ECE 333 – Green Electric Energy

9. Energy Economics Concepts

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ENERGY ECONOMICS CONCEPTS

- **The economic evaluation of a renewable energy resource requires a meaningful quantification of the cost elements**
  - **fixed costs**
  - **variable costs**
- **We use engineering economics notions for this purpose since they provide the means to compare on a consistent basis**
  - **two different projects; or,**
  - **the costs with and without a given project**

TIME VALUE OF MONEY

- **Basic underlying notion: a dollar today is not the same as a dollar in a year**
- **We represent the time value of money by the standard approach of *discounted cash flows***
- **The notation is**

$$P \;=\; \textit{principal}$$

$$i \;=\; \textit{interest value}$$

- **We use the convention that every payment occurs at the *end of a period***

SIMPLE EXAMPLE

loan P for 1 *year*

repay $P + iP = P(1+i)$ at the end of 1 *year*

year *0* P

year 1 $P(1+i)$

loan P for n *years*

year *0* P

year 1 $(1+i)\ P$ repay/reborrow

year 2 $(1+i)^2 P$ repay/reborrow

year 3 $(1+i)^3 P$ repay/reborrow

⋮ ⋮ ⋮

year n $(1+i)^n P$ repay

COMPOUND INTEREST

end of period	*amount owed*	*interest for next period*	*amount owed at the beginning of the next period*
0	P	$P\,i$	$P + P\,i = P(1+i)$
1	$P(1+i)$	$P(1+i)\,i$	$P(1+i) + P(1+i)\,i = P(1+i)^2$
2	$P(1+i)^2$	$P(1+i)^2\,i$	$P(1+i)^2 + P(1+i)^2\,i = P(1+i)^3$
3	$P(1+i)^3$	$P(1+i)^3\,i$	$P(1+i)^3 + P(1+i)^3\,i = P(1+i)^4$
⋮	⋮		
n–1	$P(1+i)^{n-1}$	$P(1+i)^{n-1}\,i$	$P(1+i)^{n-1} + P(1+i)^{n-1}\,i = P(1+i)^n$
n	$P(1+i)^n$		

the value in the last column at the *e.o.p.* (*k*-1) provides the amount in the first column for the *period k*

TERMINOLOGY

$$F = P\underbrace{(1 + i)}_{\text{compound interest}}{}^{n}$$

compound interest

lump sum repayment at the end of n periods

need not be integer-valued

TERMINOLOGY

- We call $(1+i)^n$ the single payment compound amount factor
- We define

$$\beta \triangleq (1+i)^{-1}$$

- Then,

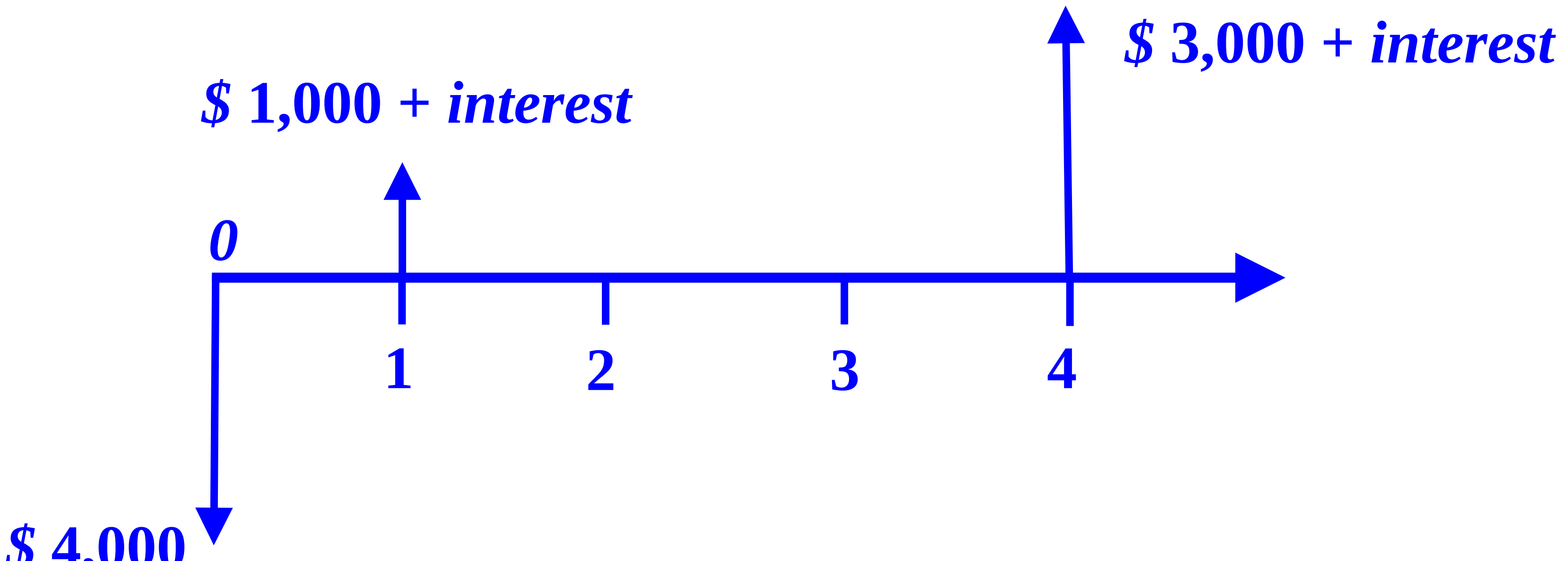
$$\beta^n = (1+i)^{-n}$$

is the single payment present worth factor

- *F* denotes the *future worth*; *P* denotes the *present worth* or *present value* at interest *i* of a future sum *F*

EXAMPLE 1

- Consider a loan of *$* 4,000 at 8 % interest to be repaid in two installments
  - *$* 1,000 and interest at the *e.o.y.* 1
  - *$* 3,000 and interest at the *e.o.y.* 4



EXAMPLE 1

- The cash flows are
  - *e.o.y.* 1: $1,000 + 4,000\,(.08) = \$\,1,320.00$
  - *e.o.y.* 4: $3,000\,(1 + .08)^3 = \$\,3,779.14$
- Note that the loan is made in year 0 ***present*** dollars, but the repayments are in year 1 and year 4 ***future*** dollars

EXAMPLE 2

- Given

$$P = \$1{,}000 \qquad \text{and} \qquad i = .12$$

then

$$P(1+i)^5 = \$1{,}000(1+.12)^5 = \$1{,}762.34 = F$$

- We say that with the cost of money of 12 %, P and F are *equivalent* in the sense that $ 1,000 today has the same worth as $ 1,762.34 in 5 years

EXAMPLE 3

- Consider an investment that returns

  $\$\ 1{,}000$ at the *e.o.y.* 1

  $\$\ 2{,}000$ at the *e.o.y.* 2

  $i = 10\%$ ⟵ rate at which money can be freely lent or borrowed

- We evaluate P

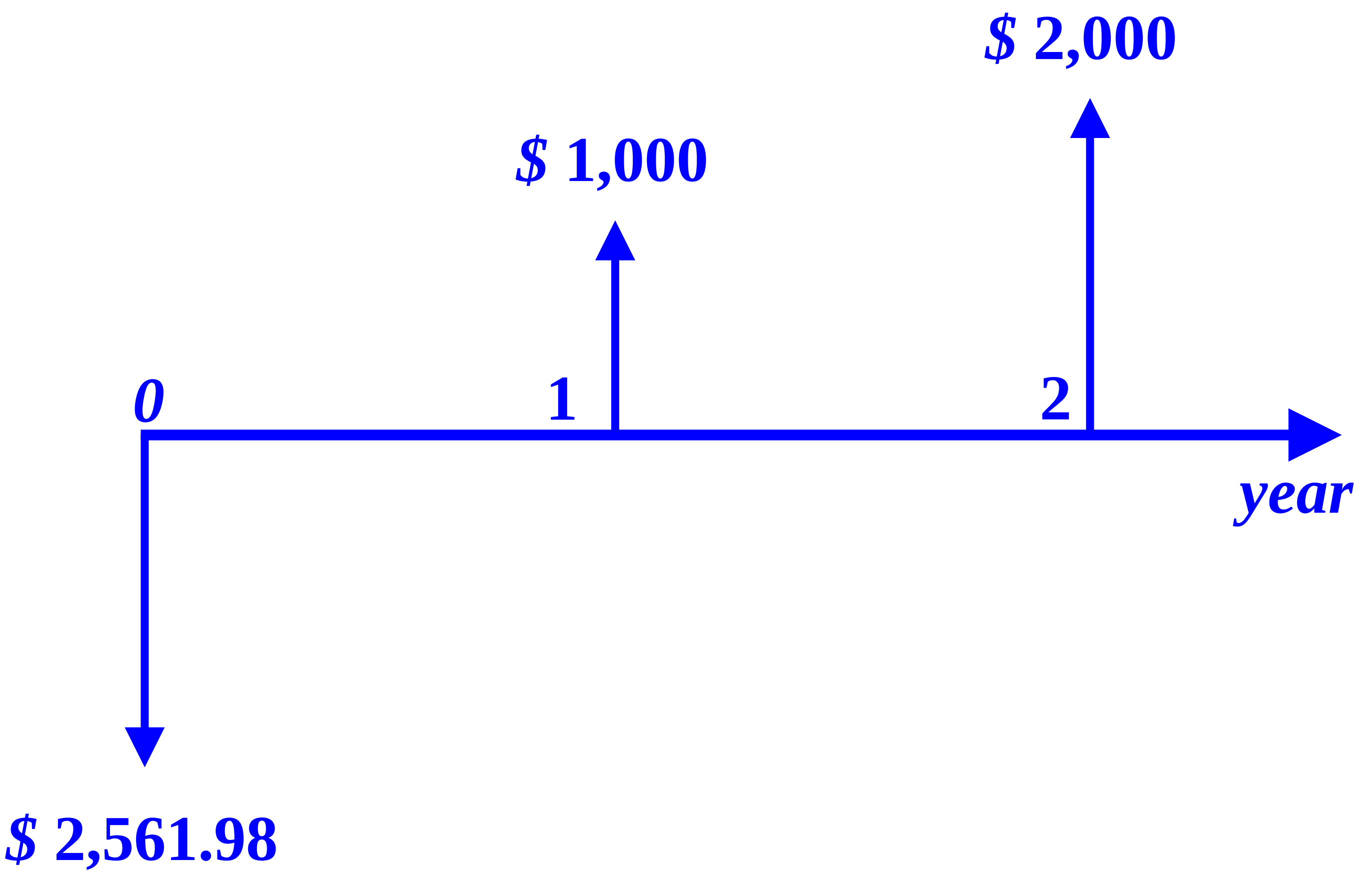
$$P = \$\,1{,}000\underbrace{(1+.1)^{-1}}_{\beta} + \$\,2{,}000\underbrace{(1+.1)^{-2}}_{\beta^2}$$

$$= \$\,909.9 + \$\,1{,}652.09$$

$$= \$\,2{,}561.98$$

EXAMPLE 3

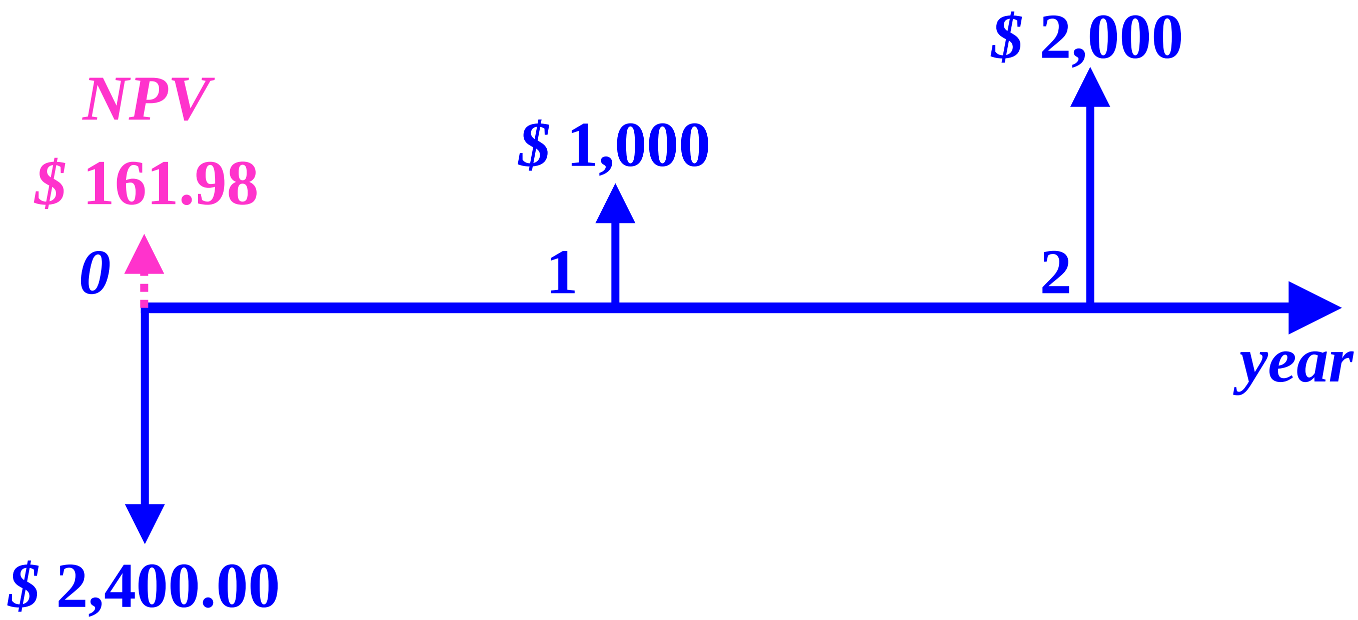
- We review this example with a *cash – flow diagram*



EXAMPLE 3

- Next, suppose that this investment requires $ 2,400 now and so at 10 % we say that the investment has a ***net present value*** or

$$NPV = \$\,2{,}561.98 - \$\,2{,}400 = \$\,161.98$$



CASH FLOWS

- A *cash – flow* is a transfer of an amount A_t from one entity to another at the *e.o.p. t*
- We consider the cash – flow set $\{ A_0, A_1, A_2, \ldots, A_n \}$
- This set corresponds to the set of the transfers in the periods $\{ 0, 1, 2, \ldots, n \}$

CASH FLOWS

- We associate the transfer A_t at the *e.o.p. t*,

  $t = 0, 1, 2, \ldots, n$

- The convention for cash flows is

  $+$ *inflow*

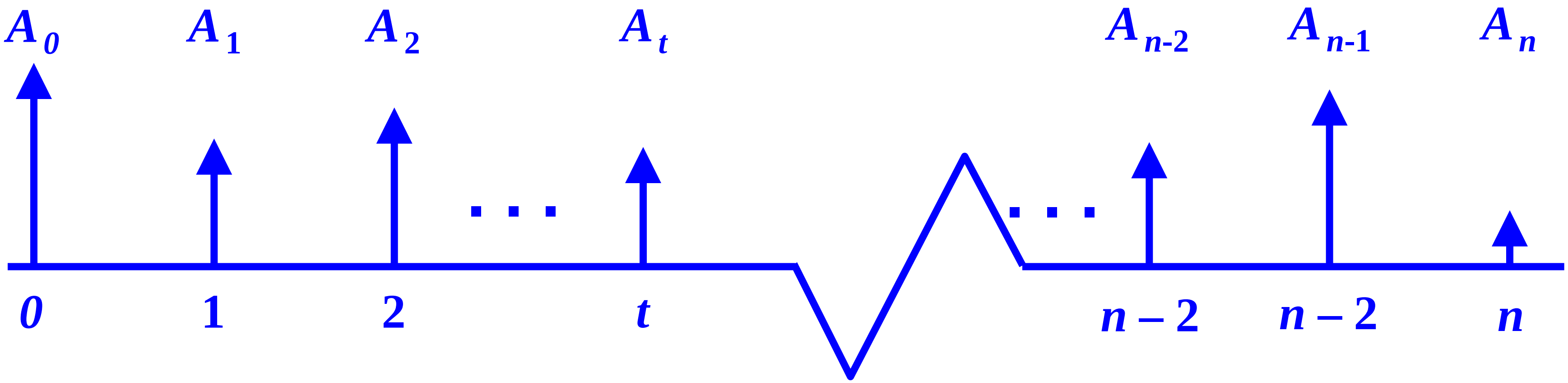
  $-$ *outflow*

- Each cash flow requires the specification of:
  - amount;
  - time; and,
  - sign

CASH FLOWS : FUTURE WORTH

- Given a cash – flow set $\left\{ A_0, A_1, A_2, \ldots, A_n \right\}$ we define the future worth F_n of the cash flow set at the *e.o.y.* n as

$$F_n = \sum_{t=0}^{n} A_t \left(1 + i\right)^{n-t}$$



CASH FLOWS : FUTURE WORTH

- Note that each cash flow A_t in the $(n + 1)$ period set contributes differently to F_n:

$$
\begin{array}{ccc}
A_0 & \rightarrow & A_0(1+i)^n \\
A_1 & \rightarrow & A_1(1+i)^{n-1} \\
A_2 & \rightarrow & A_2(1+i)^{n-2} \\
\vdots & & \vdots \\
A_t & \rightarrow & A_t(1+i)^{n-t} \\
\vdots & & \vdots \\
A_n & \rightarrow & A_n
\end{array}
$$

CASH FLOWS : PRESENT WORTH

- We define the present worth P of the cash – flow set as

$$P = \sum_{t=0}^{n} A_t \beta^t = \sum_{t=0}^{n} A_t (1+i)^{-t}$$

- Note that

$$P = \sum_{t=0}^{n} A_t (1+i)^{-t}$$

$$= \sum_{t=0}^{n} A_t (1+i)^{-t} \underbrace{(1+i)^{n} (1+i)^{-n}}_{1}$$

CASH FLOWS

$$= \underbrace{(1+i)^{-n}}_{\beta^n} \underbrace{\sum_{t=0}^{n} A_t (1+i)^{n-t}}_{F_n}$$

$$= \beta^n F_n$$

or, equivalently,

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

UNIFORM CASH – FLOW SET

- Consider the cash – flow set $\left\{ A_1, A_2, \ldots, A_n \right\}$ with

$$A_t = A \qquad t = 1, 2, \ldots, n$$

- Such a set is called an *equal payment cash flow set*

- We compute the present worth at $t = 0$

$$P = \sum_{t=1}^{n} A_t \beta^t = A \sum_{t=1}^{n} \beta^t = A\beta\left[1 + \beta + \beta^2 + \ldots + \beta^{n-1}\right]$$

UNIFORM CASH – FLOW SET

- Now, for $0 < \beta < 1$, we have the identity

$$\sum_{j=0}^{\infty} \beta^{j} = \frac{1}{1 - \beta}$$

- It follows that

$$1 + \beta + \ldots + \beta^{n-1} = \sum_{j=0}^{\infty} \beta^{j} - \beta^{n} \overbrace{\left[1 + \beta + \beta^{2} + \ldots + \beta^{n-1} + \ldots \right]}^{\sum_{j=0}^{\infty} \beta^{j}}$$

$$= \left(1 - \beta^{n} \right) \sum_{j=0}^{\infty} \beta^{j}$$

UNIFORM CASH – FLOW SET

$$= \frac{1-\beta^{n}}{1-\beta}$$

- Therefore

$$P = A\beta \frac{1-\beta^{n}}{1-\beta}$$

- But

$$\beta = \left(1+d\right)^{-1}$$

and so

UNIFORM CASH – FLOW SET

$$1 - \beta = 1 - \frac{1}{1+d} = \frac{d}{1+d} = \beta d$$

- We write

$$P = A \, \frac{1 - \beta^{n}}{d}$$

and we call $\dfrac{1 - \beta^{n}}{d}$ the *equal payment series present worth factor*

EQUIVALENCE

- We consider two cash – flow sets

$$\left\{ A_t^a : t = 0,1,2, \ldots ,n \right\} \text{ and } \left\{ A_t^b : t = 0,1,2, \ldots ,n \right\}$$

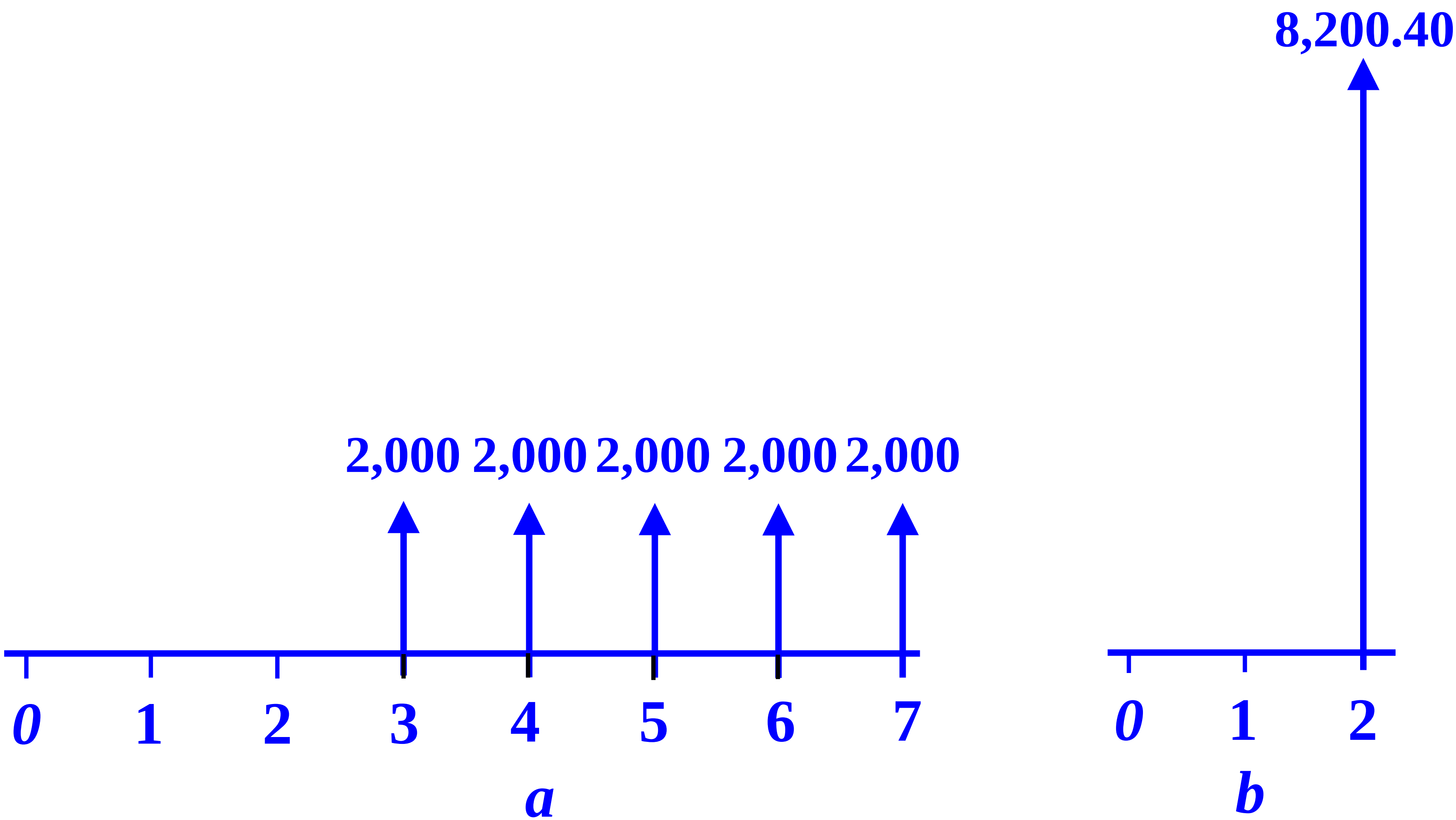
under a given discount rate d

- We say $\left\{ A_t^a \right\}$ and $\left\{ A_t^b \right\}$ are *equivalent* cash – flow sets if and only if

$$F_m \textit{ of } \left\{ A_t^a \right\} = F_m \textit{ of } \left\{ A_t^b \right\} \textit{ for each value of } m$$

EQUIVALENCE EXAMPLE

- Consider the two cash – flow sets under $d = 7\%$



EQUIVALENCE

- We compute

$$P^{a} = 2{,}000 \sum_{t=3}^{7} \beta^{t} = 7{,}162.33$$

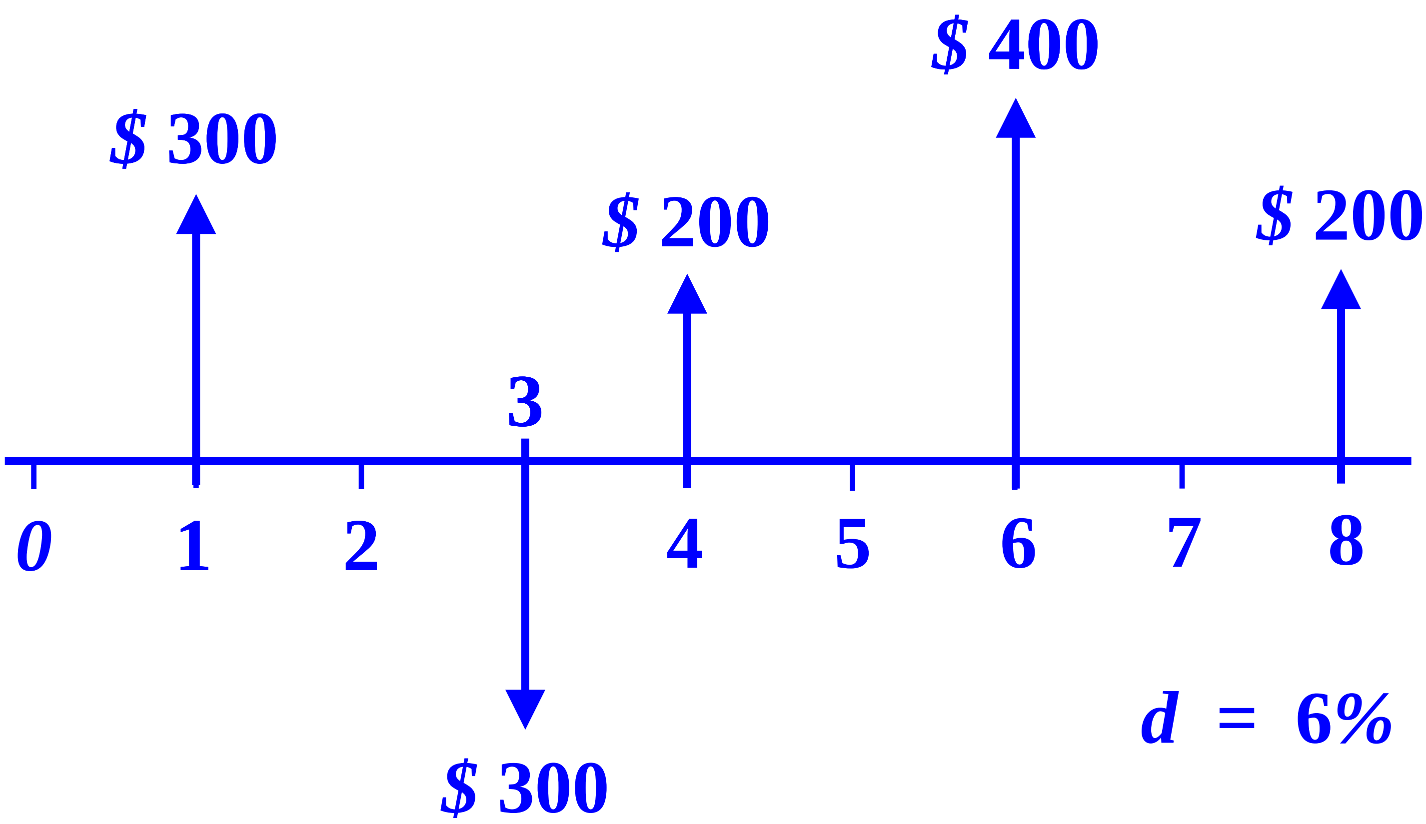
and

$$P^{b} = 8{,}200.40 \;\; \beta^{2} = 7{,}162.33$$

- Therefore, $\left\{ A_t^a \right\}$ and $\left\{ A_t^b \right\}$ are equivalent cash flow sets under $d = 7\%$

EXAMPLE

- Consider the cash – flow set illustrated below



- We compute F_8 at $t = 8$ for $d = 6\ \%$

EXAMPLE

$$F_8 = 300\left(1+.06\right)^7 - 300\left(1+.06\right)^5 +$$

$$200\left(1+.06\right)^4 + 400\left(1+.06\right)^2 + 200$$

$$= \$951.56$$

- We also compute P

EXAMPLE

$$P = 300\left(1+.06\right)^{-1} - 300\left(1+.06\right)^{-3} +$$

$$200\left(1+.06\right)^{-4} + 400\left(1+.06\right)^{-6} + 200\left(1+.06\right)^{-8}$$

$$= \$597.04$$

- We check that for $d = 6\%$

$$F_8 = 597.04\left(1+.06\right)^{8} = \$951.56$$

DISCOUNT RATE

- The interest rate i is, typically, referred to as the *discount rate* and is denoted by d
- In converting the future amount F to the present worth P we can view the *discount rate* as the interest rate that may be earned from the best investment alternative
- A postulated savings of $\$10{,}000$ in a project in 5 years is worth at present

$$P = F_5 \beta^5 = 10{,}000 \left(1 + d\right)^{-5}$$

DISCOUNT RATE

- For $d = 0.1$

$$P = \$\,6{,}201,$$

while for $d = 0.2$

$$P = \$\,4{,}019$$

- In general, for a specified future worth, the lower the discount factor, the higher the present worth is

DISCOUNT RATE

- We may state this notion slightly differently; the lower the discount factor, the more valuable a future payoff becomes

- The present worth of a set of costs under a given discount rate is called the *life – cycle costs*, an important term in economic assessment studies

EXAMPLE

- We consider the purchase of two – *a* and *b* – 100 – *hp* motors to be used over a 20 – year period; the discount rate is given to be 10 %
- The relative merits of *a* and *b* are

motor	*costs* ($)	*load* (*kW*)
a	2,400	79.0
b	2,900	77.5

EXAMPLE

- The motor is used 1,600 *hours* per year and electricity costs are constant at 0.08 *$/kWh*

- We evaluate yearly energy costs for *the two motors*

$$A_t^a = (79.0\ kW)(1600\ h)(.08\ \$/kWh) = \$10,112$$

$$t = 1, 2, \ldots, 20$$

$$A_t^b = (77.5\ kW)(1600\ h)(.08\ \$/kWh) = \$9,920$$

EXAMPLE

- We next evaluate the present worth of *a* and *b*

$$P^{a} = 2,400 + 10,112 \sum_{t=1}^{20} (1.1)^{-t} \longleftarrow 8.5136$$

$$= \$88,489$$

$$P^{b} = 2,900 + 9,920 \sum_{t=1}^{20} (1.1)^{-t} \longleftarrow 8.5136$$

$$= \$87,354$$

EXAMPLE

- The difference

$$P^{a} - P^{b} = 88,489 - 87,354 = \$1,135$$

- Therefore, the purchase of motor b results in the savings of $\$\ 1,135$ under the specified $10\ \%$ discount rate due to the use of the smaller load motor over the $20 -$ *year* horizon

INFINITE HORIZON CASH – FLOW SETS

- Consider a uniform cash – flow set with $n \rightarrow \infty$

$$\left\{ A_t = A : t = 0, 1, 2, \ldots \right\}$$

- Then,

$$P = A \frac{\left(1 - \beta^n\right)}{d} \xrightarrow[n \rightarrow \infty]{} A \frac{1}{d}$$

- For an infinite horizon uniform cash – flow set

INFINITE HORIZON CASH – FLOW SETS

$$\frac{A}{P} = d$$

- We may view d as the *capital recovery factor* with the following interpretation:

  for an initial investment of P, the amount

  $$d * P = A$$

  is recovered annually in terms of returns on investment

INTERNAL RATE OF RETURN

- We consider a cash – flow set

$$\left\{ A_t = A : t = 0, 1, 2, \ldots \right\}$$

- The value of d for which

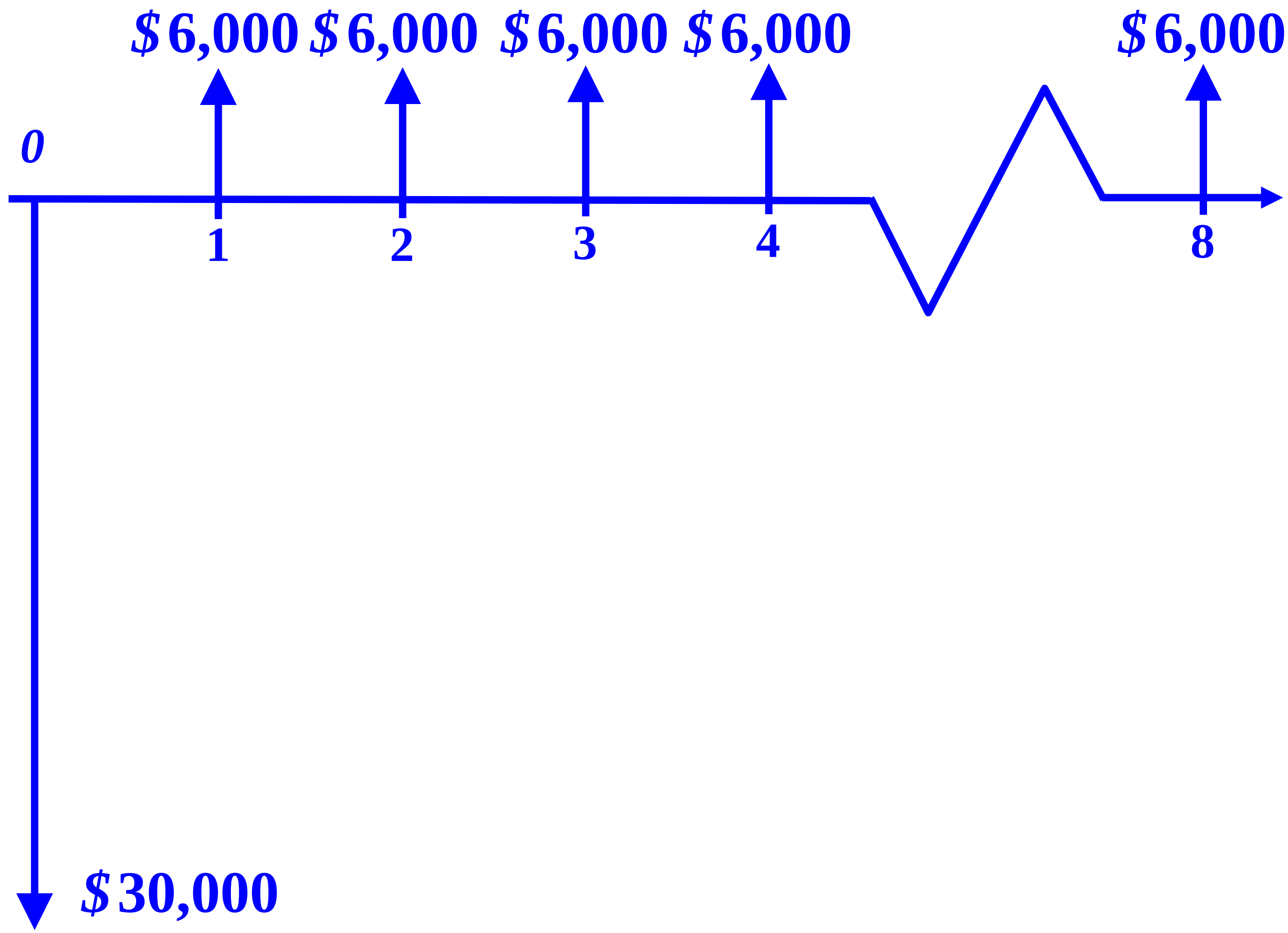
$$P - \sum_{t=0}^{n} A_t \beta^t = 0$$

  is called the *internal rate of return* (*IRR*)

- The *IRR* is a measure of how fast we recover an investment, or stated differently, the speed with or rate at which the returns recover an investment

EXAMPLE: INTERNAL RATE OF RETURN

- Consider the following cash – flow set



INTERNAL RATE OF RETURN

- The present value

$$P = -30{,}000 + 6{,}000 \frac{1-\beta^{8}}{d} = 0$$

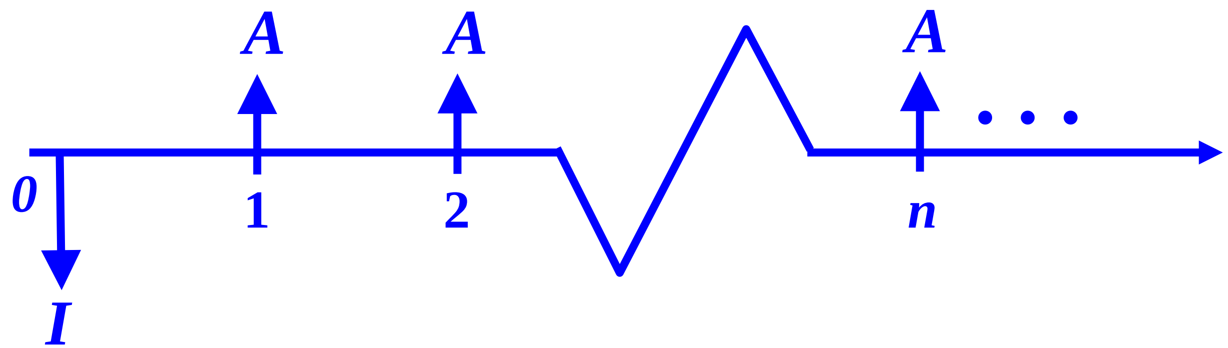
has the solution

$$d \approx 12\%$$

- The interpretation is that under a 12 % *discount rate*, the *present value* of the cash – flow set is *0* and so $d \approx 12\%$ is the *IRR* for the given cash – flow set

INTERNAL RATE OF RETURN

- Consider an infinite horizon simple investment



- Therefore

$$d = \frac{A}{I}$$

← ratio of annual return to initial investment

INTERNAL RATE OF RETURN

- **Consider**

$$I = \$\ 1{,}000$$

$$A = \$\ 200$$

and

$$d = 20\ \%$$

we interpret that the returns capture 20 % of the investment each year or equivalently that we have a *simple payback period* of 5 years

EXAMPLE: EFFICIENT REFRIGERATOR

- A more efficient refrigerator incurs an investment of additional *$* 1,000 but provides *$* 200 of energy savings annually
- For a lifetime of 10 years, the *IRR* is computed from the solution of

$$0 = -1{,}000 + 200 \, \frac{1 - \beta^{10}}{d}$$

or

EXAMPLE: EFFICIENT REFRIGERATOR

$$\frac{1-\beta^{10}}{d} = 5$$

- *IRR* tables show that

$$\left.\frac{1-\beta^{10}}{d}\right|_{d=15\,\%} = 5.02$$

and so the *IRR* is approximately 15 %

INFLATION IMPACTS

- **Inflation is a general *increase* in the level of prices in an economy; equivalently, we may view inflation as a general *decline* in the value of the purchasing power of money**
- **Inflation is measured using prices: different products may have distinct escalation rates**
- **Typically, indices such as the *CPI* – the *consumer price index* – use a market basket of goods and**

INFLATION IMPACTS

services as a proxy for the entire U.S. economy

- reference basis is the year 1967 with the price of $\$$ 100 for the basket $\longrightarrow L_0$
- in the year 1990, the same basket cost $\$$ 374 $\longrightarrow L_{21}$
- the average inflation rate j is estimated from

$$(1 + j)^{23} = \frac{374}{100} = 3.74$$

and so

$$j = (3.74)^{\frac{1}{23}} - 1 \approx 0.059$$

INFLATION RATE

- The inflation rate contributes to the ***overall market interest rate i***, sometimes called the ***combined interest rate***
- We write, using d for i

$$(1 + d) = (1 + j)\ (1 + d')$$

combined interest rate → d ; *inflation rate* → j ; *real interest rate* → d'

INFLATION

- We obtain the following identities

$$d' = \frac{d - j}{1 + j}$$

and

$$j = \frac{d - d'}{1 + d'}$$

CASH – FLOWS INCORPORATING INFLATION

- **We express the cash – flow in the set**

  $\left\{ A_t : t = 0, 1, 2, \ldots, n \right\}$ **in then current dollars**

- **The following is synonymous terminology**

  $$\textit{current} \equiv \textit{then current} \equiv \textit{inflated} \equiv \textit{after inflation}$$

- **An** ***indexed*** **or** ***constant – worth*** **cash – flow is one that does not explicitly take inflation into**

CASH – FLOWS INCORPORATING INFLATION

account, i.e., whatever amount in current inflated dollars will buy the same goods and services as in the reference year, typically, the year *0*

- **The following terms are synonymous**

constant ≡ indexed ≡ inflation free ≡ before inflation

and we use them interchangeably

CASH – FLOWS INCORPORATING INFLATION

- We define the set of constant currency flows

$$\left\{ W_t : t = 0, 1, 2, \ldots, n \right\}$$

corresponding to the set

$$\left\{ A_t : t = 0, 1, 2, \ldots, n \right\}$$

with each element A_t given in period *t* currency

CASH – FLOWS INCORPORATING INFLATION

- **We use the relationship**

$$A_t = W_t \left(1 + j\right)^{t}$$

or equivalently

$$W_t = A_t \left(1 + j\right)^{-t}$$

with W_t expressed in reference year 0 (today's) dollars

CASH – FLOWS INCORPORATING INFLATION

- We have

$$P = \sum_{t=0}^{n} A_t \beta^t$$

$$= \sum_{t=0}^{n} W_t (i+j)^t (i+d)^{-t}$$

$$= \sum_{t=0}^{n} W_t (i+j)^t (i+j)^{-t} (i+d')^{-t}$$

$$= \sum_{t=0}^{n} W_t (i+d')^{-t}$$

CASH – FLOWS INCORPORATING INFLATION

- **Therefore, the** ***real interest rate*** d' **is used to discount the indexed cash – flows**

- **In summary,**

we discount current *dollar* cash – flow at d

we discount indexed *dollar* cash – flow at d'

CASH – FLOWS INCORPORATING INFLATION

- Whenever inflation is taken into account, it is convenient to carry out the analysis in ***present worth*** rather than future worth or on a ***cash – flow basis***

- Under inflation $\left(j > 0 \right)$, it follows that a uniform set of cash flows $\left\{ A_t = A : t = 1, 2, \ldots, n \right\}$ implies a real decline in the cash flows

EXAMPLE: INFLATION CALCULATIONS

- Consider an annual inflation rate of $j = 4\ \%$ and the cost for a piece of equipment is assumed constant for the next 3 years in terms of today's $\$$

$$W_0 = W_1 = W_2 = W_3 = \$\,1{,}000$$

- The corresponding cash flows in current $\$$ are

$$A_0 = \$\,1{,}000$$

$$A_1 = 1{,}000(1+.04) = \$\,1{,}040$$

EXAMPLE: INFLATION CALCULATIONS

$$A_2 = 1,000(1+.04)^2 = \$\,1,081.60$$

$$A_3 = 1,000(1+.04)^3 = \$\,1,124.86$$

- The interpretation of A_3 is that under 4 % inflation, $\$\,1,125$ in 3 years will have the same value as $\$\,1,000$ today; it must not be confused with the present worth calculation

MOTOR ASSESSMENT EXAMPLE

- For the motor a or b purchase example, we consider the escalation of electricity at an annual rate of $j = 5\ \%$
- We compute the NPV taking into account the inflation (price escalation of $5\ \%$) and $d = 10\ \%$
- Then,

$$d' = \frac{d - j}{1 + j} = \frac{.10 - .05}{1 + .05} = \frac{.05}{1.05} = 0.04762$$

MOTOR ASSESSMENT

- The savings of $ 192 per year are in constant dollars

$$P_{savings} = \sum_{t=1}^{20} W_t \left(1 + d'\right)^{-t}$$

$d' = 0.04762$

and so

$$P_{savings} = \$\,2{,}442$$

- The total savings are

$$P = -\,500 + P_{savings} = \$\,1{,}942$$

which are larger than those of $ 1,135 without electricity price escalation

EXAMPLE: *IRR* FOR *HVAC* RETROFIT WITH INFLATION

- An energy efficiency retrofit of a commercial site reduces the *HVAC* load consumption to 0.8 *GWh* from 2.3 *GWh* and the peak demand by 0.15 *MW*
- Electricity costs are 60 *$/MWh* and demand charges are 7,000 *$/(MW–mo)* and these prices escalate at an annual rate of $j = 5\ \%$
- The retrofit requires a *$* 500,000 investment today and is planned to have a 15 – *year* lifetime

EXAMPLE: *IRR* FOR *HVAC* RETROFIT WITH INFLATION

- We evaluate the *IRR* for this project

- The annual savings are

$$energy\ :(2.3-0.8)GWh\,(60\ \$/\ MWh)\qquad = \ \$\ 90,000$$

$$demand: (.15\,MW)(7000\ \$/(MWh-mo))12mo = \$\ 12,600$$

$$total\qquad :90,000+12,600\ =\ \$\,102,600$$

- The *IRR* is the value of d' that results in

EXAMPLE: *IRR* FOR *HVAC* RETROFIT WITH INFLATION

$$0 = -500,000 + 102,600 \frac{1-\left(\beta'\right)^{15}}{d'}$$

- The table look up produces the d' of 19 % and

  with inflation factored in, we have

$$\left(1+d\right) = \left(1+j\right)\left(1+d'\right)$$

$$= \left(1.05\right)\left(1.19\right)$$

$$= 1.25$$

resulting in a combined *IRR* of 25 %

ANNUALIZED INVESTMENT

- A capital investment, such as a renewable energy project, requires funds, either borrowed from a bank, or obtained from investors, or taken from the owner's own accounts
- Conceptually, we may view the investment as a loan that converts the investment costs into a series of equal annual payments to pay back the loan with the interest

ANNUALIZED INVESTMENT

- For this purpose, we use a uniform cash – flow set and use the relation

$$P = A \underbrace{\frac{1-\beta^{n}}{d}}$$

present worth → P

equal payment term → A

equal payment series present worth factor → $\frac{1-\beta^{n}}{d}$

ANNUALIZED INVESTMENT

- Therefore, the equal payment is given by

$$A = P \left(\frac{d}{1 - \beta^{n}} \right)$$

← capital recovery factor

- The capital recovery factor measures the speed with which the initial investment is repaid

EXAMPLE: EFFICIENT AIR CONDITIONER

- An efficiency upgrade of an air conditioner incurs a $ 1,000 investment and results in savings of $ 200 *per year*
- The $ 1,000 is obtained as a 10 – *year* loan repaid at 7 % interest
- The repayment on the loan is done as a uniform cash flow

$$A = 1{,}000 \frac{0.07}{1 - \beta^{10}} = \$\, 142.38$$

EXAMPLE: EFFICIENT AIR CONDITIONER

- The annual net savings are

$$200 - 142.38 = \$\,57.62$$

and not only are the savings sufficient to pay back the loan in 10 *years*, they also provide a yearly surplus of $ 57.62

- The *benefits/costs ratio* is

$$\frac{200}{142.38} = 1.4$$

EXAMPLE: PV SYSTEM

- We consider a $3 - kW\ PV$ system whose capacity factor $\kappa = 0.25$
- The investment incurred $\$10{,}000$ and the funds are obtained as a $20 -$ year $6\ \%$ loan
- The annual loan repayments are

$$A = 10{,}000\ \frac{0.06}{1 - \beta^{20}} = 10{,}000\left(0.0872\right) = \$\ 872$$

EXAMPLE: PV SYSTEM

- The annual energy generated is

$$\left(3\right)\left(0.25\right)\left(8,760\right) = 6,570 \ kWh$$

- We can compute the unit costs of electricity for break-even operation to be

$$\frac{872}{6,570} = 0.133 \ \$ / kWh$$

LEVELIZED BUS – BAR COSTS

- The comparison of various alternatives must be carried out on a consistent basis taking into account
  - inflation impacts
  - fixed investment costs
  - variable costs
- The customary approach for cost valuation consists of the following steps:

LEVELIZED BUS – BAR COSTS

- present worthing of all the cash – flow
- determining the equal amount of an *equivalent* annual uniform cash – flow set
- determination of the yearly total generation

- The ratio of the equal amount to the total generation is called the *levelized bus – bar* costs of power

EXAMPLE: MICROTURBINE ENGINE

- We consider the economics of a microturbine with the characteristics given in the table
- We calculate
  - annualized fixed costs
  - initial year variable costs
  - inflation impacts

EXAMPLE: MICROTURBINE ENGINE

characteristic	*value*	*units*
investment costs	850	*$ / kW*
heart rate	12,500	*Btu / KWh*
capacity factor	0.7	—
fuel costs (year 0)	4.00×10^{-6}	*$ / Btu*
annual fuel escalation rate	6	*%*
variable O&M costs	0.002	*$ / kWh*
annual investor discount rate	10	*%*
fixed charge rate	12	*%*
life time	20	*y*

EXAMPLE: MICROTURBINE ENGINE

- The annualized fixed costs are

$$\frac{(850\ \$/kW)(12\ \%)}{(8760\ h)(0.70)} = 0.0166 \quad \$/kWh$$

- The initial year variable costs are

$$A_0 = (12.500\ \ Btu/kWh)(4\times 10^{-6}\ \ \$/Btu) + 0.002\ \ \$/kWh$$
$$= 0.052\ \ \$/kWh$$

- We next account for inflation and we compute

$$d' = \frac{d - j}{1 + j} = \frac{0.1 - 0.06}{1 + 0.06} = 0.037736$$

EXAMPLE: MICROTURBINE ENGINE

- The constant uniform cash – flow set with fuel escalation incorporated is

$$A_0 \cdot \frac{1-(\beta')^{20}}{d'} = 0.052\left(\frac{1-\left(\frac{1}{1.037736}\right)^{20}}{0.0037736}\right)$$

and the levelized annual costs are

EXAMPLE: MICROTURBINE ENGINE

$$0.052\left(\frac{1-\left(\dfrac{1}{1.037736}\right)^{20}}{0.0037736}\right)\left(\frac{0.10}{1-\left(\dfrac{1}{1.1}\right)^{20}}\right)= 0.0847\ \$/kWh$$

- The levelized bus – bar costs are, therefore,

$$0.0166\ +\ 0.0847\ =\ 0.1013\ \$/kWh$$

