Problem Set 3 Solutions

1. Nuclear power plant construction lead-times have ranged from less than 4 years (for some units in France) to 15 years or more (for the most delayed units in the United States).
   a. Compare the 'ratebase cost' i.e., the future worth of the project at the start of commercial operation) for two identical units which started construction in 1978, one with a lead time of 4 years and the other with a lead time of 15 years. Assume that the overnight cost in 1978 dollars was the same for both plants, and that in each case the rate of expenditure in constant dollars was constant throughout the construction period. Also assume an interest rate of 11% per year and an escalation rate for nuclear construction of 15% per year during the period in question. In your calculation, use the approximate expression for the future worth of the project at the date of startup that was presented in class.

We will start with a comparative cash flow diagram:
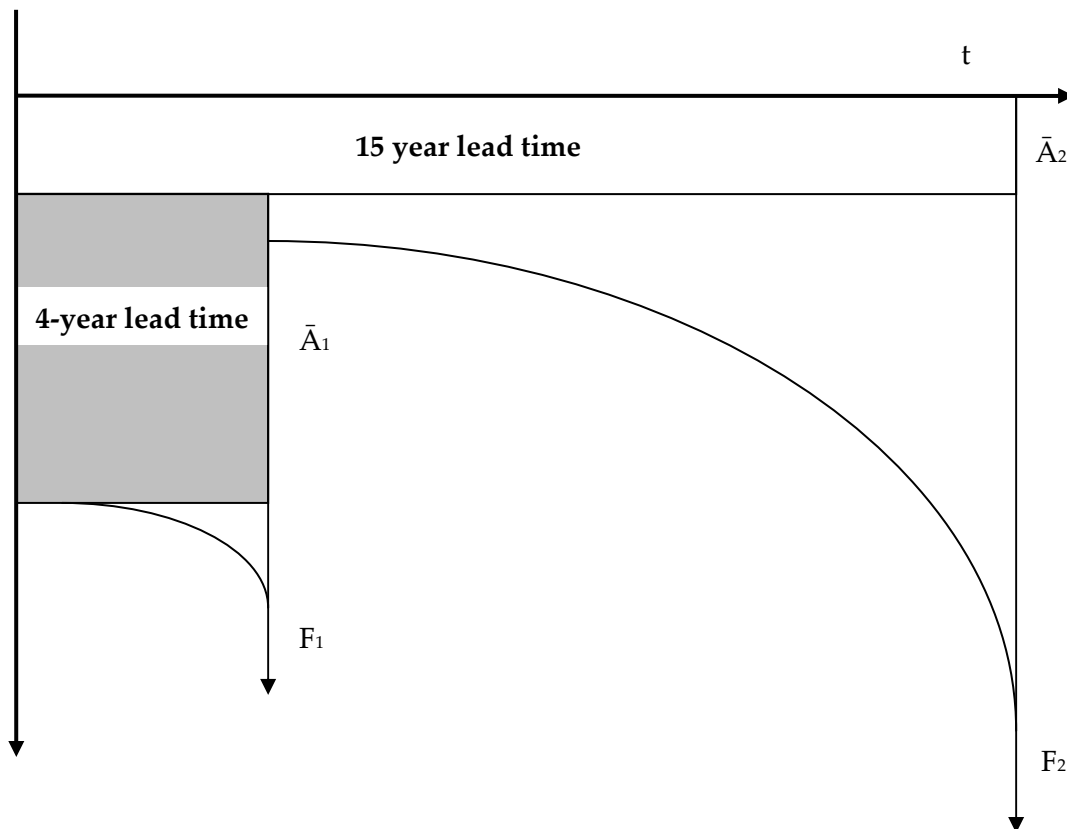
Given the overnight cost I_{ON}, the interest rate x, and the escalation rate y, the approximate expression given for the future worth of a plant is:

$$F \sim I_{ON}\left(1 + \frac{x+y}{2}T\right)$$

$$F_1 \propto \left(1 + \frac{0.11+0.15}{2}4\right) = 1.52$$

$$F_2 \propto \left(1 + \frac{0.11+0.15}{2}15\right) = 2.95$$

$$\frac{F_2}{F_1} = 1.536$$

The comparison illustrates that a 15-year lead time will result in a ratebase cost that is 1.54 times more than that of a 4-year lead time.

> b. Repeat the problem in (a) using an exact expression for the future worth. What do you conclude regarding the validity of the approximation you used in part a?

The exact expression given for the future worth of a plant is:

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

The two future worths are compared as

$$\frac{F_2}{F_1} = \frac{\left(\dfrac{e^{xT_2} - e^{yT_2}}{(x-y)T_2}\right)}{\left(\dfrac{e^{xT_1} - e^{yT_1}}{(x-y)T_1}\right)} = \left(\frac{e^{xT_2} - e^{yT_2}}{e^{xT_1} - e^{yT_1}}\right)\left(\frac{T_1}{T_2}\right)$$

Substitution of x=0.11 and y=0.15, with T_1=4, and T_2=15, we get 4.24. With the exact solution, we can expect the 15-yr plant to cost 4.24 times as much as the 4-yr plant when comparing the ratebase costs.

Therefore, we conclude that the approximate expression is not valid in this case, due to the very long lead time of the second plant. The approximate expression is correct to within 10% for the short lead time plant. This is because the Taylor series approximation for the exponential is only correct when the exponent is relatively small, and this will not be the case for long lead times.

2. Construction work on a new coal-fired plant began on January 1, 2002. Construction is expected to take 4 years. The construction budget (specified in constant 1996 dollars) calls for an initial rate of expenditure of $80M/yr, increasing continuously and in linear fashion to $160M/yr by the end of the construction period. Assume an escalation rate for coal plant capital costs of 4%/year, and a cost of funds of 7%/year, continuously compounded. Calculate the following:

   a. The overnight cost of the plant in 2002 dollars

   First, we must compute the overnight cost of the plant in 1996 dollars. We are working under an assumption that the construction budget contains only the direct cost, and not the financing costs.

   $$A_{1996}(t) = \frac{\$160M - \$80M}{4\,yr}(t) + \$80M = 80 + 20t$$

   $$I_{ON,\,1996} = \int_0^4 A_{1996}(t)\,dt$$

   $$I_{ON,\,1996} = \int_0^4 80 + 20t\,dt$$

   $$= \$480M$$

   Next, we must escalate the cost to 2002 dollars using the given escalation rate of 4%:

   $$I_{ON,2002} = I_{ON,1996}e^{yt}$$
   $$= \$480M\left(e^{0.04\times6}\right)$$
   $$= \$610.2M$$

   b. The overnight cost of the plant in year 2006 dollars

   $$I_{ON,2006} = I_{ON,1996}e^{yt}$$
   $$= \$480M\left(e^{0.04\times10}\right)$$
   $$= \$716.1M$$

   c. Total direct construction expenditures in current dollars

   Current dollars is the same as actual dollars. Therefore, we must include the escalation rate as we integrate through the payments towards

construction. However, we must not include the cost associated with financing.

$$TDE = \int_0^T A_{1996}(t)\left(e^{y(2002-1996)}\right)e^{yt}dt$$

$$TDE = \int_0^4 (80+20t)e^{0.04(6+t)}dt$$

$$TDE = \$667.6M$$

d. The value of the plant at start of operation

For this calculation, we take the direct expenditure in 1996 dollars and escalate the amount to 2002 dollars. Secondly, we adjust for the escalation during the project, and lastly, we include the costs associated with the interest rate. The integral over the life of the project is the future value of the plant.

$$F_V = \int_0^T A_{1996}(t)\left[e^{y(2002-1996)}\right]\left[e^{yt}\right]\left[e^{x(T-t)}\right]dt$$

$$F_V = \int_0^4 (80+20t)e^{0.04(6+t)}e^{0.07(4-t)}dt$$

$$F_V = \$755.7M$$

e. The 'ratebase' cost (assuming the plant is to be built under traditional economic regulatory conditions)

By definition, the ratebase cost is the same as the future value calculated in part d.

$$RBC = F_V$$

f. The time-related costs of the project

$$TRC = F_V - I_{ON}$$
$$TRC = \$145.5M$$

3. Suppose that the actual escalation rate for the project in Question 2 turned out to be 7% per year, and that the cost of funds was 10% per year. Suppose also that the project budget consistently underestimated actual expenditures by 10%. Find new answers for parts a through f in Question 2 under these conditions. Also, in this case, what fraction of the project cost increase relative to the original budget estimate would you attribute to changes in the macroeconomic environment for the project (i.e., in escalation and interest rates) – changes that presumably could not have been controlled by the construction project team?

a. The overnight cost of the plant in 2002 dollars

First, we must compute the overnight cost of the plant in 1996 dollars. We are working under an assumption that the construction budget contains only the direct cost, and not the financing costs.

$$A_{1996}(t) = (1.10)(80 + 20t)$$

$$I_{ON,\ 1996} = \int_{0}^{4} A_{1996}(t)dt$$

$$I_{ON,\ 1996} = 1.10\int_{0}^{4} 80 + 20tdt$$

$$= \$528M$$

Next, we must escalate the cost to 2002 dollars using the given escalation rate of 7%:

$$I_{ON,2002} = I_{ON,1996}e^{yt}$$
$$= \$528Me^{0.07\times6}$$
$$= \$803.6M$$

b. The overnight cost of the plant in year 2006 dollars

$$I_{ON,2006} = I_{ON,1996}e^{yt}$$
$$= \$528Me^{0.07\times10}$$
$$= \$1063.3M$$

c. Total direct construction expenditures in current dollars

$$TDE = \int_{0}^{4} 1.10(80 + 20t)e^{0.07(6+t)}dt$$
$$TDE = \$941.7M$$

d. The value of the plant at start of operation

$$F_V = \int_0^4 1.10(80 + 20t)e^{0.07(6+t)}e^{0.10(4-t)}dt$$
$$F_V = \$1122.2M$$

e. The 'ratebase' cost (assuming the plant is to be built under traditional economic regulatory conditions)

$$RBC = F_V$$

f. The time-related costs of the project

$$TRC = F_V - I_{ON}$$
$$TRC = \$318.6M$$

We can now take the cost figures from problem 2 and problem 3 and see what impact the macroeconomic environment has on the costs associated with plant construction. There are three costs computed in each problem, the overnight, the ratebase, and the time-related. The ratebase cost is merely the sum of the overnight and time-related.

The macroeconomic changes manifest themselves in the escalation and interest rates. The construction team is responsible for the 10% cost overruns that were incurred during the project. If we are to compare purely what the effect of the macroeconomics is on the cost of the project, we cannot compare the results from problem 2 and problem 3 directly.

Comparison of macroeconomic (escalation and interest) vs. budget-related increases in cost:

First, consider the difference in costs from Case 2 (on-budget, economics as forecast) and Case 3 (10% budget overrun, and higher escalation and interest rates):

	Case 2	Case 3	Difference
Overnight	610.2	803.6	193.4
Ratebase	755.7	1122.2	366.5
Time-Related	145.5	318.6	173.1

In order to find the portion of that increase resulting from the budget underestimation, we consider Case 2*, which contains a 10% budget correction, under the forecast economic conditions. This means we multiply all values of Case 2 by 1.10:

	Case 2	Case 2*	Budget Difference
Overnight	610.2	671.22	61.02
Ratebase	755.7	831.27	75.57
Time-Related	145.5	160.05	14.55

Finally, we compare differences. We know the total difference and the budget contributor to the total difference. Thus, we conclude that the remaining portion of the total difference is attributable to the macroeconomic environment:

Difference:	Total Cost Difference	A*-A	M.E. Difference	Overrun Percentage	Economic Percentage
Overnight	193.4	61.02	132.38	31.5%	68.5%
Ratebase	366.5	75.57	290.93	20.6%	79.4%
Time-Related	173.1	14.55	158.55	8.4%	91.6%

Thus, we conclude that 79.4% of the ratebase cost is attributable to macroeconomic conditions, whereas 20.6 of the cost is attributable to the budget underestimation.

4. In class we discussed the overnight construction costs in 1982 dollars for 75 U.S. nuclear power plants estimated by the Energy Information Administration based on the mixed current dollar construction costs reported by plant owners. Compare this cost range with the predicted overnight construction costs in the DOE 2010 Roadmap Study (also discussed in class).

Using the table given in the lecture slides (17,18), we compute the minimum, maximum, and mean of the given group of plant overnight costs in 2000$ and 2001$. The values are adjusted for inflation using a continuous inflation model adapted from the given CPI – All Price data in lecture slide 5 as shown below.

$$I_{ON,2000} = I_{ON,1982} \prod_{i=1982}^{1999} e^{f_i} = I_{ON,1982} \exp\left\{ \sum_{i=1982}^{1999} f_i \right\}$$

The following table summarizes calculations of the overnight capital costs of a nuclear plant based on industry experience.

	Industry Experience	
Overnight Cost	2000$/kWe	2001$/kWe
Minimum	$730.84	$756.13
Maximum	$7,035.10	$7,278.56
Average	$2,674.73	$2,767.29

First, adjusting the cost to 2000$ and 2001$ was carried out using the average inflation rate for all goods and services in the economy, however, we know that the escalation rate for direct costs for a nuclear plant tend to be higher than the average inflation rate, therefore, these overnight costs as predicted by industry experience are probably underestimated.

We can compare the overnight costs according to industry experience with the overnight costs suggested by the DOE 2010 Roadmap study, which are shown in the following table.

	DOE 2010 Roadmap
Overnight Cost	2000$/kWe
Minimum	$1,000.00
Maximum	$1,600.00

As one can see from the industry experience in building power plants, the DOE study's suggestion is very optimistic. The EIA is similarly optimistic, although somewhat more realistic.

	EIA Estimate
Overnight Cost	2001$/kWe
Advanced	$1,535.00
Reference	$2,044.00

From the bar graph shown in lecture slide 16, one can see that the average overnight cost is not the best metric for predicting the overnight costs of nuclear plants today; the graph indicates that the capital costs of more advanced nuclear plants are higher than those built earlier. If we look at only those plants built more recently, we find that the overnight cost will be higher than the average shown in the first table. It is also important to note that predicted or estimated costs have always been dramatically lower than the actual costs.