Capacity Expansion

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Capacity Expansion

Objective of Presentation:

- Show economics of capacity expansion
- Stress contrasting implications of
  - Economies of scale (expand bigger) and
  - Discount rate (expand smaller)
- Explore optimal expansion policies
  - Deterministic condition: base case
  - Uncertain condition: what implications?
- Make connection to Flexibility in Design

Thought Problems

- Capacity Expansion is a form of flexibility
- To what extent is garage case general?
  - Do expansions always require prior design? NO
  - Do later modules cost more? NO, sometimes less
- If all modules cost the same, what should our expansion policy be? Build as Needed?
- Why should we build in advance (apart from implementation time)? Economies of Scale!
- Keep these thoughts in mind…

Base case

- Given a system with known capacity
- For which we anticipate continued steady growth over indefinite future

Year	0	1	2	3	4	5	6	…	N
Demand increase	0	5	10	15	20	25	30	…	5N

- The question is:
  What size of capacity addition
  minimizes present costs ?

Implication of 'infinite' horizon

- If growth is steady (e.g.: constant annual amount or percent),
- Does optimal policy change over time?

- Policy should not change -- Best policy now should be best at any other comparable time
- If we need addition now, and find best to add for N years, then best policy for next time we need capacity will also be an N year addition
- Best policy is a ***repetitive cycle***

Cost assumptions

- Cost of Capacity additions is:
  - Cost = K (size of addition) ^{a}
  - If a < 1.0 we have economies of scale
- Cost of a policy of adding for N years, C(N), of growth annual growth "Δ" is:
  - Initial investment = $K (N \Delta)^a$
  - Plus Present Values of stream of future additions. Value in N years is C(N) WHY?
  - $C(N) = K (N \Delta)^a + e^{-rN} C(N)$
  - $C(N) = K (N \Delta)^a / [1 - e^{-rN}]$

If Constant Economies of Scale

- This means exponent a = 1
- Thus for example

Year	0	1	2	3	4	5	6	…	N
Demand Increase	0	5	10	15	20	25	30	…	5N
Capacity Addition	15			15			15	…	
Proportional Cost	15			15			15	,,,	
Present Value at 10% = C(t=0) + C/r (for period)	15 + 15(/0.33) = 60								

- Present Value for cyclical payments in Excel is: = PV(DR over cycle beyond year 0, number of cycles, amount/cycle)
- How does present cost vary over longer cycles?

Optimal policy in linear case

- The general formula for the present value of a series of infinite constant amounts is:

  PV = (Constant Amount)[1 + 1 / (DR over period)]

- In linear case:
  - Constant Amount = K (N Δ)
  - DR over period = N (annual DR)
  - PV = K(N Δ) [1 + 1 / N (annual DR)] =
    = K(Δ) [N + 1 / (annual DR)]
- In this case, contributions of future cycles is irrelevant. Only thing that counts is first cost, which [= f (N Δ)] that we minimize.

Consider diseconomies of scale

- In this case, it is always <u>more</u> expensive per unit of capacity to build bigger – that is meaning of <u>dis</u>economies of scale
- Thus, incentive to build smaller
- Any countervailing force?

- No !
- In this case, shortest possible cycle times minimize present costs

… and economies of scale?

- Economies of scale mean that bigger plants => cheaper per unit of capacity
- Thus, incentive to build larger
- Any countervailing force?

- Yes! Value of deferring expenses…
- Economies of scale are a power function so advantage of larger units decreases, while they cost more now
- Best policy not obvious

Manne's analysis

- **Alan Manne developed an analytic solution for the case of constant linear growth**
- **Reference:**

Manne, A. (1967) <u>Investments for Capacity Expansion: Size, Location and Time-phasing</u>, MIT Press, Cambridge, MA

Details of Manne's analysis (1)

- **Cost of Stream of replacement cycles is:**

$$C(N) = K (N \Delta)^a + e^{-rN} C(N)$$

- **Thus:** $C(N) = K (N \Delta)^a / [1 - e^{-rN}]$
- **This can be optimized with respect to N, decision variable open to system designer**

Details of Manne's analysis (2)

- It's convenient to take logs of both sides

  $\log [C(N)] = \log [K (N \Delta)^a] - \log [1 - e^{-rN}]$

  $= \log [N^a] + \log [K (\Delta)^a] - \log [1 - e^{-rN}]$

  $d(\log [C(N)]) / dN = a/N - r / [e^{-rN} - 1] = 0$

- So: $a = rN^* / [e^{-rN^*} - 1]$
- Optimal cycle time, N*, determined by (a, r) which are the known factors
  -- for assumed conditions

Key results from Manne

- There is an optimal cycle time…
- It depends on
  - Economies of scale: lower "a" ➔ longer cycle
  - Discount rate: higher DR ➔shorter cycle
- It does not depend on growth rate!
- Higher growth rate ➔ larger units
- However, this is driven by cycle time
  Capacity addition = (cycle time)(growth rate)

Here's the picture (from Manne)

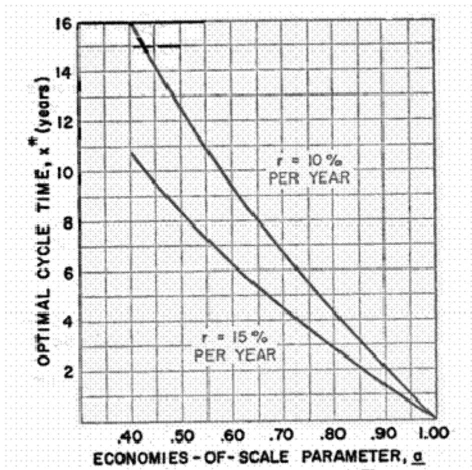


Figure 2.4.—Cross-Plot for Optimal Cycle Time

Interpretation:
1. Optimal cycle time defines increment size = growth x yrs

2. Higher discount rate (r)
=> smaller increments
EoS Savings are discounted

3. Greater EoS (<u>smaller</u> a)
=> larger increments
EoS Savings more important

Note: Best EoS factor ~ 0.6
Generally, "a" is higher

Graphical View of Results

- **Manne's present costs versus cycle time**
  - **steep for small cycle times**
  - **quite flat at bottom and for larger cycle times**
- **See following figure…**
- **What are implications?**

Sensitivity of results (Manne)

- Total Cost vertically
- Cycle Time, N, horizontally
- Optimum is flat, around 6.75 years for a = 0.7 and r = 0.1 = 10%

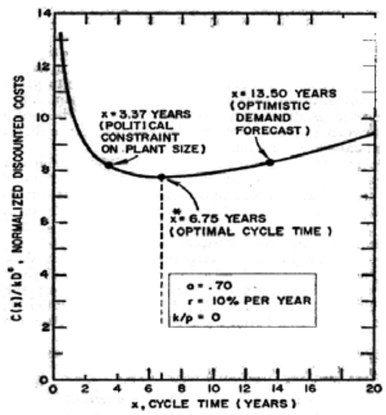


Figure 2.6.—Discounted Cost Function

Applications of M's Analysis

- Still widely used
- In industries that have steady growth
- In particular in Electric power
- See for example
- Hreinsson, E. B. (2000) "Economies of Scale and Optimal Selection of Hydropower projects," Proceedings, Electric Deregulation and Restructuring of Power Technologies, pp. 284-289.
  -- An application for Iceland

Design implications

- For industries with Economies of Scale,
- Which are they? and why?
- Electric power, chemical processes
- For conditions assumed (constant steady growth forever) …
  - Small plants (for small N) are uneconomical
  - Optimum size in range of between 5 and 10 years
  - Corresponding to maybe 30 to 50% expansion
  - Results not especially sensitive to higher N
  - Which is good because forecasts not accurate.

What if assumptions wrong? (1)

- Growth assumed "for ever" …
- Is this always so?

- Not always the case:
  - Fashion or technology changes
  - Examples –
    - Analog film -- once digital cameras came in
    - Land lines – once everyone had cell phones

What if assumptions wrong? (2)

- Growth assumed steady…(no variability)
- Is this always so?

- Generally not correct.
  - Major economic cycles are common
  - Examples:
    - Airline industry
    - Consumer goods of all sorts
    - Industrial products….

Optimal policy if growth stops, decreases

- What is the risk?
- Building capacity that is not needed

- What can designer do about it?
- Build smaller, so less reliance on future

- What is the cost of this policy?
- Tradeoff: higher cost/unit for small plants (when operating at capacity!!) versus saving by not paying for extra capacity

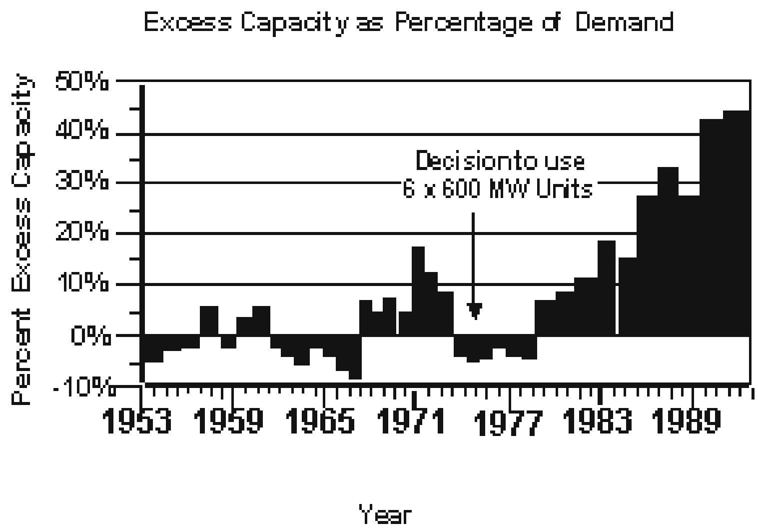
Take-aways for discussion so far

- If no economies of scale (EoS), do not build in anticipation of demand: expand as needed
- If EoS, there is a reason to build for anticipated needs – for next 5 to 10 years
- Size depends on discount rate, “a” factor
- Uncertainty => smaller increments
- Point often missed – see example

Example: Power in S. Africa

- Eskom, power generator for South Africa, adopted Manne’s model in mid-1970s
- They committed to units of 6 x 600 MW
- This led them to over 40% overcapacity within 15 years – an economic disaster!
- Aberdein, D. (1994) “Incorporating Risk into Power Station Investment Decisions in South Africa, S.M. Thesis, MIT, Cambridge, MA.

Expansion of Established Industry
Power Station Investment in South Africa



Why did oversupply persist?

- Build up of oversupply was not sudden, lasted over a decade
- Why did system managers let this happen?

- Not clear. Some likely explanations:
  - Managers committed to plan – thus it was too shameful to admit error of fixed plan
  - They had locked themselves in contractually – no possibility to cancel or defer implementation
- In any case, system was inflexible

What could have been done?

- They would have been better off (less unnecessary or premature construction) if they had:
  - not committed themselves to a fixed plan, but had signaled possibility of change
  - contractual flexibility to cancel orders for turbines, defer construction (they would have had to pay for this, of course)
  - Planned for smaller increments
- In short, they should have been flexible

Recap
Capacity Expansion Problem

- How should system designers "grow" the system over time?
- Main tensions:
  - For early build – if economies of scale
  - For delays –
    - defer costs, lower present values
    - resolution of uncertainties
- Need for flexible approach

Summary

- Capacity Expansion Issue is a central problem for System Design
- Deterministic analysis offers insights into major tradeoffs between advantages of economies of scale and of deferral
- In general, however, the uncertainties must be considered
- A flexible approach is needed
  - How much? In what form?
- This is topic for rest of class