A more accurate way to estimate LRMC

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1 Summary

We are presently consulting on our draft report on our Water Regulatory Framework. This package of reforms includes simplifications to the modelling work that supports our price assessments. As part of this review we are reviewing the way utilities estimate their Long Run Marginal Cost (LRMC) of water supply and wastewater treatment.

This IPART Secretariat research note seeks comment on a new, potentially more accurate way to estimate the Long Run Marginal Cost (LRMC) for water supply. This method has not yet been endorsed by the Tribunal. We are publishing it to promote discussion within the community of practitioners and support more robust LRMC estimations. We encourage stakeholders to provide feedback and make alternative suggestions.

The LRMC is an important guide to the efficient level for water usage prices. There may be situations where a regulator may choose to set the water usage price either higher or lower than the LRMC, subject to further considerations, including the importance of incentives for conservation and bill affordability for certain customer groups.

The focus in this document is on the problem of accurately estimating the LRMC. Irrespective of the exact role of LRMC in the process of setting usage prices, it is important to estimate it accurately. If usage prices are set much lower than the true LRMC, it will encourage excessive water consumption and place pressure on future water supplies. If usage prices are set much higher than the true LRMC, then value-adding uses of water will be avoided unnecessarily.

The LRMC is an efficient usage price, because it reflects the opportunity cost of additional consumption on the long-run costs of a water utility. To estimate it, we rely on the equality of two present values:

- the future costs to supply the necessary amount of water for a population in the most efficient way over a long period of time
- the future revenues that would be earned by applying a constant real usage price to the volume of water supplied over the same period.

The constant real usage price is the LRMC. It is equal to the present value of future costs divided by the present value of future volumes of water supplied.[a]

[a] Strictly speaking, volumes of water don't have a present value because volumes are not naturally expressed in dollar units. In this case what we mean is that future volumes are discounted as if they were dollar values.

To make this forward-looking estimate, it is necessary to forecast the time series of new costs and new water volumes supplied. There are two main methods of making these forecasts: “probabilistic simulation”, which typically involves simulating a distribution of future rainfall and demand using Monte Carlo method and what we call “deterministic simulation,” which adopts fixed values for these parameters. This note motivates and describes a third method, which we call “algebraic estimation” which overcomes some of the common drawbacks with a deterministic simulation using algebraic estimates.

2 Weaknesses of existing methods

Monte Carlo simulation is complex, but it does explicitly represent the uncertainties that are inherent in any forecasting exercise. Unfortunately, it yields a wide range of outcomes and is overly sensitive to certain input assumptions. For example, the treatment of drought events and usage restrictions can profoundly influence the results. Monte Carlo results that come with large standard errors, or are not stable and replicable, are not very useful.

Some of these uncertainties, notably rainfall variation, can be handled through a separate hydrological modelling process. Hydrological modelling may also rely on Monte Carlo simulations, but these are usually done by specialists with a detailed understanding of specific water catchments who use well-accepted techniques (as opposed to Monte Carlo simulations done in a bespoke way by economists). These hydrological models can establish an expected yield figure for each potential water supply augmentation. The yield is the amount of water that can reliably be supplied, even when allowing for uncertainty including (ideally) the forecast impacts of climate change e.g. on the incidence of droughts.

Once these uncertainties have been sufficiently accounted for, a single simulation run is sufficient to estimate the LRMC. This type of simulation is called “deterministic” because the stochastic effects have been captured in a separate hydrological modelling step. The focus is instead to model a reliable set of supply augmentations (such as dams, desalination plants, water conservation measures) that are costed and appraised for yield. The augmentation options are placed in a least-cost merit order, and then each one is brought on-line in time to meet the projected growth in demand over a period of several decades. That timing, along with the costs and demands is all the information required to do the present value calculations.

Deterministic simulation is relatively straightforward, and it can be implemented in a spreadsheet. However, it is easy to introduce inaccuracies, and sometimes hard to recognise them. Among the most common inaccuracies are:

- In some years of the forecast, the combined yield of the activated augmentation options is not sufficient to meet demand. This will cause an underestimate of the LRMC but it is often not obvious it has occurred.
- Deterministic simulation models must choose a time frame over which to simulate behaviour. Usually this is 40 – 50 years. Any new capacity augmentations that occur near the end of the simulation period will be counted in the cost, but the full benefit of water production will not be accounted for as it will be truncated. This will cause an overestimate of the LRMC but again it is hard to detect.

- The average incremental cost (AIC) LRMC method considers the costs and benefits of augmentations that provide for an increment in demand. How, precisely, that increment is defined can have a material impact on the LRMC estimate. If the increment is measured relative to existing usage, then a lower LRMC estimate will be obtained, compared to an increment measured relative to existing capacity. The reason is that the spare capacity of existing supply options is low cost. The usage increment will include the benefit of existing spare capacity, but the capacity increment will not. Deterministic simulation models submitted to IPART by various public water utilities take differing approaches to this important question and do so in a way that lacks transparency.
- The spreadsheets are still fairly complex and often rely on macros to perform the calculation. Overall, they tend to lack transparency.

3 Algebraic estimation

It is possible to estimate the present value of costs associated with any supply augmentation without resorting to simulation at all. This can be done using closed form algebraic expressions that will be derived below.

Similarly, if the future demand profile is known, it is also possible to estimate the discounted value of water supplied by any supply augmentation during the period between its implementation and when its capacity is reached. Again, closed form algebraic expressions are available, if we make a simplifying assumption that demand increases in a linear fashion until all known augmentations are exhausted, and then is held constant at that level.

To generate the LRMC for a series of individual supply augmentations, all that is necessary is to divide the cumulative present value of costs by the cumulative discounted value of water supplied.

4 LRMC for a single supply augmentation

This section provides the algebraic derivations of formulae for the present value of cost and the discounted value of the volume of water supplied for a single supply augmentation option with linear growth in demand. The variables are:

d discount rate (set equal to the regulatory WACC in real terms)

y the delay in years between start of construction and first water production (lead time)

K the maximum yield, or capacity of the supply augmentation

u the increase in demand each year. This will be constant for linear demand growth

t a time variable in units of years used in summations

t^* the number of years before an augmentation's capacity is fully utilised

C the capital cost of the augmentation option

E the variable (energy, for example) cost of an augmentation option per kL of water produced

M the fixed annual maintenance cost of an augmentation option

4.1 Present value of water supplied

Consider one capacity enhancement option that is undertaken at time t=0, which will generate a maximum supply capacity of K GL/yr. Assume that water demand is a linear function of time and that the volume of water supplied by this option is

$$v(t) = min(K, t\,u)$$

This option will be capable of meeting growing water demand between when it first generates water and when a new enhancement is required. That period will last for time t^*, which is the t value at which demand equals capacity: $t^* = K/u$.

After that period, this option will continue to generate, on average, $v(t) = K$ in perpetuity.

Allowing for a delay y between when the option is built and when it first generates water, the present value of water supplied is:

$$PV\ water\ supply = \sum_{t=t*+y+1}^{\infty} K\,(d+1)^{-t} + \sum_{t=y+1}^{t*+y} t\,u\,(d+1)^{-t}$$

$$PV\ water\ supply = (d+1)^{-y}\left[K \sum_{t=t*+1}^{\infty} (d+1)^{-t} + \sum_{t=1}^{t*} t\,u\,(d+1)^{-t}\right]$$

Closed-form expressions are available for the two summations. For the first:

$$\sum_{t=1}^{t*} (d+1)^{-t} = \frac{(1-(d+1)^{-t*})}{d}$$

The infinite version of this summation is simply 1/d since (d+1) > 1.

With a bit more effort we can see that, for the second summation:

$$\sum_{t=1}^{n} t(x)^{-t} = \frac{x^{-n}[x^{n+1} - x - nx + n]}{(x-1)^2}$$

Substituting for these summations and simplifying:

$$PV\ water\ supply = (d+1)^{-y}\left[\frac{K}{d}(d+1)^{-t*} + \frac{(d+1)^{-t^*}[(d+1)^{t^*+1} - (d+1) - t^* d]}{d^2}\,u\right]$$

$$= \frac{(d+1)^{-y-t^*}}{d}\left[K + \frac{(d+1)^{t^*+1} - d(1+t^*) - 1}{d}u\right]$$

4.2 Cost characteristics of a generic augmentation option

Any augmentation, be it rainfall-dependent (a dam) or rainfall-independent (such as a desalination plant) will involve capital costs, energy costs and maintenance costs. We develop below a generic formula for the present value of costs that would work for any of these augmentation options. It accounts for up-front capex, ongoing opex and periodic maintenance and renewals.

First note that, unlike a dam, the maximum yield of a desalination plant, is known with certainty. When a desalination plant reaches its capacity and a new capacity increment is installed, one of two things could happen:

- If the new capacity is another desalination plant, then the current desalination plant will keep operating at its capacity.
- If the new capacity is a dam, then the current desalination plant will be switched off once the new dam is in service. We assume, in this case, that the desalination plant will not be used again.[b]

We only consider the case where the desalination plant keeps operating at capacity.

In addition to the capital cost, owners of a desalination plant must spend M annually to replace the membranes and incur energy costs to operate the plant. The amount of energy required is proportional to the amount of water produced, and we assume that the energy price per unit of water supplied, E, is constant in real terms.

In real terms, if desal operation is ***expected to continue indefinitely***, the present value of desalination costs is:

$$PV\ costs = C + E * PV\ water\ supply + \frac{M}{d}(d+1)^{-y}$$

The same cost function works for a dam, but the relative importance of the cost parameters C, E and M changes. For a dam, E and M would be close to zero, but any energy or maintenance costs can be captured with this formula.

The present value of water supply is the same for a desalination plant as it was for a dam, since the amount of water supplied is equal to the incremental water demand in either case.

Dividing the PV costs by PV water supplied:

$$LRMC = \frac{C\ d(d+1)^{y} + M}{(d+1)^{-t*}\left[K + \frac{(d+1)^{t^*+1} - d(1+t^*) - 1}{d}u\right]} + E$$

[b] While the desal plant might be kept for future use, any such use will be distant in time. At the soonest it will be when the new dam reaches its capacity, or later.

5 Combining LRMC estimates for augmentations

Each augmentation will have its own LRMC, which is the present value of costs divided by the present value of water. These present values depend on the start year. Let the following variables represent the key quantities:

j augmentation number, starting at 1 and going in merit order

sj build start year for augmentation j, given merit order and rate of demand growth

lj lead time for augmentation j

PCj present value of costs of augmentation j, assuming a start year of 0

PWj present value of water produced by augmentation j, assuming a start year of 0

The LRMC for a suite of augmentation options that are needed to meet demand over a period of time is given by this formula:

$$LRMC = \frac{\sum_{j=1}^{N} PCj\ (1+d)^{-sj}}{\sum_{j=1}^{N} PWj\ (1+d)^{-(sj+lj)}}$$

Note that the water production must be discounted more than the costs because water production begins several years after construction began and the costs were incurred.