

MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
Department of Nuclear Engineering

---

**22.812 Nuclear Energy Economics and Policy Analysis (S '04)**

**Lecture #4: Treatment of Inflation**

**1. Introduction**

In the discussion so far we have only paid glancing attention to inflation. We have, of course, paid much more attention to the fact that the 'worth' of any given cash flow depends on when it occurs in time, but that phenomenon has nothing to do with inflation. Rather, it is a consequence of the simple fact that in a modern economy funds need not ever be idle but rather can be put to productive use.

But especially when we are considering investment projects with long lifetimes we must also pay attention to inflation, the upward price movement of goods and services in an economy, or, equivalently, the erosion of the purchasing power of money over time.

At different times and in different societies inflation may be either very high or very low. There have also been occasions when it has been negative, i.e., when the purchasing value of money has actually increased with time. (This may be true in Japan at present.) But it is almost never absent. So we must develop ways of dealing with it in our investment analyses.

The current and expected future rate of inflation is one of the most important issues addressed by government economic policies. The reason is that a high rate of inflation disrupts economic activity in a variety of ways. One negative effect is to reduce private incentives to save. In the United States, during the 1970s, inflation approached 10% per year. This caused significant economic and political dislocations and instability, and "inflation aversion" is a strong influence on U.S. macroeconomic policy to this day, even though the rate of inflation has been much lower for more than a decade.

In some countries, at certain times, the rate of inflation has been far higher. The most infamous case, perhaps, is that of Germany during the 1920s, when inflation for a time exceeded 60 percent per week! "Hyperinflation" of this magnitude is not common, but when it does occur its consequences are almost always devastating. It is generally believed that the hyperinflation in Germany was a major factor leading to the rise of the Nazi party.

## **2. Measuring Inflation**

The government publishes several measures of the rate of inflation in the economy.

- a) Consumer Price Index (CPI) – a composite index that measures the average price change experienced by consumers in their day-to-day living expenses, i.e., in the prices paid for food, shelter, medical care, transportation, apparel, and other selected goods and services used by individuals and families.
- b) Producer Price Index (PPI) – another composite measure of average changes over time in the selling prices received by producers of goods and services. (In general, sellers' prices and purchasers' prices may differ because of the effect of government subsidies, sales taxes, and distribution costs.)
- c) Price indexes for particular commodities, goods, etc. (see <http://data.bls.gov/cgi-bin/surveymost?ap>)
- d) GDP Deflator – measures the combined inflation experience of governments, business and individuals

These indices are calculated monthly by the Bureau of Labor Statistics of the U.S. Department of Labor (see <http://www.bls.gov/bls/inflation.htm>)

(For more information on the CPI, see: <http://www.bls.gov/cpi/cpifaq.htm>.)

PPIs and CPI are used for a variety of purposes, e.g., as a basis for escalating purchase and sales contracts. (E.g., a 10-year electric power sales contract may be specified such that the price is linked to the escalation rate for natural gas – the general fuel price risk is borne by the purchaser in this case.)

We have to take account of inflation both with reference to cash flows themselves, and also with reference to the interest rate.

## **3. Inflation and Interest Rates**

The 'market' or 'nominal' interest rate -- the interest rate (or, more accurately, the many different interest rates) quoted each morning in the newspaper -- makes allowance for the change in the purchasing power of money. If inflation is high, interest rates will adjust upwards in an attempt to preserve the value of investments.

Let's say I make a loan of \$1000 dollars today to a project with a lifetime of 1 year. At the end of the year, I would like to recover my original loan, together with a reasonable

sum that reflects payment for the service I have provided in making the capital available -- i.e., interest -- and let's say that the prevailing rate of interest is 5%/year.

Now if there is no inflation, I will be happy if, at the end of the year, I get back the \$1000, along with a \$50 interest payment.

But suppose there is inflation of 50%/year. Then if I am to preserve the purchasing power of my original investment, I will want to recover not \$1000 but rather \$1500 at the end of the year, along with my interest payment.

In this case, the effective rate of interest that I will seek on my loan is about 55%.

In general, the 'market' or 'nominal' interest rate is pegged at a few percentage points above the prevailing rate of inflation in the economy. (If inflation increases, interest rates will adjust upwards to preserve the earning power of money.)

Historically, over the long sweep of history the rate on premium bonds -- the lowest risk variety -- has been 2.5-3.0% above the prevailing level of inflation.

Note, though, that at any given moment, the differential may be more or less than this historical average. The magnitude of the differential reflects not only the current rate of inflation in the economy, but the market's expectations about what will happen to inflation over the life of the bond.

[For example, last Friday the yield for 30-year T-Bonds was 4.937%%, and for a 10-year Treasury note was 4.052%. The U.S. inflation rate (as measured by CPI) was 1.9% in 2002.]

#### **4. Treatment of Inflation in Investment Analysis**

We have two basic approaches for dealing with inflation in our engineering economy studies:

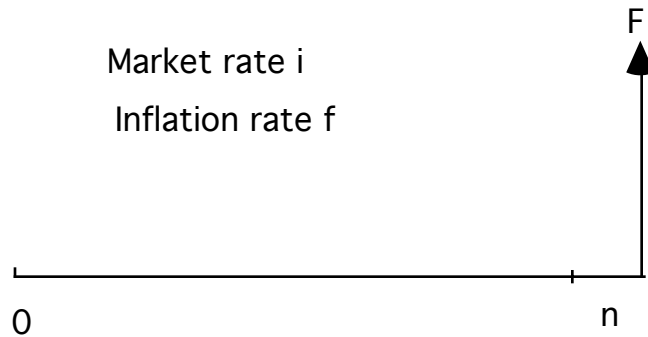
1. Estimate cash flows in "actual" (also referred to as 'nominal' or 'current') dollars, and use 'market' ( or 'nominal') interest rates.
2. Estimate cash flows in terms of the purchasing power of the dollars of some base year (usually the year in which the investment is made) -- i.e., in constant dollars -- and use a constant dollar, or real interest rate, which represents the true earning power of money.

Q: What is the real interest rate that corresponds to a given market interest rate?

Let the market interest rate be  $i$

Let the real interest rate be  $i'$

Consider a 'current dollar' cash flow of  $F$  occurring at the end of  $n$  years (i.e., expressed in dollars of year  $n$ )



We can also express the cash flow occurring at that time in terms of the dollars of today, i.e., in constant dollars. Let's call this  $F'$

Then, if the inflation rate is  $f/\text{yr}$ , we must have that

$$F = F'[(1 + f)^n]$$

NOTE: This is not a statement of value equivalence in the sense we have discussed previously. We are not saying that the present worth of  $F$  today is  $F'$ . We are saying that if there was no inflation,  $F'$  is what we would need to spend at time  $n$  in order to purchase what in the presence of inflation will cost  $F$  at time  $n$ .

Now to find  $i'$ , the real interest rate corresponding to the market or nominal rate  $i$ , we must have that

$$\begin{aligned}
 F(1+i)^n &= F(1+i)^n \\
 &= F(1+f)^n(1+i)^n
 \end{aligned}$$

So

$$i = i + f + i$$

or,

$$i = \frac{i + f}{1 + f}$$

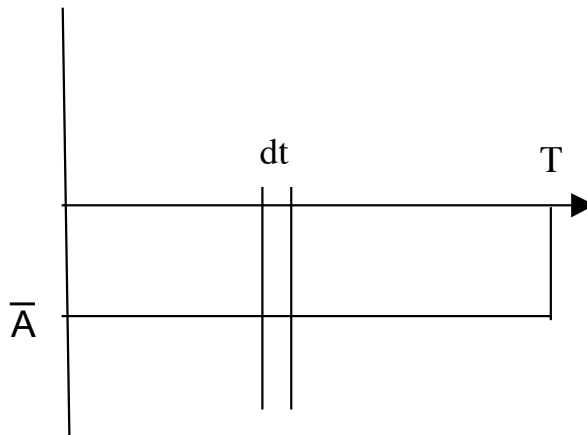
We next use these ideas to estimate the construction cost of a power plant.

### **5. Calculation of plant capital cost including escalation and interest during construction.**

a) Constant rate of construction expenditures during project (in constant dollars)

a.1) No inflation

Here we assume a uniform annual rate of expenditure,  $\bar{A}$ , (in \$/yr), and a construction period of T yrs.



We define the 'overnight cost',  $I_{on}$ , as

$$I_{on} = \bar{A}T$$

We want to calculate the 'future worth of the project',  $F$ , at the end of the construction period (i.e., at plant startup). This is the equivalent value at time  $T$  of all construction outlays over the life of the project. We find this by summing the future worths of each 'slice' of expenditure  $\bar{A}dt$ :

$$\begin{aligned} F &= \int_0^T \bar{A}e^{x(T-t)} dt \\ &= (\bar{A}T)e^{xT} \frac{e^{-xT} - 1}{-x} \\ &= I_{ON} \frac{e^{xT} - 1}{xT} \\ &\approx I_{ON} \left( 1 + \frac{xT}{2} \right) \end{aligned}$$

where  $x$  is the interest rate, and the approximate expression is valid for  $xT \ll 1$

Note: The future worth of the project,  $F$ , is the value of the project at time  $T$ . What does this mean? Suppose the construction project was financed by a line of credit from a bank (i.e., a continuously available loan) offered at an interest rate  $x$  per year. Then  $F$  is the amount of money that would have to be repaid to the bank at time  $T$  to retire completely the line of credit. Another way to think about  $F$  is that it is the amount of money that would have to be paid to the plant builder to cover all of his costs of construction, i.e., both direct expenditures and financing costs.

This result shows that the future worth of the plant increases with the interest rate,  $x$ . For a given value of the overnight cost  $I_{ON}$ , the future worth also increases with the construction period,  $T$ .

## a.2) Construction with inflation

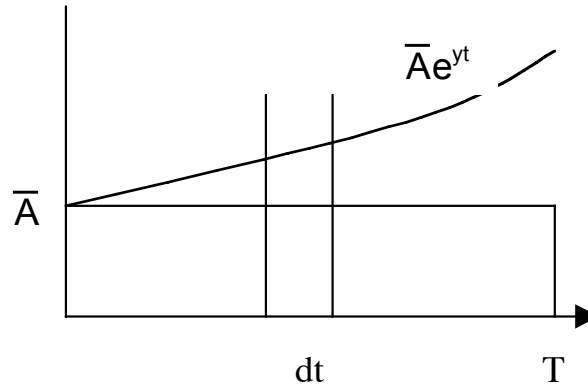
Again we assume a uniform annual rate of expenditure  $\bar{A}$ , (in \$/yr), expressed in dollars of time 0. But in this case we further assume that construction costs escalate at a rate  $y$ /yr over the construction period  $T$ .

Let the nominal interest rate be  $x$ /yr.

We again define the 'overnight cost',  $I_{on}$ , as

$$I_{on} = \bar{A}T$$

where the overnight cost is expressed in the dollars of time  $t=0$ .



(Note we have reversed the direction of cash flows in this cash flow diagram.)

We again want to calculate the future worth of the plant,  $F$ , at time  $T$  (i.e., plant startup):

$$\begin{aligned} F &= \int_0^T \bar{A} e^{yt} e^{x(T-t)} dt \\ &= (\bar{A}T) e^{xT} \frac{e^{yT} e^{-yxT} - 1}{(x-y)T} = (\bar{A}T) \frac{e^{xT} - e^{yT}}{(x-y)T} \end{aligned}$$

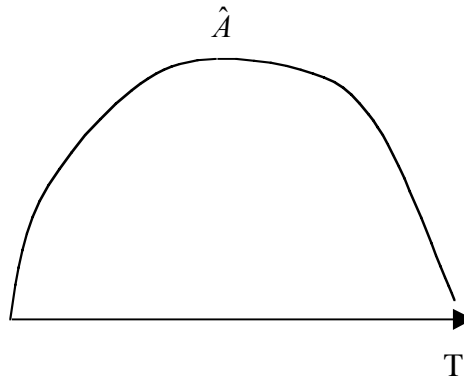
and a first order series expansion gives

$$\begin{aligned} F &= (\bar{A}T) \left[ 1 + xT \right] \frac{(x-y)T}{2} \\ &= (\bar{A}T) + \frac{x+y}{2} T I_{on} + \frac{x-y}{2} T^2 \end{aligned}$$

b) Constant dollar expenditure profile is a sine wave

In this case we assume a constant dollar rate of expenditure  $A(t)$  given by:

$$A(t) = \hat{A} \sin \frac{\pi t}{T}$$



In this case, the overnight cost,  $I_{on}$ , is given by

$$I_{on} = \hat{A} \int_0^T \sin \frac{\pi t}{T} dt = \hat{A} T \frac{2}{\pi}$$

If we again assume an inflation rate of  $y$ /yr, the rate of expenditure in current dollars (i.e., including escalation) is:

$$A(t) = A(t)e^{yt}$$

And the future worth,  $F$ , of the plant at the time of construction completion (i.e., startup),  $T$  is given by:



$$\begin{aligned}
 F &= \int_0^T \hat{A} \sin\left(\frac{t}{T}\right) e^{yt} e^{x(T-t)} dt \\
 &= e^{xT} \hat{A} \int_0^T \sin\left(\frac{t}{T}\right) e^{(y-x)t} dt \\
 &= e^{xT} \hat{A} \frac{e^{(y-x)t} \left( (y-x) \sin\left(\frac{t}{T}\right) - \frac{1}{T} \cos\left(\frac{t}{T}\right) \right)}{(y-x)^2 + \left(\frac{1}{T}\right)^2} \Bigg|_0^T \\
 &= e^{xT} \hat{A} \frac{e^{(y-x)T} \left( \frac{1}{T} \right) + \frac{1}{T}}{(y-x)^2 + \left(\frac{1}{T}\right)^2}
 \end{aligned}$$

and since the overnight cost,  $I_{on}$ , is given by

$$I_{on} = \hat{A} T^2$$

we have that

$$F = I_{on} \frac{e^{yT} + e^{xT}}{2} + \frac{(x-y)^2}{\left(\frac{1}{T}\right)^2}$$

and since, for small values of T (i.e.,  $T \sim 0$ )

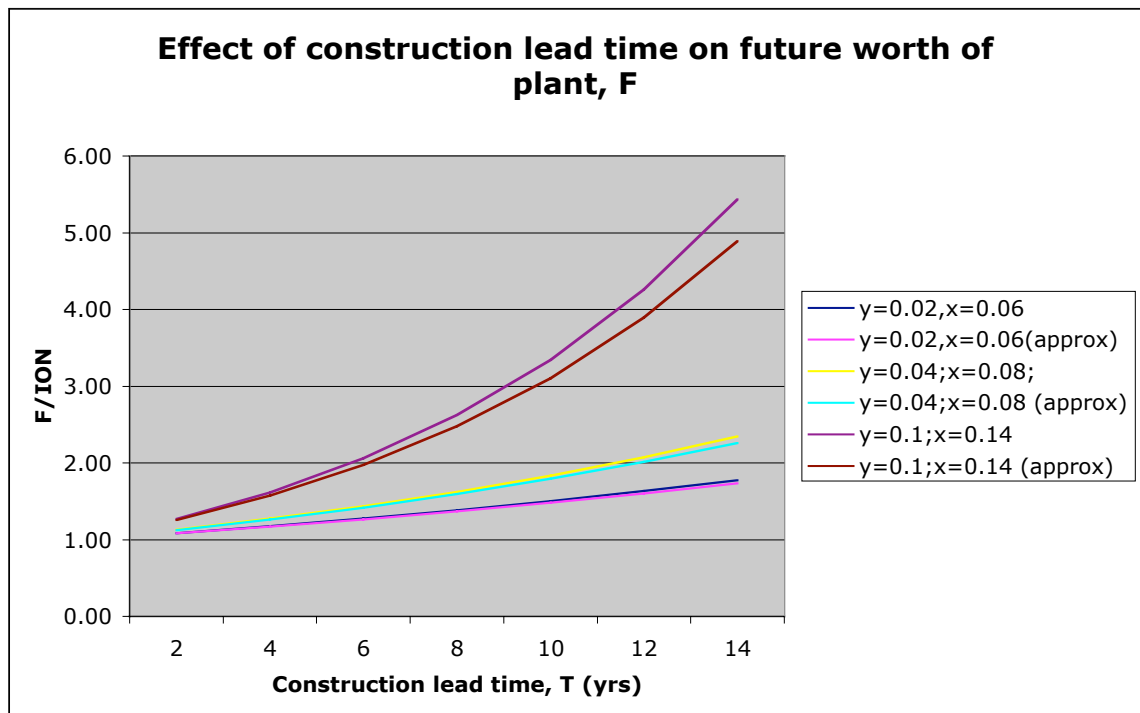
$$\frac{(x - y)^2}{\left(\frac{\Delta}{T}\right)^2} \ll 1, \text{ and } e^{yT} \approx 1 + yT \text{ and } e^{xT} \approx 1 + xT$$

we have

$$F \approx I_{on} + \frac{x + y}{2} T$$

Again, note that the 'Overnight Cost',  $I_{on}$ , is expressed in dollars in the year of the start of construction.

Both expressions show that the longer the construction time the higher the future worth of the plant at the time of startup. Moreover, the effect of construction stretchout will be exacerbated during periods of high interest and inflation rates (see figure below – uniform constant dollar expenditure profile assumed.)



## 6. Interpretation of Capital Cost Measures

$I_{on}$ : The 'overnight cost' of the project, expressed in dollars of the year of construction start. This is what the plant would cost if there were no inflation and no interest charges on capital, i.e., if the plant were built 'overnight'. It consists of the direct costs of labor, materials, equipment, engineering and design, etc.

F: The future worth of the project at the construction completion date. This is the amount of money that, if paid to the constructor at the completion of the project, would be just sufficient to cover all costs incurred during construction, i.e., both the direct costs and the interest accruing on funds borrowed (or equity invested) during construction. In the days when power plants were constructed by regulated electric utilities, this was also often referred to as the ratebase cost.

$F-I_{on}$ : The 'time-related' costs of the project.

As the previous graph shows, during periods of high inflation (and high interest rates) the time-related costs may account for a large portion of the final cost of the project, especially when the construction lead time is long. These were in fact the conditions during the 1970s, when many of today's nuclear plants were built.

## 7. Alternative Ways of Reporting Capital Costs

As the above discussion indicates, there are several different ways to report construction costs, and depending on which measure is used, you can get quite different results.

Example:

Consider the example of a project begun in year 1990. Suppose the construction time was 10 years, and the annual rate of expenditure on the direct costs of the project was \$50 million per year, in 1990 dollars. Suppose also that the rate of inflation during the 1990s was 10%/yr (in reality, it was much lower in the U.S.), and that the nominal interest rate during this period was 12%/yr (continuously compounded.)

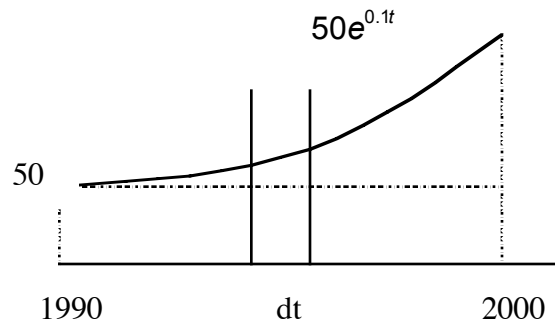
Thus we have:

$$\bar{A} = 50 \times 10^6 \text{ (\$/yr)}$$

$$y = 0.1/\text{yr}$$

$$x = 0.12/\text{yr}$$

$$T = 10\text{yrs}$$



Then we have the following ways to report the cost of the project:

1. Overnight cost in 1990\$,  $I_{on} = 50 \times 10^6 \times 10 = \$500M$
2. Overnight cost expressed in 2000 \$,  $= 500 \times 10^6 \times e^{0.1 \cdot 10} = \$1296M$

(NOTE: This is not the future worth of the project in the year 2000. Nor, unless there was no change in the construction environment, would it be the cost of building the plant 'overnight' in the year 2000. It is the cost of building the plant 'overnight' in 1990, expressed in year 2000 dollars.)

3. 'Direct cost' in current dollars:

$$\begin{aligned}
 &= \int_0^{10} 50e^{0.1t} dt \\
 &= 50 \frac{e^{0.1t}}{0.1} \Big|_0^{10} \\
 &= \$855M
 \end{aligned}$$

4. Future worth of project in 2000

$$\text{future worth in 2000 of expenditure in } dt = (50e^{yt} dt)e^{x(T-t)}$$

future worth of project in 2000, F, is

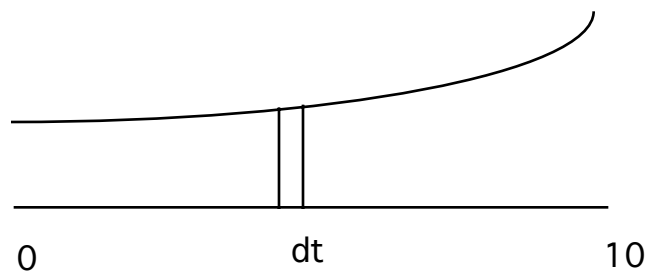
$$\begin{aligned}
 F &= \int_0^{10} 50e^{yt} e^{x(10-t)} dt \\
 &= \frac{50}{x-y} [e^{10x} - e^{10y}] \\
 &= \$1504M
 \end{aligned}$$

5. Estimation of future worth of project in 2000, using approximation derived above:

$$\begin{aligned}
 F &\approx I_0 n \left[ 1 + \frac{x+y}{2} \right]^T \\
 &= 500 \cdot 1.11^{10} \\
 &= \$1420M
 \end{aligned}$$

6. 'Mixed current dollar cost'

This is the total amount of money actually spent on direct costs (i.e., labor, materials, etc.), expressed in current dollars + the accrued interest on accumulated expenditures (assuming interest is paid continuously)



Total spent in  $dt$  = direct cost + interest on accumulated expenditures through  $t$

$$\begin{aligned}
 &= 50e^{yt} dt + \int_0^t 50e^{y(t-x)} e^{-x(t-x)} dx dt \\
 &= 50e^{yt} dt + \frac{50x}{y-x} [e^{yt} - e^{xt}] dt \\
 &= 50 \frac{y}{y-x} e^{yt} dt - 50 \frac{x}{y-x} e^{xt} dt \\
 &= \frac{50}{y-x} [ye^{yt} - xe^{xt}] dt
 \end{aligned}$$

$$\text{Total expenditure during project} = \int_0^{10} \frac{50}{y-x} [ye^{yt} - xe^{xt}] dt$$

{This is described as the 'mixed current dollar cost': mixed dollars, because it includes accrued interest as well as direct costs, and current dollars because we are adding dollars of different purchasing value}

Total expenditure during project

$$\begin{aligned}
 &= \frac{50}{x-y} [e^{xT} - e^{yT}] \\
 &= \$1504M
 \end{aligned}$$

NOTE: This is identical to the future worth of the project in year 2000.

We can obtain from this an interpretation of the meaning of the future worth of the project at T. It is equal to the 'mixed current dollar cost' of the project, or the sum of direct expenditures in current dollars and interest payments on accumulated expenditures during the construction period.