APPENDIX B

COST ESTIMATION

IN CHAPTER 3 we discussed the formulation of objective functions without going into much detail about how the terms in an objective function are obtained in practice. The purpose of this appendix is to provide some brief information that can be used to obtain the coefficients in objective functions in economic optimization problems. Various methods and sources of information are outlined that help establish values for the revenues and costs involved in practical problems in design and operations. After we describe ways of estimating capital costs, operating costs, and revenues, we look at the matter of project evaluation and discuss the many contributions that make up the net income from a project, including interest, depreciation, and taxes. Cash flow is distinguished from income. Finally, some examples illustrate the application of the basic principles.

The estimation of operating and capital costs is an important facet of process design and optimization. In the absence of firm bids or valid historical records, you can locate charts, tables, and equations that provide cost estimates from a wide variety of sources based on given values of the design variables.

1. Specialized books on cost estimation such as Garrett (1989) or Ostwald (1992).
2. Textbooks on plant design such as Turton et al. (1998) and Seider et al. (1999).
3. Handbooks such as *Perry's Chemical Engineering Handbook* (Green and Maloney, 1997).
4. Trade magazines such as *Chemical Engineering* or the *Oil and Gas Journal.*
5. Literature provided by equipment vendors.
6. Reports and books published by professional societies.
7. Local, state, and federal government publications.
8. Databases in process simulators such as Aspen (1998), HYSYS (1998), and ProII (1998).
9. The Internet (http://www.chempute.com or http://www.chemengineer .miningco.com).
10. Commercial software for process equipment cost estimation such as CHEM-COST (Icarus Corp., 1999).

The preceding listed sources provide information on current and often historical capital and operating costs that can be used in your current and projected economic evaluation.

B.1 CAPITAL COSTS

In carrying out an economic analysis, recognize that various levels of detail in the design of a process exist.

1. Rough feasibility estimate based on a general flowsheet using historial costs, charts, or the literature and using multiplying factors based on experience to scale for inflation, size differences, and tax rates. Examine Figure B.1 for cost estimates based on entire plants as a function of capacity.

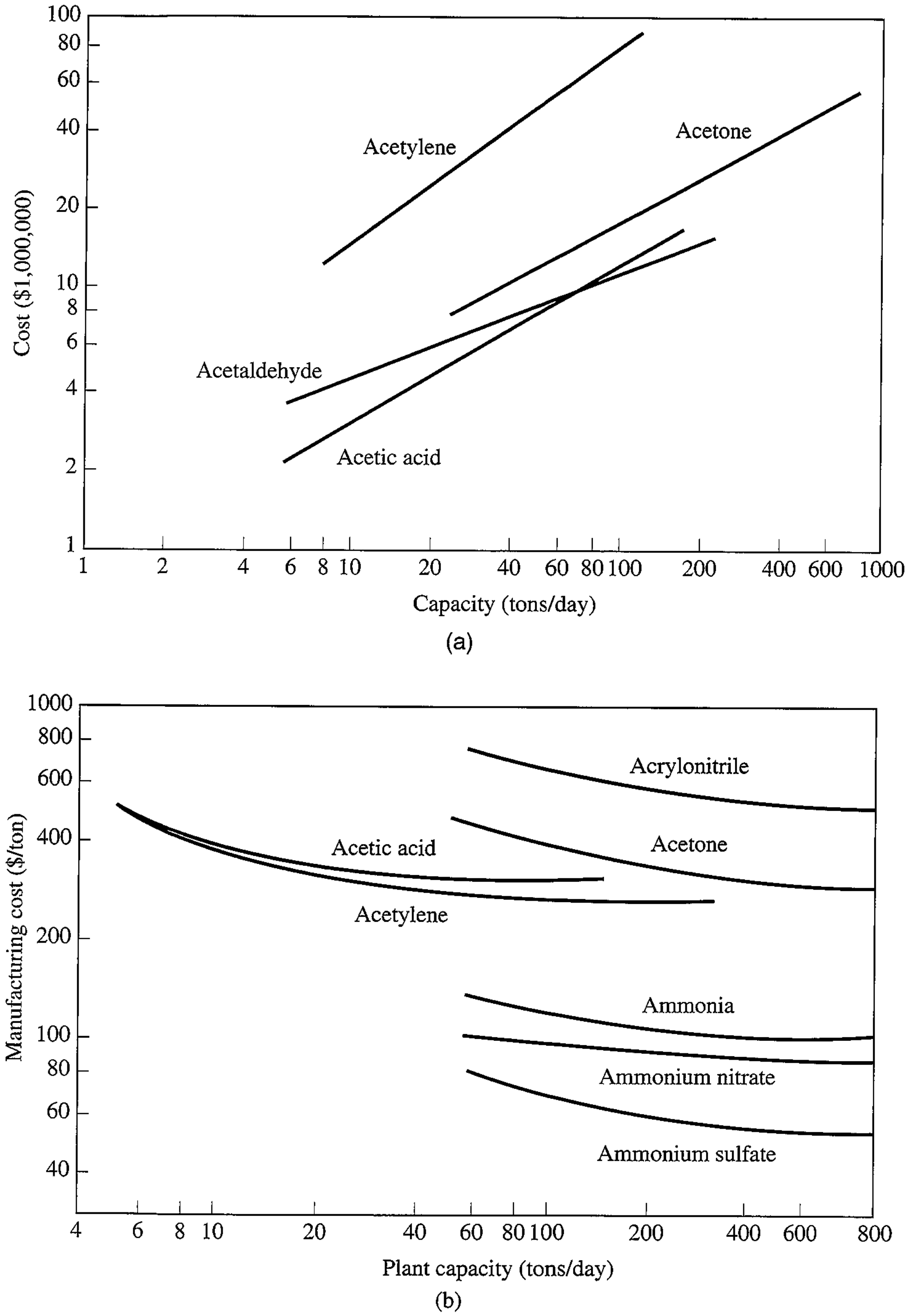

FIGURE B.1
Rough estimates of (a) complete plant costs and (b) manufacturing costs (in tons/day) based on historical data (from Garrett, 1989 with permission from Kluwer Academic Publishers).

Purchased cost of tank, delivered basis:		$100.00	
Installation costs:			
Piping	12.8		
Concrete	8.6		
Instruments	3.8		
Electrical	0.6		
Paint	1.2	27.0	
Total materials			127.0
Labor costs:			
Man hours/$ materials: 0.044			
Average hourly labor costs including fringe: $28.50			
(0.044) (127.0) ($28.50) =		159.3	
Total		286.3	
Indirect (overhead) cost factor: 1.26			
1.26 (286.3) = 360.7			
Total cost		360.7	

FIGURE B.2
Approximate relative proportions of the cost of a 30,000-gallon tank erected in the field (1 unit of 12 in the flowsheet).

2. Major equipment estimates based on a more detailed given flowsheet that includes all of the equipment of significance roughly sized with approximate costs. Optimization using process flow simulators (refer to Chapter 15) can be employed. Figure B.2 illustrates a typical analysis for a tank. Refer to Brown (2000) for additional details.
3. Confirmed design in which additional detail and costs are developed for the arrangement of equipment, piping, utilities (water, steam, electrical, air), instrumentation, and control systems.
4. Final design that provides the plans, specifications for all equipment, detailed sections for the flowsheets, quotes from vendors, inhouse budgets, and a schedule for implementation.

As you may well surmise, more approximate designs lead to larger error bounds, running from perhaps ±50% of the total cost for category 1 to ±5% for category 4. The cost of making the estimates, of course, increases as the extent of the information about the design increases. A very preliminary design might cost from $5000 to $10,000, whereas the final design runs from 1% to as much as 5% of the total plant cost. Process simulators (refer to Chapter 15) make the preliminary stages of a design fairly easy to implement.

TABLE B.1
Components to include in capital cost estimation

Purchased equipment such as	
Towers, columns	Boilers
Reactors	Generators
Heat exchanger	Air conditioning
Cooling towers	Refrigeration
Tanks	
Piping	
Electrical	
Instrumentation	
Utilities such as	
Power	
Water	
Sewage, waste handling	
Electricity	
Insulation	
Buildings (and possibly land)	
Installation costs such as	
Labor	
Painting	
Fireproofing	
Supervision	
Inspection	
Safety, fire fighting	
Engineering, design, licensing	
Laboratory	
Shipping (working capital start-up expenses)	

What components must be included in estimating plant capital costs? Table B.1 is a partial list with some specific details.

Charts, correlations, and tables in the sources cited earlier relate capital costs to various parameters characteristic of the equipment to be evaluated. Table B.2 lists typical parameters used to correlate equipment costs for common types of process equipment. Figure B.3 is an example of such correlations for the cost of heat exchangers as a function of exchanger area. These forms of cost curves generally appear as nearly straight lines on log–log plots, indicating a power-law relationship between capital cost and capacity, with exponents typically ranging from 0.5 to 0.8.

If you want to scale up or scale down process equipment using one of the parameters in Table B.2, a typical rule of thumb is the following relation

$$\log C_B = a_1 + a_2 \log S \tag{B.1}$$

where C_B = base cost
S = size parameter
a_1, a_2 = coefficients to be estimated from valid data

TABLE B.2
Process parameters used in cost estimation for typical process equipment

Equipment type	Economic variables
1. Flashdrum	Diameter, height, material of construction, internal pressure
2. Distillation column, tray absorber	Diameter, height, internal pressure, material of construction, tray type, number of trays, condenser, reboiler (see item 3)
3. Condenser, reboiler, heat exchanger (shell and tube)	Heat transfer surface area, type, shell design pressure, materials for shell and tube
4. Absorber (packed)	Diameter, height, internal pressure, material of construction, packing type, packing volume
5. Process furnace or direct-fired heater	Design type, absorbed heat duty, pressure, tube material, capacity
6. Pumps (centrifugal, reciprocating)	Fluid density, capacity, dynamic head, type, driver, operating condition limits, material of construction
7. Gas compressor	Brake horsepower, driver type
8. Storage tank	Tank capacity, type, and storage pressure
9. Boiler	Steam flow rate, design pressure, steam superheat
10. Reactor	Type, diameter, height, design pressure, material of construction, capacity

A base cost typically corresponds to carbon steel construction and pressure below 100 psi. Note that Equation (B.1) is equivalent to

$$C_B = a' x_1 S^{a_s} \tag{B.2}$$

the familiar formula for scale-up, where a_2 is typically about 0.6. A slightly different correlation provides a more accurate fit of cost data by using three coefficients.

$$\log C_B = a_1 + a_2 \log S + a_3 (\log S)^2 \tag{B.3}$$

The estimated capital cost C_E for equipment can be found from base cost C_B from

$$C_E = C_B f_D f_M f_p \tag{B.4}$$

where f_D = design type cost factor
f_M = material of construction cost factor
f_p = pressure rating factor

The design type refers to variations in equipment configuration (e.g., fixed head versus floating head in a heat exchanger). The adjustment for material of construction is used principally to account for the use of alloy steel instead of carbon steel. The pressure rating factor allows adjusting costs for pressures other than the refer-

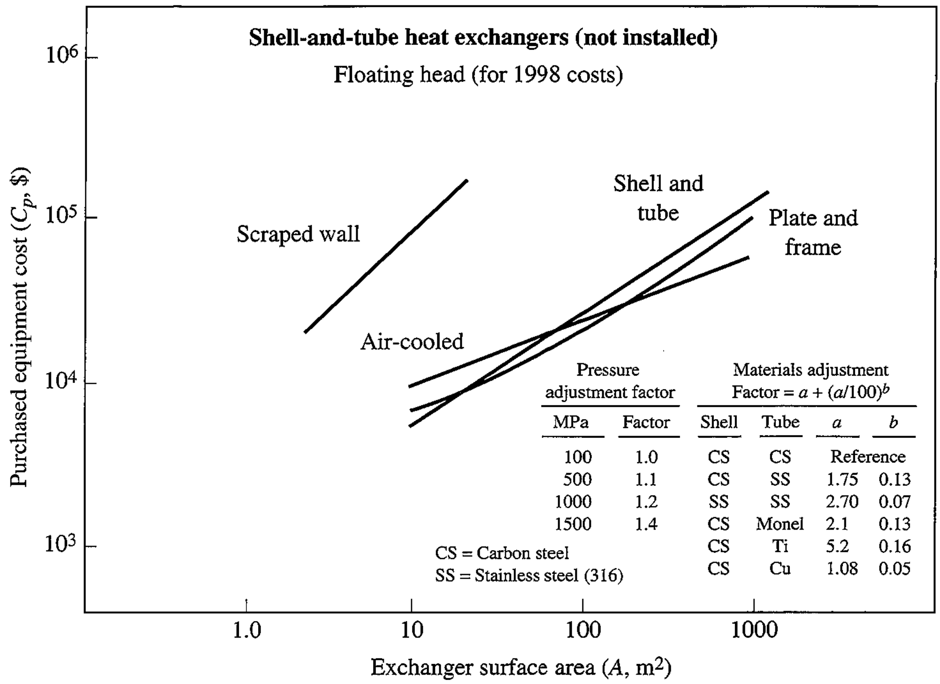

FIGURE B.3
Purchased equipment costs for various types of heat exchangers.

ence pressure. Obviously, higher pressure operation causes additional capital costs because of thicker vessel walls, and so on; f_p may be a discontinuous function.

EXAMPLE B.1 CAPITAL COST ESTIMATION

Suppose the cost for a fixed-head heat exchanger constructed of 316 stainless steel operating at 300–600 psi is to be estimated. The base case is a carbon steel, floating-head exchanger operating at 100 psi of area A. For such operation (Kuri and Corripio 1984), the base cost is

$$C_B = \exp[8.551 - 0.30863(\ln A) + 0.06811(\ln A)^2] \qquad (a)$$

where A is the exchanger heat transfer area in square feet ($150 \leq A \leq 12{,}000$ ft^2) and C_B is in dollars. Multiply C_B by factors f_D, f_p, and f_M, calculated as follows:

For a fixed head (versus floating head)

$$f_D = \exp[-1.1156 + 0.0906(\ln A)] \qquad (b)$$

For 300 to 600 psi, the correction is

$$f_p = 1.0305 + 0.07140(\ln A) \qquad (c)$$

For 316 stainless steel, the correction is

$$f_M = 2.7 \qquad (d)$$

Equation (B.4) can then be used to determine the actual capital cost for a specified area A.

For equipment such as distillation columns, the costs of several components (trays, shell) must be calculated.

B.2 OPERATING COSTS

In carrying out an economic evaluation of a proposed process or a modification of an existing one, estimation of future operating costs is just as important as estimating the capital costs involved in the analysis.

Operating costs include the costs of raw materials, direct operating labor, labor supervision, maintenance, plant supplies, utilities (steam, gas, electricity, fuel), property taxes, and insurance. Sometimes certain operating cost components are directly expressed as a fraction of the capital investment cost. Table B.3 is a brief checklist

TABLE B.3
Preliminary operating cost estimates

A. Direct production cost
   1. Materials
      a. Raw materials: estimate from price lists, government and trade group reports
      b. Byproduct and scrap credit: estimate from price lists
   2. Utilities: from literature or similar operations
   3. Labor: from historical data, manning tables, literature, or similar operations
   4. Supervision: 10–25% of labor
   5. Fringe benefits and FICA: 30–45% of labor plus supervision
   6. Maintenance: 2–10% of investment per year
   7. Operating supplies: 0.5–1.0% of investment per year, or 6–10% of operating labor
   8. Laboratory: 10–20% of labor per year
   9. Waste disposal: from literature, similar operations, or separate estimate
   10. Royalties: 1–5% of sales
   11. Contingencies: 1–5% of sales

B. Indirect costs
   1. Depreciation: 10–20% of investment per year
   2. Real estate taxes: 1–2% of investment per year
   3. Insurance: 0.5–1.0% of investment per year
   4. Interest: 10–12% of investment per year
   5. General administrative overhead: 50–70% of labor, supervision, and maintenance, or 6–10% of sales

C. Distribution costs
   1. Packaging: estimate from container costs
   2. Shipping: from carriers or 1–3% of sales

Sources: Jelen and Black (1983), Garrett (1989), Turton et al. (1998).

TABLE B.4
Rates for industrial utilities, 1998

Utility	Cost ($)	Unit
Steam		
500 psi (250°C)	8.00–9.00	1000 kg
(200°C)	6.00–8.00	1000 kg
Exhaust (100°C)	5.00–7.00	1000 kg
Electricity		
Purchased	0.03–0.08	kWh
Self-generated	0.02–0.06	kWh
Cooling water (30°C)		
Well	8.6–46	1000 m^3
River or salt	6.0–17	1000 m^3
Tower	6.0–8.0	1000 m^3
Process water		
City	5.00–8.00	1000 m^3
Boiler feed	1.70–2.70	1000 m^3
Compressed air		
Process air	1.60–4.80	1000 m^3
Instrument	3.20–10.00	1000 m^3
Natural gas	2.00–4.00	10^6 Btu
Fuel oil	0.30–0.50	gal
Coal	4.00–5.00	mton
Refrigeration (−30°C)	2.00–3.00	ton/day (288,000 Btu removed)

for estimating operating costs; note that such items as property taxes, insurance, and maintenance are computed as fractions of total fixed capital investment.

You may wonder how you can determine operating costs for a plant or process that is not yet operating. In Table B.4 you will note various rules of thumb that can be used to compile specific categories of approximate operating costs. If more detail is needed and if the appropriate information is not in your existing databases, then you can refer to some of the sources cited at the beginning of this chapter. For example, to collect more detailed information on utility costs you could prepare a table such as Table B.4 from data in financial newspapers and the Internet. As another example, detailed labor costs for operators can be assembled by considering the number of operators per shift for a section of the plant or piece of equipment, the number of days you expect to operate per year, the number of shifts per day, the expected average wage per operator to which have to be added fringe benefits and FICA taxes. Raw materials costs are available from bids, the *Chemical Marketing Reporter*, or the *Chemical Buyer's Guide*. Operating costs can vary from location to location so you should obtain local data whenever possible.

B.3 TAKING ACCOUNT OF INFLATION

Frequently you can find cost data that are appropriate for your economic evaluation, but they may be out of date. By taking account of the inflation in cost you can escalate old costs to current values and project current (or old) costs into the future.

Figure B.4 displays four well-known cost indexes for capital costs from 1950 to 1999:

1. ENR: *Engineering News-Record* Construction and Building Indexes
2. CE: *Chemical Engineering* Plant Cost Index
3. M & S: Marshall and Swift Equipment Index (also appears in *Chemical Engineering*)
4. NRC: Nelson–Farrar Refinery Construction Index (appears in *Oil and Gas Journal*)

Note that from 1950 to 1965–1970, the slopes (except the CE plant cost) of the indices were similar, that the slopes increased substantially during the inflationary period from 1965–1970 to about 1985; thereafter they returned roughly to their original values of about 6 percent per year.

If you need historical values for the cost of specific types of equipment, materials, fuels, and so on, rather than a general index, consult the references cited at the beginning of the chapter. To determine capital costs (C_x) in the year X in the future, given a known cost C_y in year Y, you simply multiply C_y by the ratio of the index (I_x/I_y):

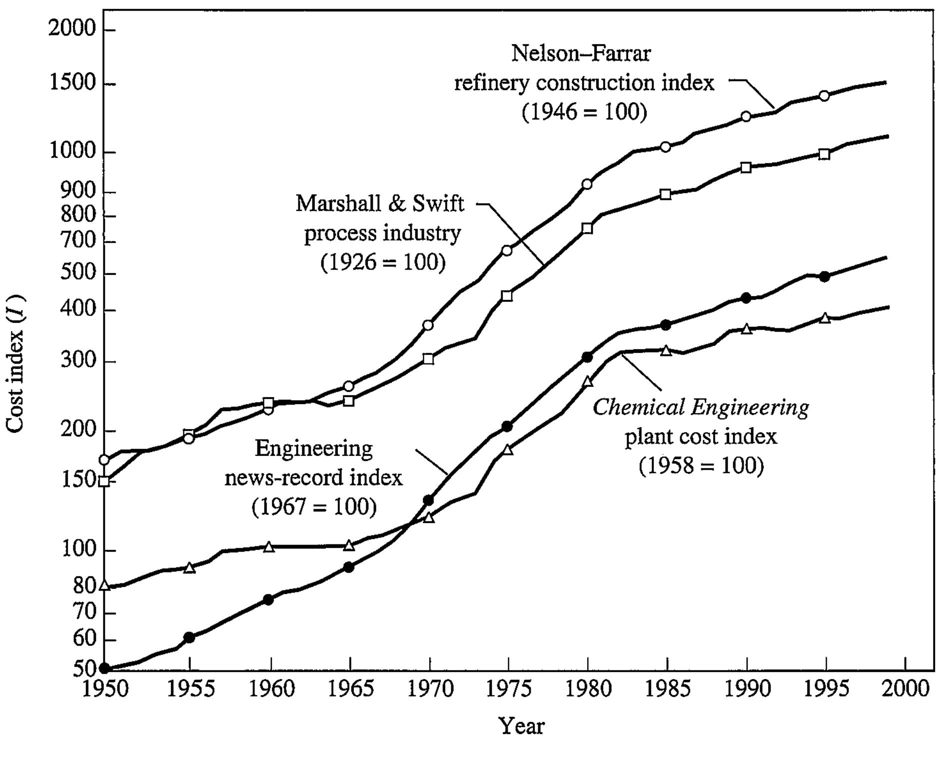

FIGURE B.4
History of selected cost indexes pertinent to chemical process construction (1950–1998)

$$C_x = C_y \cdot \frac{I_x}{I_y} \tag{B.5}$$

The U.S. Bureau of Labor Statistics provides information that permits computation of estimated future labor and material costs. You can project costs to the future by fitting a cost index values for several time periods. If the slope b of the index is constant, then the ratio I_x/I_y versus t is a semilog plot

$$\ln\left(\frac{I_x}{I_y}\right) = bt \tag{B.6}$$

Labor costs experience inflation just as do capital costs as Figure B.5 demonstrates. Raw materials and fuel costs are subject to considerable erratic fluctuations as demonstrated by oil and metals prices, which have rapidly risen and fallen several times over the last five decades. For example, Figure B.6 shows the changes in refinery fuel price index since 1955. Prediction of refinery fuel prices in the future is clearly much more difficult than predicting capital costs.

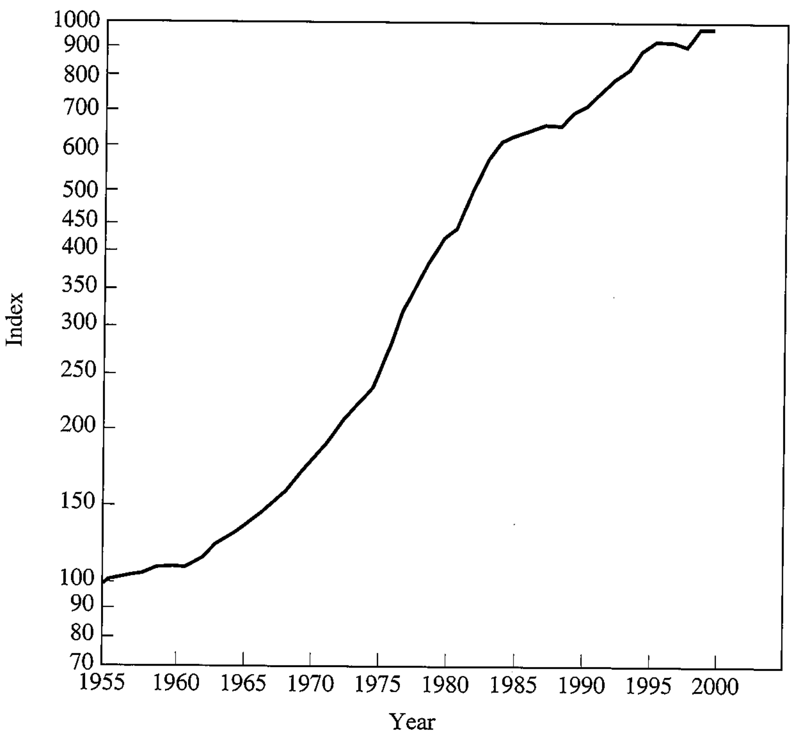

FIGURE B.5
Nelson–Farrar index of operating labor cost (wages plus benefits) 1955– 1999 (1956 = 100).

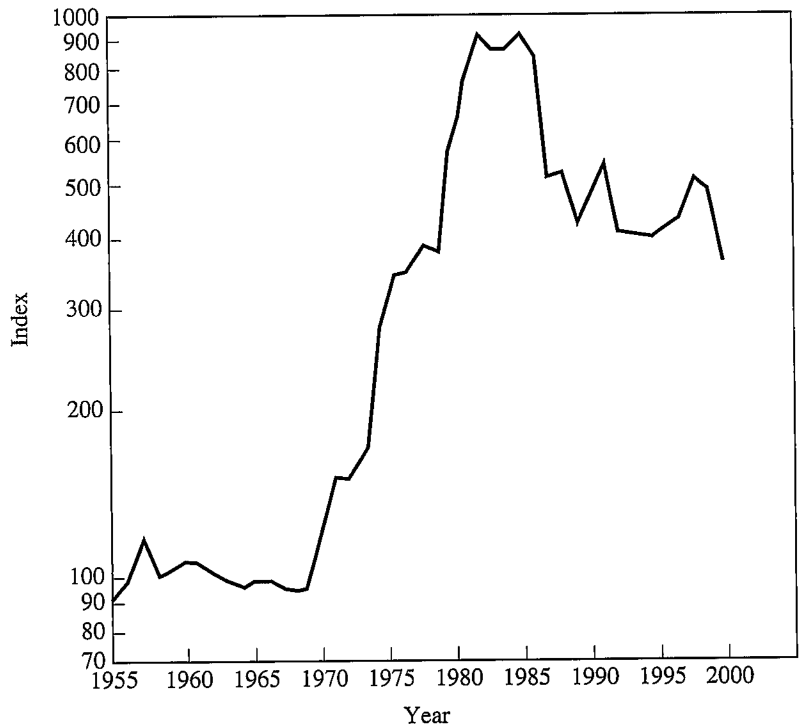

FIGURE B.6
Nelson–Farrar index of refinery fuel: 1955–1999 (1956 = 100).

B.4 PREDICTING REVENUES IN AN ECONOMIC-BASED OBJECTIVE FUNCTION

In maximizing profits over future periods, you have to estimate revenues along with costs. Revenues involve both quantities sold and their prices. The *top-down approach* involves disaggregation, namely starting with estimates of revenues of an entire industry or specialized market that includes the categories of products using company economic models or predictions by industrial trade associations. Then you estimate your company's share of each category. Next, you estimate revenues for a specific product in the category and estimate your company's share for the specific product. The categories can be nested within each other by sales territory, distributor, salesperson, and so on.

The other approach is the *bottom-up procedure*, which proceeds to aggregate projected sales data. You start with the projected sales data in each territory for each product and sum up the forecasts into successively larger amalgamations.

Forecasting revenues fundamentally rests on models plus judgment. More formal methods project the trends of past revenues into the future adjusting for known or expected fluctuations. Typical models employed are

1. Time series
2. Moving averages and smoothing
3. Regression
4. Kalman filters
5. Stochastic models
6. Error models
7. Neural nets

and are adjusted periodically based on the available data. Data can be historical in your database or taken from the reference cited at the start of this chapter. Keep in mind that estimates of future revenues have greater uncertainty than estimates of capital and operating costs. Look at Figure B.6 and imagine you were selling refinery fuel rather than buying it. How much error would occur in predictions of price made in 1969? 1980? 1988? Although sales volume changes with price to some extent, severe price fluctuations are more likely to occur than severe quantity fluctuations. In forecasting, expect unexpected disturbances and allow a margin for error in terms of probability distributions or "worst case" scenarios.

B.5 PROJECT EVALUATION

In Chapter 3, we discussed several criteria involving profitability including:

Payback period (PBP): the cost of an investment divided by the cash flow per period.
Net present value (NPV): the present value (including the time value of money) of initial and future cash flows given by Equation (13.4).
Internal rate of return (IRR): the interest or discount rate for which the future net cash flows equal the initial cash outlay.

Table 3.2 compared the respective features of these three criteria, and in the next two examples we illustrate the specific calculations involved in evaluating projects.

EXAMPLE B.2 USE OF PBP, NPV, AND IRR TO EVALUATE TWO POTENTIAL PROJECTS

Two alternative projects are under consideration. Project *A* has a project life of 10 years and requires an initial investment of $100,000 with an annual cash flow after taxes of $20,000/year for each of 4 years followed by $10,000/year for years five through ten. Project B has a life of 10 years and requires the same investment but has cash flows of \$15,000/year for each year. Based on the information presented in Chapter 3, evaluate projects A and B using (a) payback period, (b) internal rate of return, and (c) net present value, assuming an interest rate of 10 percent ($i = 0.10$).

Solution

(a) The respective payback periods are

Project A. It requires 4 years @ \$20,000 plus 2 years @ \$10,000, or a total of 6 years to recover the investment.

Project B.

$$\frac{\$100{,}000}{\$15{,}000} = 6.67 \text{ years}$$

These payback periods are quite close.

(b) To find the NPV of the two projects we calculate using Equation (3.4).

Project A.

$$\text{NPV} = -\frac{100{,}000}{(1+0.10)^0} + \frac{20{,}000}{(1+0.10)^1} + \frac{20{,}000}{(1+0.10)^2}$$

$$+ \frac{20{,}000}{(1+0.10)^3} + \frac{20{,}000}{(1+0.10)^4} + \sum_{k=5}^{10} \frac{10{,}000}{(1+0.10)^k} = -\$7{,}128.67$$

Project B.

$$\text{NPV} = -\frac{100{,}000}{(1+0.10)^0} + \sum_{k=1}^{10} \frac{15{,}000}{(1+0.10)^k} = -\$7{,}831.49$$

Again the values are quite close.

(c) To find the IRR of the two projects we calculate i with NPV 5 0 using Equation (3.4).

Project A.

$$0 = -\frac{100{,}000}{(1+i)^0} + 20{,}000 \sum_{k=1}^{4} \frac{1}{(1+i)^k}$$

$$+ 10{,}000 \sum_{k=5}^{10} \frac{1}{(1+i)^k}, \quad \text{the solution is } i = 8.06\% \text{ annually}$$

Project B.

$$0 = -\frac{100{,}000}{(1+i)^0} + 15{,}000 \sum_{k=1}^{10} \frac{1}{(1+i)^k}$$

The solution is $i = 8.14\%$ annually.

Presumably, neither of the projects would be favorable. Calculations such as made in this example engender a high degree of uncertainty because of the long periods involved, so that a decision between projects, if implemented, is a toss-up.

NPV does not require that the total lives (or multiples thereof) of projects be equal for a comparison to be made. Thus, ambiguous and sometimes contradictory results can arise in using IRR versus NPV [Brigham (1982), Woinsky (1996)]. Jelen and Black (1983) have suggested a comparison based on uniform annual cost, called *unacost.*

EXAMPLE B.3 CALCULATION OF IRR AND NPV FOR PROJECTS WITH DIFFERENT LIFETIMES

Suppose project C has a 20-year life and a yearly after-tax cash flow of \$48,000 for an initial investment of \$300,000. Project D has a 5-year life, with a yearly cash flow of \$110,000 for an initial investment of \$300,000. Compare the internal rate of return and net present value (for $i = 0.08$) for each option.

Solution. Because the annual cash flows are uniform for projects C and D, we can apply Equation (3.4a). The internal rates of return are $i_C = 0.15$ for project C and $i_D = 0.25$ for project D. The advantage of project D is a more concentrated period of early cash generation at a high level. For a value of $i = 0.08$, the NPV of each project is as follows:

Project C:

$$\text{NPV} = \left(\sum_{j=1}^{20} \frac{48{,}000}{(1+i)^j} \right) - 300{,}000$$

$$= 470{,}600 - 300{,}000 = \$170{,}600$$

Project D:

$$\text{NPV} = \left(\sum_{j=1}^{5} \frac{110{,}000}{(1+i)^j} \right) - 300{,}000$$

$$= 438{,}200 - 300{,}000 = \$138{,}200$$

Therefore, based strictly on this calculation, project C would be favored over D because over its lifetime (20 years versus 5 years), it would generate more (discounted) cash flow. This conclusion is in conflict, however, with that obtained by comparing the IRRs of the two projects. The ranking based on NPV may change if a

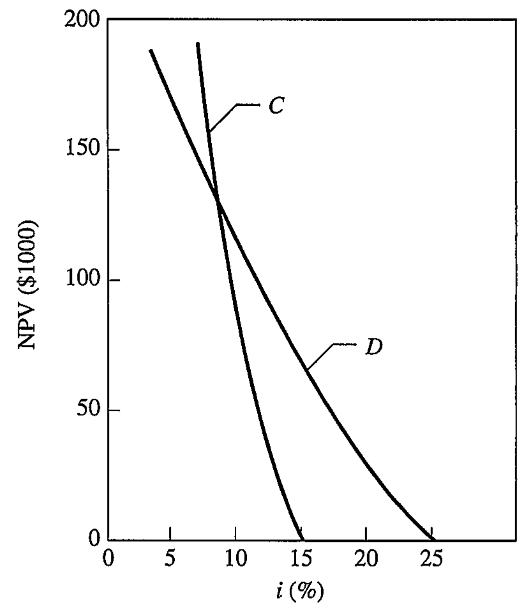

FIGURE EB.3
Comparison of the net present value (NPV) for two projects as a function of i.

different interest rate is assumed. Figure EB.3 shows how NPV varies for each project as a function of i (note the crossover point). Brigham (1982) has concluded that the use of NPV is preferable to IRR, because NPV gives more realistic results for a wide variety of cases, especially when cash flows vary greatly from year to year.

One important assumption to keep in mind in the calculations outlined earlier is that the interest rate (discount rate) has been assumed to be constant over time even though it is not in practice. Examine Figure B.7, which shows how the interest rate for U.S. Treasury securities has changed over time for various durations of investment ranging from 3 months to 30 years (called the yield curve).

To make a decision about investing in a project, more than just cash flows need to be taken into account. Cash flows are reasonably clear-cut, whereas using earnings as a criterion in a multiyear project involves a number of accounting and legal decisions that affect the profitability.

To distinguish between cash flows and earnings, let us look at a grossly simplified set of financial statements for a company. The three statements are a

1. Balance sheet
2. Cash flow statement
3. Income and expense statement

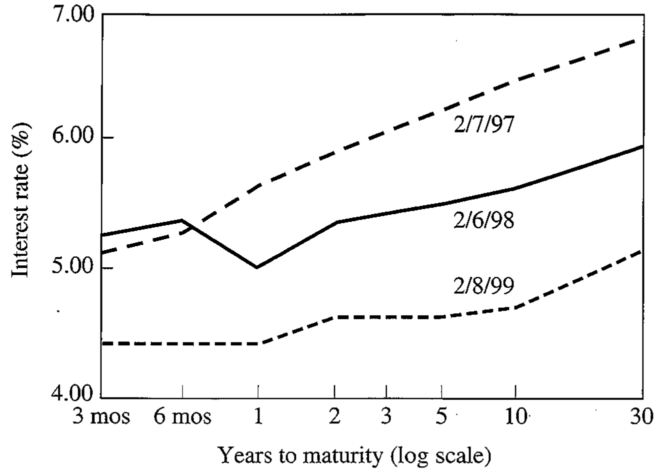

FIGURE B.7
Interest rate provided by U.S. Treasury bills, notes, and bonds at different dates.

Balance Sheet

Assets:		
Cash	$100,000	
Building	900,000	
Total	$1,000,000	(Must always be equal)
Liabilities and equities:		
Long-term debt	$600,000	
Equity	400,000	
Total	$1,000,000	

FIGURE B.8
A simplified balance sheet.

Figure B.8 illustrates the balance sheet. A balance sheet is a snapshot of the assets and liabilities at one point in time. It tells nothing about the transactions and adjustments that led to the numbers presented in the statement. A comparison of balance sheets over time can help indicate earnings.

Next, Figure B.9 represents a simplified cash flow statement for a retail computer store. The bottom number in the statement does not represent profit (income, earnings)—just the net of the cash flows, because the $30,000 mortgage payment

Cash Flow Statement	
Receipts from sales during the year	$180,000
Disbursements during the year:	
Maintenance	$(10,000)
Property taxes	(30,000)
Mortgage payments to principal	(30,000)
Mortgage payments, to interest	(60,000)
Net before taxes	$50,000
Less income tax	(10,000)
Cash left after paying taxes	$40,000

FIGURE B.9
A simplified cash flow statement.

applied to principal is not deemed to be an item of expense, and the statement does not include a noncash expense incurred for depreciation of $20,000.

The third statement shown in Figure B.10 is for income and expense that leads to net after-tax profits (earnings), a quantity that transfers to the balance sheet periodically in the category called equity.

Figure B.10 gives you the correct $50,000 "bottom line." Note that both depreciation and interest are listed as deductible expenses. Interest is clearly an expense; but why depreciation? Unlike interest and other expense deductions, depreciation does not actually reduce operating cash. Nevertheless, we know that aging and obsolescence over a period of years does decrease the value of most things; depreciation is a loss. So you subtract it from income as you do for a cash expenditure.

The reconciliation between the cash flow statement and the income and expense statement is as follows. Start with the $40,000 from the last line in the cash flow statement, subtract $20,000 for the depreciation expense, and add back the $30,000 mortgage loan principal payment (not an allowed expense). The result is the net after-tax earnings. Figure B.11 is a set of statements from a small oil company. The statement of operations lists revenue and expenses, whereas the balance sheet lists various assets, liabilities, and stockholders' equity ("net worth"). So-called capital items such as buildings, equipment, oil and gas property, and various intangibles are assets. Operating costs are deductions from revenues for operations not including expenditures for capital items.

Some of the categories and terms on the statement require brief additional explanation.

Income and Expense Statement	
Income from sales	$180,000
Expenses	
Maintenance, property taxes	$ 10,000
Property taxes	30,000
Interest	60,000
Depreciation	20,000
Total expenses	120,000
Before tax earnings	$ 60,000
Income tax on $60,000 of earnings	10,000
Net after-tax earnings	$ 50,000

FIGURE B.10
A simplified statement of income and expenses.

Revenues

Revenues include cash received from sales of products and services. Cash received from the sale of equipment, buildings, and equipment is not considered revenue but is instead a decrease in the property and equipment accounts (assets).

Operating expenses

These cash expenses are those necessary to carry on the business, that is, expenses paid to generate revenue. A capital expenditure for plant or equipment generally is not an expense but an addition to the plant or equipment account (an asset). Typical expenses include cost of products sold, repairs, insurance, salaries, property taxes, and so on.

General and administrative expense

These are expenses that are not directly attributed to products, services, or plant, or equipment, such as legal fees, corporate salaries, research expenditures, charitable contributions, and so on.

Interest

Interest paid on loans and mortgages is usually segregated from other expenses.

Statements of Operations (Unaudited)	*Three Months Ended September 30,*		*Nine Months Ended September 30,*	
	2000	1999	2000	1999
Revenues	$ 3,724,004	$ 2,745,590	$ 9,927,736	$ 7,451,986
Operating expenses	(1,898,765)	(1,163,249)	(4,907,689)	(3,306,535)
Gross margin	1,825,239	1,582,341	5,020,047	4,145,451
General and administrative expense	(489,843)	(597,905)	(1,405,316)	(1,722,717)
Interest	(235,645)	(182,192)	(734,376)	(409,974)
Minority interest	2,919	—	17,854	75,086
Income before depletion, depreciation and amortization	1,102,670	802,244	2,898,209	2,087,846
Depletion, depreciation and amortization	(858,534)	(650,492)	(2,275,608)	(1,699,073)
Income before taxes	244,136	151,752	622,601	388,773
Income taxes	(53,154)	(33,825)	(139,754)	(86,025)
Net income	$ 190,982	$ 117,927	$ 482,847	$ 302,748

Balance Sheets (Unaudited)	*September 30, 2000*	*December 31, 1999*
Assets		
Current assets	$ 5,328,619	$ 4,753,476
Notes receivable and investments	—	1,403,640
Oil and gas properties, net	17,797,004	16,260,990
Property and equipment, net	3,267,741	1,913,897
	$ 26,393,364	$ 24,332,003
Liabilities and stockholders' equity		
Current liabilities	$ 5,313,891	$4,681,323
Senior debt	10,493,784	9,565,428
Subordinated notes	1,753,400	2,123,188
Minority interest	72,888	—
Stockholders' equity	8,759,401	7,962,064
	$ 26,393,364	$ 24,332,003

FIGURE B.11
Statement of a small oil company.

Depletion

Depletion is noncash allowance deductable from revenue for the recovery of the costs of a natural resource such as oil, gas, coal, or timber. The concept is that as the natural resource is exhausted, the assets of the company are depleted.

Amortization

Amortization is the recovery of certain capital expenditures that can be deducted from revenue in a manner similar to depreciation (discussed in the next section). Typical capital expenditures that can be amortized are pollution control facilities, removal of architectural barriers for the handicapped, reduction of goodwill (an asset not shown in Figure B.11), or patents and trademarks, and so on.

Depreciation

Depreciation is a noncash deduction from revenues for the reasonable exhaustion, wear and tear of, or obsolescence of, property used in the business. With respect to federal income taxes, the government has an enormous number of rules and regulations specifying how depreciation may be determined. Because these regulations change somewhat from year to year, new project evaluations should be based on the most recent regulations. Revisions in the income tax laws are often instituted with the express purpose of making capital investment more attractive by yielding a higher rate of return.

In the *straight-line (SL) depreciation*, it is assumed that the equipment value declines linearly with respect to time. The annual depreciation cost (d) is

$$d = \frac{I_0 - S_v}{n} \tag{B.7}$$

where I_0 = capital investment (in dollars)
S_v = salvage value (in dollars)
n = economic life (years)

The book value of the equipment can be found for any year j as $I_0 - jd$. For example, if the investment I_0 = \$10,000 and the salvage value S_v = \$1000, the annual depreciation for an asset with a 5-year life is \$9000/5 = \$1800.

Property other than buildings (18-year property) placed into service at the present time must use the *modified accelerated cost recovery system* (MACRS) in calculating depreciation. Property is classified as having 3, 5, 7, 10, 15, or 20 years life. Some examples are:

Three-year:	Special tools, televisions, furniture, computers
Five-year:	Cars, light trucks, technological equipment, telephone switching, research equipment
Seven-year:	Office furniture and fixtures
Ten-year:	Barges, fruit bearing trees

Rather than explain the complicated rationale behind the allowable rates of depreciation for those classes, Table B.5 just lists the rates for what is called accelerated depreciation (MACRS). Note that for each class you deduct some depreciation after the "useful life" (class life) expires. You can find other tables for accelerated depreciation for various circumstances in any guide to federal income taxes. If you do not want to choose accelerated rates of depreciation, you can choose straight-line depreciation (SL) using the rates listed in Table B.6. The specific

TABLE B.5
MACRS depreciation rates

(Half-year convention*)

Year	3-year property (%)	Year	5-year property (%)	Year	7-Year property (%)
1	33.33	1	20.00	1	14.29
2	44.45	2	32.00	2	24.49
3	14.81	3	19.20	3	17.49
4	7.41	4	11.52	4	12.49
		5	11.52	5	8.93
		6	5.76	6	8.92
				7	8.93
				8	4.46

*Half-year convention assumes the property is placed in service midyear no matter when it was actually placed in service.

TABLE B.6
Straight-line depreciation rates (half-year convention)

Year	3-Year property (%)	5-Year property (%)	7-Year property (%)	10-Year property
1	16.6	10.00	7.14	5.00
2	33.33	20.00	14.29	10.00
3	33.33	20.00	14.29	10.00
4	16.67	20.00	14.28	10.00
5		20.00	14.29	10.00
6		10.00	14.28	10.00
7			14.29	10.00
8			7.14	10.00
9				10.00
10				10.00
11				5.00

choice of MACRS, SL, or another method is quite complex because of the extensive detailed rules for depreciation allowance and corresponding federal income tax consequences and is therefore beyond our scope here.

EXAMPLE B.4 COMPARISON OF DEPRECIATION METHODS

A piece of capital equipment costs $6000, has a service life of 3 years, and has no salvage value. Compute the depreciation schedules using the following methods: SL and MACRS.

Solution. Assume the equipment falls into the 3-year class life schedule. The depreciation allowances are as follows:

Year	SL	MACRS
1	1000	2000
2	2000	2667
3	2000	889
4	1000	444

Salvage value

Salvage value is the price that can be actually obtained or is imputed to be obtained from the sale of used property if, at the end of its usage, the equipment (property) still has some utility. Salvage value is influenced by the current cost of equivalent equipment, its commercial value, whether the equipment must be dismantled and relocated to have utility for others, and the (projected) physical condition of the equipment. Salvage value can be thought of as a cash flow that may occur several years in the future, but does not represent income for federal income tax purposes when received.

Income taxes

The federal income tax on profits from corporations is based on income after all costs, including depreciation, have been deducted. Because depreciation affects taxable income, it is an important consideration in estimating profitability. The federal income tax rate for large corporations (profit greater than $75,000) was recently roughly 34–35 percent. State income taxes may push the total tax rate to about 40 percent. Therefore as an expense a depreciation amount of $1 reduces taxes about $0.40. At this level of taxation, the before-tax rate of return will be roughly 1.67 times the after-tax rate of return.

Tax credit

Periodically Congress has permitted the use of tax credits as a direct reduction from income taxes. Examples are tax credits for installing energy conservation devices, use of alcohol fuels and electric vehicles, development of orphan drugs, creation of low-income housing, and some research expenditures. Tax credits have been used historically to stimulate capital investment in the United States. Such deductions are more valuable than depreciation because they represent direct deductions from the tax bill after taxes are computed on income.

Two other factors that need to be considered in project evaluation that are not expressly found in financial statements are inflation and debt–equity ratio.

Inflation

Inflation can be a significant factor in analysis of profitability. High inflation rates frequently occur in many countries. In computing the rate of return or net present value, you need to obtain a measure of profitability that is independent of the inflation rate. If you inflate projections of future annual income, the computed rate of return may largely result from the effects of inflation. Most companies strive for an internal rate of return (after taxes) of 10–20 percent in the absence of inflation;

this figure would rise if projected future income is increased to include the effects of inflation (i.e., selling prices are raised yearly). Furthermore, costs will also rise because of inflation.

Griest (1979) has discussed the effects of inflation on profitability analysis and has pointed out that the percentage change in profits after income taxes rarely increases at the rate of inflation, largely due to the effects of taxation. Assumptions about inflation can change the relative ranking of project alternatives based on net present value; special techniques based on probability may be required because inflation is difficult to predict.

Debt–Equity ratio

The debt-to-equity ratio quantifies the sources of funds used for capital investment and is generally expressed as percent/percent, for example, 75/25 means 75 percent debt, 25 percent equity. Debt financing involves borrowing funds (from banks, insurance companies, or other lenders, or by selling bonds) based on fixed or adjustable interest rates and specified lengths of time until the loan is due. Equity financing involves selling shares of stock or partnership shares to raise investment funds or the expenditure of retained earnings of the company. Both debt and equity financing can be used on the same project. Compared with 100-percent equity financing, the rate of return on an investment can be increased if the interest rate for borrowed capital is favorable because interest payments are considered to be an expense in computing income taxes. Suppose that the debt interest rate is 12 percent and the equity interest rate is also 12 percent. Because interest payments are deductible, the effective debt interest rate after taxes for a tax rate of 40 percent is 7.2 percent.

Next, let us go through an example of project evaluation that includes most of the factors just discussed.

EXAMPLE B.5 EVALUATION OF USING EQUITY VERSUS DEBT FINANCING

Suppose you are asked to evaluate the purchase of the multicone cyclone referred to in Example 3.4. The capital investment is $35,000 (see Example 3.4), and the equipment has a class life of 5 years, after which it will be sold for the salvage value of $4000. The income stream generated by the machine is on line A in Tables EB.5A and EB.5B. As the equipment ages, its operating and maintenance costs increase, and line B lists the expense profile. Assume a tax rate of 35 percent with no investment tax credit. Evaluate two possible scenarios: (a) 100 percent use of equity and (b) 100 percent debt financing. Use straight-line depreciation; for debt financing, for simplicity assume equal annual payments (principal plus interest) to the lender for the 5 years at a rate of 10.5%.

Solution. Tables EB.5A and EB.5B list the data needed in the evaluation. Depreciation is straight line (SL). The gain on sale of the cyclone at the end of the year 5 is $500 (which is subject to ordinary income tax)

TABLE EB.5A
Calculations for purchase of cyclone (100% equity)

	Year				
	1	2	3	4	5
A. Income	$18,000	$28,000	$30,000	$30,000	$30,000
B. Expenses	2,000	3,000	5,000	7,000	8,000
C. Profit (A − B)	16,000	25,000	25,000	23,000	22,000
D. Depreciation (straight line)	3,500	7,000	7,000	7,000	7,000
E. Net income before taxes (C − D)	12,500	18,000	18,000	16,000	15,000
F. Gain on sale at end of year 5	—	—	—	—	500
G. Income taxes (0.35(E + F))	4,375	6,300	6,300	5,600	5,425
H. Net income after taxes (E + F − G)	8,125	11,700	11,700	10,400	10,075
I. Salvage value	—	—	—	—	4,000
J. Cash flow (D + H + I)	11,625	18,700	18,700	17,400	21,075

TABLE EB.5B
100 percent debt financing for cyclone

	Year				
	1	2	3	4	5
A. Income	$18,000	$28,000	$30,000	$30,000	$30,000
B. Expenses	2,000	3,000	5,000	7,000	8,000
Interest	3,675	3,079	2,420	1,693	889
C. Profit (A − B)	12,325	21,921	22,580	21,307	21,111
D. Depreciation (straight line)	3,500	7,000	7,000	7,000	7,000
E. Net income before taxes (C − D)	8,825	14,921	15,580	14,307	14,111
F. Gain on sale at end of year 5	—	—	—	—	500
G. Taxes (0.35(E + F))	3,089	5,222	5,453	5,007	5,114
H. Net income after taxes (E + F − G)	5,736	9,699	10,127	9,300	9,497
I. Principal payments	5,676	6,272	6,931	7,658	8,463
J. Salvage value	—	—	—	—	4,000
K. Cash flow (D + H + I + J)	3,560	10,427	10,196	8,642	12,034

Cost	$35,000
Accumulated depreciation	31,500
Adjusted basis for income tax	$ 3,500

Sales price	$4,000
Basis	3,500
Gain	$ 500

What criterion should you use to make the evaluation? You can calculate the internal rate of return for case (a) from

$$0 = \frac{-35{,}000}{(1+i)^0} + \frac{11{,}625}{(1+i)^1} + \frac{18{,}700}{(1+i)^2} + \frac{18{,}700}{1+i)^3} + \frac{17{,}400}{(1+i)^4} + \frac{21{,}075}{(1+i)^5}$$

the solution for which is IRR = 38 percent. But what about case (b)? The input and outflow in year 1 would be $35,000 received as a loan, less $35,000 paid out as the purchase price of the cyclone, leaving 0 as the initial cash flow. The IRR would be infinite!

Consequently, a better criterion for evaluation is to use the net present value for each case. Select an interest (discount) rate of 15 percent per annum.

Case (a):

$$\text{NPV}_a = \frac{-35{,}000}{(1+i)^0} + \frac{11{,}625}{(1+i)^1} + \frac{18{,}700}{(1+i)^2} + \frac{18{,}700}{(1+i)^3} + \frac{17{,}400}{(1+i)^4} + \frac{21{,}075}{(1+i)^5}$$

$$= \$52{,}500$$

Case (b):

$$\text{NPV}_b = \frac{0}{(1+i)^0} + \frac{3{,}560}{(1+i)^1} + \frac{10{,}427}{(1+i)^2} + \frac{10{,}196}{(1+i)^3} + \frac{8{,}642}{(1+i)^4} + \frac{12{,}034}{(1+i)^5}$$

$$= \$28{,}608$$

Clearly case (a) appears better. But other interest rates could be chosen and similar calculations made for NPV. For example, for an interest rate of 25 percent per annum

$$\text{NVP}_a = \$9{,}875$$

$$\text{NVP}_b = \$17{,}780$$

so that at the higher discount rate case (b) is preferred.

The change in the NPV using debt financing of assets is known as the principle of *leverage*. A similar result can often be obtained by leasing equipment because the lease payments are completely deductible as expenses for income tax purposes.

REFERENCES

Aspen Technology, Inc. *Aspen Plus*. Cambridge, MA (1998).

Brigham, E. F. *Financial Management: Theory and Practice*, 3d ed. Dryden Press, Chicago (1982).

Brown, T. R. "Capital Cost Estimating." *Hydrocarbon Processing*, pp. 93–100 (October, 2000).

CHEMCOST. Process Equipment Cost Estimation. Icarus Corp., Rockville, MD (1999).

Garrett, D. E. *Chemical Engineering Economics*. Kluwer, New York (1989).

Green, D. W.; and J. O. Maloney, eds. *Perry's Chemical Engineering Handbook*, 7th ed. McGraw-Hill, New York (1997).

Griest, W. H. "Making Decisions in an Inflationary Environment." *Chem Eng Prog* p. 13 (June, 1979).

HYSYS. Hyprotech Ltd. Calgary, Alberta, Canada (1998).

Jelen, F. C.; and J. H. Black. *Cost and Optimization Engineering*. McGraw-Hill, New York (1983).

Kuri, C. J.; and A. B. Corripio. "Two Computer Programs for Equipment Cost Estimation and Economic Evaluation of Chemical Processes." *Chem Engr Educ* pp. 14–17 (Winter, 1984).

Oil and Gas Journal. Tulsa, OK.

Ostwald, P. F. *Engineering Cost Estimating*, 3rd ed. Prentice-Hall, Upper Saddle River, NJ (1992).

ProII. Simulation Sciences, Brea, CA (1998).

Rusnak, I.; A. Guez; and I. Bar-Kana. "Multiple Objective Approach to Adaptive Control of Linear Systems." In *Proceedings of the American Control Conference*. San Francisco, June 1993, pp. 1101–1105.

Seider, W. D.; J. D. Seader; and D. R. Lewin. *Process Design Principles*. John Wiley, New York (1999).

Turton, R.; R. C. Baile; W. B. Whiting; and J. A. Shaeiwitz. *Analysis, Synthesis, and Design of Chemical Processes*. Prentice-Hall, Upper Saddle River, NJ (1998).

Woinsky, S. G. "Use Simple Payout Period to Screen Projects." *Chem Eng Prog* pp. 33–37 (June, 1996).