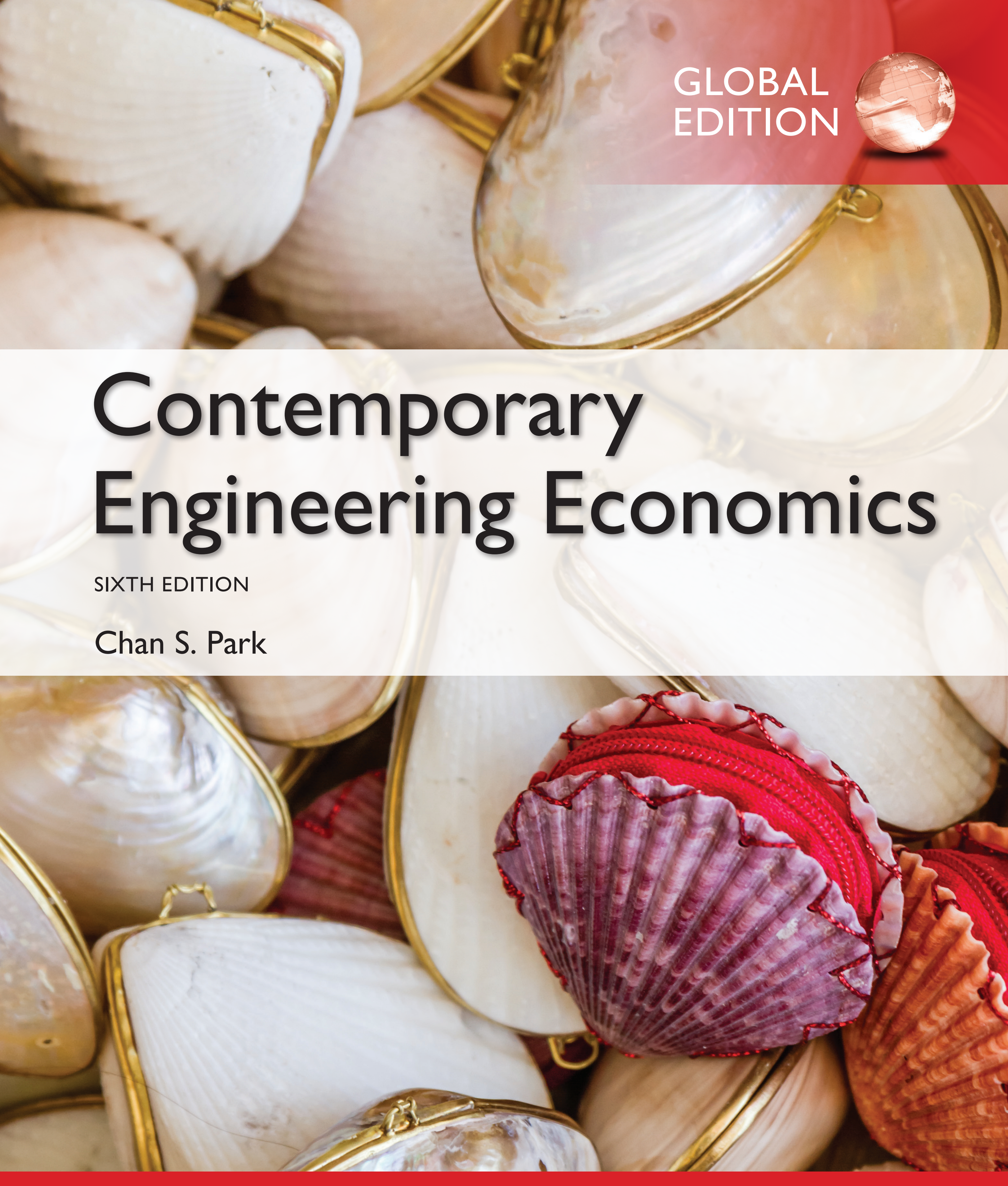

GLOBAL EDITION

Contemporary Engineering Economics

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Chan S. Park

ALWAYS LEARNING

PEARSON

but executives said it would take much longer to reach that target. It's clear that automation is the future trend in China, but the big question is how to bring down the costs for robots. Replacing people with robots would reduce the *operating cost* at the expense of increasing *capital cost*.

Now put yourself in a factory as a manager. Over the next five years these technologies will transform China's factories and also fill a growing labor shortage as the country's youth become increasingly unwilling to perform manual labor. At what annual equivalent cost of owning and operating the robots could you replace the human assemblers?

Suppose the robot assembly plant is fully operational by 2016 and you expect to operate it continuously for 20 years. How would you calculate the operating cost per hour? Suppose you are considering buying a new car. If you expect to drive 12,000 miles per year, can you figure out how much the car costs per mile? You would have good reason to want to know the cost if you were being reimbursed by your employer on a per-mile basis for the business use of your car. Or consider a real-estate developer who is planning to build a 500,000-square-foot shopping center. What would be the minimum annual rental fee per square foot required to recover the initial investment?

Annual equivalence analysis is the method by which these and other unit costs (or profits) are calculated. Along with present-worth analysis, annual equivalence analysis is the second major equivalence technique for putting alternatives on a common basis of comparison. In this chapter, we develop the annual equivalent-worth criterion and demonstrate a number of situations in which annual equivalence analysis is preferable to other methods of comparison.

CHAPTER LEARNING OBJECTIVES

After completing this chapter, you should understand the following concepts:

- How to determine the equivalent annual worth (cost) for a given project.
- Why the annual equivalent approach facilitates the comparison of unequal service-life problems.
- How to determine the capital cost (or ownership cost) when you purchase an asset.
- How to determine the unit cost or unit profit.
- How to conduct a life-cycle cost analysis.
- How to optimize design parameters in engineering design.

6.1 Annual Equivalent-Worth Criterion

In this section, we will describe a fundamental decision rule based on annual equivalent worth by considering both revenue and cost streams of a project. If revenue streams are irrelevant, then we make a decision solely on the basis of cost. This leads to a popular decision tool known as "life-cycle cost analysis," which we will discuss in Section 6.4.

6.1.1 Fundamental Decision Rule

The **annual equivalent worth (AE)** criterion provides a basis for measuring the worth of an investment by determining equal payments on an annual basis. Knowing that any lump-sum cash amount can be converted into a series of equal annual payments, we may first find the net present worth (NPW) of the original series and then multiply this amount by the capital recovery factor:

$$AE(i) = PW(i)(A/P, i, N) \tag{6.1}$$

- **Single-project evaluation:** The accept–reject selection rule for a single *revenue* project is as follows:

  If $AE(i) > 0$, accept the investment.

  If $AE(i) = 0$, remain indifferent to the investment.

  If $AE(i) < 0$, reject the investment.

  Notice that the factor $(A/P, i, N)$ in Eq. (6.1) is positive for $-100\% < i < \infty$, which indicates that the value of $AE(i)$ will be positive if, and only if, $PW(i)$ is positive. In other words, accepting a project that has a positive $AE(i)$ is equivalent to accepting a project that has a positive $PW(i)$. Therefore, the AE criterion for evaluating a project is consistent with the NPW criterion.
- **Comparing mutually exclusive alternatives:** As with present-worth analysis, when you compare mutually exclusive *service* projects whose revenues are the same, you may compare them on a *cost*-only basis. In this situation, the alternative with the minimum *annual equivalent cost* (AEC) or least negative annual equivalent worth is selected.

Example 6.1 illustrates how to find the equivalent annual worth for a proposed energy-savings project. As you will see, you first calculate the net present worth of the project and then convert this present worth into an equivalent annual basis.

EXAMPLE 6.1 Annual Equivalent Worth: A Single-Project Evaluation

A utility company is considering adding a second feedwater heater to its existing system to increase the efficiency of the system and thereby reduce fuel costs. The second feedwater heater to go with the 150 MW system will cost $1,650,000 and has a service life of 25 years. The expected salvage value of the unit is considered negligible. With the second unit installed, the efficiency of the dual system will improve from 55% to 56%. The fuel cost to run the feedwater is estimated at $0.05 kWh. The system unit will have a load factor of 85%, meaning that the system will run 85% of the year. Is it worth having a mere 1% improvement in efficiency at the expense of $1,650,000?

(a) Determine the equivalent annual worth of adding the second unit with an interest rate of 12%.

(b) If the fuel cost increases at the annual rate of 4% after first year, what is the equivalent annual worth of having the second feedwater heater at $i = 12\%$?

DISCUSSION: Whenever we compare machines with different efficiency ratings, we need to determine the input powers required to operate the machines. Since the percent efficiency is equal to the ratio of the output power to the input power, we can determine the input power by dividing the output power by the motor's percent efficiency:

$$\text{Input power} = \frac{\text{output power}}{\text{percent efficiency}}$$

For example, a 30-HP motor with 90% efficiency will require an input power of

$$\begin{aligned}\text{Input power} &= \frac{(30\text{ HP} \times 0.746\text{ kW/HP})}{0.90} \\ &= 24.87\text{ kW}\end{aligned}$$

Therefore, energy consumption with and without the second unit can be calculated as

- Before adding the second unit, $\dfrac{150{,}000\text{ kW}}{0.55} = 272{,}727\text{ kW}$.
- After adding the second unit, $\dfrac{150{,}000\text{ kW}}{0.56} = 267{,}857\text{ kW}$.

So the reduction in energy consumption is 4,870 kW. Since the system unit will operate only 85% of the year, the total annual operating hours are calculated as

$$\text{Annual operating hours} = (365)(24)(0.85) = 7{,}446\text{ hours/year}$$

SOLUTION

Given: $I = \$1{,}650{,}000$, $N = 25$ years, $S = 0$, annual fuel savings, and $i = 12\%$.
Find: AE of fuel savings due to improved efficiency.

(a) With the assumption of constant fuel cost over the service life of the second heater,

$$\begin{aligned}A_{\text{fuel savings}} &= (\text{reduction in fuel requirement}) \times (\text{fuel cost}) \\ &\quad \times (\text{operating hours per year}) \\ &= (4{,}870\text{ kW}) \times (\$0.05/\text{kWh}) \\ &\quad \times (7{,}446\text{ hours/year}) \\ &= \$1{,}813{,}101\text{ per year}\end{aligned}$$

$$\begin{aligned}\text{PW}(12\%) &= -\$1{,}650{,}000 + \$1{,}813{,}101(P/A, 12\%, 25) \\ &= \$12{,}570{,}403 \\ \text{AE}(12\%) &= \$12{,}570{,}403(A/P, 12\%, 25) \\ &= \$1{,}602{,}726\end{aligned}$$

(b) With the assumption of escalating energy cost at the annual rate of 4%, since the first year's fuel savings is already calculated in part (a), we use it as A_1 in the geometric-gradient series present-worth factor $(P/A_1, g, i, N)$:

$$A_1 = \$1{,}813{,}101$$

$$\begin{aligned} \text{PW}(12\%) &= -\$1{,}650{,}000 + \$1{,}813{,}101(P/A_1, 4\%, 12\%, 25) \\ &= \$17{,}459{,}783 \\ \text{AE}(12\%) &= \$17{,}459{,}783(A/P, 12\%, 25) \\ &= \$2{,}226{,}122 \end{aligned}$$

Clearly, either situation generates enough fuel savings to justify adding the second unit of the feedwater heater. Figure 6.1 illustrates the cash flow series associated with the required investment and fuel savings over the heater's service life of 25 years.

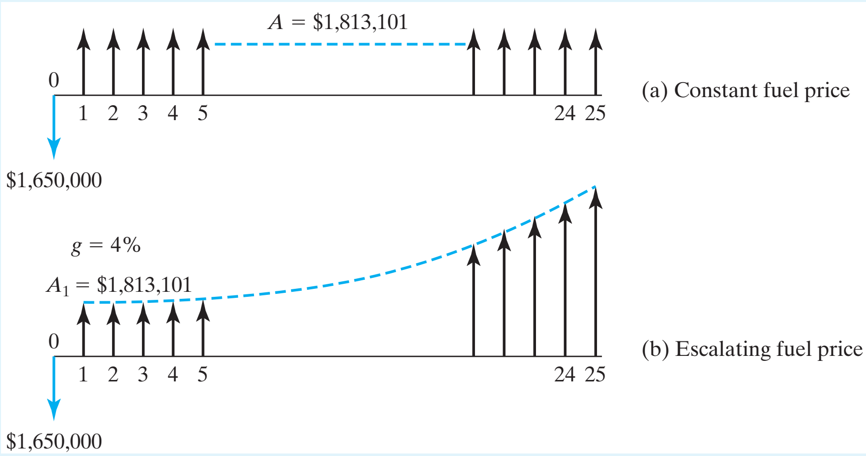

Figure 6.1 Cash flow diagram (Example 6.1).

6.1.2 Annual-Worth Calculation with Repeating Cash Flow Cycles

In some situations, a **cyclic cash flow pattern** may be observed over the life of the project. Unlike the situation in Example 6.1, where we first computed the NPW of the entire cash flow and then calculated the AE, we can compute the AE by examining the first cash flow cycle. Then we can calculate the NPW for the first cash flow cycle and derive the AE over that cycle. This shortcut method gives the same solution when the NPW of the entire project is calculated, and then the AE can be computed from this NPW.

EXAMPLE 6.2 Annual Equivalent Worth: Repeating Cash Flow Cycles

SOLEX Company is producing electricity directly from a solar source by using a large array of solar cells and selling the power to the local utility company. SOLEX decided to use amorphous silicon cells because of their low initial cost, but these cells degrade over time, thereby resulting in lower conversion efficiency and power output. The cells must be replaced every four years, which results in a particular cash flow pattern that repeats itself, as shown in Figure 6.2. Determine the annual equivalent cash flows at $i = 12\%$.

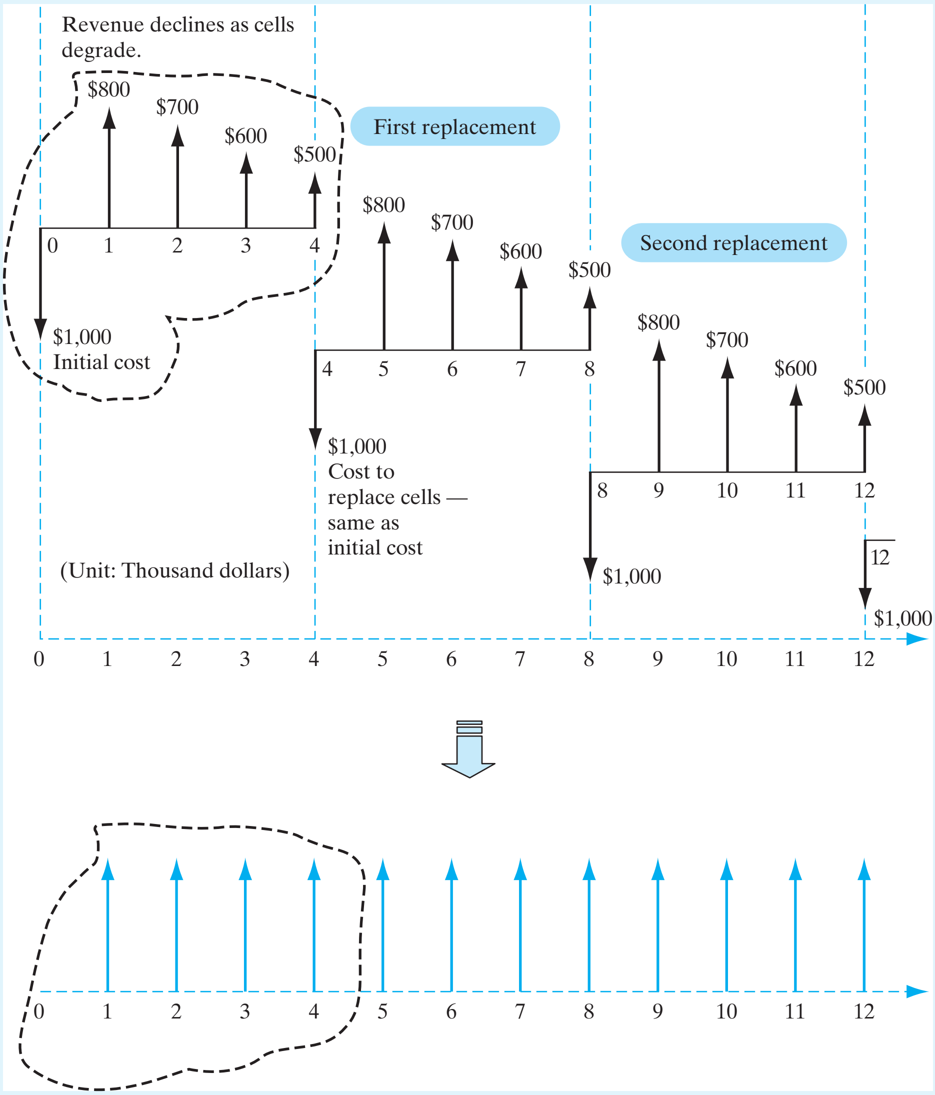

Figure 6.2 Conversion of repeating cash flow cycles into an equivalent annual payment (Example 6.2).

SOLUTION

Given: Cash flows in Figure 6.2 and $i = 12\%$.

Find: Annual equivalent benefit.

To calculate the AE, we need only consider one cycle over the four-year replacement period of the cells. For $i = 12\%$, we first obtain the NPW for the first cycle as

$$\begin{aligned} PW(12\%) &= -\$1{,}000{,}000 \\ &\quad + [(\$800{,}000 - \$100{,}000(A/G, 12\%, 4)](P/A, 12\%, 4) \\ &= -\$1{,}000{,}000 + \$2{,}017{,}150 \\ &= \$1{,}017{,}150 \end{aligned}$$

Then we calculate the AE over the four-year life cycle:

$$\begin{aligned} AE(12\%) &= \$1{,}017{,}150(A/P, 12\%, 4) \\ &= \$334{,}880 \end{aligned}$$

We can now say that the two cash-flow series are equivalent:

Original Cash Flows		Annual Equivalent Flows	
n	***A_n***	***n***	***A_n***
0	−\$1,000,000	0	0
1	800,000	1	\$334,880
2	700,000	2	334,880
3	600,000	3	334,880
4	500,000	4	334,880

We can extend this equivalency over the remaining cycles of the cash flow. The reasoning is that each similar set of five values (one disbursement and four receipts) is equivalent to four annual receipts of \$334,880 each. In other words, the \$1 million investment in the solar project will recover the entire investment and generate equivalent annual savings of \$334,880 over a four-year life cycle.

6.1.3 Comparing Mutually Exclusive Alternatives

In this section, we consider a situation in which two or more mutually exclusive alternatives need to be compared on the basis of annual equivalent worth. In Section 5.5, we discussed the general principles that should be applied when mutually exclusive alternatives with unequal service lives were compared. The same general principles should be applied in comparing mutually exclusive alternatives on the basis of annual equivalent worth: Mutually exclusive alternatives in equal time spans must be compared. Therefore, we must give careful consideration to the period covered by the analysis: the **analysis period**. We will consider two situations: (1) The analysis period equals project lives, and (2) the analysis period differs from project lives.