Australian Climate Change Adaptation Network for Settlements and Infrastructure

Discussion Paper
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Abstract

Conventional investment appraisal for infrastructure tends to be carried out deterministically,

supplemented with sensitivity or scenario analysis in order to incorporate possible deviations. However with climate change, such steady state assumptions no longer hold. Infrastructure, in the future due to climate change, could be expected to have to deal with increased temperatures, altered rainfall patterns, altered frequencies of extreme weather events and sea level rise. These in turn will lead, for example, to changed demand patterns, increased maintenance and operation costs, decreased longevity, increased costs of retrofitting, changed land use and demographics, and more frequent disruption to use. And all of these consequences are only known to within defined probabilities. Future costs and benefits for infrastructure are now inherently probabilistic, and any anonvestmayn1 ppra9(nisal)4(n0(muc,)-3(a)4(nts)-(

the future, such that the infrastructure is tailored to the changing climate or adapts to the changing climate; or (III) build for future conditions whereby the infrastructure is overdesigned in the near future but adequate for the longer term. Each choice represents different levels of feasibility. The paper explores the different possible mechanisms by which feasibility levels can be evaluated, including the feasibility associated with having flexible and adaptable infrastructure, such that rational investment decisions can be made within the uncertainty introduced by climate change.

1. Introduction

Commonly, economic feasibility of new infrastructure is based on a present worth (net present value) analysis, and this is done deterministically whereby all costs and benefits are assumed known, and the future is assumed to be a continuation of the present, or trend from the present. Where variability is anticipated in future costs and benefits, a sensitivity analysis or scenario analysis might also be carried out.

However with climate change, the future becomes less certain because of the underlying incomplete science and associated lack of confidence in prediction. Future benefits and costs and infrastructure lifespans cannot be predicted with any degree of accuracy, because of uncertainty associated with anticipated sea level and temperature rises, and changed occurrences and magnitudes of extreme weather events and rainfall patterns. Increases are expected in infrastructure maintenance, repair and operation costs, damage, and insurance premiums, while demands on infrastructure, energy, water and transport will change - both increase and decrease on a situation-by-situation basis. The locations of infrastructure needs will also change as demand changes. The operation of infrastructure will be disrupted more frequently. The longevity of infrastructure will decrease and external facades of infrastructure will experience accelerated degradation. Infrastructure will need to be replaced more frequently. Much has been written on this, for example [1], [2] and [3].

Climate change will expose vulnerabilities in existing infrastructure and infrastructure established along business-as-usual lines. And such vulnerability could be expected to vary between locations. Existing infrastructure could be expected to have limited ability or capacity to adapt, and may be fou6iho>apt, o1-110(a)4(re)7( )] TJET3 infrastrucrainfalestd1(a)4(n4pa)4m[(e take account of risks that are likely to change with climate over an extended timeline. Alternative financial and business models need to be investigated for use by government and private sectors for adoption in options assessment and investment decision making in the new

The present paper addresses the concerns in both these quotations. The methodology advanced in this paper incorporates uncertainty and values options and flexibility.

3. Infrastructure development choices

Three main choices for new infrastructure are possible:

I.

Figure 1 Schematic example cash flow diagrams (with variability in benefits removed) for the three possible infrastructure investment cases. Benefits are above the line. The costs below the line are in the order I, II and III at time now, while the costs are in the order I and II for later times.

4. Applicable tools

With such a probabilistic problem, available solution tools include Monte Carlo simulation (for example, [6]), fuzzy set approaches (for example, [7]) and second order moment analysis ([4] and [5]). The first two are numerical and only give a little insight into underlying behaviour. Black-Scholes and binomial lattices (for example, [8]), as used in financial options theory, could also be used but lack intuitive appeal to many. Second order moment analysis is used in the following because of its ease of use and requires very little adjustment for those familiar with conventional discounted cash flow (DCF) analysis. The method gives equivalent results to real options analysis via Black-Scholes or binomial lattices.

Conventional deterministic approaches would commonly use a risk-adjusted discount rate, leading to a high discount rate, which in turn leads to future cash flows having little value in present worth terms. As such, deterministic approaches effectively ignore any long term climate change impacts, and decisions would favour projects with short lifespans and short term returns. Probabilistic approaches on the other hand, because the uncertainty is already encapsulated within the future cash flows, use the lower risk-free discount rates, which give value (in present worth terms) to the future. With many of climate change impacts being long term and infrastructure lifespans being long term, it is accordingly more rational to adopt a probabilistic approach; this is on top of the issue as to what a risk-adjusted discount rate means in present worth calculations.

Deterministic approaches hide the fact that there is potential downside to any investment, while probabilistic approaches acknowledge that there is always a finite probability that the present worth of any investment can turn out to be negative.

5. DCF formulation covering infrastructure choices

Infrastructure choices I, II and III can be incorporated under a general model that has cash flows at each time period. The nature, magnitude and sign of these cash flows will differ between the three choices.

Let the net cash flow at each time period, i = 0, 1, 2, ..., n, be the result of a number of cash flow components Y_{ik}, k = 1, 2, ..., m. The cash flow components are benefit, disbenefit and cost related. There may be correlation between the cash flow components at the same period.

The net cash flow X_i in any period can be expressed as,

$$X_i \quad Y_{i1} \quad Y_{i2} \quad \ldots \quad Y_{im} \tag{1}$$

where Y_{ik}, i = 0, 1, 2, ..., n; k = 1, 2, ..., m, is the cash flow in period i due to component k, with mean E[Y_{ik}] and variance Var[Y_{ik}].

The expectation and variance of X_i become,

$$E[X_i] = \sum_{k=1}^{m} E[Y_{ik}] \qquad (2)$$

$$Var[X_i] = \sum_{k=1}^{m} Var[Y_{ik}] + 2\sum_{k=1}^{m-1}\sum_{\ell=k+1}^{m} Cov[Y_{ik}, Y_{i\ell}] \qquad (3)$$

where Cov[ ] is the covariance. Alternatively, the variance expression can be written in terms of the component correlation coefficients, $\rho_{k\ell}$, between Y_{ik} and $Y_{i\ell}$, $k, \ell = 1, 2, \ldots, m$,

$$Var[X_i] = \sum_{k=1}^{m} Var[Y_{ik}] + 2\sum_{k=1}^{m-1}\sum_{\ell=k+1}^{m} \rho_{k\ell}\sqrt{Var[Y_{ik}]}\cdot\sqrt{Var[Y_{i\ell}]} \qquad (4)$$

The present worth, PW, is the sum of the discounted X_i, i = 0, 1, 2, ..., n, according to,

$$PW = \sum_{i=0}^{n} \frac{X_i}{(1+r)^i} \qquad (5)$$

where r is the discount rate. The expected value and variance of the present worth become ([9], [10], [11]),

$$E[PW] = \sum_{i=0}^{n} \frac{E[X_i]}{(1+r)^i} \qquad (6)$$

$$Var[PW] = \sum_{i=0}^{n} \frac{Var[X_i]}{(1+r)^{2i}} + 2\sum_{i=0}^{n-1}\sum_{j=i+1}^{n} \frac{Cov[X_i, X_j]}{(1+r)^{i+j}} \qquad (7)$$

Alternatively, the variance expression can be written in terms of the intertemporal correlation coefficients between X_i and X_j, namely ρ_{ij}, rather than the covariance of X_i and X_j,

$$Var[PW] = \sum_{i=0}^{n} \frac{Var[X_i]}{(1+r)^{2i}} + 2\sum_{i=0}^{n-1}\sum_{j=i+1}^{n} \frac{\rho_{ij}\sqrt{Var[X_i]}\cdot\sqrt{Var[X_j]}}{(1+r)^{i+j}} \qquad (8)$$

For independent cash flows X_i,

$$Var[PW] = \sum_{i=0}^{n} \frac{Var[X_i]}{(1+r)^{2i}} \qquad (9)$$

For perfect correlation of the cash flows X_i,

$$Var[PW] = \left(\sum_{i=0}^{n} \frac{\sqrt{Var[X_i]}}{(1+r)^i}\right)^2 \qquad (10)$$

Var[PW] is smaller for the assumption of independence compared with the assumption of correlation.

6. Feasibility and upside value

Having characterized the present worth in terms of its moments, some measure is needed to establish the suitability of an investment. Feasibility is one appropriate measure.

Feasibility, , is defined as the probability that the present worth is positive ([4], [5]).

$$P[PW \quad 0] \qquad (11)$$

This may be readily evaluated where present worth follows a normal distribution. A normal distribution is commonly held to be a good representation of present worth ([9], [12], [10], [13])

Where competing infrastructure choices exist, that with the largest feasibility might be preferred.

Feasibility is a probability, and some people may not feel comfortable working with this measure. The question arises as to what is a level of feasibility acceptable to the investor, that is, what is an acceptable level of probability that the present worth will turn out to be positive. The answer to this will depend on whether the investor is risk prone, risk averse or

An alternative deterministic measure is to use the mean of the present worth upside, that is the mean of the portion of the present worth distribution that is positive. This is referred to as the upside value, UV, in this paper.

$$UV = E[PW \text{ upside}] \qquad (12)$$

The Black-Scholes formula and binomial lattices calculate something similar.

For a given Var[PW], a larger E[PW] means higher feasibility and higher upside value, while a lower E[PW] means a lower feasibility and lower upside value. That is for a given Var[PW], as increases/decreases, so too does UV increase/decrease respectively. Accordingly the preferred infrastructure, where alternatives exist, is that with the largest UV. With an individual investment, what is considered a minimum upside value will depend on

With climate change comes increasing uncertainty. With increased uncertainty comes the

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