# Uncertainty and the Economic Implications of Weather Modification – Integrating Hypothesis Testing into Benefit-Cost Analysis

*Stephen Beare[1], Ray Chambers[2], Scott Peak[3]*
*[1]Analytecon, 4 Johnston Street, Narrabundah, ACT 2604, Australia, stephenbeare@analytecon.com.au*
*[2]Centre for Statistical and Survey Methodology, University of Wollongong, Wollongong, Australia. ray@uow.edu.au*
*[3]Australian Rain Technologies, 23 Hickson Road, Millers Point, NSW 2000 Australia. peak@australianrain.com.au*

## 1. Introduction

The localised modification of weather, intended or inadvertent, is difficult to detect due high level of natural variation in weather conditions and the reliance on observational as opposed to controlled experimental data. As a consequence statistical analysis often generates inconclusive results when using standard scientific precedents with respect to hypothesis testing. In fact, most cloud seeding experiments still do not provide evidence sufficient to reject the null hypothesis of no enhancement, and usually produce data 'not sufficient to reach statistical conclusions' (NRC 2003). However these standard precedents are not always useful in an industry or public policy context when a decision to invest in a rainfall enhancement program or regulate emissions from a power plant is being considered.

Weather modification technologies in general, are relatively low-cost and the prospective economic benefits of increased rainfall can be great. The economic costs of inadvertently caused reductions in rainfall may be equally high. Therefore, it seems appropriate to adopt a framework of decision-making under uncertainty when considering the testing and adoption of rainfall enhancing technologies or monitoring and evaluating the impacts of air pollution.

Expected benefit-cost analysis is perhaps the most common method for decision making under uncertainty. However, this approach has shortcomings when levels of uncertainty are sufficiently high to question whether there is a weather modification effect. A more appropriate approach that integrates hypothesis testing into benefit-cost analysis is developed in this paper. The benefit-cost analysis framework is restructured to admit the distribution associated with the null hypothesis against the alternative associated with the observational data. The objective is to construct an economic measure of acceptable risk .The approach is placed into the context of weather modification trials.

## 2. Benefit-cost analysis

The benefits and cost of alternative actions should have clear role in the decision process. Statistical measures of error bounds are readily incorporated into benefit-cost analysis. This kind of analysis provides an economic ranking of the options and a measure of risk associated with a particular decision. However, benefit-cost analysis does not resolve the underlying scientific uncertainty nor does it provide a sense of acceptable risk. The latter is because the level of uncertainty or lack of statistical precision does not alter the economic rankings.

We can take a standard benefit-cost approach and take into account the probability of achieving a positive rate of return from a future weather modification trial, given the results from past trials. The focus on benefits of a trial intentionally abstracts from broader benefits of proving the technology if it is in fact effective for simplicity. The costs of the trial are compared to the expected net benefits of additional rainfall. The calculation of these benefits can be quite complex as they depend critically on timing and location of any increase in precipitation. However, the calculation of the benefits is not at issue here. Importantly, the level and variability in the expected net benefits can be weighed against other options for managing the effects of adverse climatic variability such as the purchase of water from other users and agricultural investments in varietal breeding, genetically modified crops, crop management and increased water use efficiency.

A hypothesis-testing framework can also be used to account for the costs of falsely rejecting either the null hypothesis or the alternative hypothesis (there are no opportunity costs associated with a correct decision). In a business or public policy context the cost of falsely rejecting the null hypothesis that there is no effect (that is, the cost of running trials when there is no positive outcome) must be evaluated in light of the foregone benefits of falsely rejecting the alternative hypothesis that there is an effect. In contrast to traditional benefit-cost analysis, this approach can lead to the rejection of an investment with a high-expected return if the level of uncertainty is high enough. A traditional benefit-cost approach allows the comparison of alterative investments but would only reject an option if either negative or same return could be achieved with a greater level of certainty. The hypothesis-based approach has an additional advantage in that it can place a value on information that would increase the precision of the estimated level of enhancement.

## 3. An alternative view of risk and return

The traditional benefit-cost analysis described in the previous section is predicated on the assumption that the average level of effect is an unbiased, and therefore an acceptable estimate of the true level of the effect. There is uncertainty about that estimate which can be characterised by error bounds. From the average effect and the error bounds, the expected level and variability in net returns is calculated. The decision under uncertainty is simple:

- Any investment option with a positive average net return is viable; and
- If one or more investment options have the same return the option with the lowest variability is preferred.

The scientific process of hypothesis testing gives rise to an alternative perspective on the idea of risk and return. Consider the following standard one-tailed hypothesis test:

- $H_o$: Effect = 0
- $H_a$: Effect > 0

Here, risk and return are couched in terms of the direct and opportunity costs of false rejection. That is, the cost of falsely rejecting the null hypothesis $H_o$ versus the cost of false rejection of the alternative hypothesis $H_a$. This, in turn, is linked to the confidence levels associated with these decisions. Clearly, if the cost of falsely rejecting $H_o$ is far greater than the cost of falsely rejecting $H_a$ it would be rational to try to limit the likelihood of a type-I error and set a confidence level for $H_a$ which is quite high. Conversely, if the cost of falsely rejecting $H_o$ is less than falsely rejecting $H_a$, it would be rational to try to limit the likelihood of a type-II error and set a confidence level for $H_a$ which is relatively low. It is possible to try and limit the potential for a type-II error by increasing the power of the test through, for example, more extensive trials.

Given the inability to control trial weather, a high level variability in natural rainfall and the lack of longer-term stationarity in weather systems, the capacity to increase the power of the test and reduce type-II error may limited and costly. As a consequence, setting an appropriate level of confidence for $H_a$ becomes the central issue for which commonly used “precedents”, such as the 99 per cent confidence level provide little, if any, guidance.

In comparing the opportunity cost of falsely rejecting the null hypothesis and the opportunity cost of falsely rejecting the alternative it is possible to find a confidence level for a standard one-tailed hypothesis test that equates the two costs. That is, it generates a net economic benefit of zero. This confidence level, in a fiducial or Bayesian context, can be interpreted as a threshold level of risk. For a discussion of fiducial and Bayesian analyses see Hannig (2009).

If the error associated with the estimate of interest generates confidence level below this threshold the best economic option is to accept the null hypothesis even though the net returns under the alternative may clearly warrant an investment or some form of intervention. Alternatively, if the confidence level is above the threshold then the best economic option is to accept the alternative even if by scientific standards the results are not conclusive.

It is also possible to ascribe an ex ante economic benefit to additional experimental data or statistical methods that reduce estimation error (assuming the estimate itself is unchanged). The reduction in error changes the weighting of the opportunity costs, which in turn changes the expected net benefit associated with the preferred option.

## 4. Application to Weather Modification trial

The new approach described in the previous section is formally set out and then contrasted with traditional benefit-cost analysis using a stylised example. The technique is then applied to data from rainfall enhancement trials conducted in South Australia using a ground-based ionisation technology known as Atlant (Beare et al. 2011). The analysis clearly shows that even with substantively greater levels of uncertainty associated with the estimated level of enchantment, the opportunity cost of foregoing the direct benefits of future trials would be greater than the trial costs.

## 5. Concluding remarks

In this paper an alternative risk and return framework based on the principles of hypothesis testing was developed. The approach is appropriate for evaluating investment and decisions based on experimental evidence are subject to high degree of uncertainty. The approach yields an economic measure of an acceptable level of risk.

The tool seems particularly useful in the context of weather modification and the observational analysis of natural systems more generally, due to the difficulty of detecting signal against high background noise, when that signal is associated with substantial benefits or costs.

### References


Beare, S., R. Chambers, S. Peak, J. Ring, Accounting for Spatiotemporal Variation of Rainfall Measurements when Evaluating Ground-Based Methods of Weather Modification. *Journal of Wea. Modif.* **43**, 44-63, 2011.

Hannig, J., On Generalized Fiducial Inference, *Statistica Sinica*, **19**, 491-544, 2009.

National Research Council (NRC), *Critical Issues in Weather Modification Research*, National Academy Press, pp. 41. 2003.