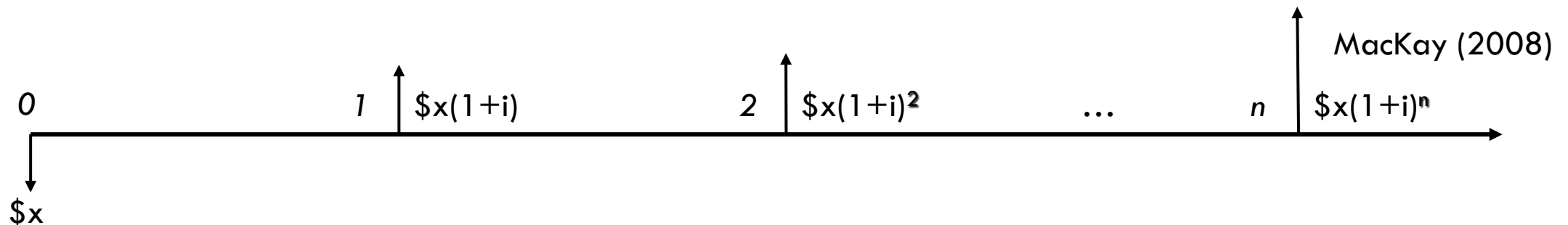
Frequently, the interest rate is given as a percentage, indicating the amount added per one hundred of the monetary unit.

$$F = P (1 + ni)$$

Basic Compounding

The interest may be calculated several times a year and then added to the amount on which interest is computed in order to determine the interest over the next time period.

- Suppose we invest $\$x$ in a bank offering interest rate i
- If interest is compounded annually, asset will be worth:
 - $\$x(1+i)$ after 1 year
 - $\$x(1+i)^2$ after 2 years
 - $\$x(1+i)^3$ after 3 years
 - $\$x(1+i)^n$ after n years



Basic Compounding

This implies that for yearly compounding, the final sum F after n years is given by the expression

$$F = P (1 + i)^n$$

If the interest is compounded m times a year, the interest on a unit amount in the time between two compounding is i/m . Then the final sum F , which includes the principal and interest, is obtained after n years as

$$F = P \left(1 + \frac{i}{m} \right)^{mn}$$

Continuous Compounding

The number of times per year that the interest is compounded may be increased beyond monthly or even daily compounding to reflect the **financial status of a company or an investment at a given instant**. The upper limit on the frequency of compounding is *continuous compounding*, which employs an infinite number of compounding periods over the year.

$$F = \left[P \left(1 + \frac{i}{m} \right)^{mn} \right]_{m \rightarrow \infty}$$

$$\ln\left(\frac{F}{P}\right) = mn \left[\ln\left(1 + \frac{i}{m}\right) \right]_{m \rightarrow \infty} = mn \left[\frac{i}{m} - \frac{1}{2} \left(\frac{i}{m}\right)^2 + \frac{1}{3} \left(\frac{i}{m}\right)^3 + \dots \right]_{m \rightarrow \infty} = ni$$

$$F = Pe^{ni}$$

Effective Interest Rate

It is often convenient and useful to express the compounded interest in terms of an effective, or equivalent, simple interest rate

$$F = P (1 + i_{\text{eff}})$$

$$i_{\text{eff}} = \frac{F}{P} - 1 = \left(1 + \frac{i}{m}\right)^m - 1$$

It is also possible to obtain an equivalent interest rate over a number of years n .

$$i_{\text{eff}} = \frac{1}{n} \left(\frac{F}{P} - 1 \right) = \frac{\left[\left(1 + \frac{i}{m}\right)^{mn} - 1 \right]}{n}$$

TASK-1

Calculate the resulting sum F for an investment of \$100 after 1, 2, 5, 10, 20, and 30 years at a nominal interest rate of 10%, using simple interest as well as yearly, monthly, daily, and continuous compounding. From these results, calculate the effective interest rates over a year and also 10 years.

Solution Procedure

$$F = P(1 + ni)$$

$$F = P\left(1 + \frac{i}{m}\right)^{mn}$$

$$F = Pe^{ni}$$

$$i_{\text{eff}} = \frac{F}{P} - 1$$

$$i_{\text{eff}} = \frac{1}{n}\left(\frac{F}{P} - 1\right)$$

Effect of Compounding Frequency on the Resulting Sum for an Investment of \$100 after Different Time Periods at 10% Nominal Interest Rate

Number of years	Simple Interest	Yearly Comp.	Monthly Comp.	Daily Comp.	Continuous Comp.
1	110.0	110.0	110.47	110.52	110.52
2	120.0	121.0	122.04	122.14	122.14
5	150.0	161.05	164.53	164.86	164.87
10	200.0	259.37	270.70	271.79	271.83
20	300.0	672.75	732.81	738.70	738.91
30	400.0	1744.94	1983.74	2007.73	2008.55

the effective interest rates for yearly, monthly, daily, and continuous compounding are obtained as 15.937, 17.070, 17.179, and 17.183%, respectively

WORTH OF MONEY AS A FUNCTION OF TIME

If I know this is coming...



I can borrow this from the bank now

$PV(x)$



I'll pay this back to the bank later

$PV(x)$



The net result is that I can convert a sure x at time t into a (smaller) $PV(x)$ now!

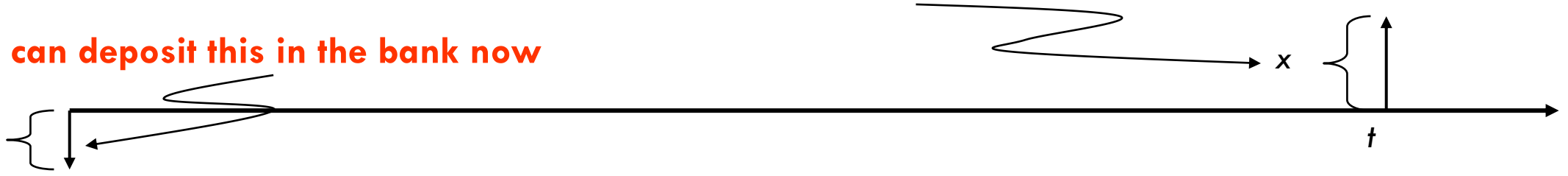


If I know this cost is coming...

I retrieve this back from the bank later

I can deposit this in the bank now

$PV(x)$



$PV(x)$



The net result is that I can convert a sure cost x at time t into a (smaller) cost of $PV(x)$ now!

The present worth of a given sum F may be written, for yearly compounding

$$PW = P = F(1 + i)^{-n} = (F)(P/F, i, n)$$

If the interest is compounded m times yearly

$$PW = P = (F) \left(P/F, \frac{i}{m}, mn \right)$$

for continuous compounding

$$P/F = e^{-ni}$$

the future worth (FW) of P after n years with an interest rate of i , compounded yearly or m times yearly

$$FW = F = P (1 + i)^n = (P)(F/P, i, n)$$

$$FW = F = P \left(1 + \frac{i}{m} \right)^{mn} = (P) \left(F/P, \frac{i}{m}, mn \right)$$

TASK-2

The design of the cooling system for a personal computer requires a fan. Three different manufacturers are willing to provide a fan with the given specifications. The first one, Fan A, is at \$54, payable immediately on delivery. The second one, Fan B, requires two payments of \$30 each at the end of the first and second years after delivery. The last one, Fan C, requires a payment of \$65 at the end of two years after delivery. Since a large number of fans are to be purchased, the price is an important consideration. Consider three different interest rates, 6, 8, and 10%. Which fan is the best buy?

Solution Procedure

Discount rate 6.00%



Cash flow

\$ -\$30.00

\$ -\$30.00

NPV (\$55.00)

Fan B:
$$\begin{aligned} PW &= (30)(P/F, 6\%, 1) + (30)(P/F, 6\%, 2) \\ &= \frac{30}{(1+0.06)} + \frac{30}{(1+0.06)^2} = 28.30 + 26.70 = \$55.00 \end{aligned}$$

Fan C:
$$PW = (65)(P/F, 6\%, 2) = \frac{65}{(1+0.06)^2} = \$57.85$$

Inflation refers to the decline in the purchasing power of money with time due to increase in the price of goods and services. This implies that the return on an investment must be considered along with the inflation rate in order to determine the *real* return in terms of buying power.

$$F = P (1 + i)^n = P (1 + j)^n (1 + i_r)^n$$

$$i_r = \frac{1 + i}{1 + j} - 1$$

Task-3

An engineering firm has to decide whether it should withdraw an investment that pays 8% interest, compounded monthly, and use it on a new product. It would undertake the new product if the real rate of increase in buying power from the current investment is less than 4%. The rate of inflation is given as 3.5%. Calculate the real rate of increase in buying power. Will the company decide to go for the new product? What should the yield from the investment be if the company wants a 5% rate of increase in buying power?

Solution

The real rate of increase in buying power i_r is given by the equation

$$i_r = \frac{1 + i_{\text{eff}}}{1 + j} - 1$$

where j is the inflation rate and the effective interest rate i_{eff} is given by

$$i_{\text{eff}} = \left(1 + \frac{i}{m}\right)^m - 1$$

Here, the nominal interest rate is given as 8%. Therefore, for monthly compounding,

$$i_{\text{eff}} = \left(1 + \frac{0.08}{12}\right)^{12} - 1 = 0.083$$

This gives the value of i_r as

$$i_r = \frac{1.083}{1.035} - 1 = 0.0464$$

Therefore, the real increase in purchasing power from the present investment is 4.64%. Since this is not less than 4%, the firm will continue this investment and not undertake development of the new product. However, if the inflation rate were to increase, the real rate will decrease and the company may decide to go for the new product.

To obtain a 5% real rate of increase in buying power from the current investment, the effective interest rate i_{eff} is governed by the equation

$$i_{\text{eff}} = (1 + i_r)(1 + j) - 1$$

which gives

$$i_{\text{eff}} = (1.05)(1.035) - 1 = 0.087$$

The nominal interest rate i may be obtained from the relationship between i and i_{eff} , given above, as

$$i = 12[(1 + i_{\text{eff}})^{1/12} - 1] = 12(1.087^{1/12} - 1) = 0.0835$$

Therefore, a nominal interest rate of 8.35%, compounded monthly, is needed from the current investment to yield a real rate of increase in buying power of 5%.

SERIES OF PAYMENT

A series of fixed payments over a period of time-such as rent or car payments-or receiving a series of payments for a period of time, such as interest from a bond are technically known as "annuities".

Two Types of Annuities:

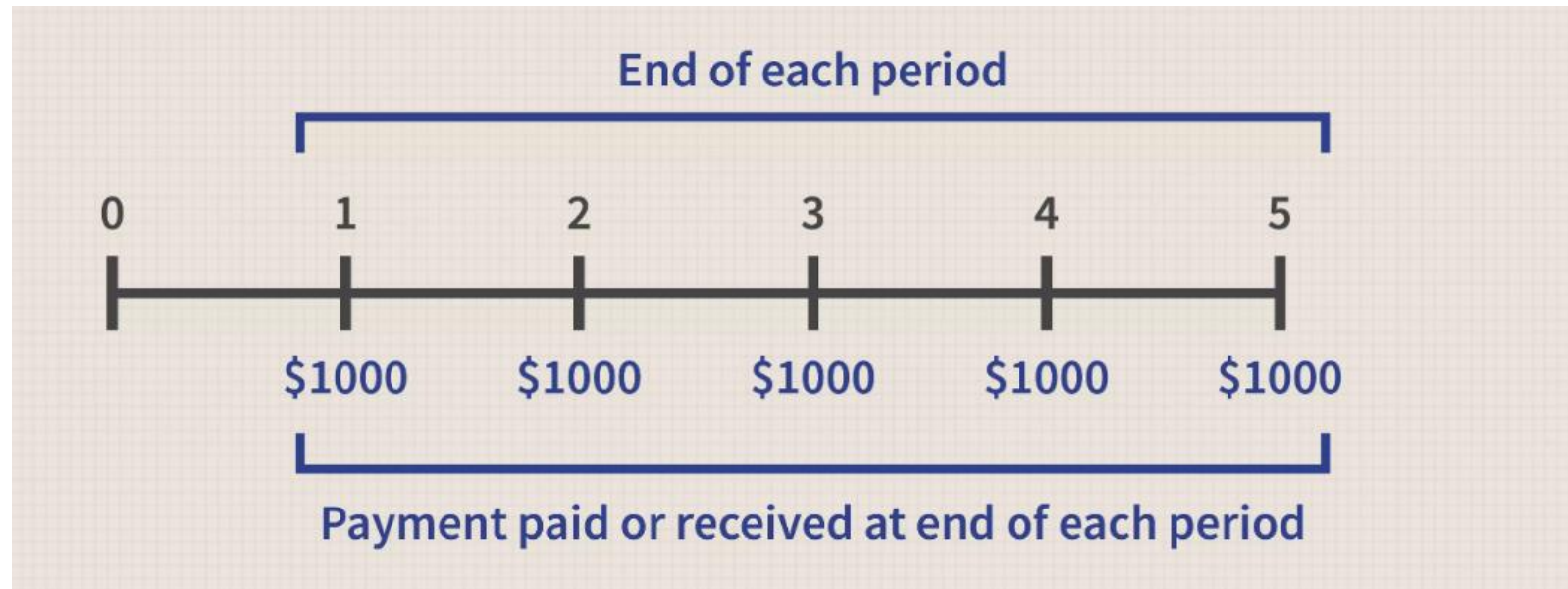
Annuities, in this sense of the word, break down into two basic types: ordinary annuities and annuities due.

Ordinary annuities: An ordinary annuity makes (or requires) payments at the end of each period. For example, bonds generally pay interest at the end of every six months.

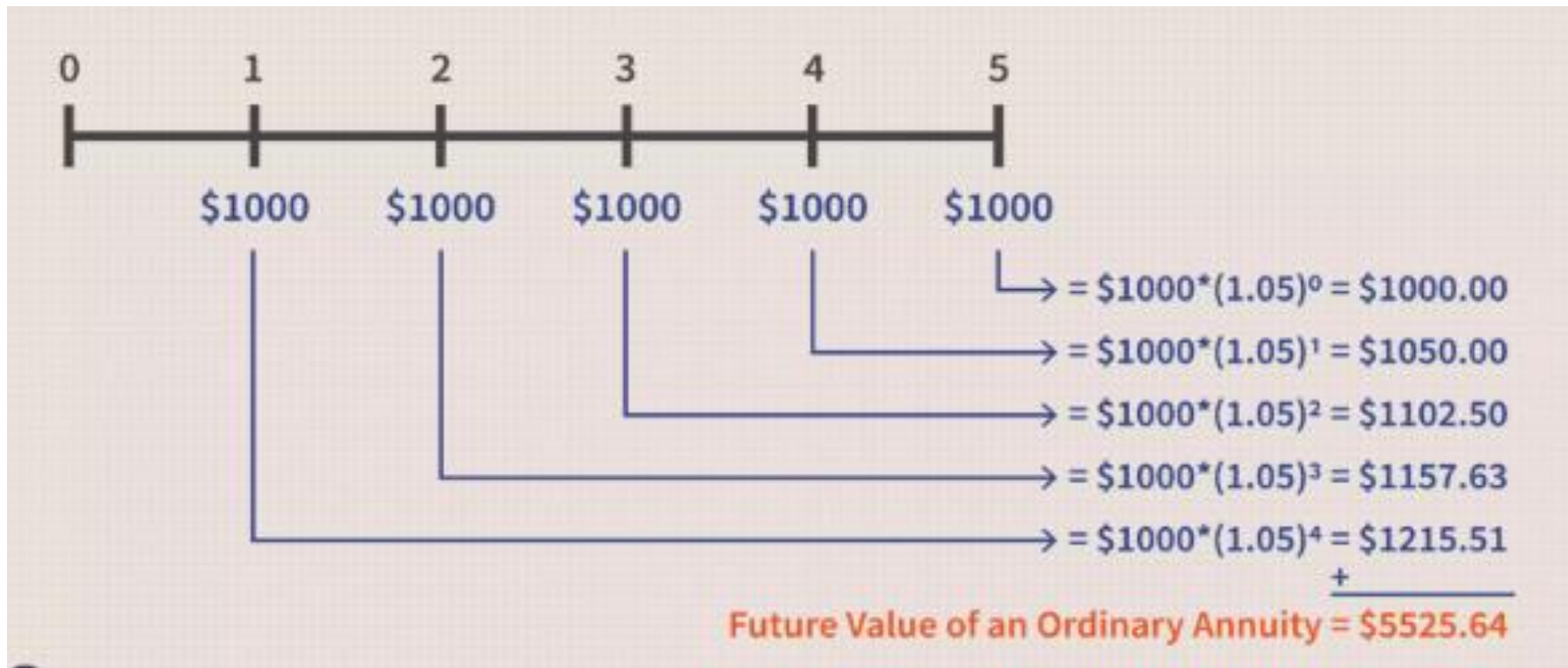
Annuities due: With an annuity due, by contrast, payments come at the beginning of each period. Rent, which landlords typically require at the beginning of each month, is a common example.

Calculating the Future Value of an Ordinary Annuity

Future value (FV) is a measure of how much a series of regular payments will be worth at some point in the future, given a specified interest rate.



Because of the **time value of money**—the concept that any given sum is worth more now than it will be in the future because it can be invested in the meantime—the first \$1,000 payment is worth more than the second, and so on. So, let's assume that you invest \$1,000 every year for the next five years, at 5% interest. This is how much you would have at the end of the five-year period:



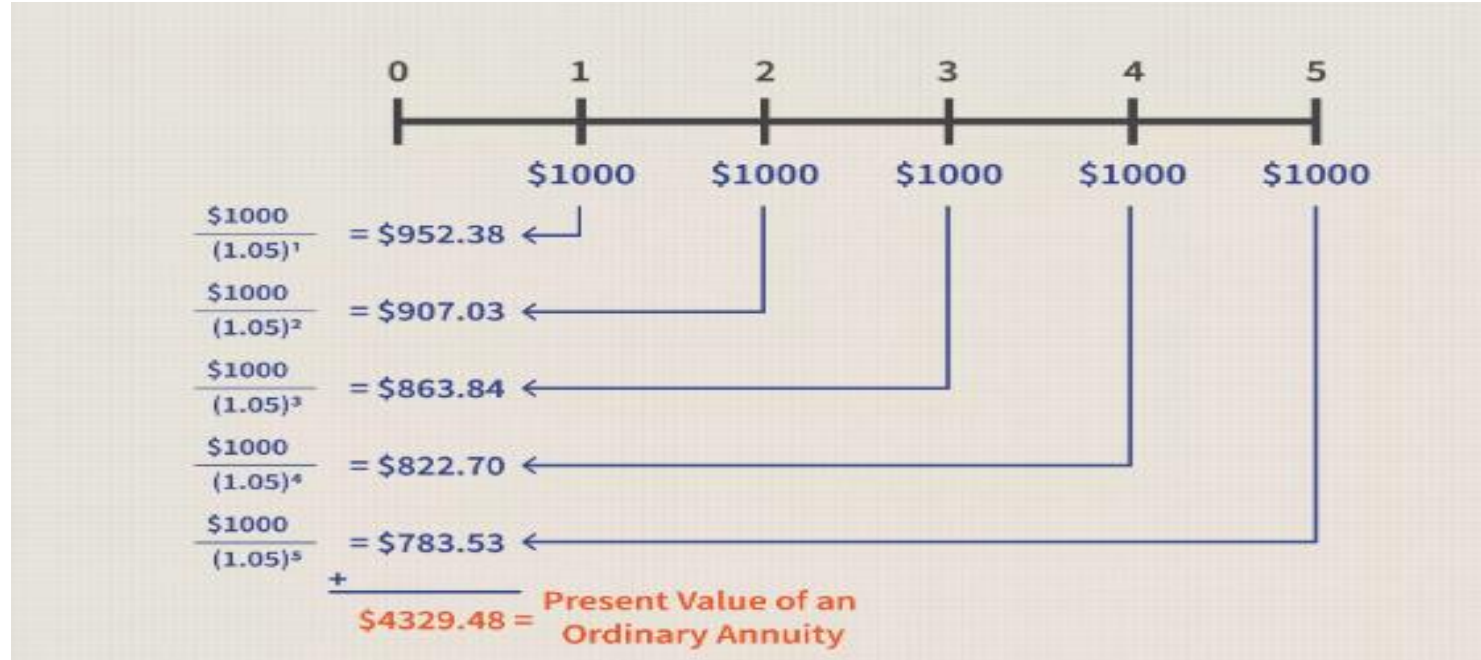
Rather than calculating each payment individually and then adding them all up, however, you can use this formula, which will tell you how much money you'd have in the end:

$$FV_{\text{Ordinary Annuity}} = C * \left[\frac{(1 + i)^n - 1}{i} \right]$$

where: C=cash flow per period, i=interest rate, n=number of payments

Calculating the Present Value of an Ordinary Annuity

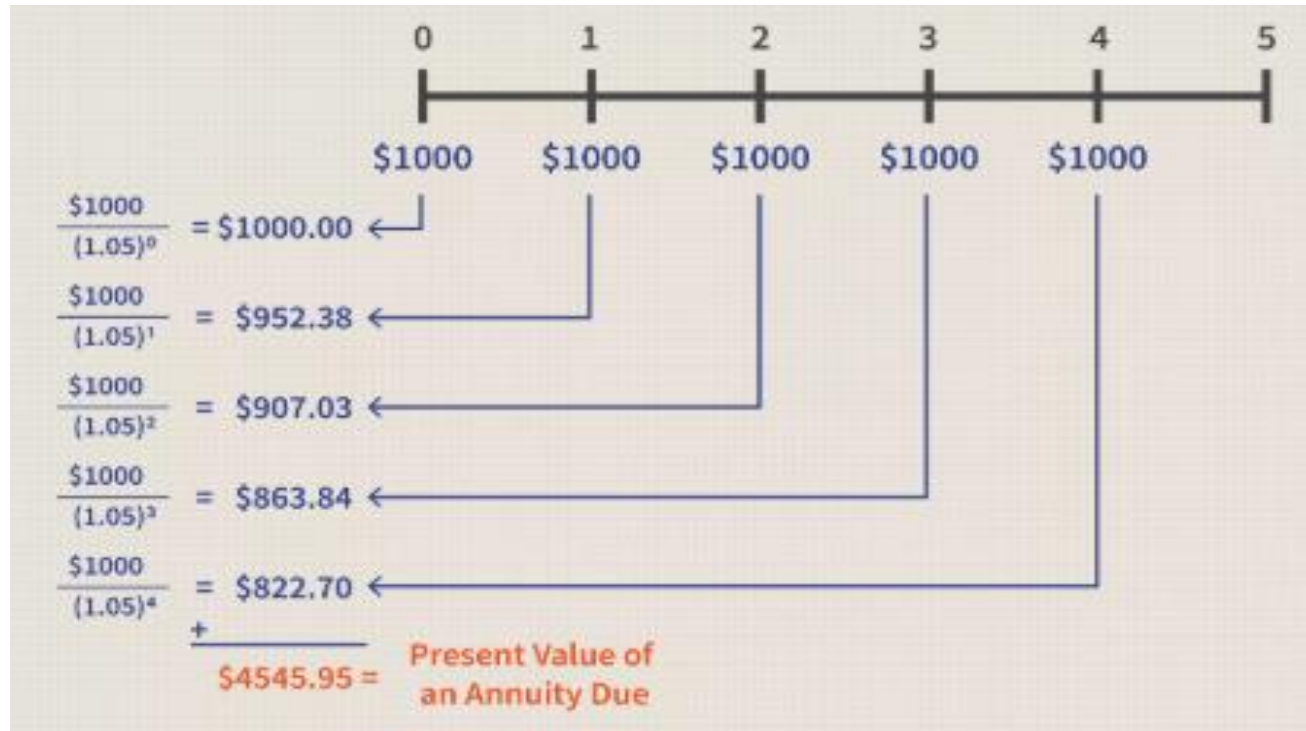
In contrast to the future value calculation, a present value (PV) calculation tells you how much money would be required now to produce a series of payments in the future.



This is the applicable formula:

$$PV_{\text{Ordinary Annuity}} = C * \left[\frac{1 - (1+i)^{-n}}{i} \right]$$

Calculating the Present Value of an Annuity Due:



This is the formula for calculating the present value of an annuity due:

$$PV_{Annuity\ Due} = C * \left[\frac{1 - (1 + i)^{-n}}{i} \right] * (1 + i)$$

DEPRECIATION

An important concept with respect to the calculation of taxes is that of *depreciation*. Since a given facility has a finite useful life, after which it must be replaced, at its salvage value. In essence, an amount is allowed to be put aside each year for its replacement at the end of its useful life. This amount is the depreciation and is taken as an expense each year, thus reducing the taxes to be paid by the company.

There are several approaches to calculating depreciation:

$$D = \frac{P - Q}{n}$$

There are several approaches to calculating depreciation:

- Straight line depreciation:

$$D = \frac{P - Q}{n}$$

- The sum of-years digits (SYD) :

$$D = \left[\frac{n - n_1 + 1}{n(n + 1)/2} \right] (P - Q)$$

- Modified accelerated cost recovery method :

$$D = rP$$

Recovery Rates r (%) Used in Modified Accelerated Cost Recovery Method for Calculating Depreciation

Year	$n = 3$	$n = 5$	$n = 7$	$n = 10$	$n = 15$
1	33.3	20.0	14.3	10.0	5.0
2	44.5	32.0	24.5	18.0	9.5
3	14.8	19.2	17.5	14.4	8.6
4	7.4	11.5	12.5	11.5	7.7
5		11.5	8.9	9.2	6.9
6		5.8	8.9	7.4	6.2
7			8.9	6.6	5.9
8			4.5	6.6	5.9
9				6.5	5.9
10				6.5	5.9
11				3.3	5.9
12–15					5.9
16					3.0

Source: G.E. Dieter (2000) *Engineering Design*, 3rd ed., McGraw-Hill, New York.

Economic Consideration of Thermo-fluid System Design

Cost Comparison

Rate of Return

Payback Period

□ Difference between PV (v) and FV ($=v(1+i)^t$) depends on i and t .

□ Interest Rate

- Contractual arrangement between a borrower and a lender

□ Discount Rate (real change in value to a person or group)

- Worth of Money + Risk
- Discount Rate $>$ Interest Rate

□ Minimum Accepted Rate of Return (MARR)

- Minimum discount rate accepted by the market corresponding to the risks of a project (i.e., minimum standard of desirability)

CHOICE OF DISCOUNT RATE

$$r = r_f + r_i + r_r$$

Where:

- r is the discount rate
- r_f the risk free interest rate. Normally government bond
- r_i Rate of inflation. It is measured by either by consumer price index or GDP deflator.
- r_r Risk factor consisting of market risk, industry risk, firm specific risk and project risk

$$r_r = \begin{matrix} \text{Market Risk} \\ \text{Industry Risk} \\ \text{Firm specific Risk} \\ \text{Project Risk} \end{matrix}$$

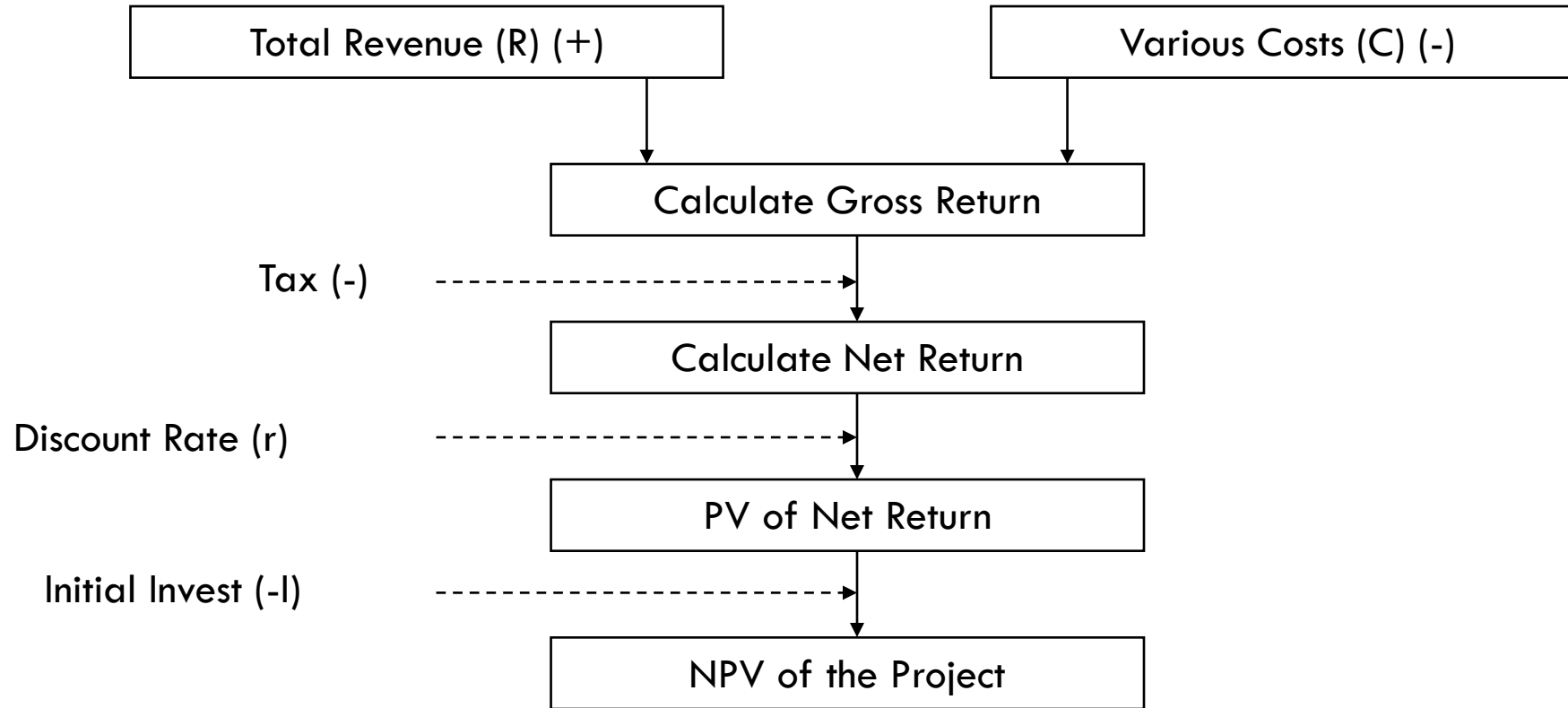
NET PRESENT VALUE (NPV)

Suppose we had a collection (or stream, flow) of costs and revenues in the future

The net present value (NPV) is the sum of the present values for all of these costs and revenues

- Treat revenues as positive and costs as negative

CALCULATION OF NET PRESENT VALUE



	0	1	2	3	4	5
INITIAL INVESTMENT	I					
REVENUE		R1	R2	R3	R4	R5
COST		C1	C2	C3	C4	C5
GROSS RETURN		GR1	GR2	GR3	GR4	GR5
TAX						
NET RETURN		NR1	NR2	NR3	NR4	NR5
DISCOUNT RATE						
PRESENT VALUE		PV1	PV2	PV3	PV4	PV5
		NPV = (PV1 + ... + PV5) - I				

NET PRESENT VALUE DECISION RULE

Accept a project which has 0 or positive NPV

Alternatively,

Use NPV to choose the best among a set of (mutually exclusive) alternative projects

- Mutually exclusive projects: the acceptance of a project precludes the acceptance of one or more alternative projects.

Task-5

The cash flow profiles of four independent projects are shown below. Using a MARR of 20%, determine the acceptability of each of the projects on the basis of the net present value criterion for accepting independent projects.

	0	1	2	3	4	5
A1	-77	0	0	0	0	235
A2	-75.3	28	28	28	28	28
A3	-39.9	28	28	28	28	-80
A4	18	10	-40	-60	30	50

Excel Solution

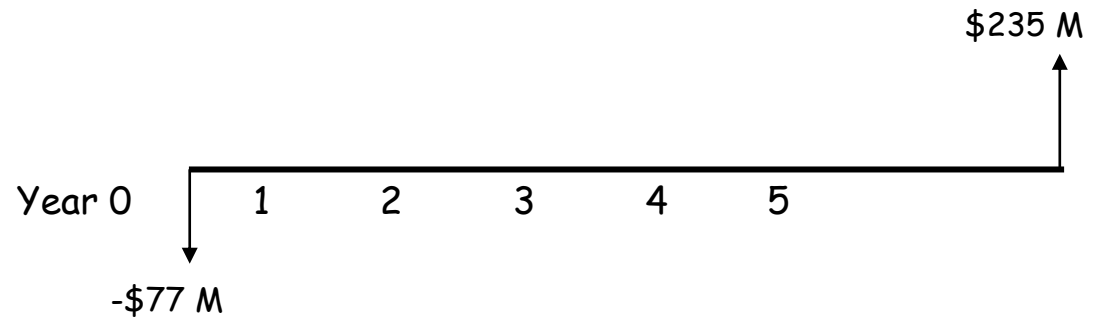
Discount rate	20.00%
Cash flow	
	0
	-75.3 investment
\$	\$28.00
\$	\$28.00
\$	\$28.00
\$	\$28.00
\$	\$28.00
NPV	\$8.44

SOLUTION

[NPV1]20%

$$\begin{aligned} &= -77 + (235)(P/F, 0.2, 5) = -77 + 94.4 \\ &= 17.4 \end{aligned}$$

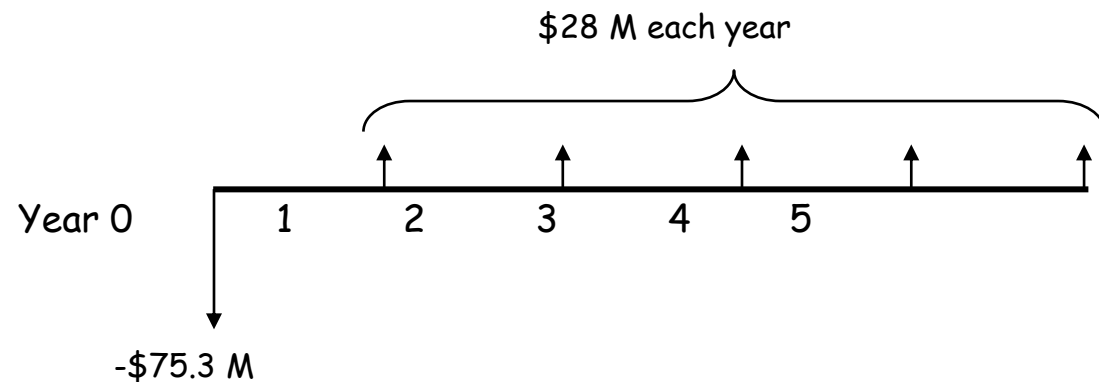
NPV1 – Cash Flow



[NPV2]20%

$$\begin{aligned} &= -75.3 + (28)(P/A, 0.2, 5) = -75.3 + 83.7 \\ &= 8.4 \end{aligned}$$

NPV2 – Cash Flow

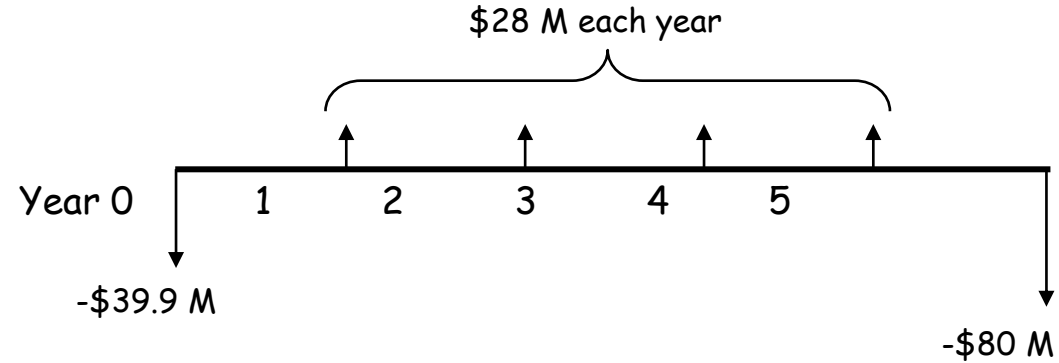


SOLUTION

[NPV3]20%

$$\begin{aligned} &= -39.9 + (28)(P/A, 20\%, 4) - (80)(P/F, 20\%, 5) \\ &= -39.9 + 72.5 - 32.2 \\ &= 0.4 \end{aligned}$$

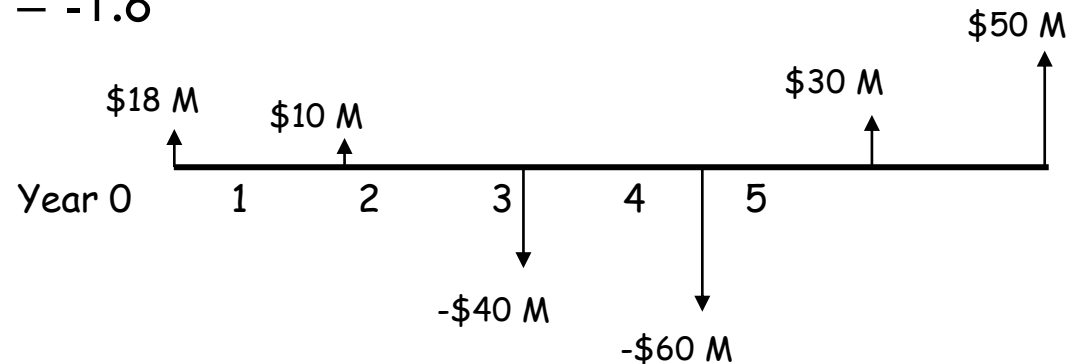
NPV3 – Cash Flow



[NPV4]20%

$$\begin{aligned} &= 18 + (10)(P/F, 20\%, 1) - (40)(P/F, 20\%, 2) \\ &\quad - (60)(P/F, 20\%, 3) + (30)(P/F, 20\%, 4) \\ &\quad + (50)(P/F, 20\%, 5) \\ &= 18 + 8.3 - 27.8 - 34.7 + 14.5 + 20.1 = -1.6 \end{aligned}$$

NPV4 – Cash Flow



SOLUTION

	0	1	2	3	4	5
A1	-77	0	0	0	0	235
A2	-75.3	28	28	28	28	28
A3	-39.9	28	28	28	28	-80
A4	18	10	-40	-60	30	50

$$[\text{NPV1}] = 17.4$$

$$[\text{NPV2}] = 8.4$$

$$[\text{NPV3}] = 0.4$$

$$[\text{NPV4}] = -1.6$$

DISCOUNT RATE IN NPV

NPV (and PV) is relative to a discount rate

In the absence of risk or inflation, this is just the interest rate of the “reliable source” (opportunity cost)

Correct selection of the discount rate is fundamental. If too high, projects that could be profitable can be rejected. If too low, the firm will accept projects that are too risky without proper compensation.

Its choice can easily change the ranking of projects.

TASK-6

	Machine A
Initial cost	\$20,000
Life	5 years
Salvage value	\$4,000
Annual receipts	\$10,000
Annual disbursements	\$4,400

$$\text{NPV} = -20,000 + 5,600 (P/A, i, 5) + 4,000 (P/F, i, 5)$$

What Is Internal Rate of Return – IRR?

The internal rate of return (IRR) is a metric used in capital budgeting to estimate the profitability of potential investments. The internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. IRR calculations rely on the same formula as NPV does.

$$0 = NPV = \sum_{t=1}^T \frac{C_t}{(1 + IRR)^t} - C_0$$

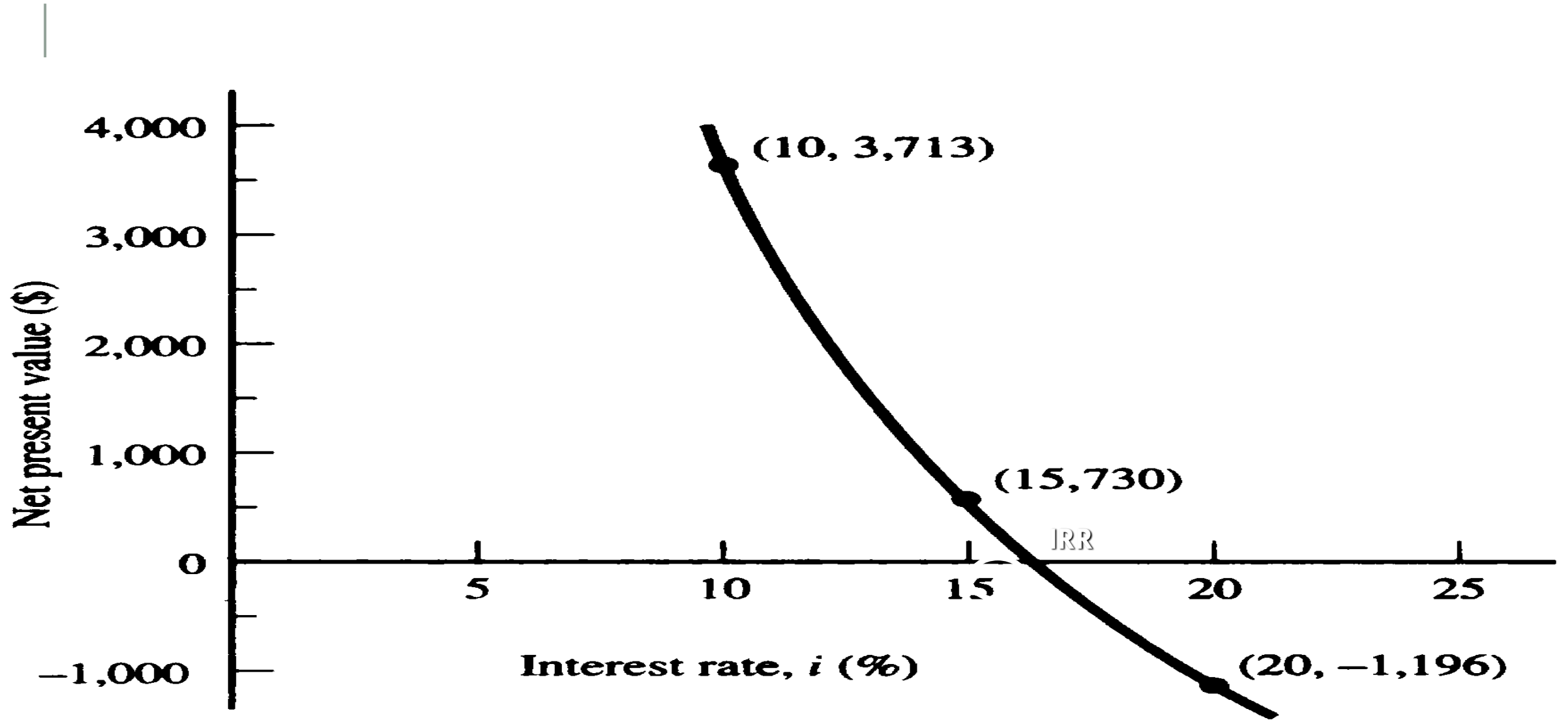
Where, C_t = Net cash inflow during the period t

C_0 = Total initial investment costs

IRR = The internal rate of return

t = The number of time periods

RELATIONSHIP BETWEEN NPV & IRR



IRR INVESTMENT RULE

$$r = \text{IRR}, r^* = \text{MARR}$$

“Accept a project with IRR larger than MARR”

Alternatively,

“Maximize IRR across mutually exclusive projects.”

IRR VS. NPV

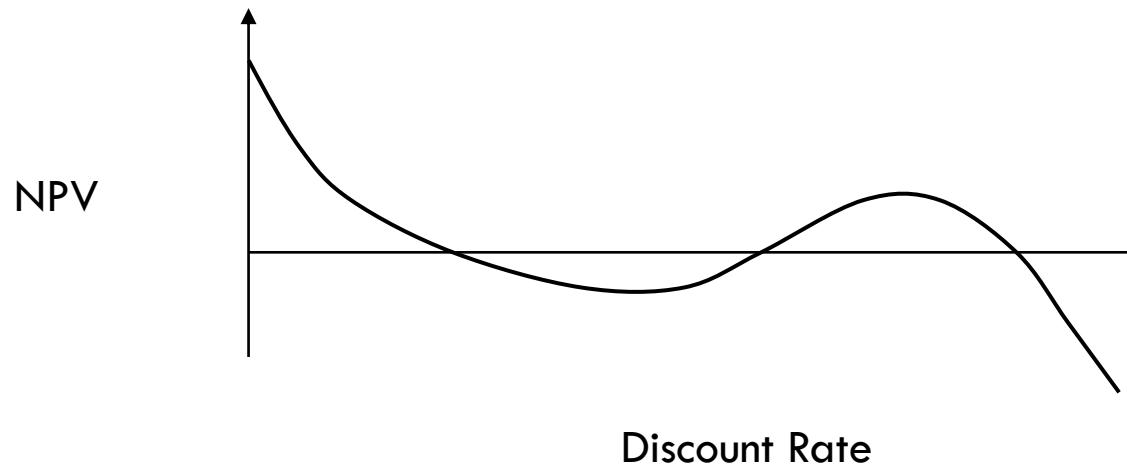
Oftentimes, IRR and NPV give the same decision/ranking among projects.

IRR only looks at *rate* of gain – not *size* of gain

IRR does not require you to assume (or compute) a discount rate.

IRR ignores capacity to reinvest

IRR may not be unique



PAYBACK PERIOD

Payback period (“Time to return”)

- Minimal length of time over which benefits repay costs
- Typically only used as secondary assessment
- Important for selection when the risk is extremely high
- Drawbacks
 - Ignores what happens after payback period
 - Does not take into account discounting

COMPARING PROJECTS

Financing has major impact on project selection

- Suppose that one had to choose between 2 investment projects

How can one compare them?

- **Use NPV**
- **Verify IRR**
- **Check payback period**

PROJECT EVALUATION

For an equipment, there are TWO cost elements:

1) Initial Cost, and

2) Operation & Maintenance Cost

The identification of cost elements and their sub-division are based on the purpose and scope of the LCC study.

COST ELEMENT

Initial Cost:

- Design & development cost,
- Investment on asset, or cost of equipment,
- Installation cost or erection & commission cost.

COST ELEMENT

Operation & Maintenance Cost:

- Labor cost,
- Energy cost,
- Spare & maintenance cost,
- Raw material cost.

STEPS FOR COMPUTATION OF LCC

Step 1: Determine time for each cost element,

Step 2: Estimate value of each cost element,

Step 3: Calculate Net Present Value of each element, for every year (over its time period),

Step 4: Calculate LCC by adding all cost element, at every year,

Step 5: Analyze the results.

Problem-01

A manufacturing system, which is being designed, needs a laser welding machine. Two machines, *A* and *B*, both of which are suitable for the manufacturing process, are being considered. The applicable costs in U.S. dollars are given as

	A	B
Initial cost	\$20,000	\$30,000
Annual maintenance cost	4,000	2,000
Refurbishing cost at end of 3 years	3,000	0
Annual savings	500	1,000
Salvage value	500	3,000

The useful life is 6 years for both machines, and the rate of interest is 8%, compounded annually. Determine which machine is a better acquisition.

Problem-02

Two plastic-forming facilities, *A* and *B*, are suitable for a plastic recycling system. The following financial data are given for the two facilities:

	A	B
Initial cost	\$50,000	\$80,000
Annual income	26,000	36,000
Annual maintenance and other costs	11,000	15,000
Salvage value	10,000	20,000

The life of the facilities is given as 5 years. Calculate the rates of return for the two cases. Also, include the effect of taxes, assuming a tax rate of 50% and using the straight-line method for depreciation. Calculate the resulting rates of return.

ASSIGNMENT-1

Excess amount of heat from a 10 TPH boiler is exhausted to the atmosphere which can be recovered by using an economizer. Annual energy savings by using an economizer would be 12,50,000 BDT. A brand new economizer would cost 15,00,000 BDT and installation cost would be around 10% of the capital cost. Yearly maintenance cost can be assumed as 1% of the capital cost and expected life of the economizer is 15 years. The company can invest by borrowing from a bank with an annual interest rate of 12%. Present the detailed financial analysis for this project (**NPV, IRR, Payback period**). It is assumed that the fuel cost may increase by 10% every 3 years.

Solve it in an excel spreadsheet and send to the email address before the next class

[Email: shamimafsan@me.buet.ac.bd](mailto:shamimafsan@me.buet.ac.bd)

Thank You!