Managing Climate Risks – the role and value of real options

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EXTENDED ABSTRACT

Climatic variability presents a different management challenge to the persistent effects of climate change. Increased climatic variability will be reflected in commercial and environmental risks as well as catastrophic risks. Adaptation requires a balance between mitigation and insurance in respect of these risks.

The balance may, in part, be struck through real options that reduce the cost of responding to risks as they emerge. A real options approach creates opportunities to respond rather than mandating a response. While real and financial options share common features they have an important difference, notably, exercising a real option may incur sunk or ongoing unavoidable costs.

Using historical natural and regulated inundation patterns for the central reaches of the Murrumbidgee River, the environmental management strategy of optimising the level of habitat quality in a riverine system, through more closely re-creating the frequency, timing and duration of naturally occurring high flow events is examined.

The environmental manager's decision is expressed as the option to store the annual allocation from a perpetual water entitlement and preserving the option to release the accumulated water at a later date when climatic conditions are such that the environmental value of the additional water is increased.

Uncertainty is introduced through unknown current and future climatic patterns, restricting the information held by the environmental manager. That is, even though extensive climatic records are available, the environmental manager does not know if recent conditions are a reliable indicator that the weather pattern has changed

The value of the option to store water can be determined in two steps: first to compare the increase in habitat quality that is achieved by incrementing the level of storage capacity, and then determining the increase in entitlements that would be required to be purchased to achieve the same increase in habitat quality.

Markov models provide a robust approach to valuing real options. States represent climatic regimes with different option values and transitions probabilities reflecting climate change. Hidden Markov models allow that the current state isn't known with certainty, a pertinent aspect of climate risk. Here a hidden Markov model is used to evaluate environmental management options.

1. INTRODUCTION

Climate change, whether driven by global warming or natural long term cycles presents a substantial risk management problem with regard to commercial and environmental assets.

In considering environmental concerns:

- longer-term shifts in climatic conditions are likely to affect management strategies;
- current management strategies will influence the resilience of environmental systems to future climate change; and
- there is little if any certainty – the problem is in large part characterised by what is not known.

Uncertainty presents serious difficulties but is not, in itself, a reason for inaction. This argument is a variation on the precautionary principle. The precautionary principle is often related to placing restrictions on actions that have a reasonable risk of generating damaging and irreversible outcomes. Therefore, for the same reason that the uncertainty surrounding the possible level of damage generated by these outcomes is no reason to undertake potentially damaging actions, the uncertainty surrounding the would-be damages due to potentially drier climates in the future is no reason to not undertake protective measures now that will improve policy flexibility and possibly environmental outcomes in the future.

However, to be able to maximise the benefits of applying the precautionary principle, potential present and future actions should be applied in the context of an investment under uncertainty. That is, rather than prescribe mitigation or prevention actions today it may be more advantageous to invest in options that create the opportunities to expand the choice and effectiveness of future management strategies, as uncertainties are resolved. These possible future options may take the form of direct investments in human and physical capital as well as investments that preserve existing environmental assets.

The capacity to value these forward options is central to the development of an optimal risk management strategy.

2. REAL OPTIONS FRAMEWORK

A real option is a current investment or expenditure that has or provides flexibility to respond to uncertain future conditions. Real options operate in a similar manner to financial options with the principal distinction being that real options are held over physical assets. The main characteristic shared between financial and real options is that they do not commit the holder to a future course of action and therefore lower the costs of responding to new information in the future (Copeland and Antikarov, 2001).

Essentially, a real option or set of real options is a contingency plan that allows for different actions to be taken in light of new information becoming available. One distinction between a real and a financial option is the pathway that can be constructed from a sequence of successive individual options. For example, an option to locate an initial investment in one of two alternative locations might then have a different sequence of expansion options.

A second distinction between financial and real options becomes important when attempting to value the real option and determine whether the option is a feasible investment. When considering financial options, the investment is relatively liquid and may be bought and sold relatively easily on secondary markets. The only costs involved in the disposal of the option are the transactions costs of the sale. Real options on the other hand generally involve some form of a sunk investment that is not easily liquidated. Therefore, when attempting to value the real option, it is important to consider the transferability of the sunk investment (that is, can it be easily on sold, or is it a firm or industry specific investment).

3. THE MANAGEMENT PROBLEM

An important management objective in regulated river systems in Australia is to strengthen the link between the river and wetland environments. Beare et al. (2005) examine this objective in the Murrumbidgee River. The Murrumbidgee is a highly regulated river with; two major storages, a number of smaller weirs and a network of irrigation delivery channels designed to meet irrigation demands. Diversions for irrigation are significant, accounting for around 95 per cent of natural median annual flow.

As part of a National Land and Water Audit, Norris et al. (2001) calculated an Index of Hydrological Disturbance for all rivers in the Southern Murray Darling Basin. The index rated the rivers on a scale of 0 to 1 from extremely disturbed to undisturbed. Of the 12 river basins assessed, the Murrumbidgee was estimated to be the most disturbed (hydrologically modified) with an index value of 0.41.

Natural and regulated flow conditions for the central reaches of the Murrumbidgee River are shown in Table 1. The results are from the NSW Department of Natural Resources Integrated Quantity and Quality Model (IQQM) and show the frequency of single day and two week flood events.

Table 1: Return frequency (per 100 years) of various flow events at the Wagga Wagga gauge (daily volumes) which persist for at least one day and at least 15 days – current and natural modeled flow. Source: Beare et al. (2005).

Minimum flow	Flow model	Return frequency (per 100 years) for events lasting at least: 1 day	15 days
25 GL/day	Current	323	38
	Natural	457	66
30 GL/day	Current	245	24
	Natural	395	39
35 GL/day	Current	190	12
	Natural	353	25
40 GL/day	Current	159	8
	Natural	301	16
50 GL/day	Current	104	3
	Natural	228	8
60 GL/day	Current	82	1
	Natural	175	2
70 GL/day	Current	55	1
	Natural	127	2

Hillman et al. (2003) showed the importance of extended flood events to the overall quality of the riverine environment. In particular, they showed that extended flood events are required to create the build up of particulate organic carbon required by bacterial and zooplankton groups which ultimately provide food for fish populations.

While the replication of natural or pre-development high flow conditions on a working river may not be possible – or desirable – the restoration of some aspects of stream ecology by more closely re-creating the frequency, timing and duration of naturally occurring high flow events is seen as an essential element of water management.

One management strategy is to augment natural high flow events with synchronised releases from storages. However, the volume and timing of water resources required to meet this objective is highly uncertain.

The following analysis considers the basic hydrological and water management aspects of the problem considered by Beare et al. and addresses the value of inter-seasonal water storage in delivering environmental outcomes more cost effectively.

4. A STYLISED PROBLEM IN AN OPTIONS FORMAT

Consider an environmental manager with a fixed water entitlement and an objective of maximizing average habitat quality by releasing water from storages to supplement existing flows and creating flood events. The water allocation derived from this entitlement is determined on the basis of available resources. The supplementary release requirement depends on the level of natural flows and other scheduled releases.

The manager is aware that there are long term cycles in rainfall, referred to here as wet and dry periods. The optimal management strategy is likely to vary between these two regimes. However, while there are extensive climatic records, the manager does not know if recent conditions are a reliable indicator that the weather pattern has changed.

The manager has two choices to manage this uncertainty. The first is to increase the level of water entitlement which has a known market value. The second is to access a greater volume of storage where storage is not traded. Here, storage is valued as a real option.

5. THE MODEL

In defining habitat quality we follow the approach of Possingham and Tuck (1997) of creating a habitat index using an alternative functional form that is continuous and non-linear:

$$h(t) = \frac{100}{\left[1\_\exp\left(\beta_0 + \beta t_1\right)\right]} \tag{1}$$

Where h is habitat quality and t is time since the last flood event. The objective of the environmental manager can be couched in a number of ways, as for example to maximize the minimum or a percentile level of habitat quality.

Here, the objective will be to maximize the average habitat quality.

The environmental manager faces two states of nature:

- a wet sequence characterised by higher than average stream flows and lower than average releases required to generate over-bank flows; and
- a dry sequence characterised by below average allocations and higher than average release requirements.

The process is represented as a hidden Markov chain where the ith state expressions are:

$$A_{i,t} = \min\left[A_{\max}, a_{i,y} \square N\left(u_{i,a}, \sigma_{i,a}\right)\right]$$
$$Q_{i,t} = \min\left[Q_{\max}, q_{i,y} \square N\left(u_{i,q}, \sigma_{i,q}\right)\right] \quad (2)$$

Where A denotes an annual allocation as a per cent of an entitlement V and Q is the supplementary flow requirement. The transition probabilities are $\omega_{1,2}$ and $\omega_{2,1}$. Given an observed sequence of allocations and flow requirements, the predicted probability of being in the first state, wet, is p.

The probability distributions associated with the wet and dry states were applied in a discrete format. These probabilities along with the transition probabilities and habitat coefficients are provided in Appendix 1.

Following Possingham and Tuck (1997) and Beare et al. (2005) we specify a release rule over which the problem is optimized. There are a number of ways in which the state probability p could be incorporated into the release rule. Here the probability is used to weight a linear release rule for each state:

$$q_{i,t} < p\left(\alpha_{1,0} + \alpha_{1,1} h_{t-1}\right) + (1-p)\left(\alpha_{2,0} + \alpha_{2,1} h_{t-1}\right) \quad (3)$$

With the option to store an entitlement, the environmental manger can either choose to make a release and bank water in excess of requirements or take the option of banking the full allocation. The manager faces a storage constraint equal to $S_{\max}$.

The optimisation problem is then:

$$\underset{\alpha}{Max}\ min \sum_{yr \subset YRS} h_{yr}$$

$$Subject\ to$$

$$t = \begin{cases} 0 & s_{yr} \geq q_{yr} \\ t_{-1} + 1 & otherwise \end{cases}$$

$$s_{yr} = \begin{cases} q_{yr} & a_{yr} V + S_{yr-1} \geq q_{yr}\ and\ q_{i,t} < \alpha_{i,0} + \alpha_{i,1} h_{t-1} \\ 0 & otherwise \end{cases}$$

$$S_{yr} = \min\left(S_{\max}, S_{yr-1} + V a_{yr} - s_{yr}\right)$$

$$i_{yr} = \begin{cases} 1 & i_{yr-1} = 1\ and\ v_{yr} \geq \omega_{1,2} \\ 1 & i_{yr-1} = 2\ and\ v_{yr} < \omega_{2,1} \\ 2 & i_{yr-1} = 2\ and\ v_{yr} \geq \omega_{2,1} \\ 2 & i_{yr-1} = 1\ and\ v_{yr} < \omega_{1,2} \end{cases}$$

$$p_{yr} = f\left[\left(a_{yr-1}, q_{yr-1}\right), \left(a_{yr-2}, q_{yr-2}\right) \ldots \left(a_{yr-n}, q_{yr-n}\right)\right] \quad (4)$$

Where s is the quantity released, S is the volume in storage. The functional f returns the posterior probability of the first state given the observed (1.2) sequence of allocations and required releases using the forward algorithm (Durbin et al. 1998).

As the flood events are discrete, the objective function will be a discontinuous function of the controls. A genetic algorithm was used to generate an approximate solution and then a pattern search was used to refine the solution.

The model was implemented in Matlab using the Statistics Toolbox and Genetic Algorithm and Direct Search Toolbox. The code is available from the authors on request.

The value of the option can be determined in two steps. The first is to compare the increase in habitat quality that can be achieved by allowing S to take on a positive or incrementally greater value. The second step is to determine the increase in the level of entitlement that yields an equivalent level of habitat quality while constraining storage to the initial level.

The market value of the water saving is then the option value. This again has two parts. The first is simply the difference in the entitlement values. (1.3) However, differences in the entitlement levels and storage capacity will lead to different levels of water utilisation. Water that is not utilised or stored may be a pure loss or may have a salvage value. In the later case, the salvage value needs to be deducted from the cost of the entitlement; estimated as:

$$Salvage\, value = \frac{\left(V - \bar{s}\right) Salvage\ price}{i} \quad (5)$$

Where $\bar{S}$ is the average release and i is the interest rate

6. RESULTS

The simulation model was run under natural conditions and for 5 allocation and storage scenarios. The hidden Markov process was simulated on an annual basis for 500 periods.

The reference case scenario allowed for 35GL of entitlement and 35GL of storage, with a release rule for each climatic state of:

$q_{i,t}<p(70.4 - 0.13h_{t-1}) + (1-p)(139.3 - 0.66h_{t-1})$ (6)

The release rule indicates that when the climatic conditions are dry, the option to save the allocation and build up a greater stock of water to be released in the future should be taken, especially if there has been a recent flood event. This is largely an artefact of the rate at which habitat quality declines over time, relative to the rate at which water can be accumulated to meet a future release requirement. If the rate of decline was slower, it may be best to build up reserves in term of habitat quality rather than water when conditions are dryer.

The time between flood events for the natural flow conditions and the reference case are presented in Figure 1. While the frequency of flood events under natural flow conditions is greater than what has been observed for the central reaches of the Murrumbidgee, the comparative results from the model are as expected. That is, the frequency of short spells between events is increased with the supplementary releases while the frequency of extended spells is reduced.

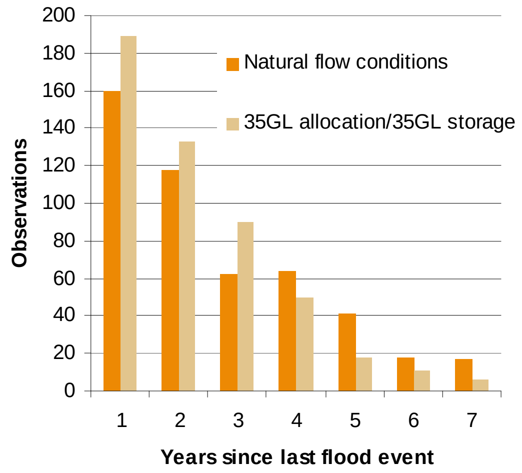

Figure 1: Years since last flood event, over 500 year period

The value of the option was calculated by determining the increase in allocation that would be required to return the same increase in habitat quality as a given increase in storage capacity. The option value calculation was run for storage capacity of both 45GL and 55GL, using both a 100 and 50 per cent salvage value of un-storable water, or storage overflow. The entitlement is assumed to be worth \$1000/ML.

The results of the simulation model are presented in Table 2.

Comparison of the results from Case 1 and Case 1a value the addition of 10GL of storage capacity. With a 100 per cent salvage value of the overflow, the costs of achieving a habitat quality index of 76 with 45GL of storage capacity is \$29.3m. However, the costs to achieve the same level of habitat quality with only 35GL of water storage are \$31.3m. Therefore, the additional storage option value is \$2m, or \$200/ML. As the salvage value of the overflow reduces to 50 per cent, the option value increases to \$4.25m, or \$425/ML.

Comparing the results from Case 2 and Case 2a, the option value of an additional 20GL of storage, at a 100 per cent salvage value is \$2.9m, or \$145/ML. As the salvage value of the overflow reduces, the option value increases to \$6.95m, or \$347.50/ML.

Table 2: Results.

	Entitlement	Storage	Habitat quality	Average utilisation	Salvage value	Costs
Reference case	35GL	35GL	69	10.4	100% of entitlement value	$24.6m
					50% of entitlement value	$29.5m
Case 1	35GL	45GL	76	5.7	100% of entitlement value	$29.3m
					50% of entitlement value	$32.15m
Case 1a	41.5GL	35GL		10.2	100% of entitlement value	$31.3m
					50% of entitlement value	$36.4m
Case 2	35GL	55GL	79	3.7	100% of entitlement value	$31.3m
					50% of entitlement value	$33.15m
Case 2a	46GL	35GL		11.8	100% of entitlement value	$34.2m
					50% of entitlement value	$40.1m

6.1. Conclusions and Recommendations

A real options approach is an effective way of looking at the value of investment and management plans that are designed to provide greater flexibility to respond uncertain future conditions and outcomes.

There are two key aspects to valuing real options. The first is the way in which uncertainty is characterised. The second is to determine the likely frequency and outcome if the option is exercised.

Using the hidden Markov chain to characterise uncertainty provides a reasonably robust approach to valuing options designed to manage longer term climatic variation. A simple approach was adopted with the transition and emissions probabilities assumed to be known.

Considerably more sophisticated approaches are available. For example, prior transition and emissions probabilities can be updated on the basis of new information using a Viterbi algorithm.

The use of a dynamic programming approach to optimise the conditions under which the option is exercised avoids two problems that are typically encountered when using traditional financial methods for evaluating options. Financial methods such as Black-Scholes are at best a good approximation to valuing non-traded options. Monte-Carlo methods tend to rely on simple heuristic decision rules.

Despite the highly stylised nature of the problem examined here, inter-annual storage capacity in excess of existing entitlements would seem to be an important tool for managing environmental flows to meet objectives a least cost.

This is most likely to be the case where environmental releases are not required on a frequent basis. The value of inter-annual storage for environmental management may be considerably greater than for agricultural use in general as trade allows water to shift from relatively low to higher valued uses when supply is low. However, this is question worth further evaluation.

The results also suggest that environmental management strategies and goals may need to change in response to longer term climatic shifts. However, to properly address this issue would require considerable refinement of the model and its calibration.

6.2. References

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APPENDIX 1.

The parameter assumptions used in the model are provided in the following tables.

Table A: Model probabilities of allocation and flow requirement

	Flow requirement				
Allocation %	0	30	60	90	120
Wet State					
100	0.010	0.013	0.019	0.008	0.001
90	0.026	0.034	0.056	0.026	0.008
80	0.053	0.070	0.131	0.070	0.026
70	0.025	0.035	0.075	0.045	0.020
60	0.010	0.015	0.038	0.025	0.013
50	0.006	0.009	0.028	0.021	0.011
40	0.003	0.005	0.019	0.015	0.009
30	0.001	0.001	0.009	0.008	0.005
Dry State					
100	0.005	0.006	0.009	0.004	0.001
90	0.009	0.011	0.019	0.009	0.003
80	0.030	0.040	0.075	0.040	0.015
70	0.031	0.044	0.094	0.056	0.025
60	0.020	0.030	0.075	0.050	0.025
50	0.009	0.016	0.047	0.034	0.019
40	0.005	0.010	0.038	0.030	0.018
30	0.001	0.003	0.019	0.016	0.010

Table B: Transition probabilities

State	1	2
1	0.85	0.15
2	0.20	0.80

Table C: Habitat coefficients

Beta 0	-3
Beta 1	1.5