CHAPTER EIGHT

Economic Evaluation

This chapter deals with the economic evaluation of engineering projects. The purpose of economic evaluation is to identify the benefits and costs of a project and hence to determine whether it is justified on economic grounds. Alternative solutions to an engineering problem can also be compared based on their respective costs and benefits. It is usually necessary to discount the future benefits and costs of a project in order to make comparisons in terms of present value. Various economic criteria have been proposed for the comparison of projects. Each of these has its merits, although the best on theoretical grounds is net present value.

8.1 INTRODUCTION

An engineering project involves the transformation of limited resources into valuable final products or outputs. For example, the construction of a dam involves the use of resources such as concrete, steel, human effort, and machine time. The dam is used to produce outputs such as water for domestic and industrial purposes, flood control, and recreation.

The engineer must be concerned not only with the technical feasibility of the project (i.e. will it work?) but also the economic feasibility. *Economic evaluation* is aimed at assessing whether the value of the final products exceeds the value of the resources used by the project. The values of the outputs when measured in economic terms are called the *benefits* of the project. Similarly the values of the resources used in its construction and maintenance when measured in economic terms are called the *costs* of the project.

In the private sector, benefits and costs are measured by cash flows into and out of the firm, respectively. That is, a conceptual boundary is drawn around the firm and benefits and costs are represented by cash flows across this boundary.

For public sector projects, benefits and costs must be considered for society as a whole. In this case, benefits and costs are not necessarily associated with cash flows. For example, the benefits of a public transport system are not necessarily measured by the revenue which it generates. The government may choose to run the system at a loss for social or environmental reasons. In this case the benefits to the users of the system would probably exceed the revenue generated by it. If, for example, public transport were offered free of charge, few people would argue that the benefits to society were zero.

Sometimes there is a different perception of benefits and costs at various levels of government. For example, the federal government may provide a subsidy of 50% of the capital costs of new sewage treatment plants. When a state government is evaluating a particular plant it would consider this subsidy as a reduction in the cost of the project. On the other hand, the federal government would consider the subsidy as merely a transfer payment from one branch of government to another and therefore not a true benefit or cost to society as a whole. In fact, the federal government may require the state to provide economic justification for the project in its (i.e. the federal government's) terms without including the subsidy effect.

8.2 THE TIME VALUE OF MONEY

The costs and benefits (or revenue) of an engineering project usually occur over a long time period. For example, consider the construction of a new freeway. A typical time stream of benefits and costs is illustrated in Figure 8.1. Costs will be high during the construction phase which may last for three or four years. These costs could include disruption and inconvenience to users of the existing and adjoining roads. Annual maintenance and repair costs will be low initially, but will increase due to ageing of the pavement, bridges, and other components. The benefits to road users will be primarily due to savings in vehicle operating costs, savings in travel time and a reduction in the number of accidents in relation to the pre-existing road network. These benefits would normally increase with time due to increasing volumes of traffic using the freeway.

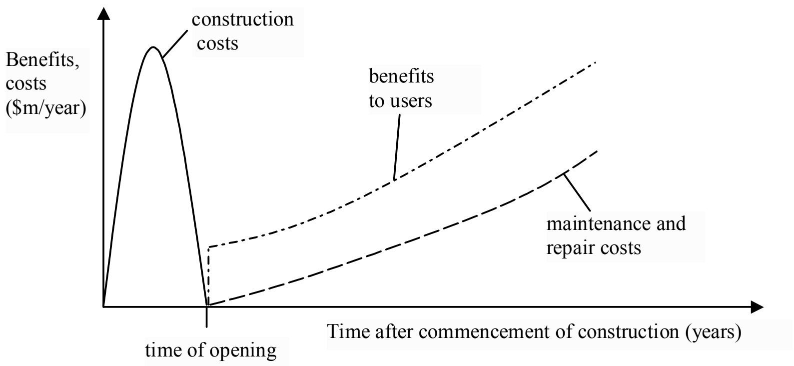

Figure 8.1 The time stream of benefits and costs for a freeway.

In carrying out an economic evaluation of such a project, it must be recognized that benefits or costs incurred in ten years cannot be directly compared with those incurred in the current year. Given the choice between $1000 now and $1000 in 10 years, very few people would choose the latter. In the first place, the effects of inflation are such that fewer goods and services could be purchased with the future sum than at present. However, even in the absence of inflation, human nature is such that there is a preference to consume goods now rather than later, and to postpone costs if possible. This is clearly evidenced by the fact that many individuals are willing to borrow money at an interest rate which exceeds the rate of inflation. Therefore, in carrying out economic evaluation, it is necessary to discount future benefits and costs in order to make them directly comparable with benefits and costs incurred now. This is carried out using discounting formulae derived from considerations of compound interest.

8.3 DISCOUNTING FORMULAE

In all the economic calculations that follow, there are two basic assumptions:

- there is a single rate of interest (the *discount rate*) that applies into the future for both borrowing and lending;
- interest is paid in a compound fashion; that is, if interest is earned, then it is added to the capital and taken into account for future calculations of interest.

Figure 8.2 Historical values of the standard variable home loan interest rate in Australia. (Source: Loansense, 2016)

If one looks at home loan interest rates and how they have varied over time in Australia (see Figure 8.2), it may be thought that the first assumption is questionable. However, despite the fact that rates do vary, it is usual for calculations to be carried out assuming an unvarying rate. If the rate does change at a later time, adjustments are made, again on the assumption of a constant rate into the future.

Present worth - lump sum

If a sum of money P is invested for one year at an interest rate of i, then after one year the value will be:

$$F = P(1+i) \tag{8.1}$$

where F is the future sum and P the present sum. For example, \$100 invested at a interest rate of 5 percent per annum ($i = 0.05$) for one year would yield \$105 at the end of the year. If that money is invested for a second year, then the value becomes:

$$F = P(1+i)(1+i) = P(1+i)^2 \tag{8.2}$$

After two years the initial \$100 yields \$110.25. After a period of n years it can be shown that the basic formula to calculate the future worth of a sum of money can be written as:

$$F = P(1+i)^n \tag{8.3}$$

where F is the future sum, P the present sum, i the interest rate and n the number of years (or to be more precise, the number of time periods over which the interest is paid). Some results for a simple situation are shown in Table 8.1.

Table 8.1 Future sums after a variable number of years with an interest rate of i and an initial sum of \$1000.

Years	Future return from \$1,000 invested for n years at various interest rates			
	2%	5%	8%	10%
1	1,020	1,050	1,080	1,100
2	1,040	1,103	1,166	1,210
5	1,104	1,276	1,469	1,611
10	1,219	1,629	2,159	2,594
100	7,245	131,501	2,199,761	13,780,612

It is convenient to show the process on a timeline (Figure 8.3) where the horizontal axis represents time and the vertical axis the units of money. While this appears trivial for the present example, once the situation becomes more complicated, the advantages of the time plot will become apparent.

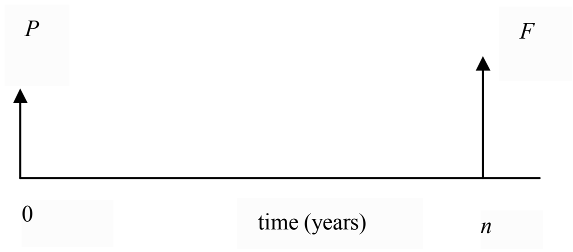

Figure 8.3 Timeline showing future value based on present value.

By rearranging Equation (8.3), it is possible to see how much must be deposited today to yield a certain sum of money after a given period.

$$P = \frac{F}{(1+i)^n} \tag{8.4}$$

where P is the present value of a lump sum of F, to be paid in n year.

Worked example

What is the present worth of $1000 that will be received in 10 years' time assuming a 10 % per annum (p.a.) compound interest rate?

Solution The timeline for the problem is shown in Figure 8.4. The present sum can be calculated from:

$$P = \frac{1000}{(1+0.10)^{10}} = \$385.54$$

The important point to grasp is that under the interest rate specified, $385.54 today and $1,000 in 10 years have equal worth. Alternatively, if $385.54 were placed in a bank account paying 10 % per annum. interest, the sum would accumulate to $1,000 in 10 years.

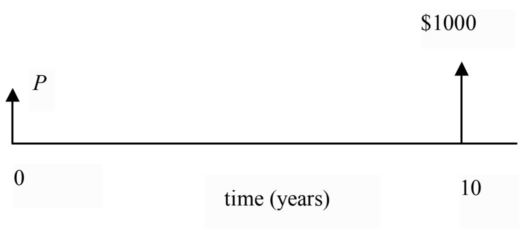

Figure 8.4 Timeline for the worked example.

Compound interest dates back to antiquity

The concept of compound interest (interest paid on interest) dates back to the ancient civilisations of Sumer and Babylon where it was usual to charge 20 % p.a. compound interest on loans of silver and 33 1/3 % p.a. compound interest on loans of barley.

Around 2400 BCE, the ruler of the Sumerian city of Lagash, Enmetena, engaged in a battle against the neighbouring city of Umma. Enmetena had a temple built to commemorate his victory and the details of the battle were recorded on the clay foundation stone of the temple. Also recorded on the foundation stone was the fact that Lagesh had loaned a large quantity of barley to Umma at 33 1/3 % interest p.a. The scribe had correctly calculated that the amount of barley to be repaid after 7 years was 7.5 times the original loan.

If the initial quantity borrowed was *X,* the future quantity owed can be calculated using Equation (8.3) as follows:

$$F = P\,(1+i)^n = X\,(1 + 0.33333)^7 = 7.492\,X$$

Source: Muroi, 2017

Present worth - uniform series

It is often necessary to find the present worth of a uniform series of annual payments. These may be regular mortgage repayments for a homeowner or the cost of leasing a particular piece of equipment for a manufacturer. The timeline for this is shown in Figure 8.5 where \$$A$ is paid at the end of each year for n years, and these payments are to be made equivalent to a single sum \$$P$ at the present time. Note that it is usual to assume that annual costs for maintenance or repair occur at the end of each year, whereas capital costs for new buildings or equipment occur at the start of the year.

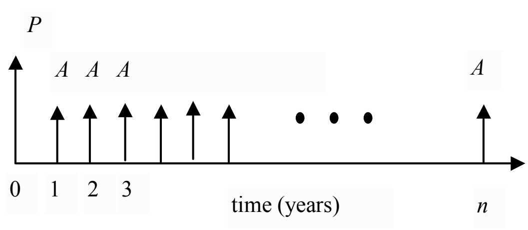

Figure 8.5 Timeline showing the equivalence between a present value, P, and a series of n annual payments of A.

Note that the first payment of \$$A$ is at the end of the first year. It is possible to discount the annual payments one by one. In this case:

$$P = \frac{A}{(1+i)} + \frac{A}{(1+i)^2} + \ldots \frac{A}{(1+i)^n} \tag{8.5}$$

However, by treating this as the sum of a geometric series, it is possible to write this in a more convenient way:

$$P = A\left[\frac{1-(1+i)^{-n}}{i}\right] \tag{8.6}$$

It is also possible to transpose the equation to determine what annual series is equivalent to have a present value of $\$P$:

$$A = P\left[\frac{i}{1-(1+i)^{-n}}\right] \tag{8.7}$$

where P is the present worth of a uniform series of payments of $\$A$ over a period of n years.

Worked example

A project is expected to yield \$3m a year in benefits for 30 years. What is the present value of the benefits assuming a discount rate of 8% ?

Solution Applying Equation (8.6):

$$P = 3\left[\frac{1-(1+0.08)^{-30}}{0.08}\right] = \$33.77 \text{ m}$$

Loan repayments and outstanding balances

When a loan is taken out, it is normal to repay the total debt over a number of years with repayments that are maintained at the same level over the whole period. This raises the problem of knowing how much is left to repay at any particular time. For example, in the case of a loan of \$100,000 taken out at a 7.5% annual interest rate over a 25 year period, how much is still owed at the end of 1 year or 10 years? In the following calculations it is assumed that repayments are made annually. A similar procedure may be applied to monthly or weekly repayments. The annual repayment on the loan can be calculated from Equation (8.7):

$$A = 100{,}000\left[\frac{0.075}{1-(1+0.075)^{-25}}\right] = \$8{,}971.07$$

To determine the outstanding debt after x years, it is necessary to consider the present value of the annual repayments that remain to be paid over a period of (n - x) years. Therefore, the outstanding debt after 1 year (P_1) is a series of annual payments over 24 years. In this case:

$$P_1 = 8971.07 \frac{1-(1+0.075)^{-24}}{0.075} = \$98{,}528.96$$

Therefore, after a single annual repayment of \$8,971.07 there is still \$98,528.96 left to repay, a debt reduction of only \$1,471.04. The other \$7,500.34 has gone in interest repayments. As time goes by, the total repayment remains the same, but interest component gradually reduces while that going to reduce the outstanding debt gradually increases. This is shown in Figure 8.6 for the current example.

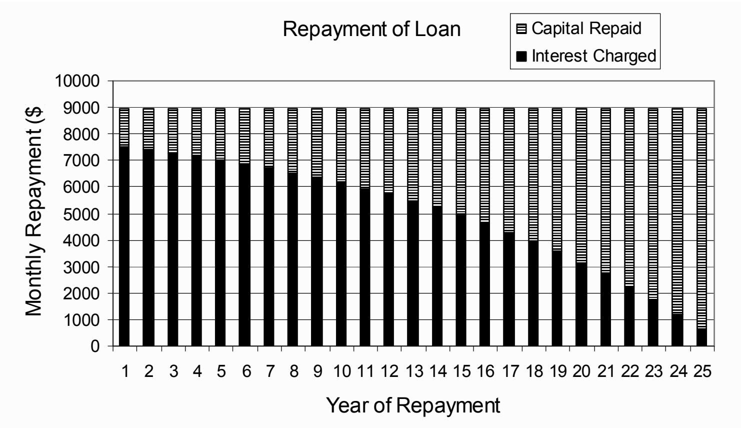

Figure 8.6 The split between interest (solid) and capital repayment (hatched) of each annual payment is shown. Note how the interest component gradually reduces over time.

After 10 years, 15 annual payments each of \$8,971.07 remain to be paid, so the remaining balance of the loan (P_{10}) can be determined as follows:

$$P_{10} = 8971.07 \frac{1-(1+0.075)^{-15}}{0.075} = \$79{,}188.71$$

To illustrate the effect that more frequent payments have on the calculations the same problem is repeated for monthly repayments for the same annual interest rate. An annual interest rate of 7.5% equates to 0.625% per month and the monthly repayment (M) can be calculates as:

$$M = 100{,}000 \frac{0.00625}{1-(1+0.00625)^{-300}} = \$738.99$$

Over one year the total annual repayment is calculated from 12 monthly payments and is equal to \$8867.89 (a slight increase on the previous figure). After one year there will be 288 repayments left to make leaving a remaining balance (P_{1m}) given by the following calculation:

$$P_{1m} = 738.99 \frac{1-(1+0.00625)^{-288}}{0.00625} = \$98{,}583.93$$

The balance still owed after one year is \$98,583.93 which is slightly higher than for annual repayments.

The subject of different repayment intervals will be dealt more formally in the next section where it will be seen that it is possible to determine a relationship between the same interest rate compounded annually and monthly.

Effective interest rate

Interest rates are generally quoted as a percentage per annum (i.e per year), but the compounding period (the frequency with which the interest is charged or paid) is often less than a year. As we have just seen, this makes a difference to the calculations, and in order to allow a valid comparison the concepts of a nominal interest rate and an effective interest rate have been developed. If the nominal interest rate is r percent per annum and it is charged in m periods over a year then the interest rate applied at each period is (r/m). For example, an annual rate of 18% charged monthly means that the interest charged each month is 1.5%. Therefore if \$$P$ is invested at the start of the year the balance at the end of m periods can be calculated using Equation 8.3 as:

$$F = P(1+r/m)^m \qquad (8.8)$$

If this monthly rate is to be quoted as an equivalent annual rate, i, then it must produce the same future sum at that equivalent annual rate:

$$F = P(1+r/m)^m = P(1+i) \qquad (8.9)$$

so the equivalent annual rate can be calculated as:

$$i = (1+r/m)^m - 1 \qquad (8.10)$$

Worked example

A credit agency claims to charge 18% p.a. but interest is calculated monthly. What is the effective rate of interest?

Solution By applying Equation (8.10) it is possible to determine the effective annual rate of interest.

$$i = (1+r/m)^m - 1 = (1+0.18/12)^{12} - 1 = 0.1956 = 19.56\% \text{ p.a.}$$

Hence, 18% per year charged monthly is equivalent to 19.56% per year charged annually. Note that in a number of countries, financial institutions must publish their interest rates as an equivalent annual rate so that consumers can make informed choices.

Interest and the natural logarithm

If the annual interest rate is 100% and $1 is invested for 1 year, then the way interest is charged (annually, monthly, etc.) can be seen to change the outcome considerably. If charged annually, the amount invested at the end of the year will be $2. If it is paid six monthly, the amount will be $2.25. These, and other possibilities, climaxing in continuous payment of interest are

Interest is paid ...	Final Sum
Annually	$2.00
Six Monthly	$2.25
Quarterly	$2.44
Monthly	$2.61
Weekly	$2.69
Daily	$2.714567
Hourly	$2.718127
Continuously	$2.71828182845 (*e*, the base of the natural logarithm)

The effect of inflation on economic evaluation

Inflation is represented by a rising general level of prices. It is important to note that during an inflationary period the prices of all goods and services are not necessarily rising nor are all prices necessarily rising at the same rate. The effect of inflation is that a dollar next year will buy less than a dollar today. There have also been periods in history when the general level of prices in some countries or regions decreased. This is called *deflation*.

Changes in the general level of prices may be measured by a price index. This is defined as 'the average price of a mixture of goods and services in a given year' divided by 'the average price of the same mixture of goods and services in a base year' (expressed as a percentage). A common price index is the consumer price index or CPI. The CPI measures changes in the prices of goods and services purchased by moderate-income families. It is based on the prices of a large number of representative items each weighted according to its relative importance in the typical family budget. Movements in the consumer price indexes for a number of countries are shown in Table 8.2.

Of particular relevance to engineering projects are the price indexes for construction and building costs. These indexes for a number of North American cities are available from the Engineering News Record website (Engineering News Record, 2017). In Australia, current and historical values of the building cost index can be obtained from Rawlinsons (2016).

It is important to distinguish clearly between the concepts of inflation and the time value of money. Even in the absence of inflation, very few people would be prepared to lend money at zero interest. As most people would prefer to consume goods and services now rather than later, there is clearly a real time value of money. In times of inflation, lenders expect a real rate of return on their money which exceeds the inflation rate. For example, anyone who receives 3 percent p.a. interest on an investment when the inflation rate is 5 percent p.a. is clearly losing money.

Table 8.2 Consumer price index for a selection of world countries. Base year (100.0) = 2010. Adapted from World Bank (2016)

Country	2013	2014	2015
Australia	107.7	110.4	112.0
Brazil	119.4	126.9	138.4
Canada	105.5	107.5	108.7
China	111.2	113.4	115.0
Germany	105.7	106.7	106.9
India	132.0	140.4	148.6
Indonesia	116.9	124.4	132.3
Japan	100.0	102.8	103.6
Korea	107.7	109.1	109.8
New Zealand	106.3	107.6	107.9
Russia	121.6	131.2	151.5
South Africa	117.5	124.7	130.3
Switzerland	99.3	99.3	98.2
United Kingdom	110.1	111.8	111.8
United States of America	106.8	108.6	108.7

Before we consider how inflation is taken into account in economic evaluation, some definitions are required.

Actual dollars (or *then-current dollars*) are dollars which are current in the particular years that the benefits and costs occur. For example, if a person bought a block of land in 1970 for $50,000 (in then-current dollars) and sold it in 2000 for $200,000 (in then-current dollars) have they made a profit on the investment? The answer is yes if $200,000 in 2000 will buy more goods and services than $50,000 in 1970. Otherwise, they have lost on the investment.

Constant-worth dollars are dollars which have the same purchasing power at a defined point in time, e.g., 2010 dollars. For example, a new power station is designed to provide 8000 GWh of electrical energy per year under certain operating conditions. The benefits to consumers of this energy are estimated to be $600m in 2010 (the first year of operation). Thereafter, the station will continue to provide 8000 GWh of energy per year for its estimated operating life of 40 years. The annual benefits expressed in actual dollars will continue to increase throughout the life of the station due to inflationary increases in the price of electricity and the prices of goods produced with it. However, when expressed in constant-worth dollars (e.g., 2010 dollars) the annual benefits are likely to be constant over the life of the station if the same amount of energy is produced each year.

The *nominal interest rate* is the rate received on invested money (or paid on borrowed money) when calculated in terms of actual (or inflated) dollars. The *real* *rate of interest* on an investment is the rate received net of inflation. For example, if money is invested at a nominal interest rate of 8% p.a. when the annual inflation rate is 5% p.a., the real interest rate (i.e., above inflation) is approximately 3% p.a.

The economic evaluation of engineering projects can be taken into account in one of two equivalent ways:

- by using actual dollars and the nominal interest rate throughout;
- by using constant-worth dollars and the real rate of interest throughout.

The first method is commonly used in evaluating private sector investments in which the future cash flows are estimated in actual dollars and the nominal interest rate is usually known. The second method is more commonly used for evaluating public sector investments, as it is often easier to estimate future benefits and costs in constant-worth dollars. In this case there is no need to estimate an inflation rate. The interest rate or discount rate used is the real rate above inflation. As will be discussed in Section 8.10, the choice of the discount rate in the public sector is the source of some controversy. In this book, constant-worth dollars and real interest or discount rates will be used unless otherwise stated.

Relationship between nominal and real interest rates

Consider the annual maintenance costs of a bridge which requires a constant number of person-hours of maintenance each year during its life of n years. (This is a gross simplification, as it would be normal for the amount of maintenance to increase as the bridge deteriorates with age.) When expressed in constant-worth dollars, the annual maintenance cost of the bridge is a constant amount (say $\$A$) per year for the life of the bridge, as shown in Figure 8.7.

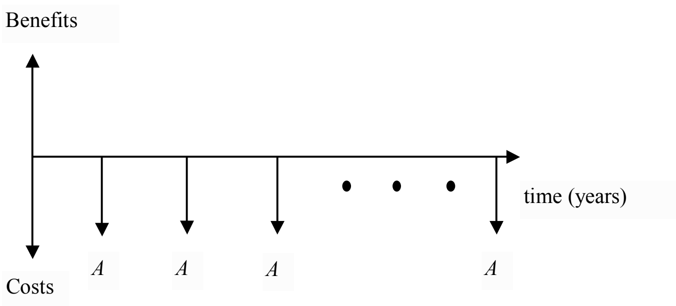

Figure 8.7 Bridge maintenance costs in constant-worth dollars.

If the anticipated inflation rate for the life of the project is f % p.a. (compound), then the maintenance costs in actual dollars are shown in Figure 8.8. The nominal rate of interest is assumed to be known and is denoted by i_n. The objective is to find a relationship between the real interest rate, i, the nominal interest rate, i_n, and the inflation rate, f. The present worth of the series shown in

Figure 8.8 is denoted by *P*. It can be determined by applying Equation (8.4) to each annual payment using actual dollars and the nominal interest rate:

$$P = \frac{A(1+f)}{(1+i_n)} + \frac{A(1+f)^2}{(1+i_n)^2} + \cdots \frac{A(1+f)^n}{(1+i_n)^n} \tag{8.11}$$

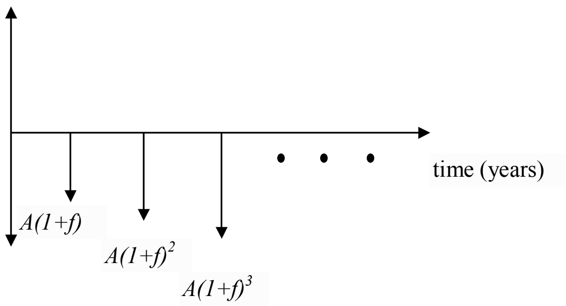

Figure 8.8 Bridge maintenance costs in actual dollars (*f* = annual inflation rate).

The right-hand side of Equation (8.11) can be simplified, as it is the sum of a geometric series:

$$P = \frac{A(1+f)}{(1+i_n)} \left\{ \frac{1-(1+f)^n/(1+i_n)^n}{1-(1+f)/(1+i_n)} \right\} \tag{8.12}$$

Now, the present worth of the series shown in Figure 8.7 is found using constant-worth dollars and the real interest rate, *i*. Rewriting Equation (8.5):

$$P = \frac{A}{(1+i)} + \frac{A}{(1+i)^2} + \cdots \frac{A}{(1+i)^n} \tag{8.13}$$

It should be apparent that the two equations (Equations (8.11) and (8.13)) are equivalent if:

$$(1+i) = \frac{(1+i_n)}{(1+f)} \tag{8.14}$$

Therefore, the real interest rate can be calculated using the following equation:

$$i = \frac{(1+i_n)}{(1+f)} - 1 \tag{8.15}$$

Worked example

In Kenya in 1998 the nominal rate of interest for borrowing was 21% and the annual inflation rate 15% (Adeoti et al., 2000). What was the real rate of interest under these conditions?

Solution The real rate of interest, i, can be found by applying Equation (8.15):

$$i = \frac{(1+i_n)}{(1+f)} - 1 = \frac{1+0.21}{1+0.15} - 1 = 0.052 \text{ or } 5.2\% \text{ p.a.}$$

8.4 EVALUATION CRITERIA

Various economic criteria have been proposed for use in comparing engineering projects. The following criteria are described briefly and compared:

- payback period;
- net present value;
- equivalent annual worth;
- benefit-cost ratio; and
- internal rate of return.

Payback Period

The payback period is defined as the time it takes for the project to generate sufficient net benefits to cover its initial cost of construction and implementation. For example, if a project has an initial capital cost of \$10m, annual benefits of \$3m and annual operating costs of \$1m, the payback period can be calculated as:

Net annual benefits = \$3 m - \$1 m = \$2 m
Payback period = \$10 m / \$2 m = 5 years

Net Present Value

The net present value (NPV) of a project is defined as the present value of all benefits minus the present value of all costs. It can be written as:

$$NPV = PVB - PVC \tag{8.16}$$

where *PVB* is the Present Value of Benefits and *PVC* is the Present Value of Costs. By using the formulae for *PVB* and *PVC* we can write:

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \tag{8.17}$$

where B_t is the benefit in year t, C_t is the cost in year t, i is the discount (or interest) rate and n is the life of the project (years). The calculation of NPV therefore involves discounting all costs and benefits back to the present time to allow them to be compared at the same point in time. It is important to note that while Equation (8.17) is mathematically correct, it is unlikely that it would be the way the actual calculation will be carried out. For example, if the costs are a series of annual payments, Equation (8.6) would most likely be used to discount them back to the present time.

Payback period case studies

Best (2000) quotes a payback period of 4 years for the lighting and heating of a building for Lockheed in the 1980s where natural light was used in place of electric lights, and where this also reduced the need for air conditioning. It was further stated that productivity gains due to the healthier environment in the building gave the company a competitive advantage in its bid for a large contract, the profit from which would have paid for the entire building.

Morgan and Elliot (2002) used payback period to justify the implementation of a mechanical mixing system for a water supply reservoir. The motors used only 8.5% of the power required for a traditional aerator plant and had an estimated payback period of 4 years based on direct savings in energy costs.

The price of solar cells has been reported (*The Australian* - 8/8/01) as falling to 20% of that of 25 years ago. Rooftop systems that can meet half a home's electricity needs for more than 20 years now cost as little as US$10,000. This was quoted as having a five- to six-year payback period in California compared with 20 years a few years ago.

Equivalent annual worth

The NPV brings all benefits and costs to the present time and gives the answer as a single present day sum of money. There may be an argument for representing the project in terms of its net annual earnings over the period of the project. In this case the Equivalent Annual Worth (EAW) may be more appropriate. The EAW is found by converting all project benefits into a series of constant annual benefits for n years, where n is the life of the project. Similarly all project costs are converted into a series of constant annual costs for n years. The equivalent annual worth is then equal to the equivalent annual benefit minus the equivalent annual cost. A reliable method for calculating EAW is to determine it from the NPV applying Equation (8.7) which gives:

$$EAW = NPV\left[\frac{i}{1-(1+i)^{-n}}\right] \tag{8.18}$$

Benefit-cost ratio

The benefit-cost ratio (B/C) is widely used for evaluating projects in the public sector. As normally defined, it is the present value of all benefits divided by the present value of all costs:

$$B/C = \frac{PVB}{PVC} \tag{8.19}$$

where PVB is the Present Value of Benefits and PVC is the Present Value of Costs. It can be calculated as:

$$B/C = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}} \tag{8.20}$$

where the terms are as defined previously.

Again, it is worth noting that while Equation (8.20) is mathematically correct, it is unlikely that it would be the way the actual calculation would be carried out. It is much more likely that the benefits and costs would be discounted back to present worth using appropriate formulae for lump sums or uniform annual series.

Benefits and costs of natural and nature-based coastal defences

Narayan et al. (2016) studied the coastal protection benefits and costs of 52 projects that involved restoration of natural systems including coral reefs, oyster reefs, salt marshes and mangroves. The benefits were based on the reduction of wave heights and included savings in erosion damage costs, savings in damage costs from storms and savings in costs of adjacent coastal structures. They found that 41% of the mangrove projects and 6% of the salt marsh projects had a benefit-cost ratio greater than one.

Furthermore, Narayan et al. (2016) compared the cost of these restoration projects with the cost of constructing submerged reefs at the corresponding locations. The dimensions of the reefs were chosen to give the same reduction in wave heights. They estimated that the ratio of the cost of a submerged reef to the cost of nature-based defences averaged 5 for the mangrove projects and 2 for the salt marshes.

Internal rate of return

The economic criteria discussed so far (with the exception of the payback period) involve the use of a discount rate to convert all future benefits and costs to present value. The internal rate of return (also called "yield") is a different concept in that it is the implied interest rate of the investment. The internal rate of return is the discount rate at which the present value of benefits just equals the present value of costs over the life of the project. The internal rate of return (IRR) of a project, *r*, can be determined by finding the discount rate at which the present value of the benefits equals the present value of the costs:

$$PVB = PVC \tag{8.21}$$

This can also be written as:

$$\sum_{t=0}^{n} \frac{B_t}{(1+r)^t} = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} \tag{8.22}$$

where the terms are as defined previously. In general this will involve the solution of a polynomial in order to determine *r*.

Internal rate of return case studies

Campus Review (2002) reported results from an OECD evaluation of the benefits of a university education. It was found that the private rate of return to the individual was about 11% p.a. and the return to society ranged between 6% and 15% p.a. This was based on higher average earnings and lower risks of unemployment. It was suggested that the rates were higher than conventional investments and therefore money spent on a university education was money well spent.

8.5 A COMPARISON OF THE EVALUATION CRITERIA

There are three basic types of decisions requiring economic evaluation. They are:

1. go or no-go decisions, for example, whether or not to build a new airport;
2. the choice of a single project from a list of mutually exclusive projects, for example, the choice between a bridge and a tunnel for crossing a major waterway; and
3. the choice of a number of projects when the total funds available are limited, for example, how to allocate an annual capital works budget between feasible projects.

Go or no-go decisions (type 1 decisions)

In deciding whether or not an individual project is justified on economic grounds, any one of the following criteria may be applied:

$$NPV > 0 \quad \text{or} \quad EAW > 0 \quad \text{or} \quad B/C > 1 \quad \text{or} \quad IRR > i$$

Only one of these needs to be looked at since they will all lead to the same decision. For example, if the present value of benefits exceeds the present value of costs, then *NPV* will be positive, *EAW* will be positive, *B/C* will exceed 1 and the *IRR* will exceed the discount rate.

Choice from a list of mutually exclusive options (type 2 decisions)

Often economic decisions are used to choose from a number of different options where only one will be chosen. For example, what sort of car to buy, or which laptop computer to purchase. In each case, one will be chosen in preference to the others. For example, consider two air-conditioning systems that are identical in performance but differ in their costs. A summary of relevant information is given in Table 8.3. For this example, an equivalent annual benefit has been added to make the comparison more interesting. A discount rate of 12% p.a. will be used in the comparison. The question is: which is the better system on economic grounds?

Table 8.3 Costings for two air-conditioning systems. (Adapted from Rawlinsons, 2004). Note: salvage value is not available at end of project.

Characteristic	System X	System Y
Capital cost	\$115,600	\$158,800
Life of plant	10 years	15 years
Annual costs	\$37,800	\$28,200
Annual benefits	\$80,000	\$80,000
Salvage value	\$3,000	\$7,000

As the two systems have different lives, it is important to undertake the economic evaluation over an appropriate time period. If 10 years is used, System X will be due for salvage at the end of the period, whereas System Y will have 5 years life remaining. If, on the other hand a period of 15 years is used, System Y will be due for salvage at the end of the period, whereas System X will need to be replaced after 10 years and the replacement system will have 5 years left at the end of the period of analysis, The basic principle is to use a period of analysis that is the lowest common multiple of the lives of the various alternatives. In this case this is 30 years, as this allows for the initial purchase plus exactly two replacements of System X and the initial purchase plus exactly one replacement of System Y. The exception to this would be if the company plans to close operations after a certain period (e.g., a mine because it is expected to run out of ore). In this case the period of operations should be used for the comparison.

Having chosen 30 years as the period of analysis, a timeline is drawn for the whole 30-year period for System X (see Figure 8.9). Note that since the plant only lasts 10 years, it will have to be replaced twice. If System X is the better choice initially, it will also be the preferred choice after 10 years and 20 years. In the absence of better information, it is assumed that the original prices are the best estimate for the values to be used in subsequent purchases.

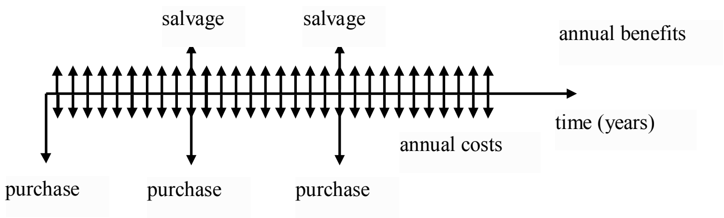

Figure 8.9 The timeline for System X showing the purchase and salvage of three units, each lasting 10 years together with the annual costs.

The Present Value of the Costs can be calculated as:

$$PVC = 115600 + \frac{115600}{1.12^{10}} + \frac{115600}{1.12^{20}} + 37800\frac{1-1.12^{-30}}{0.12} = \$469{,}289.94$$

The Present Value of the Benefits can be calculated as:

$$PVB = \frac{3000}{1.12^{10}} + \frac{3000}{1.12^{20}} + 80000\frac{1-1.12^{-30}}{0.12} = \$645{,}691.64$$

Therefore, $NPV = PVB - PVC = \$176{,}401.70$

The Internal Rate of Return is calculated by solving for the rate, r, such that:

$$115600 + \frac{115600}{(1+r)^{10}} + \frac{115600}{(1+r)^{20}} + 37800\frac{1-(1+r)^{-30}}{r} =$$
$$\frac{3000}{(1+r)^{10}} + \frac{3000}{(1+r)^{20}} + 80000\frac{1-(1+r)^{-30}}{r}$$

The solution is $r = 0.347$, that is 34.7%.

The same calculations are now carried out for System Y over the whole 30-year investment period (see Figure 8.10). Since System Y has a longer life, it will only have to be replaced once as is evident from Figure 8.10.

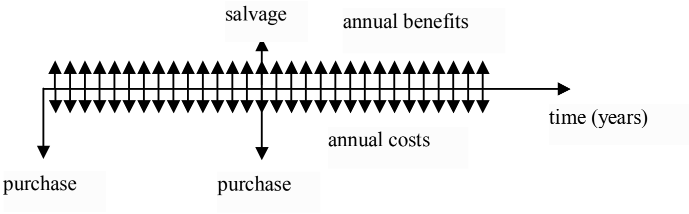

Figure 8.10 The timeline for System Y showing the purchase of two units, each lasting 15 years together with the annual costs and salvage benefits.

$$PVC = 158800 + \frac{158800}{1.12^{15}} + 28200\frac{1-1.12^{-30}}{0.12} = \$414{,}968.35$$

$$PVB = \frac{3000}{1.12^{15}} + 80000\frac{1-1.12^{-30}}{0.12} = \$644{,}962.81$$

$$NPV = \$229{,}994.45$$

The Internal Rate of Return is solved in a similar fashion to the previous value. The solution is $r = 0.321$ or 32.1%. Based on the calculations it is possible to list the various economic indicators as shown in Table 8.4 for the two systems.

Table 8.4 Comparison between System X and System Y.

Economic Criterion	System X	System Y
NPV	\$176,401	**\$229,994**
B/C	1.38	**1.55**
IRR (%)	**34.7**	32.1

It is evident that not all indicators agree on the better system, but, economists support the use of the NPV criterion for this type of decision. Hence System Y should be selected despite having an inferior Internal Rate of Return.

A variation on the above decision-making situation is when one design must be chosen from among a number of alternatives, each of which performs substantially the same function. For example, the choice between two designs for a road bridge, one of which has prestressed concrete girders and the other steel girders. In both cases, the girders act compositely with a reinforced concrete deck. The benefits of the bridge may be assumed to be the same for both designs and may therefore be ignored in the decision. In this case the NPV criterion is equivalent to finding the design which minimises the present value of costs (assuming that the present value of benefits exceeds the present value of costs for the chosen design). Alternatively, the choice may be made by minimising the equivalent annual cost. The B/C and IRR criteria cannot be used in this situation.

Capital budgeting problems (type 3 decisions)

It will be the case for most organisations that the cost of the full list of desirable projects exceeds the available funds and a choice has to be made regarding which projects will proceed in the current budget round and which will not. In the previous section, it was found that the different methods of economic comparison (B/C ratio, NPV and IRR) can give different results when used to choose one project from among a list of options. This problem will also occur in capital budgeting.

Capital budgeting using B/C or IRR

When making a capital budgeting decision based on the use of the benefit cost ratio or the internal rate of return, the general procedure is to rank the projects from best to worst in terms of the criterion. Projects are then chosen from the top down until the budget is exhausted. The method is demonstrated with an example.

Worked example

A city council is attempting to plan its capital works for the coming year and must decide which projects should be selected using B/C ratio. The available budget is \$35 m. A list of possible projects is given in Table 8.5. It is assumed that all of the costs are capital costs for this example.

Table 8.5 Potential projects, their benefits and costs.

Project	*PVB* (\$m)	*PVC* (\$m)	*NPV* (\$m)	*B/C*
A	40	15	25	2.67
B	18	10	8	1.80
C	18	12	6	1.50
D	50	20	30	2.50
E	28	10	18	2.80
F	26	20	6	1.30

Solution Using B/C, the projects are ranked in order as shown in Table 8.6 and selected off the top until the budget is exhausted. Selecting from the top gives Project E with a cost of \$10 m. This leaves \$25 m to spend. Therefore, Project A can also be selected as it has the next highest B/C ratio and a cost of \$15 m. This leaves \$10 m in the budget. Project D is next on the list in terms of B/C, but its cost of \$20 m exceeds the \$10 m that remains in the budget, so the search continues. Project B is next and costs \$10 m which exactly exhausts the budget. Therefore, the projects selected are E, A and B with a total PVC of \$35 m and a NPV of \$51 m.

Table 8.6 Potential projects, their benefits and costs sorted in order of B/C ratio.

Project	PVB($m)	PVC($m)	NPV($m)	B/C
E	28	10	18	2.80
A	40	15	25	2.67
D	50	20	30	2.50
B	18	10	8	1.80
C	18	12	6	1.50
F	26	20	6	1.30

Capital budgeting using NPV

When using NPV, the procedure is a little more complicated in that a set of projects must be chosen which maximise NPV, subject to the available capital budget. Therefore, it is necessary to set up an optimisation model which is, in fact, an integer linear programming problem. This will be demonstrated using the same example above.

To set up the problem in a standard format, the first step is to define variables X_i where i = A, B, C, D, E, F such that if $X_i = 1$ the project is selected, and $X_i = 0$ if not. The aim is to maximise the NPV so a value Z is defined which will be the total NPV over all the projects:

$$\text{Maximise } Z = 25X_A + 8X_B + 6X_C + 30X_D + 18X_E + 6X_F$$

The cost of all projects selected must not exceed the available budget so the following constraint applies:

$$15X_A + 10X_B + 12X_C + 20X_D + 10X_E + 20X_F \le 35$$

and $X_i = 1$ or 0 (binary variables) for i = A, B, C, D, E, F.

The solution of integer linear programming problems is beyond the scope of this book. The solution of linear programming problems with continuous variables is discussed in Chapter 13. For simple problems, the solution can be found by inspection or a limited trial and error procedure as:

$$X_D = X_A = 1 \text{ with all other } X_i = 0.$$

That is, Projects A and D should be undertaken, but not the others. In this case the adopted projects have a PVC of \$35m and NPV of \$55m. This NPV is \$4m higher than for the projects chosen using B/C. In general it can be shown that NPV is a better criterion than B/C for capital budgeting projects. It can also be shown that IRR is inferior to NPV in capital budgeting.

World Bank programs and projects

According to Talvitie (2000), when the World Bank lends money for infrastructure programs (e.g., road development) in the form of individual projects in developing countries, it does so with the aim of reducing poverty, but is also mindful of ensuring that projects are well engineered and technically feasible. For major road projects, steps are taken to safeguard the environment, cultural heritage, indigenous people, and endangered species, and in fact approximately 50% of project preparation costs are spent on these issues while the design and traffic engineering component may only be 20–25%.

In terms of selecting actual projects, Talvitie states that the project priority setting and program development and evaluation steps occur together rather than simply picking projects off the top of the list until the funds are exhausted; an approach which may lead to a less-than-optimal mix of projects.

8.6 ADVANTAGES AND LIMITATIONS OF EACH CRITERION

From the previous section it should be clear that each economic criterion may lead to a different choice of project(s) when choosing one or more from a list of feasible alternatives. It is important therefore to consider the advantages and limitations of each criterion in turn.

Payback period

Although the payback period is often quoted in the press, there are various problems with the method. Firstly, the criterion does not deal with the time value of benefits and costs. Secondly, and equally importantly, the method may ignore significant benefits or costs that occur after the payback period. On the other hand, the advantage of the method is that it is an intuitively appealing concept and can make a compelling argument for implementing a project.

Payback period has also been used in other aspects of economic decision making. For example, in an assessment of the economic viability of a biogas project for Nigeria, Adeoti et al. (2000) promoted the payback period as a measure of project riskiness.

However, because of its limitations, payback period is not recommended for use in the evaluation of major engineering projects.

The internal rate of return

This criterion has the advantage of not requiring a prescribed value of discount rate for its determination. As the specification of a discount rate may be the source of considerable controversy, particularly in the public sector, this is an advantage in project selection. However, this advantage is outweighed by the disadvantages of the criterion, namely:

- to determine the IRR involves the solution of a polynomial equation;
- sometimes more than one value of IRR may be obtained for a particular project.

Worked example

Figure 8.11 shows the time stream of expected revenue and costs for a proposed open-cut mining development. There is an initial cost to establish the mine and associated works and a high cost at the end of the project due to clean-up and re-vegetation activities. What is the IRR for the project?

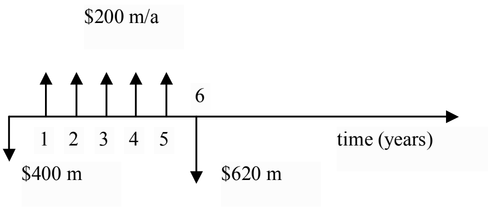

Figure 8.11 Timeline showing costs and benefits for open cut mining development.

Solution Let i = the discount rate of the project. Then the Net Present Value can be calculated as:

$$NPV = 200\frac{1-(1+i)^{-5}}{i} - \frac{620}{(1+i)^6} - 400$$

Figure 8.12 shows a plot of NPV as a function of i.

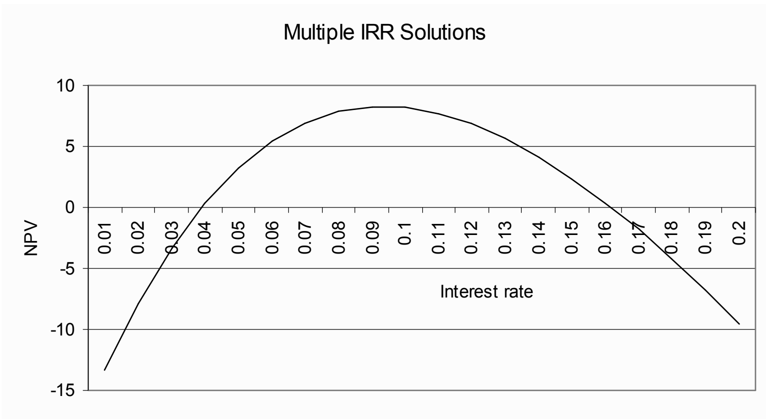

Figure 8.12 Plot of NPV versus interest or discount rate. The IRR is where NPV = 0.

It can be seen that there are two values of *i* for which the NPV is zero, namely 3.8% and 16%. Both of these values may be interpreted as the internal rate of return of the project. If the project were being ranked in a capital budgeting exercise it could receive a high or low place depending on the value of IRR used. Although this is a somewhat unusual case, it does demonstrate one difficulty with using the IRR criterion, i.e., it is the solution of a polynomial equation for which more than one root may exist.

Equivalent annual worth

To determine the EAW of a general time series of benefits and costs, it is necessary first to compute the NPV of the series and convert the NPV into a uniform annual payment throughout the life of the project. Considering that EAW gives the same ranking as NPV for projects with equal lives, a strong case can be made for using NPV directly.

Benefit-cost ratio

The benefit-cost ratio has been used extensively in a number of countries for comparison of projects of various sizes. It has some degree of appeal when used in the context of allocating scarce capital funds, i.e., capital budgeting. However, there is some ambiguity in its definition for projects with high recurrent costs (e.g., operating, maintenance, and repair costs). The basic issue here is whether the present value of recurrent costs should be treated as negative benefits and deducted from the numerator of the B/C ratio, or treated as costs and added to the denominator. A different value of B/C ratio will result in each case. For example, consider the economic comparison of two projects with the relevant economic data summarized in Table 8.7.

Table 8.7 Potential projects, their benefits and costs.

Economic Parameter	Project 1	Project 2
PV of benefits B ($m)	1.5	4.0
Construction costs C ($m)	1.0	1.0
PV of OMR costs K ($m)	0.0	2.0
B/C No. 1 = B/(C + K)	1.50	1.33
B/C No. 2 = (B - K)/C	1.50	2.00
NPV = B - K - C	0.5	1.0
OMR cost = operating, maintenance and repair costs		

For B/C Ratio No.1 in Table 8.7, the present values of all costs are included in the denominator. For B/C Ratio No.2, the present values of recurrent costs are subtracted from the present value of benefits in the numerator. The rationale for this latter definition is that in many cases it is really the capital costs which are limited; the recurrent costs may be met from the annual benefits.

If the projects are compared using the first definition of B/C ratio, Project 1 is preferable. Conversely, if the second definition of B/C ratio is used, Project 2 is preferable. On the other hand, NPV always gives an unambiguous ranking of projects, as it does not matter whether OMR costs are subtracted from the benefits or added to the construction costs. In this case, the NPV criterion favours Project 2.

It might be argued that this is not a major problem; why not just define the B/C ratio in one way or the other and proceed? However, in many situations the project benefits are composed entirely of savings in cost. For example, the benefits of most road projects consist of savings in travel time, savings in operating cost, and savings in cost due to a reduction in accidents. In such cases the B/C ratio obtained depends on the arbitrary definitions of benefits and costs, whereas NPV is unambiguous.

Net present value

Most economists advocate NPV as the most appropriate criterion for comparing projects. It measures the net gain to society (or the company) of the proposed project. It can be used in any of the three decision-making contexts discussed above. In the case of a go or no-go decision, the choice is independent of the criterion used. However, in choosing a single project from a list of mutually exclusive projects, NPV appears to favour large projects.

Worked example

An engineering firm is considering the purchase of a multi-core computer since it currently pays for the use of a super computer on a time-sharing basis. Two models of multi-core computer are being considered. The relevant economic data are given in Table 8.8. Which option should be chosen?

Table 8.8 Potential projects, their benefits and costs.

Economic data	System A	System B
Purchase Price ($)	10,000	20,000
Annual benefits	4,000	8,000
Life (years)	5	5
PV of benefits ($)	18,914	37,828
NPV ($)	8,914	17,828
EAW ($/year)	1,226	2,452
B/C	1.89	1.89
IRR (%)	28.65	28.65

Solution The benefits represent the estimated savings in computing cost due to reduced usage of the super computer. From Table 8.8 it can be seen that System B has the same life as System A, but twice the cost and twice the benefits. Its NPV and EAW are therefore twice those of System A, while its B/C ratio and IRR are the same. The tendency for NPV (and EAW) to favour large projects is apparent. If there is no constraint on the amount of money that can be spent, the increased NPV of System B is a net gain to the firm and therefore it is the better option. If there are limited funds available for investment due to other equipment needs, the problem should be treated as part of a capital budgeting exercise.

8.7 ECONOMIC BENEFITS

One important issue which needs to be addressed in economic evaluation is the estimation of the benefits and costs of any particular project. In order to understand the basis for this estimation some concepts from microeconomic theory can be drawn upon. The theory of price determination in perfectly competitive markets is presented in Appendix 8A in this chapter.

A fundamental distinction should be drawn between the estimation of benefits in the private and public sectors. In the private sector, the benefits (or revenue) of a particular project can be identified as *cash flows* into the firm. Benefits may be determined by the additional output of goods and services multiplied by the market prices for these commodities. In a competitive market situation, each individual firm is obliged to sell its output at the ruling market price due to pressure from its competitors. In this situation, the output of any one firm is so small that it has a negligible impact on the market price. Furthermore, the market price is a measure of the willingness-to-pay of the marginal consumer of that product. Therefore, the market price is a measure of the marginal benefit to society of providing additional units of the commodity.

In the public sector, the basic economic objective is to maximize benefits minus costs for society as a whole. In many cases benefits (and costs) will not equal the cash flows which result from the project. For example, public transport could be heavily subsidised (or even offered at no charge to some members of the community). Few would argue that the price paid for a public transport trip is a true measure of the benefit of that trip.

The theoretically correct measure of public sector benefits is the *willingness-to-pay* by consumers for the outputs of the project. The amount that a consumer is willing to pay for a commodity is a measure of the value of the commodity to that consumer. This concept is illustrated in Figure 8.13 for the provision of a new good (e.g. a new type of smart phone) to a community. It is assumed that there is a maximum price, P_1, that any person is willing to pay for the new good. The market price, as determined by the intersection of the demand and supply curves for the good, is P_0. However, as indicated by the demand curve, one consumer is willing to pay $\$P_1$ for the good. Thus $\$P_1$ is a measure of the value of the good to that consumer. Someone is willing to pay $\$P_2$ ($< \$P_1$) for the second unit and so on. Finally, someone is only willing to pay $\$P_0$ for the good. Anyone not willing to pay

$\$P_0$ will, of course, not purchase the good at the current market price. Therefore, the total willingness-to-pay for the good is represented by the total shaded areas ($A + C$) in Figure 8.13. The amount actually paid by the consumers will equal the revenue P_0Q_0 (area C). The difference between the willingness-to-pay and the revenue is called the *consumers' surplus* (i.e., the area A). It represents the *net* benefits to the consumers of the good. The revenue is a benefit to the producers.

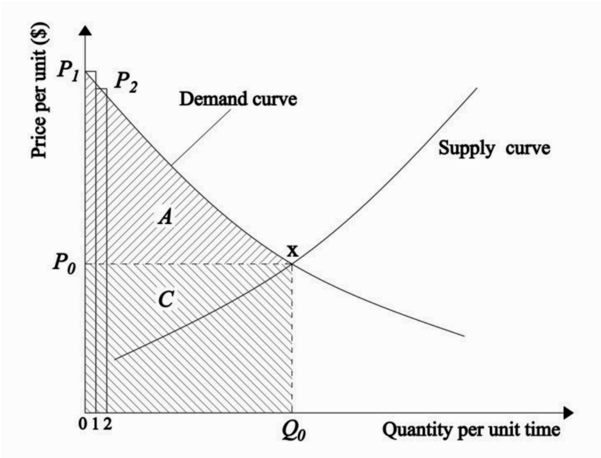

Figure 8.13 The willingness-to-pay concept.

In many cases the benefits of a public project can be assessed by the increase in consumers' surplus resulting from the project. For example, a state highway authority proposes to duplicate an existing two-lane highway which is currently heavily congested. The benefits of this project can be assessed using the increase in consumers' surplus. Figure 8.14 shows the demand-supply situation for the highway. The price per trip is represented by the sum of the operating cost plus the value of travel time per trip. The supply curve for the existing highway represents the price per trip as a function of the two-way volume.

The equilibrium volume on the existing highway is Q_1 vehicles per hour at a cost per trip of P_1. The new equilibrium volume on the duplicated highway will be Q_2 at a cost per trip of P_2. Note that an increase in volume is expected because an additional number of motorists now find it attractive to travel on the highway at the reduced price of P_2 per trip.

The benefit to all motorists is equal to the increase in consumers' surplus which is the shaded area in Figure 8.14. This consists of two parts:

- a reduction in cost to the existing users of the road (the rectangular area A)
- the consumers' surplus to new users (the approximately triangular area B)

If the demand curve is linear, the benefits are given by:

Increase in consumers' surplus = $(P_1 - P_2) \times (Q_1 + Q_2)/2$ (8.23)

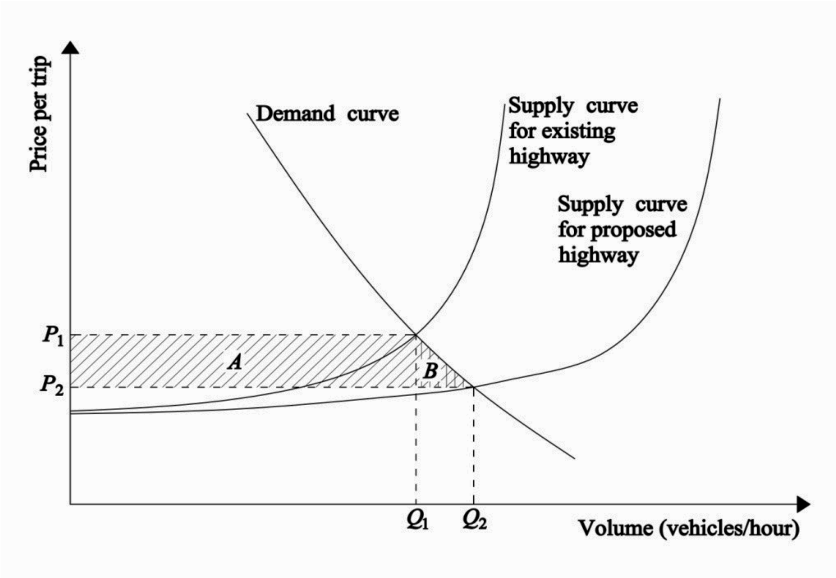

Figure 8.14 Increase in consumers' surplus of a duplicated highway.

Note that the concept of revenue is not relevant in this problem, as the price is not paid to a producer but represents a resource cost to society.

As a second example, the demand-supply situation for the provision of water to a city by a water authority is shown in Figure 8.15. The authority is considering constructing a new dam which would cause the supply curve to move to the right as shown, as the dam will increase the supply of water at any particular price. Assume that the authority sets the price of water equal to that which would apply in a competitive market situation.

Under the existing situation, Q_1 units of water are supplied per year at a price of P_1. With the new dam in place, the price would fall to P_2 and the volume supplied would increase to Q_2.

The benefits of the new dam will consist of the following:

- the benefits to the consumers as represented by the increase in consumers' surplus. This is area $(A + B)$ in Figure 8.15
- the increase in revenue to the water authority. This is given by $(P_2 Q_2 - P_1 Q_1)$ in Figure 8.15 or area $(C + D)$ minus area $(A + C)$

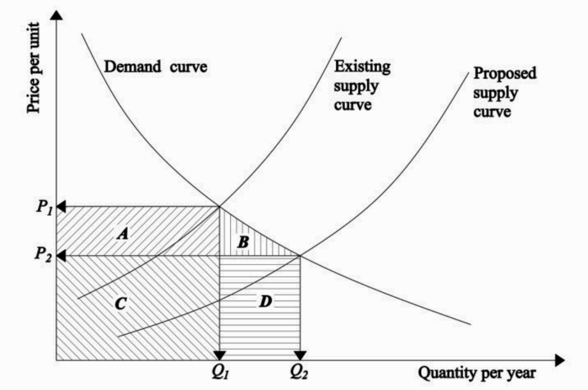

Figure 8.15 Benefits of an increase in urban water supply under market pricing.

The total benefits will be the sum of these, i.e., total benefits = increase in consumers' surplus plus increase in revenue

$= (A+B) + [(C+D) - (A+C)]$

$= (B+D)$

As shown in Figure 8.15 this is simply the increase in willingness-to-pay of the consumers. Assuming a linear demand curve it is given by

$$\text{total benefits} = (Q_2 - Q_1) \times (P_1 + P_2)/2 \qquad (8.24)$$

If the increase in Q is small, $P_1 = P_2$ and Equation (8.24) becomes

$$\text{total benefits} = (Q_2 - Q_1) \times P_1 \qquad (8.25)$$

i.e., total benefits = increase in output x market price

Note that in the case of a large public authority (or a private monopoly) an increase in supply could be large enough to cause a price change.

Now suppose the water authority does not charge the market price for water, but instead charges a price of P_3 as set by the government (see Figure 8.16). If the initial quantity supplied is Q_1 the authority would have to ration the water between consumers as the total demand Q_3, at a price P_3, exceeds the available supply Q_1. This is common practice in the supply of water for irrigation purposes in which each irrigator has an annual allocation that cannot be exceeded under normal circumstances.

With the existing supply curve and a rationed quantity Q_1 the total willingness-to-pay is given by areas ($A' + C'$). This is composed of the authority's revenue (area C') and the consumers' surplus (area A'). The quantity Q_1 (P_1 - P_3) is the difference between the revenue for the water under a competitive market system and the actual revenue. It represents a transfer payment from the authority to the consumers as a result of the government pricing policy.

Desalination benefits

In 2006 the Israeli government was planning the construction of desalination plants to supplement the water supply for its people. While the costs were relatively easy to quantify, based on the cost of new plant, running costs due to electricity and the replacement of reverse-osmosis membranes, the benefits were more nebulous. However, by considering effects such as reduced scaling in pipes, extended lifetimes of electric and solar heaters, savings in soap in washing clothes and dishes, it was possible to determine a benefit of approximately US$0.11 /m3. When savings in pumping costs were taken into account, the total benefit rose to approximately US$0.15 /m^3.

Source: Dreizin, 2006

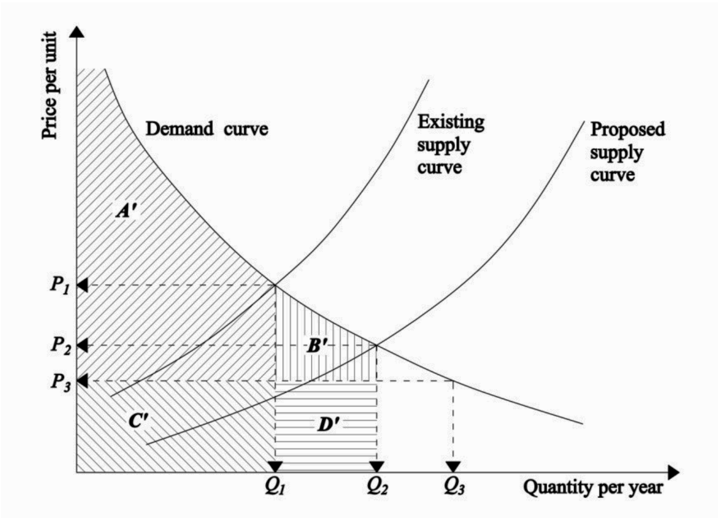

Figure 8.16 Benefits of an increase in urban water supply under non-market pricing.

If the supply curve shifts as a result of building a new dam and quantity Q_2 is supplied at price P_3, the increase in benefits will be the increase in consumers' surplus plus the increase in revenue, i.e. area (B' + D') in Figure 8.16. This is identical to the increase in willingness-to-pay given by (B + D) in Figure 8.15. Therefore, the government pricing policy does not affect the total benefits of the scheme, only the way in which these benefits are distributed between consumers and the water authority.

Humans to Mars?

Ehlmann et al. (2005), in a paper promoting a mission to land humans on Mars, estimate the costs of such a venture at between US$20 billion and US$450 billion where the latter included using the moon as an intermediate staging post. With the costs firmly established, the challenge was to detail the benefits for such a mission. These, it was suggested, were to be found in the promotion of industry, engineering, technology and science. The authors put forward the US$85 billion satellite industry as a quantifiable benefit of previous space exploration and suggested that future work would contribute in similar ways. They also argued that the work would create new markets, allow for more efficient use of resources and create high-wage jobs.

8.8 ECONOMIC COSTS

The concept of cost is a subtle one which may cause confusion in some engineering studies. Essentially, the same concept of cost is applicable to public sector and private sector projects, although the question of cost to whom must be addressed. For the private sector, only costs incurred by the firm are of relevance, whereas for public sector projects the total cost to all members of society must be evaluated. The correct concept of cost is the incremental opportunity cost of resources used plus any *externalities* (for example pollution, social disruption) as a direct result of the project.

The opportunity cost of a resource is its value when used in the best available alternative use. This is a measure of the value which must be forgone by using the resource in the project under consideration. The opportunity cost may be quite different from what was actually paid for the resource.

For example, a company has a vacant block of land which is valued at $500,000 on the open market. The company paid only $100,000 for the land some 10 years ago. If the company is considering building an office block on the land, the opportunity cost of the land is at least $500,000 because the land could be sold at this price. This is the cost which should be used in an economic evaluation of the proposed office block. The opportunity cost may be higher if a better alternative use is available. The actual price paid for the land is not relevant to this decision.

As a further example of this concept, consider a contractor who has a crane which costs $500 per day to operate and which can be hired out for $1,000 per day. The opportunity cost to the contractor of using the crane on a particular construction project is $1,000 per day, as this is the benefit which he must forgo in order to use the crane.

The opportunity cost concept has particular significance in public sector evaluation. If, for example, a project in the public sector employs labour which was previously unemployed, the opportunity cost of doing so is considerably less than the actual wage rate. As the alternative use of the labour is, in fact, unemployment, the opportunity cost is the value which the workers place on their additional recreation time when unemployed. The question of unemployment benefits paid to the individual by the government does not enter the evaluation, as these are a transfer payment between one section of the community and another, i.e. the benefit of this payment to the unemployed equals the cost to the taxpayers, so its net effect on the total community is zero.

The incremental or marginal costs of a project must be carefully assessed. In project evaluation, the marginal costs are the additional costs of undertaking the project compared with not undertaking it. There is sometimes a tendency to confuse marginal cost with average cost. The distinction between the two is illustrated by the following example.

Worked example

An engineer purchases a new car for $20,000. She uses the vehicle to commute to work and for recreational travel on weekends. The estimated annual costs for the vehicle are divided into standing costs (loss of interest on capital, depreciation, registration and insurance) which are estimated to be $8,200 p.a. and running costs (maintenance and repairs, petrol and oil, tyres) which are estimated to be $1,800 p.a. If she travels 20,000 km per year, the average cost of travel is $0.50/km ($10,000/20,000 km). Now if her employer asks her to use her own vehicle to make a single trip of 50 km to a construction site, what is the cost of this trip? One possible answer would be to use the average cost of $0.50/km and thereby estimate a trip cost of $25. However, the extra trip is incremental to her private travel and therefore the incremental or marginal cost should be used. The registration and insurance costs and loss of interest on capital are unaffected by the extra trip and hence are irrelevant in this situation. Likewise depreciation is more strongly related to the ageing of the vehicle rather than distance travelled so it does not enter the calculation. The only incremental costs are petrol and oil, tyres, and maintenance and repairs (assuming these depend on distance travelled). Therefore, the marginal cost for a short trip is $0.09/km ($1,800/20,000 km). This gives a cost of $4.50 for the 50 km trip. If the engineer is reimbursed at the average cost of $0.50/km, she makes a nice profit on the trip.

Now consider a different situation in which the engineer uses her car for 15,000 km of business travel and 5,000 km of personal travel per year. It could be argued in this case that the vehicle is primarily for business purposes and the private travel is the marginal component. It would then be reasonable for the company to reimburse all standing costs of the vehicle as well as the running costs associated with the business travel. Alternatively, the company may provide a vehicle and ask the engineer to pay the running costs associated with private travel.

Sunk and recoverable costs

A further distinction needs to be made between sunk and recoverable costs. Sunk costs are costs which have been incurred in the past and are no longer recoverable. As such they are irrelevant to decisions about future actions.

Worked example

A firm has a printer which originally cost $12,000 to purchase and now costs $2,500 per year to operate and maintain. It can be sold for $5,000. An equivalent new printer costs $15,000, but it is estimated that it costs only $1,500 per year to run because of an attractive maintenance contract being offered by the manufacturer. What are the benefits and costs which should be considered in deciding whether or not to purchase the new printer? A time-frame of 5 years should be used in analysing the decision. At the end of this time the new printer is expected to be worth $4,000 and the old printer nothing.

Solution We need to consider the incremental benefits and costs of the new printer relative to the old. These are shown in Figure 8.17. The incremental costs of purchasing the new printer is $10,000 ($15,000 minus the $5,000 sale value of the old printer). The incremental benefit is the $1,000 per year savings in operating cost plus the $4,000 value of the new printer at the end of 5 years. Note that the original purchase price of the old printer (i.e. the $12,000) is a sunk cost and does not enter the decision. Clearly the decision would be no different if the old printer had cost $100,000 or had been obtained for nothing.

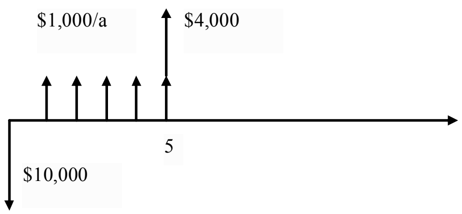

Figure 8.17 Benefits and costs of purchasing a new printer.

8.9 COST ESTIMATION

In the preparation of tenders, where engineering firms bid to undertake jobs, it is important to be able to estimate costs accurately. For example, the cost of a complete building, or the cost of installation of air conditioning, or in fact any of the many possible components that ultimately make up the total job. To assist in this process there are publications available that contain this type of information, taking into account the current year, the location of the proposed work and many other variables. These publications include:

- *The Building Construction Cost Data Book* 74th Edition by R.S. Means (2016) that provides building cost data for 930 locations in the US and Canada

- European construction costs available at www.constructioncosts.eu that has an online cost calculator as well as construction cost handbooks for all countries in Europe
- Rawlinsons (2016) *Australian Construction Handbook* that provides construction cost data for all capital cities in Australia

As an example of the types of information offered by these references, Rawlinsons (2016) contains estimates and detailed prices on the following:

- whole buildings (based on area or usage);
- electrical services (lighting, power, heating, closed circuit television installations, uninterruptable power supply);
- mechanical services (air-conditioners, hot water convectors, water boilers, heat exchangers, pipe work, duct work, natural ventilation); and
- civil services (excavation, laying concrete, installing structural steel).

The 2016 edition of Rawlinsons, book also contains useful environmental information on topics such as green design, environmental management and the embodied carbon of various materials.

The costs given are based on average values of actual contracts let in the preceding 12 months in the respective cities. It is difficult to summarise the full scope of the publication but some examples (current for 2016 prices) may assist in the process.

- The price of a 300 to 500 seat cinema in suburban Adelaide that includes air conditioning, ancillary facilities, seats and projectors, etc. is between $7290 and $7860 per seat. Hence a 300-seat theatre would cost around $2.2 m.
- To supply and install an evaporative air conditioner that meets a recommended 30 air changes per hour in a suburban house with 2.6 metre (nominal) ceiling height in Perth would cost between $41 and $53 per square metre of floor area.
- The supply and placing of an unreinforced strip footing in 25 MPa concrete in Melbourne costs $264 per cubic metre.
- To supply and trench 300 mm diameter ductile iron cement lined (DICL) water supply pipe (PN 35) with rubber ring joints in Adelaide costs $325 per metre of length.
- The installation of a set of traffic lights, including fully activated detectors, electrical services between signals, control box, pedestrian push buttons and indication signs to the intersection of an access road with a dual carriageway costs between $125,000 and $155,000 in Sydney.

8.10 SELECTION OF DISCOUNT RATE AND PROJECT LIFE

The choice of the discount rate and project life may have an important influence on the economic viability of a particular project. Many engineering projects, for example roads, water supply, electricity supply and communications networks, involve high initial costs and benefits which grow steadily with time over many years. The computed NPV of such projects falls with increasing values of the discount rate, and may become negative for high values. For example, a proposed new highway will cost \$10 m to construct. The benefits due to savings in operating costs and travel time are estimated to be \$1.2 m in the first year of operation but will grow at 2% p.a. (compound) due to growth in the volume of traffic using the road. Maintenance costs are expected to be constant at \$200,000 per year of operation. The NPV (\$m) of the road for various values of life and discount rate can be calculated as follows:

$$NPV = \frac{1.2}{(1+i)}\left\{\frac{1-(1.02)^n/(1+i)^n}{1-(1.02)/(1+i)}\right\} - \frac{0.2\left\{1-(1+i)^{-n}\right\}}{i} - 10$$

The results are shown in Figure 8.18. Clearly, for any given value of the discount rate, the NPV increases with increasing values of project life. Also, for any given value of project life, the NPV decreases with increasing values of the discount rate. It should be noted that the economic desirability of the project depends strongly on the discount rate. For example, if i = 5%, NPV is positive provided the project life exceeds 12 years. On the other hand, for a value of discount rate of 15% the NPV is negative for all values of project life. For high values of discount rate, the NPV is relatively insensitive to changes in project life. For example, with a discount rate of 10% the NPV is \$2.0 m if the project life is 35 years and \$2.76m if the project life is 50 years.

There has been considerable controversy associated with the selection of discount rate (and project life), particularly for public sector projects. For example, consider the case of a public authority which is required to justify all projects on an economic basis and only undertake projects which have a positive NPV. Clearly the list of economically viable projects will be much greater if the authority uses a low value of discount rate than if a high value is used. This fact has led to those who support large public works expenditure to argue for a low value of discount rate, whereas those who wish to reduce public works expenditure often argue for a high value. Before discussing this matter further, we shall consider the choice of discount rate for evaluating private sector projects

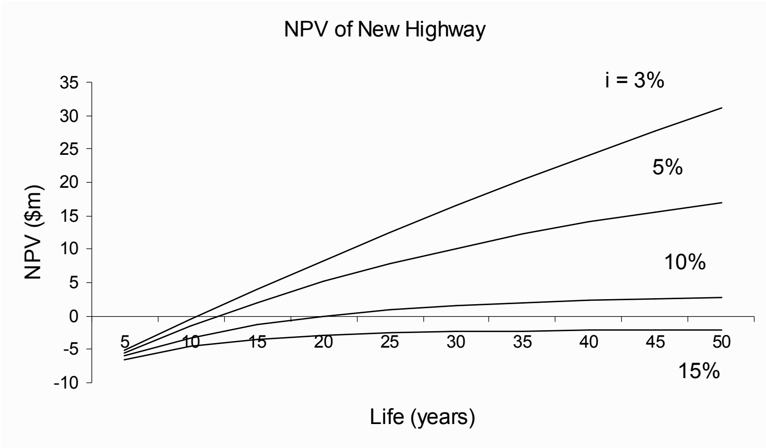

Figure 8.18 The effect of discount rate and life on the NPV of a road project.

The discount rate in the private sector

The correct concept for the discount rate is the ***opportunity cost of capital.*** The opportunity cost of capital for a particular company or individual at a particular point in time is the highest rate of return that it could obtain by having extra capital available. Obviously this depends on the investment opportunities at that time.

Most companies raise their capital by a combination of borrowing from financial institutions (called ***debt capital***) and reinvesting some of the company profits or retained earnings (called ***equity capital***). In this case the opportunity cost of capital is a weighted average of the interest rate paid on debt capital and the rate of return that the shareholders could obtain by investing their capital to the best advantage elsewhere. This usually results in a higher rate than the interest paid on debt capital.

The discount rate in the public sector

As noted above, the choice of a discount rate in the public sector is often controversial. The three most common theoretical bases for the choice of a discount rate are

- the average yield on long-term government bonds;
- the social opportunity cost; and
- the social time preference rate.

As there is no agreed method, we shall consider the arguments for and against each one in turn.

The average yield on long-term government bonds

It has been argued that the interest rate paid on long-term government bonds is the rate at which the government borrows money from the public. It is therefore appropriate that it should be used as the discount rate for evaluating public sector investments. In Australia, this rate is typically 1 to 2 % p.a. above the inflation rate. However, if we examine the federal budget as a whole, it is clear that most government revenue is raised by taxes, not by the sale of government bonds. In fact, bonds are used by the government to regulate the money supply rather than to raise revenue. The argument to link the discount rate to the government bond rate is therefore questionable.

Another argument which supports the use of the long-term government bond rate is that this represents the risk-free interest rate in the private sector. Most investments carry some element of risk, due to uncertainties in the future economic climate. Even banks and building societies have been known to default on interest payments during major depressions. The interest on government bonds is guaranteed by the government and so carries no risk. Any private investment should return at least this interest rate, otherwise investors would withdraw their money and put it into government bonds. It is argued that it is therefore appropriate to use it for public sector investments.

The social opportunity cost

It is argued that funds invested by the government in major capital works have basically been displaced from the private sector and should, therefore, earn a rate of return at least as high as that prevailing in the private sector (based on the opportunity cost of capital concept). However, not all revenue raised by government taxation would have been invested in the private sector. In fact a high percentage of government revenue is taken from expenditure that would have gone into consumption and would produce no investment return. This fact must be taken into account when assessing the social opportunity cost. A further difficulty is in determining the appropriate marginal rate of return in the private sector. A typical rate for the social opportunity cost is 10–15% above inflation.

The social time preference rate

It is argued that, by undertaking investments in the public sector, society is effectively forgoing consumption in the current time period in order to achieve increased consumption in the future. The choice of a discount rate is equivalent to placing a weight on benefits and costs incurred in future years when compared with the present. Some economists consider that society is free to choose whatever stream of future consumption that it likes, and accordingly it may choose any set of relative weights on benefits and costs in future years.

The discount rate corresponding to this chosen set of relative weights is the social time preference (STP) rate, which will in general differ from the interest rate prevailing in the private sector.

To illustrate the concept of a social time preference rate, suppose that society (or its elected representatives) decides that benefits and costs received in one year should have a weight W_1 relative to benefits received in the present. Similarly, benefits and costs received in two years have a weight W_2 relative to the present. In general, W_t is the weight placed on benefits and costs received at the end of year t relative to benefits and costs received in the present. (Clearly $W_0 = 1$).

Then the net community benefits (NCB) can be defined as:

$$NCB = \sum W_t \, (B_t - C_t) \tag{8.26}$$

Based on the preference of most individuals to consume now rather than later, it is reasonable to assume that:

$W_0 > W_1 > W_2 > \ldots$, etc.

A somewhat stronger assumption is that the weight placed on the benefits and costs in any particular year is a constant fraction of the weight placed on the benefits and costs in the previous year, i.e.,

$$\begin{aligned} W_1 &= kW_0 = k \\ W_2 &= kW_1 = k^2 \\ &\ldots\ldots\ldots \\ W_t &= kW_{t-1} = \mathrm{k}^t \end{aligned} \tag{8.27}$$

where k is a chosen parameter between 0 and 1.

Suppose we define k as follows:

$$k = 1/(1 + r) \tag{8.28}$$

where r is the **social time preference** (STP) rate.

Combining Equations 8.26, 8.27 and 8.28 we obtain:

$$NCB = \Sigma \, \{ B_t \,/\, (1 + r)^t \, - C_t \,/\, (1 + r)^t \} \tag{8.29}$$

The similarity with Equation (8.17) should be noted. It should be clear that choosing the STP rate, r, is equivalent to choosing a set of weights on future benefits and costs for society as a whole.

The STP rate may be any rate chosen by society (even 0%). Proponents of the STP rate usually argue for a low rate (in the order of 2–5%) on the grounds that government investments provide basic community infrastructure and therefore benefits over a long time scale should be considered.

Summary: Discount rate for public sector projects

Ultimately, the choice of the discount rate for public sector projects tends to be a political decision. Often, sensitivity analyses are carried out in which the NPV for all projects is calculated using a low, medium, and high value of the discount rate. For example, the NPV of all projects can be determined using discount rates of 3, 6 and 10% p.a. and the results compared.

Project life

Many engineers consider the life of an engineering project to be equal to the physical life of the constructed facilities. The physical life of a system ends when it can no longer perform its intended function. For example, a building is at the end of its physical life when it is no longer fit for habitation. A road pavement is at the end of its physical life when it is suffering total break-up and can no longer be repaired. However, two other concepts of project life are relevant in economic evaluation. These are the economic life and the relevant period of analysis.

The economic life of an engineering system ends when the incremental benefits of keeping the system operating for one more year are less than the incremental costs of maintenance and repair for one more year. As most engineering systems can be kept operating almost indefinitely with suitable replacement parts, the economic life is usually less than the physical life.

The relevant period of analysis is the maximum period beyond which the system performance has virtually no effect of its present value of benefits and costs. For high values of discount rate, the NPV of a project does not significantly increase beyond a certain time. This time is the relevant period of analysis. For example, if a discount rate of 15% p.a. is being used, it is pointless arguing whether the life of a building will be 30 years or 100 years as it will make no difference whatsoever in its economic evaluation. For lower values of discount rate, more care must be taken in choosing the project life.

In general, the project life is the smallest of the physical life, the economic life and the relevant period of analysis. Some typical lives used for civil engineering projects are given in Table 8.9.

Table 8.9 Lives of some engineering systems.

Engineering system	Life
Vehicles	5–10 years
Roads	20–30 years
Bridges, buildings	30–50 years
Dams	50 years
Tunnels, cuttings, embankments	100 years

8.11 SUMMARY

The aim of economic evaluation is to assess if the benefits of a project exceed its costs and hence whether or not it is worth undertaking from an economic perspective. The benefits and costs of a project need to be carefully defined as they do not necessarily correspond to cash flows, particularly in the public sector where a number of goods and services are supplied to the community at a subsidised price.

The benefits and costs of engineering projects often occur over a long time period. Hence, the effects of the time value of money need to be taken into account in assessing the economic viability of a project. A discount rate is applied to future benefits and costs in recognition that they are less significant than benefits and costs incurred today.

There are a number of economic criteria for evaluating projects. These include the payback period, net present value, equivalent annual worth, the benefit-cost ratio and the internal rate of return. In general, economists favour net present value as it is not sensitive to the issue of whether savings in cost should be counted as positive benefits or negative costs and it produces an unambiguous ranking of projects.

The selection of the discount rate, particularly in the public sector, can be controversial and there are a number of bases for its selection. The social time preference rate is preferred as it is recognises that the choice involves social values that can be expressed through the political process.

PROBLEMS

8.1 \$2000 is invested at 5% p.a. for 20 years. What sum will be received at the end of the investment period?

8.2 What is the present value of \$2,000 that will be received in 5 years if the interest rate is 6% p.a.?

8.3 What is the present value of a series of annual payments of \$10,000 over 10 years if the interest rate is 8% p.a.?

8.4 What are the annual repayments for a loan of \$100,000 if the interest rate is 8% p.a. and the period of the loan is 45 years?

8.5 Following on from Question 8.4, how much is still owed after the first annual repayment on a \$100,000 loan taken out at an interest rate of 8% p.a. over a 45-year period?

8.6 What are the monthly repayments for a loan of \$100,000 if the annual interest rate is 6% p.a. (computed monthly) and the loan is over 50 years?

8.7 A project has initial costs of $100,000 and annual benefits of $10,000. What is the net present value of the project assuming an 8% p.a. discount rate over 25 years? Assume all costs and benefits occur at the end of the year.

8.8 If the benefit-cost ratio is defined as B/(O+K) where B are the benefits, K the initial costs and O the ongoing costs, what is the benefit-cost ratio in the case where initial costs are $20,000, ongoing costs $5,000 p.a. and benefits $10,000 p.a. for a discount rate of 6.8% p.a. and over a period of 20 years? Assume all costs and benefits occur at the end of the year.

8.9 If the benefit-cost ratio is defined as (B-O)/K where B are the benefits, K the initial costs and O the ongoing costs, what is the benefit-cost ratio in the case where initial costs are $20,000, ongoing costs $5,000 p.a. and benefits $10,000 p.a. for a discount rate of 6.8% p.a. and over a period of 20 years? Assume all costs and benefits occur at the end of the year.

8.10 As engineer for a company developing high efficiency solar panels, you have an annual research and development budget of $500,000. Each year you call for submissions from within the company for projects that could be done. As part of this, the proponents must estimate the cost of the proposal and what benefits would come from a successful outcome. This year you have eight proposals to consider, and one criterion for funding is economic benefits. The details of the proposals are given in Table 8.10. Any calculations that you do should assume a project life of 5 years and a discount rate of 20% p.a.

(a) Use the B/C ratio to determine which projects you would select. In this case the best proposals are chosen from a ranked list.

(b) Use NPV to determine which projects you would select. In this case the problem can be considered as one that could be solved using linear programming, but you may attempt to find a solution by inspection. As an additional exercise, set the problem up in EXCEL and use Solver to verify the solution obtained by hand.

Table 8.10 Summary of economic factors associated with the eight research proposals to be assessed.

Project	Initial Cost($)	Annual Benefit($)
A	100,000	55,000
B	200,000	100,000
C	50,000	24,000
D	10,000	8,000
E	20,000	20,000
F	345,000	120,000
G	100,000	34,000
H	250,000	160,000

8.11 A manufacturing company has space for one additional automated machine in its factory. It can purchase either Machine A which produces gadgets or Machine B which produces widgets. Economic data for the two machines are presented in Table 8.11.

Table 8.11 Costs and benefits for two machines.

	Machine A	Machine B
Initial Cost ($)	310,000	370,000
Revenue ($ p.a.)	70,000	120,000
Maintenance ($ p.a.)	15,000	20,000
Life (years)	10	5
Scrap value ($)	20,000	0

(a) Compute the net present value, equivalent annual worth, B/C ratio for each machine using a discount rate of 7% p.a. and a planning horizon of 10 years.

(b) Which machine should be chosen and why?

8.12 A car that was purchased 10 years ago for $20,000 is now thought to be worth $5,000 as a trade-in on a new model. Due to its age, the old car now costs $2,000 per year in repairs alone, which it is assumed a new car would not need. Based on economics, should a new car be purchased for $30,000 if it is intended to keep it and evaluate it over a 10-year planning horizon? Assume that at the end of the 10 years a car purchased now would be worth $5,000 and the existing car would be worthless.

REFERENCES

Adeoti, O., Ilori, M.O., Oyebisi, T.O. and Adekoya, L.O., 2000, Engineering Design and Economic Evaluation of a Family-Sized Biogas Project in Nigeria. *Technovation*, 20, 103–108.

Baumol, W. J. 1977. *Economic theory and operations analysis,* 4th edn. Englewood Cliffs, NJ: Prentice Hall.

Best, R., 2000, Low Energy Building Design: Good for the Environment and Good for Business. The Environmental Engineer. *Journal of the Environmental Engineering Society*, I.E.Aust., 1(1), 12–15.

Brookshire, D.S., Burness, H.S., Chermak, J.M. and Krause, K., 2002, Western Urban Water Demand, *Natural Resources Journal* 42, 873–898

Campus Review, 2002, https://www.campusreview.com.au

DeGarmo, E. P., Sullivan, W. G. and J. R. Canada 1984. *Engineering economy,* 7th edn. New York: Macmillan.

deNeufville, R. and Stafford, J. H. 1971. *Systems analysis for engineers and managers*. New York: McGraw-Hill.

Dreizin, Y., 2006, Ashkelon Seawater Desalination Project – Off-Taker's Self Costs, Supplied Water Costs, Total Costs and Benefits. *Desalination*, 190, 104–116.

Ehlmann, B.L., Chowhury, J., Marzullo, T.C., Collins, R.E., Litzenberger, J., Ibsen, S., Krauser, W.R., DeKock, B., Hannon, M., Kinnevan, J., Shepard, R. and Grant, F.D., 2005, Humans to Mars: a feasibility cost benefit analysis, *Acta Astronautica* 56 (9-12) 851-858

Engineering News Record, 2017, http://www.enr.com/economic

Forkenbrock, D.J. and Foster, N.S.J., 1990, Economic Benefits of a Corridor Highway Investment. *Transport Research Part A: General*, 24A(4), 303–312.

Hensher, D.A., 2008, Assessing systematic sources of variation in public transport elasticities: Some comparative warnings, *Transportation Research Part A* 42, 1031–1042

Jackson, J., Jorge, J.-D. and de Rus, G., 2004, Cost-Benefit Analysis of Investments in Airport Infrastructure: A Practical Approach. *Journal of Air Transport Management*, 10, 311–326.

McConnell, C.R., 1980, *Economics (Australian Edition).* Sydney: McGraw-Hill.

Lipsey, R. G., Langley, P. C. and Mahoney, D. M. 1981. *Positive economics for Australian students.* London: Weidenfeld & Nicolson.

Loansense 2016, Information on the Reserve Bank of Australia – Australian Interest Rates for 1959 to 2016. http://www.loansense.com.au/historical -rates.html (accessed on March 28, 2017).

Means, R.S., 2016, *Building Construction Cost Data Book* 74th Edition (available at www.rsmeans.com/products/books/2016-cost-data-books/2016-building-construction-cost-data-book.aspx).

Meredith, D. D., Wong, K. W., Woodhead, R. W. and Wortman, R.H., 1985, *Design and planning of engineering systems,* 2nd edn. Englewood Cliffs, NJ: Prentice Hall.

Mishan, E. J., 1982, *Cost-benefit analysis,* 3rd edn. London: George Allen & Unwin.

Morgan, P. and Elliott, S.L., 2002, Mechanical Destratification for Reservoir Management: An Australian Innovation. Water, *Journal of the Australian Water Association*, 29(5), 30–35.

Muroi, K., 2017, The oldest example of compound interest in Sumer: seventh power of four-thirds, *Cornell University Library, Mathematics Archive*, https://arXiv.org/abs/1510.00330, (accessed on April 6, 2017).

Narayan, S., Beck, M.W., Reguero, B.G., Losada, I.J., van Wesenbeeck, B., Pontee N., Sanchirico, J.N., Carter Ingram, J., Lange, G. and Burks-Copes, K.A., 2016, The effectiveness, costs and coastal protection benefits of natural and nature-based defences, *PLoS ONE* 11(5): e0154735. doi:10.1371/journal.pone.0154735

Ossenbruggen, P. J., 1984, *Systems analysis for civil engineers.* New York: Wiley.

Riggs, J. L., 1977, *Engineering economics.* New York: McGraw-Hill.

Rawlinsons, 2016, *Australian Construction Handbook 34th Edition.* (Rawlhouse Publishing Pty. Ltd.), 1005pp.

Sage, A. P., 1982, *Economic systems analysis. Microeconomics for systems engineering, engineering management and project selection.* Amsterdam: Elsevier.

Scheierling, S. M., Loomis, J.B. and Young, R.A., 2006, Irrigation water demand: A meta-analysis of price elasticities, *Water Resources. Research,* 42, W01411, doi:10.1029/2005WR004009.

Smith, A. A., Hinton, E. and Lewis, R. W., 1983, *Civil engineering systems analysis and design*. London: Wiley.
Steiner, H. M., 1980, *Public and private investments.* New York: Wiley.
Talvitie, A., 2000 Evaluation of Road Projects and Programs in Developing Countries. *Transport Policy*, 7, 61–72.
The Australian, 2001, http://www.theaustralian.com.au
World Bank, 2016, www.data.worldbank.org/indicator/FP.CPI.TOTL (accessed on Nov 22, 2016).

APPENDIX 8A: PRICE DETERMINATION IN PERFECTLY COMPETITIVE MARKETS

The perfectly competitive market is a theoretical model used by economists to analyse market behaviour in much the same way that engineers use free-body diagrams to analyse the forces on a group of rigid bodies.

It is hypothesized that there is a market of buyers and sellers which determines the market price for any particular good or service (called a "commodity").

The assumptions inherent in the perfectly competitive market are as follows

- there are a large number of buyers and sellers of the commodity
- any particular commodity is identical for all sellers
- all buyers and sellers have perfect information about prices and production costs
- there is free entry and exit of firms into the market

The market supply curve

For any particular commodity there is a market supply curve which shows the total amount of the commodity which will be produced per unit time at any particular price. For example, Figure 8.19 shows the market supply curve for timber in a particular economy. (Note that it is traditional to plot price on the vertical axis.) As price increases, we would expect a greater production of timber as more producers come into the market and existing producers increase their output by working overtime, investing in new machinery, and so on.

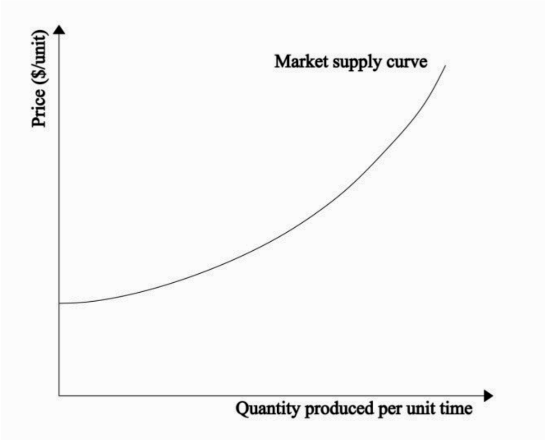

Figure 8.19 Market supply curve for timber.

Other factors apart from the price of the commodity can affect the quantity supplied. If these change, they will cause a shift in the position of the market supply curve in Figure 8.19. These factors are as follows:

- The price of inputs (for example, labour or materials) to the production process
- The price of competing outputs. For example, an oil refinery can be used to produce many products including petrol and fuel oil. If the price of petrol increases relative to the price of kerosene, the market supply curve for fuel oil would tend to shift to the left
- The state of technology. Technological advances can reduce production costs and cause the market supply curve to shift to the right
- The time period. The market supply curve for a short time period tends to be near vertical, as there is little time to respond to changes in price. In the longer term, the curve tends to be flatter, as there is more time for producers to respond to changes in price
- Expectations. The quantity supplied at any particular price will depend on whether producers expect prices to increase, decrease or remain the same in the next time period

The market demand curve

For any particular commodity there is also a market demand curve. This shows the quantity per unit time of the commodity which would be purchased at any particular price. Figure 8.20 shows the market demand curve for timber in a particular economy. As the price of timber increases, we would expect the demand to fall as consumers use substitute materials such as plastic, steel, and aluminium.

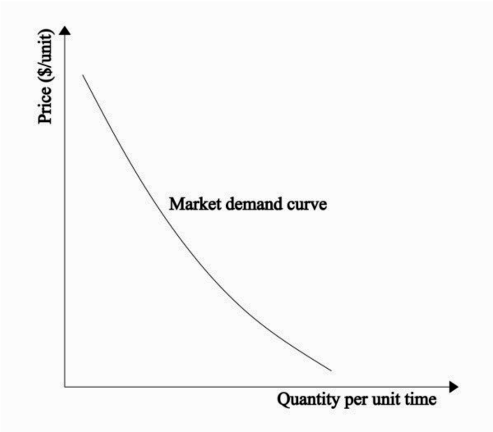

Figure 8.20 Market demand curve for timber.

Apart from price, a number of other factors affect the position of the market demand curve. These include the following:

- The prices of other commodities. Certain commodities are substitutes for one another. Consider, for example, gas and electricity. If the price of gas increases, the market demand curve for electricity tends to shift to the right. Other commodities such as concrete and steel reinforcing rods are complementary goods. If the price of concrete increases, there is a shift to the left of the demand curve for steel reinforcing rods.
- Income and wealth of consumers. If there is a general rise in income levels There is an increase in demand for all normal goods. This is reflected by a shift to the right of the demand curve.
- Number of consumers. An increase in the number of consumers causes the market demand curve to shift to the right.
- Tastes of consumers. Changes in taste and fashion may cause a shift in the demand curve for some commodities, e.g., clothing.
- The time period and expectations.

Market equilibrium

The market price for any particular commodity in a perfectly competitive market is determined by the interaction of demand and supply. At equilibrium the market price corresponds to the point of intersection of the market supply and market demand curves. This point is illustrated in Figure 8.21, where the equilibrium price is given by $P*$ and the equilibrium quantity by $Q*$.

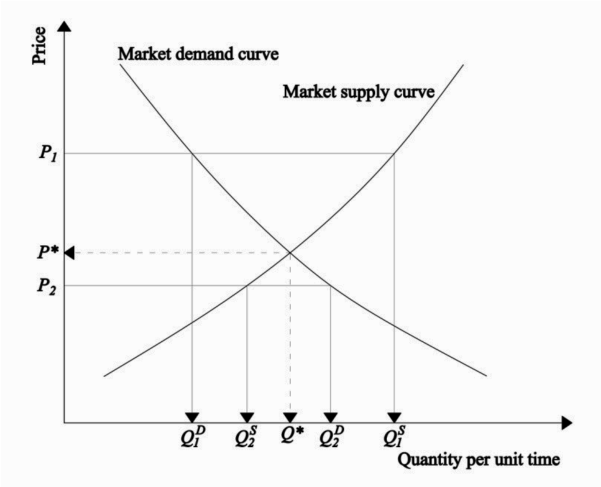

Figure 8.21 Demand-supply equilibrium.

Suppose the price is set at a value greater than P^*, for example P_1. Then the quantity supplied, $Q^S{}_1$ exceeds the quantity demanded, $Q^S{}_1$. The product therefore stockpiles and there is pressure on producers to reduce the price in order to sell their product. If the price is below P^* (e.g., P_2), the quantity demanded, $Q^D{}_1$ exceeds the quantity supplied, $Q^S{}_1$, and there are shortages of the commodity. In response to these shortages, consumers will tend to bid up the price of this scarce commodity. As the price increases, producers will tend to produce more and new producers will enter the market.

At a price of P^* the quantity demanded just equals the quantity supplied and an equilibrium state is established.

For example, consider the demand/supply equilibrium of traffic on a section of urban arterial road. In this case, each consumer may decide either to make one or more trips on the road or not to use it at all. The *price* of a trip is the total cost of petrol, oil, and tyre wear of making one traverse of the section of road. To this should be added the value of travel time of the driver and passengers. The *quantity* is the number of vehicles per hour travelling on the road.

Figure 8.2.2 shows supply and demand curves for the road. The supply curve indicates the total cost per trip as a function of the volume of traffic on the road in vehicles per hour. Typically, the cost per trip increases rapidly as the volume of traffic approaches the capacity of the road, *C*. This is due to the effects of traffic congestion and delays.

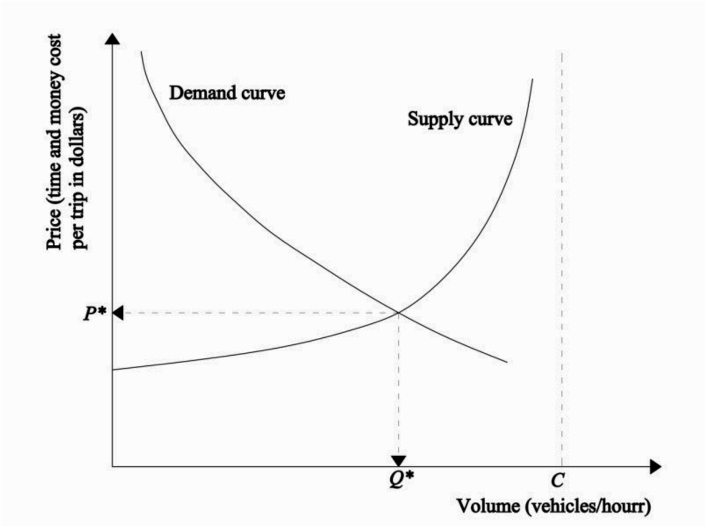

Figure 8.22 Demand-supply equilibrium for an urban arterial road.

The demand curve in Figure 8.22 indicates the number of drivers per hour wanting to use the road as a function of the total cost per trip. As the cost per trip increases, fewer drivers wish to use the road because of available substitutes such as other routes of travel or other times of the day. If the traffic conditions on the road remain steady for a sufficient period of time, equilibrium is reached with a volume of Q^* vehicles per hour on the road. The corresponding cost per trip is P^* dollars.

Shifts in demand and supply curves

As mentioned earlier, the demand curve for a particular commodity may shift with time due to changes in consumer preferences, the number of consumers, average income levels or the prices of related goods. A shift in demand leads to a new equilibrium quantity and price for the commodity. For example, suppose the demand for water in a city increases due to an increase in population. This causes the demand curve for water to shift to the right as shown in Figure 8.23. If the water supply authority charges the market price for water, one would expect the volume supplied to increase from Q_1 to Q_2 and the price of water to increase from P_1 to P_2 as less economical sources of water are used.

In a similar fashion, the construction of a new engineering system causes the supply curve to shift to the right and a new equilibrium to be established. For example, in response to increasing demand, a water supply authority builds a new dam to supply water to a city. This causes the supply curve to shift to the right as more water can now be supplied at any particular price. The situation is shown in Figure 8.24. In equilibrium, the volume of water supplied increases from Q_1 to Q_2 and the price falls from P_1 to P_2. In practice, this fall in price may take place over several years by allowing the rate of increase of the nominal price of water to fall behind the rate of inflation.

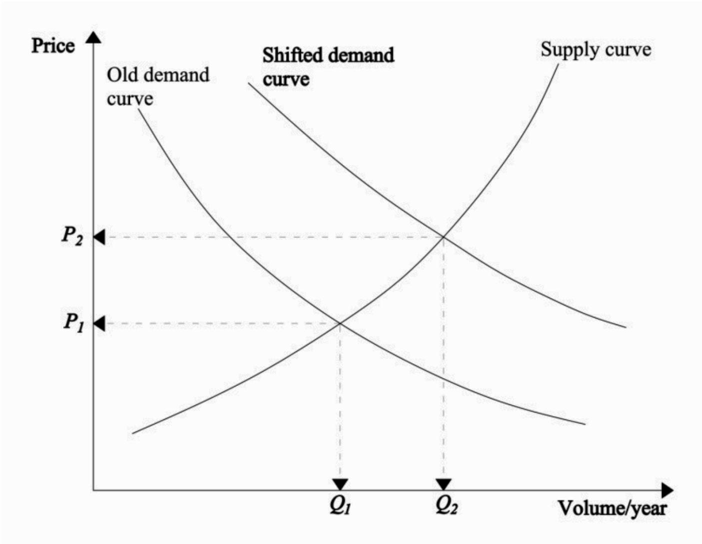

Figure 8.23 A shift in the demand curve for water.

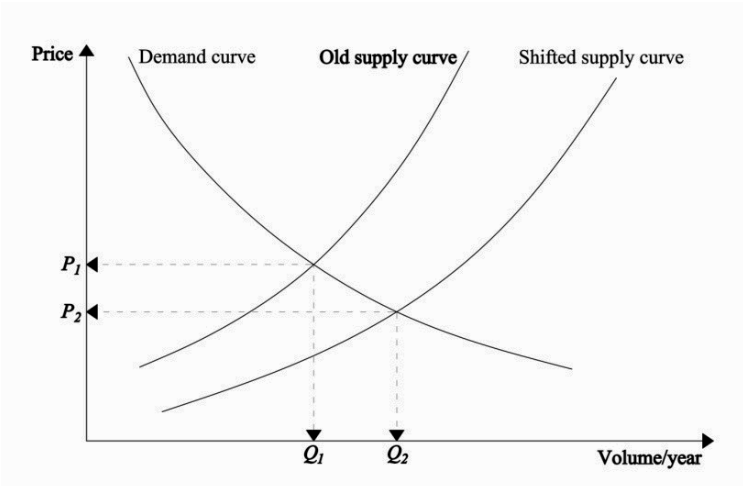

Figure 8.24 A shift in the supply curve for water.

Price elasticity of demand

In planning future engineering facilities such as transportation and water resource systems, the analyst is often concerned with the responsiveness of consumers to changes in price.

It is possible to characterize the price responsiveness of the market demand for a product at any point in time by its price elasticity of demand. This is defined as the percentage change in quantity demanded, divided by the percentage change in price, i.e. elasticity,

$$\varepsilon = \frac{\Delta Q / Q}{\Delta P / P} = \frac{\Delta Q}{\Delta P}\left(\frac{P}{Q}\right) \tag{8.30}$$

For example, the demand for water for irrigation from a particular river is 1.2 x 10^9 m^3 per year when the price of water is \$0.10/m^3. If the price increases to \$0.15/m^3 and the price elasticity of demand is -0.3, what will be the new demand? Using Equation (8.30),

$$\varepsilon = -0.3 = \frac{\Delta Q}{0.05} \times \frac{0.01}{1.2 \times 10^9}$$

Therefore

$$\Delta Q = \frac{-0.3 \times 0.05 \times 1.2 \times 10^9}{0.01} = -0.18 \times 10^9 \text{ m}^3/\text{year}$$

New demand = 1.2 x 10^9 – 0.18 x 10^9
= 1.02 x 10^9 m^3/year

Strictly speaking, the price elasticity defined by Equation (8.30) is the arc elasticity. In the limit as ΔP approaches zero, it becomes the point elasticity. This is defined as

$$\varepsilon_p = \frac{dQ}{dP}\left(\frac{P}{Q}\right) \tag{8.31}$$

For a downward-sloping demand curve the elasticity is negative. It is common to ignore the minus sign when quoting values of the price elasticity of demand. If the price elasticity of demand is less than minus one, the demand is said to be elastic, otherwise the demand is called inelastic.

Some typical estimated values of price elasticities of demand of interest to engineers are given in Table 8.12. Note that the reported values cover a wide range which would depend on a number of factors including the location and the method of estimation.

Table 8.12 Some typical values of price elasticity of demand.

Commodity	Price Elasticity of Demand		Number of Studies Considered	Reference
	Range	Average		
Urban Water	-0.11 to -1.588	-0.49	15	Brookshire et al. (2002)
Irrigation Water	-0.001 to -1.97	-0.48	24	Scheierling et al. (2006)
Public Transport	-0.002 to -1.121	-0.395	39	Hensher (2008)