OPTIMUM CAPACITY EXPANSION

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Part 1: OPTIMUM INCREMENT FOR CAPACITY EXPANSION – BASE CASE

GOALS:

1. Learn about capacity expansion problem and its possible optimal solution
2. Practice in use of NPV analysis on spreadsheets

GENERAL PROBLEM DESCRIPTION:

Alan Manne (1967), in his book “Investments for capacity expansion”, presents an analysis for calculating optimal sizes of plant capacity to be added at several points in time. Under growing demand and economies of scale there will be a choice between several time streams of expenditure. For example, if a single large plant is built, advantage can be taken of economies of scale in construction, however it requires a large initial investment. If several smaller plants are built at different times, you may sacrifice some production economies but you also gain by delaying part of the capital investment and avoiding interest payments.

In general, Manne’s result is that new capacity should be added in fixed increments that depend on the intensity of the economies of scale and on the discount rate. [If there are no economies of scale, the best policy is to build “just in time” according to need. As economies of scale become more important, it is worthwhile building larger, even though that means you have to pay immediately for capacity you will only use later.] These fixed increments represent demand growth over a specific period, known as the cycle time for the addition of capacity.

To compare expenditures incurred at different dates, Manne uses the discounted cash flow criterion (present value). In this exercise you will replicate his analysis.

MODEL BRIEF DESCRIPTION:

In his analysis, Manne assumed that (1) demand grows linearly over time and (2) there are no imports in the market. Hence, demand has to be satisfied at all times by internal production. This exercise provides you with a model (Optimal Capacity Expansion base case.xls), based on the same assumptions, that displays cash flows over 100 years. An infinite time horizon could also be used.

The model uses discrete rather than continuous time analysis implied in Manne’s analytic version. Specifically, it uses an annual discount rate so adjustments are needed to compare results produced with continuously compounded discount rate. The continuously compounded discount rate (r_c) is related to the annually compounded discount rate (r_a) according to the formula:
$r_a = \exp(r_c t)$ for t = 1 year.

The model gives results in terms of years rather than in fractions of a year as Manne did.

ACTIONS:

1. Open the model and read the “read me” worksheet for model details and necessary settings on your machine.

2. Start with an initial capacity 100 units per year, 5 units/year/year demand increments, 6 years cycle time, parameter *a* = 0.7, a constant of proportionality *k* = 1 and a discount rate r = 10.5% (equivalent to 10% compounded continuously discount rate). What is the NPV?

3. To test how the NPV result changes with different input assumptions using a data table. One variable data table tests the model by changing only one variable. Use input cycle times in the range 1 to 20 years and run the model.

4. Plot the data table results in a graph of NPV versus cycle time to define optimal cycle time.

5. Repeat step 2 through 4 using demand increments of 2 and then 8 units/year/year.

6. Determine the effect of the economies of scale parameter *a* on the optimal cycle time for different discount rates. For this step you will need to use a two variable data table. Use *a* values in the range 0.4 to 0.95 and cycle times in the range 1 to 20 years. Plot a graph of optimal cycle time versus *a* for a chosen discount rate.

7. Examine the effect of time horizon on your results. Do this by changing the formula in the NPV of costs to sum only 20 years and run the model. Note the differences on the optimal cycle times on your graphs. Explain why one is below the other, why one is smooth and the other not.

DISCUSSION QUESTIONS:

1. What is the optimal cycle time for capacity addition predicted by the model with initial assumptions as stated above in step 2? Compare your result with Manne's figure 2.6, chapter 2 –found in Appendix at the end of this document.
2. What is the effect of the economies of scale parameter *a* on the optimal timing? Compare your results with figure 2.4, Manne chapter 2 – found in Appendix 1 at the end of this document.
3. What is the NPV of costs with demand increments 8 units/year/year and 2 units/year/year? Calculate the average NPV and compare this result with the result you had with demand increments of 5 units/year/year. Are these values the same? Explain this observation.
4. What is the effect of using a 20 year time horizon in your model?

TAKE AWAYS:

1. Under a given linear demand growth rate the optimum strategy is to build a plant every 7 years of size x (where x is given in terms of the growth rate). For example for growth rate = 5 units/year/year the optimum plant size is 7*5 = 35 units/year.
2. The optimal cycle time is affected by the discount rate and the economies of scale. It is smaller when:
    a. the economies of scale are smaller (since economies of scale are the factor that motivates larger chunks of capacity); and
    b. the discount rate is the higher (since a higher discount rate penalizes early investments).
3. The NPV calculated for average growth rate (e.g.5 units/year/year) is not equal to the average NPV calculated for a distribution of growth rates (8 and 2 units/year/year that when averaged equal 5 units/year/year). This is a common mistaken assumption known as the "flaw of averages". [The mistake is to assume that the value of a function obtained using an average or expected value of a quantity – such as a 5% growth rate – equals the expected value of the function resulting from using the distribution of the quantity. In short: EV [F(x)] does not equal F[EV(x)]]

APPENDIX TO PART 1: MANNE'S GRAPHS

Scanned from Alan Manne (1967) Investments for Capacity Expansion: Size, Location, and Time-Phasing, MIT Press, Cambridge, MA (USA)

The effect of discount rate and economies of scale on the optimal cycle time.

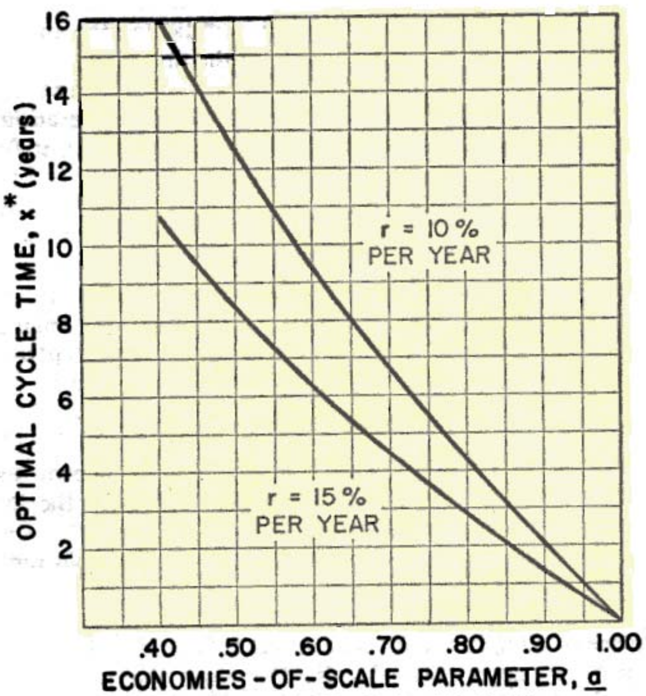


Figure 2.4.—Cross-Plot for Optimal Cycle Time

The optimal cycle time (x* = 6.75 years) with a linear demand growth

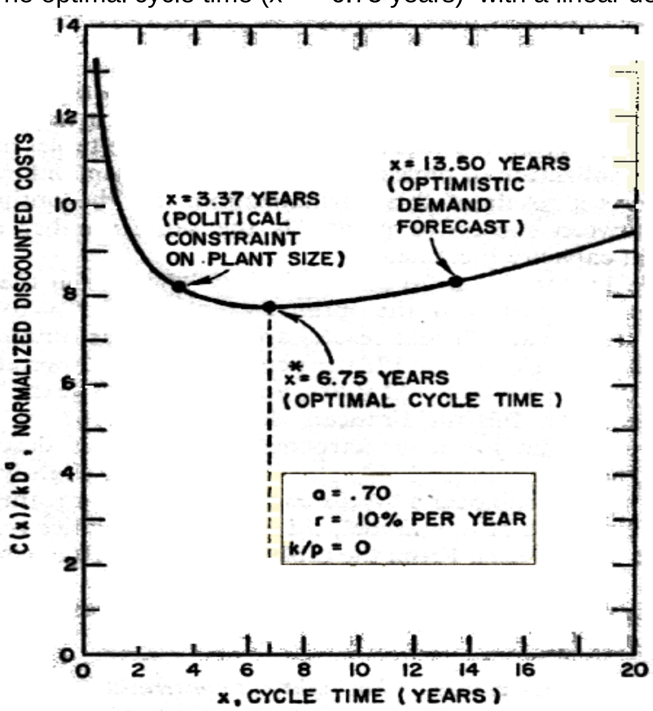


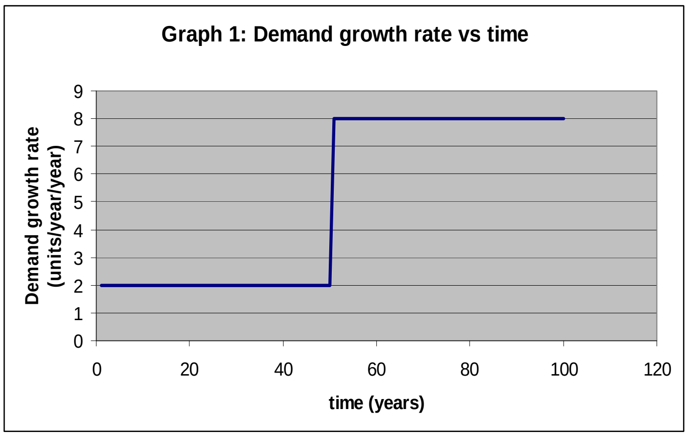
Figure 2.6.—Discounted Cost Function

Part 2: OPTIMUM CAPACITY INCREMENT -- INTRODUCING FLEXIBILITY

GOALS:
1. To introduce flexibility
2. To identify the consequences of adopting a fixed policy under changing demand

GENERAL PROBLEM DESCRIPTION:
This exercise assumes you have calculated the optimal cycle time and hence the optimal plant size under a constant linear demand growth and an exponential demand growth (Optimal increment for capacity expansion – base case and non-linear growth). In this exercise you will define optimal policy under a changing linear demand growth pattern. You are going to compare two different policies: a fixed plant size policy, and a changing one.

PROBLEM OUTLINE: You are given that the demand grows by 2 units/year/year for the first 50 years and by 8 units/year/year for the rest 50 years (see graph 1, bellow).



The average demand growth rate through the time horizon is 5 units/year/year. Hence your first policy is to use an optimal size as predicted from the base case model throughout the 100 years horizon. The second policy is to use two different plant sizes. The initial plant size will be the optimal size predicted by the base case model for the small demand growth (2 units/year/year) while the second plant size will be the optimal plant size predicted by the base case model for the high demand growth (8 units/year/year).

For this exercise you are given a new “flexible model” (Optimal Capacity Expansion –flexible.xls). In the inputs worksheet you have the same assumptions as in the base case model. In the flexible model worksheet you are given a modified base case model to allow you to enter any plant size you want at any time (this is done manually) to try different policies. Every policy that you try you have to make sure that the selected plant size is appropriate to meet the demand at any time.

Note: This means that you should check the model’s logic value to be “true” at all times. If it is not, you should adjust the addition of new capacity in line 37of the Spreadsheet.

ACTIONS:
1. In the flexible model worksheet enter the two growth rates (2 and 8) in the green cells.
All other inputs remain the same as in the base case model. According to the base case model, the optimal cycle time with linear growth is 7 years and for the average demand growth of 5 units / year /year the optimal plant size is 35 units/year. Hence enter this plant size value at the flexible model (cells: C37 to CY37) every 7 years. Run the model to find the NPV.

2. According to the base case model when demand grows by 2 units/year/year the optimal plant size is 14 units/year and when the demand grows by 8 units/year/year the optimal plant size is 56 units/year. So enter plant size 14 in cells C37 to AS37 and plant size 56 in cells AZ37 to CY37 again every 7 years. Run the model to find the new NPV.

3. Try any other growth pattern you like by changing values directly in the flexible model row 37 and compare a fixed policy based on average growth rates versus a flexible one.

DISCUSSION QUESTION:

1. What is the NPV for the fixed plant size policy and for the flexible plant size policy? What is the effect of a flexible policy?

TAKE AWAY:

1. When demand growth rate changes the flexibility to adapt to these changes and change your plant size accordingly can minimize the overall costs.