Guest Lecture

Economic Analysis of Energy (and Other) Systems

Dr. Tim Lipman
Inst. of Transportation Studies
UC Berkeley/Davis

telipman@socrates.berkeley.edu

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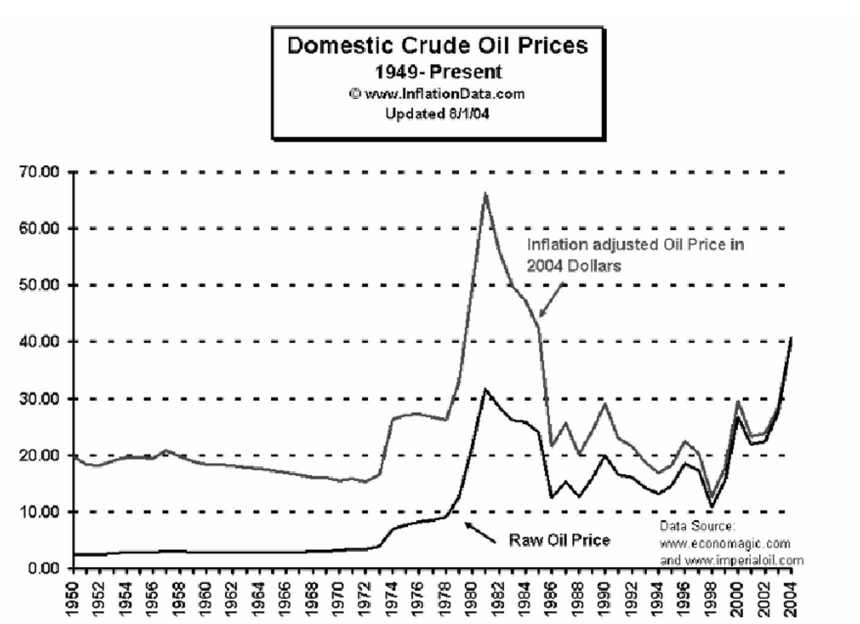
Outline

- General Concepts
  - Nominal and real dollars
  - Discount rates
  - NPV calculations
- Project Economic Assessment
  - Simple payback
  - Depreciation of capital
  - Project financing
  - Calculation of levelized costs
  - Internal rate of return
- Cost Forecasting
  - Economies of scale
  - Manufacturing experience curves

General Concepts

- Nominal Dollars
  - "The dollars of the day"
  - Subject to inflation
  - Your grandfather's allowance might have been a nickel a week, but that was real money back then!
- Real Dollars
  - Corrected for inflation
  - Depending on situation, can use CPI or other implicit price deflators
  - Allow for meaningful comparisons across years
  - Important to consistently use the dollars of a single year in a multi-year analysis

Gasoline Prices are Hitting Historical Highs in Nominal but Not Real Terms



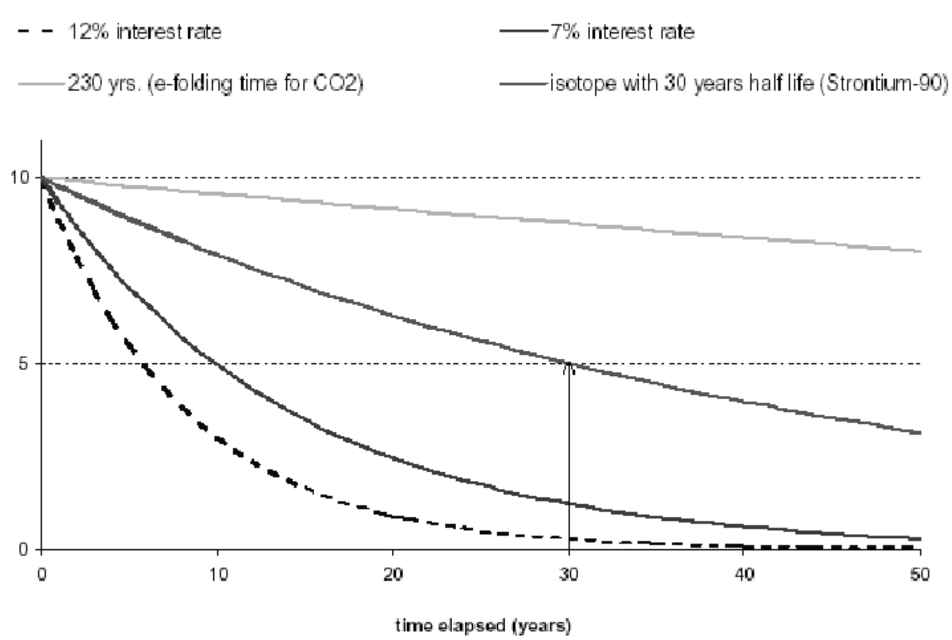
Discount Rates

- Discount rates are composed of inflation rates and interest rates (a "real" discount rate would already be corrected for inflation
  - Nominal discount rate = inflation rate + interest rate

- Interest rates address the "time value of money" that make future $s less valuable than they are today, even in real terms
- Even corrected for inflation, wouldn't you rather have $10 today than $10 in five years?
- Discount rate values are subjective and (for long term policy analysis) controversial

- Discounted Value = Original Value/$(1+DR)^t$

Exponential Rates Example



Net Present Value

The Net Present Value method of analysis simply places all costs and benefits of a technology or service as equivalent costs or benefits at the present time.

It is commonly used in engineering and financial comparisons of energy and other investment options.

In general, the Net Present Value, is the discounted series of costs and benefits :

$$\text{NPV} = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$$

Economic Analysis Methods

- Simple Payback

Simple payback is the time to recover an investment, through savings, without discounting.

Example:
A compact flourescent light, CFL, costs $6 and uses 20 Watts instead of 75 W. The savings is 55 W for the 4 hours a day that it is operated. Electricity costs 12 cents/kWh
The savings :

Energy : (55 watts) (4 hours/day) (365 days/year) = 80 kWh/year
Money : (80 kWh/year) (0.12 $/kWh) = $9.6/year

$$\text{Time (payback)} : \frac{\$6 \text{ bulb}}{\$9.6 \text{ savings/year}} = 7.5 \text{ months}$$

Net Present Value - Example

An automotive repair show purchases a system to capture emissions of VOCs.

The purchase price is $15,000 (from company cash)
The equipment will be used for 7 years, and will cost $1,000/year to operate.
After 7 years, the manufacturer will buy it back for $2,000.
What is the total present value of owning and operating the system using a 4% annual interest rate?

Capital cost, P_{cap} is already in NPV terms (t=0). P_{cap} = $15,000

$P_{O\&M}$ = uniform series of costs, so we use the uniform payment form:

$$P_{O\&M} = U\left[\frac{1-(1+r)^{-n}}{r}\right] = (\$1,000)\left[\frac{1-(1.04)^{-7}}{0.04}\right] = \$6,002$$

The resale value "salvage" of $2, 000 represents a present value of $1, 520

$$\text{NPV} = P_{resale} - P_{cap} - P_{O\&M} = \$1,520 - \$15,000 - \$6,002 = -\$19,482$$

Levelized Costs

- <u>Levelized Costs</u> are a common and useful metric
- Calculate the "levelized" cost of the commodity produced, such as $/kWh or $/kg of hydrogen
- Calculate annualized costs and divide by annual quantity produced
- Calculate annualized costs:
  - Fuel costs (may or may not have)
  - O&M costs (fixed and variable)
  - Capital costs (need depreciation schedule to annualize)
- Use discounting for multi-year analysis

Capital Costs and Depreciation

- Capital costs may be financed through debt or paid upfront
- If financed, total costs will be higher than the price of the equipment due to the cost of interest payments
- Depreciation is how capital costs are allocated over time, starting with the value when new (that shiny new car) and ending up with a salvage value (if any)
- Depreciation can be "straight line" and calculated using simple capital recovery factors or b using more complicated / accelerated schedules such as "double declining balance"
- Use straight line depreciation for "typical project year" analysis (and be clear that you're assuming an equal spread of capital costs over time) and more complicated methods for detailed cash flow assessments
- Capital Recovery Factor = $R / [1 - (1+R)^{-T}]$

Levelized Costs - Example

Example 1: Electricity cost for a Natural Gas power plant (¢/kWh)

Assumptions:

- $450 per kW of installed capacity = fixed cost
- 80% capacity factor
- 98% of operational costs is fuel
- 1 kWh = 3414 Btu
- natural gas price $3/million BTU
- life time of the power plant is 20 years, η=0.4

Life Cycle Cost -- **The overall estimated cost for a particular program alternative over the time period corresponding to the life of the program, including direct and indirect initial costs plus any periodic or continuing costs of operation and maintenance.**

Analysis:

Total cost → PV = fixed cost + PV{of recurring operational costs (O&M)}

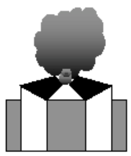
Annual Energy Output (AEO) → E = (capacity factor) • (8,760 hrs/yr) • (1kW of capacity/yr)

= (0.8) • (8,760 hrs) • (1kW) = 7,008 kWh

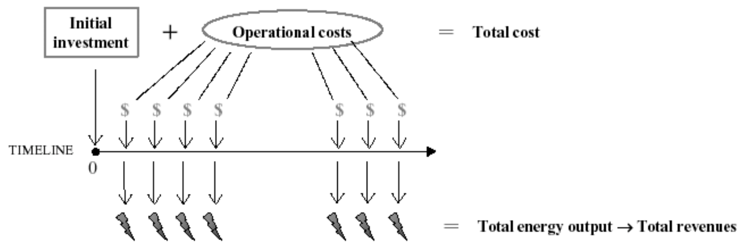
$$PV(O\&M) = \frac{AEO}{\text{conversion efficiency}} \cdot \frac{\text{fuel cost}}{98\%} \rightarrow$$

$$PV(O\&M) = \left\{\frac{7{,}008\ \text{kWh}}{0.4} \cdot (3414\ \text{Btu/kWh})\right\} \cdot \frac{(\$3/\text{MMBtu})}{0.98} = \mathbf{\$183}$$

Levelized Costs - Example



Electricity cost for a Natural Gas power plant (¢/kWh)



$$\text{electricity cost} = \frac{PV}{(\text{Total Energy output})}$$

$$PV = \$450 + \frac{\$183}{0.07}\left(1 - \frac{1}{(1+0.07)^{20}}\right)$$

total output = 7,008 x 20 = 140,160 kWh

$$\text{cost} = \frac{\$2388}{140160\,\text{kWh}} = 1.7\text{¢/kWh}$$

cheap!

- taxes,
- profits,
- externalities

Internal Rate of Return

- The IRR is the rate that makes the value of the stream of net project benefits (the NPV) equal to zero
- The IRR for simple investments is the interest rate, e.g. if you put money in a bank account at 5% that is the IRR for that investment
- Target IRR values of 10-15% are common, to beat other competing investment opportunities
- IRR values can get tricky when the stream of net benefits switches from positive to negative more than once (multiple values are possible)

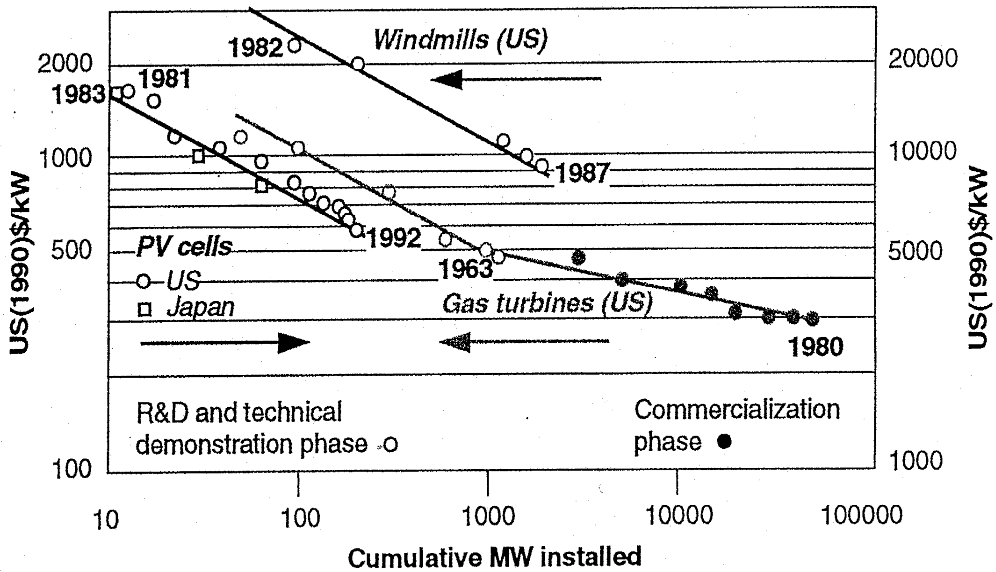
Cost Forecasting Methods

- Detailed or "Bottom Up" Method
  - New or existing product
  - Data intensive -- need good data on materials costs, manufacturing equipment costs, labor and utilities, etc.
  - Addresses economies of scale but tricky to include learning economies for forecasting
- Manufacturing Experience Curve Method
  - Also called learning curves and progress functions
  - For existing product with some cost/price history
  - Challenging to get good data here too

Cost Estimation and Forecasting

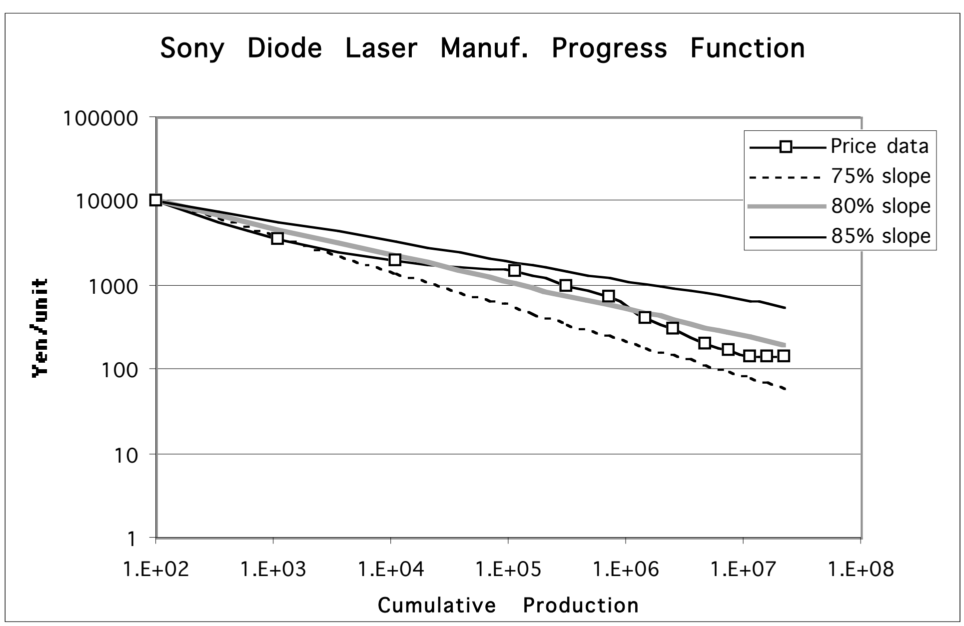
- Experience Curves/Progress Functions
  - Logarithmic relationship between manufacturing cost and cumulative (not annual) production
  - With each doubling in accumulated experience, cost drops by 10-30% (typical range)
  - 80% curve is common (20% decrease with each doubling)
  - Fast reduction at first (largely through scale economies) and then slower later
- Common Forms
  - $C_N = C_1 * V_N^{(\log\partial/\log 2)}$ or $C_N = C_1 * V_N^{-b}$

Experience Curves for Energy Technologies



Source: IIASA/WEC, 1995

Another Experience Curve Example



Source: Wood and Brown, 1998

Cost Forecasting

- Experience curve method can be powerful but beware of pitfalls -- limits can come into play particularly for products with high materials costs
- Detailed methods also have limits as learning by doing is a powerful dynamic that is hard to analyze explicitly
- Particularly consider using experience curves for novel products that will not easily be produced like other existing ones (i.e., where learning as well as scale economies are likely to be important)

Useful Definitions

Benefit-Cost Analysis -- A systematic quantitative method of assessing the desirability of government projects or policies when it is important to take a long view of future effects and a broad view of possible side-effects.

Cost-Effectiveness -- A systematic quantitative method for comparing the costs of alternative means of achieving the same stream of benefits or a given objective.

Net Present Value -- The difference between the discounted present value of benefits and the discounted present value of costs.

Discount Rate -- The interest rate used in calculating the present value of expected yearly benefits and costs.

Real Interest Rate -- An interest rate that has been adjusted to remove the effect of expected or actual inflation. Real interest rates can be approximated by subtracting the expected or actual inflation rate from a nominal interest rate. (A precise estimate can be obtained by dividing one plus the nominal interest rate by one plus the expected or actual inflation rate, and subtracting one from the resulting quotient.)

Capital Asset -- Tangible property, including durable goods, equipment, buildings, installations, and land.

Opportunity Cost -- The maximum worth of a good or input among possible alternative uses.

Sunk Cost -- A cost incurred in the past that will not be affected by any present or future decision. Sunk costs should be ignored in determining whether a new investment is worthwhile.

Fixed charge rate -- The fixed charge rate is the mechanism that distributes the cost of the plant and capital over the life of the asset. The rate incorporates the time value of money, federal and state income taxes, property taxes, and depreciation expenses.

Annual Energy Output -- Annual energy output is a function of the capacity factor and the capacity of the generating unit.

Internal Rate of Return -- The discount rate that sets the net present value of the stream of net benefits equal to zero. The internal rate of return may have multiple values when the stream of net benefits alternates from negative to positive more than once. IRR> 0 is generally required for any project.