Infrastructure Investment

An Engineering Perspective

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Preface

For any potential infrastructure or asset, such as investments, it is necessary to establish viability, both in monetary and nonmonetary terms. *Infrastructure* and *assets* here refer to buildings, roads, bridges, dams, pipelines, railways and similar, and facilities, plants, equipment and similar. Nonmonetary issues have, for example, social, environmental and technical origins.

Future demand and future costs for infrastructure and assets generally are uncertain in both timing and magnitude. As well, other investment viability analysis input such as interest rates are similarly uncertain. The book provides the methodology by which the viability of infrastructure or any asset may be appraised as investments, given future uncertainty.

In comparison, most conventional and existing practices ignore uncertainty or attempt to include it in deterministic (that is, assuming certainty) ways, often nonrationally. For example, using interest rates adjusted for investment uncertainty is common practice, as is sensitivity analysis. Business-as-usual might be assumed to repeat in the future, even though everyone knows this is not true, but it is convenient for people to assume so, and because usable approaches incorporating true uncertainty have heretofore been unavailable. Even climate change is commonly treated deterministically in existing approaches.

The book has particular applicability for decision makers presently struggling with analyzing investments with uncertain futures, including the impact of climate change and the possible use of adaptive and flexible solutions, capable of responding to changed futures, and how such uncertainty impacts the future performance of these investments.

The book represents an original contribution to investment viability analysis under uncertainty. Existing texts have not ventured into this territory, but have rather stayed with restrictive deterministic treatments. Additionally, the book gives a very systematic and ordered treatment of its subject matter. The level of required mathematics is no more than that which is familiar to undergraduates.

The formulations given provide interesting insight into investment viability calculations and will be of use to practitioners engaged in investigatory work, especially those looking at investment risk. The material presented on options analysis opens this area to all users, breaking the confines of existing financial options analogies.

The book will be of interest to students, academics and practitioners dealing with decision making on infrastructure, assets and like investments. It will be of interest to those engaged in investments, and the analysis of real options and financial options. The content is presented in straightforward terms in order to ensure as wide a readership as possible.

The book leads the reader through a structured flow, from a systematic treatment of conventional deterministic approaches to a complete probabilistic treatment incorporating uncertainty.

About the author

David G. Carmichael is professor of civil engineering and former head of the Department of Engineering Construction and Management at the University of New South Wales, Australia. He is a graduate of the Universities of Sydney and Canterbury; a fellow of the Institution of Engineers, Australia; a member of the American Society of Civil Engineers; and a former graded arbitrator and mediator. Professor Carmichael publishes, teaches and consults widely in most aspects of project management, construction management, systems engineering and problem solving. He is known for his left-field thinking on project and risk management (*Project Management Framework*, A. A. Balkema, Rotterdam, 2004), project planning (*Project Planning, and Control*, Taylor & Francis, London, 2006), and problem solving (*Problem Solving for Engineers*, CRC Press/Taylor & Francis, London, 2013).

Contents

Chapter 1

Introduction

1.1 APPRAISAL

The appraisal of potential infrastructure or assets, as investments, looks at the *benefits* and *costs* of everything related to the investments, both now and into the future. Common benefits include ongoing rental or product sales, and salvage or residual value at end-of-life. Common costs include initial capital cost; ongoing operation and maintenance costs; refurbishment, renovation or retrofitting costs; and disposal costs at end-of-life. *Infrastructure* and *assets* here refer to buildings, roads, bridges, dams, pipelines, railways and similar, and to facilities, plant, equipment and similar. An appraisal of a potential investment assists in

- (For a *single investment*, or for each investment) Establishing whether it is worthwhile proceeding with the investment. In other words, is the investment *viable*?
- (For *multiple investments*) Selecting between alternative investments (*preference*). In other words, which is the best investment?

Other names for *appraisal* include evaluation, study, analysis, feasibility study, benefit–cost analysis, and cost–benefit analysis. Of the last two names, engineers tend to use the second last version and stress the benefits side of the equation, much as engineers prefer to look at a glass half full, rather than half empty.

An appraisal involves consideration of issues that are

- Financial
- Nonfinancial (for example, environmental, social and technical)

That is, benefits and costs can be wider than just money. The social and environmental issues might be called *intangibles* and will have units of measurement that are not money. The units of measurement of benefits and costs need not be money, though many people find it hard or impossible thinking of units of measurement other than money. This rigidity in thinking is changing with time as environmental and social issues become more dominant in the eye of the public and start to enter people's thinking.

An appraisal can be carried out for every *stakeholder* involved in a potential investment. The data feeding into each stakeholder appraisal, of course, will be different depending on the concerns of the stakeholder. That is, it is possible for each stakeholder to come to a different conclusion as to viability and to the preferred investment. This raises serious issues of how the different viewpoints of different stakeholders are resolved, particularly in any investment that impacts on the public and on public interest (pressure) groups.

A financial appraisal would generally only involve items that can be expressed directly in money units and that affect the balance sheet and cash flow (money coming in and money going out) of the stakeholder. Typically, financial appraisals are done by the private sector. An economic appraisal, on the other hand, involves intangibles comprising environmental and social concerns, technical performance and so on, as well as the direct money items. An attempt may be made to put a monetary value on social and environmental items, but this is controversial. Typically, economic appraisals are done by the public sector. In some circumstances, a financial appraisal might be regarded as a special case of an economic appraisal. But there are multiple uses of the terminology. The mathematical manipulations for the financial and economic appraisals are the same if the intangibles are converted to money equivalents. Commonly, all benefits and costs are converted to a money unit for convenience, though the rationale behind this conversion is questioned by many people. The material in this book refers to both of what might generally be called economic appraisals and financial appraisals.

1.2 OUTLINE

This book gives the tools necessary for the appraisal of investments in infrastructure and other assets. The emphasis in this book is on dealing with uncertainty in investments (Part II: Probabilistic). However, it is considered that an introduction to deterministic analysis (Part I: Deterministic) is useful for understanding purposes. Most people learn by going from the particular to the general, and hence understanding Part I represents a necessary step in order to understand Part II.

'The term "probabilistic" implies some variability or uncertainty. "Deterministic", on the other hand, implies certainty. Deterministic variables are commonly described in terms of their mean, average or expected values. Probabilistic variables are commonly described in terms of probability distributions, or if using a second order moment approach, in terms of expected values and variances (standard deviation squared); the variances capture the variability information or uncertainty. Risk, for example, only exists in the presence of uncertainty, and hence risk approaches are probabilistic. With certainty, there is no risk. Generally, determinism is simpler to deal with and, wherever possible, people simplify from probabilistic to deterministic approaches' (Carmichael, 2013).

1.2.1 Part I: Deterministic

Part I is a stepping stone to Part II. It introduces many of the necessary terms used in investment appraisal. It discusses interest (and discount) rate matters, including compound interest for single and series amounts. A brief review of the concepts of compounding and discounting, and discounting equations is given. This leads to the various measures of appraisal, all of which rely on the time value of money. Information on investment viability and preference and the use of discount or compound interest equations in the various measures of appraisal is given. Last, Part I looks at issues to do with the choice of interest (and discount) rates, inflation, nonfinancial matters, sensitivity and benefits. A discussion of how investors treat uncertainty within a deterministic framework is given. Broadly, all these topics might be identified as belonging to what is called discounted cash flow (DCF) analysis.

1.2.2 Part II: Probabilistic

Part II extends the deterministic investment analysis of Part I to explicitly include uncertainty, and to include it in a proper way, rather than by adjusting deterministic thinking in an ad hoc way. This implies a probabilistic formulation as the most rational way forward. The material covers analysis involving probabilistic cash flows, interest rates and investment lifespans, and shows how this can also be used in the valuation of options. The favoured and adopted way of incorporating uncertainty into the analysis in this book is through a second order moment approach where variables are characterized solely in terms of their expected values and variances, thereby not requiring information on probability distributions, which in most applications would not be available.

1.2.3 Common formulation

The common probabilistic formulation given in this book covers many applications, with each application naturally specializing it in different ways. Any investment is converted to a collection of cash flows. A spreadsheet is all that is needed to perform the calculations.

Consider a general investment, with possible cash flows extending over the life, n, of the investment. Let the net cash flow, X_i, at each time period, i = 0, 1, 2, ..., n, be the result of a number, k = 1, 2, ..., m, of cash flow components, Y_{ik}, which can be both revenue and cost related. That is,

$$X_i = Y_{i1} + Y_{i2} + \ldots + Y_{im} \tag{1.1}$$

where Y_{ik}, i = 0, 1, 2, ..., n; k = 1, 2, ..., m, is the cash flow in period i of component k.

Introduce a *measure* called present worth (PW), which is the present-day value of these future cash flows. As shown in Chapter 2, the present worth is the sum of the discounted X_i, i = 0, 1, 2, ..., n, according to,

$$PW = \sum_{i=0}^{n} \left[\frac{X_i}{(1+r)^i} \right] \tag{1.2}$$

where r is the interest rate (expressed as a decimal, for example a rate per period of 5 % is expressed as 0.05). The term 'discounting' (and the related 'discounted') refers to converting future cash flows to their present-day value through the medium of the interest rate, which reflects the time value of money. A measure such as PW may be used to establish investment viability, and for selecting (preference) between alternative investments.

From this, information on PW, other measures such as internal rate of return (IRR), payback period (PBP) and benefit:cost ratio (BCR) can be derived. These other measures may also be used to establish investment viability, and for selecting between alternative investments. All of this is explained in detail throughout the book.

Equations (1.1) and (1.2) can be used for both the deterministic and probabilistic cases. For the probabilistic case, Y_{im}, X_i, r, n, PW, IRR, PBP and BCR become random variables. For the deterministic case, however, this formulation is perhaps more formal than it needs to be. For the deterministic case, many people find it more convenient to think in terms of benefits (B) and costs (C) rather than cash flow components (Y) or cash flows (X).

The obtained information on measures such as present worth and internal rate of return feed into the decision making regarding investments. As such, these measures might be used as objective functions, or interpreted as constraints to be satisfied in the relevant decision-making process (Carmichael, 2013). When viewed as objective functions, what is desired is that investment that maximizes or minimizes, as the case may be, the measures of PW, IRR, PBP and BCR. When viewed as constraints, what is desired is an investment that is less than or greater than, as the case may be, given values of these measures.