A Methodology to Estimate the Value of Weather Modification Projects: An Illustration for Hail Suppression

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ABSTRACT

A methodology to estimate the potential value of proposed weather modification projects is described. An illustration of the technique is given to evaluate a hypothetical hail suppression project. This methodology requires that three crucial sets of data be developed: 1) the benefits attributable to altered weather, 2) the probabilities that such alterations can be accomplished, and 3) the costs associated with this technology. Given these data, a net benefit variable is determined and present value techniques are used to discount that quantity to current dollars.

1. General setting

A basic area of concern for any researcher contemplating a possible research effort is the potential value of that effort if a successful investigation is completed. If the considered research effort requires funding from public agencies, this concern is shared by the decision makers involved in allocating those public funds. This question is particularly relevant if public monies are scarce and several research concepts are competing for resources.

Information and procedures are available, however, which can provide information helpful to solving this problem. This paper describes one of these techniques and provides an illustration for a particular weather modification activity—that of hail suppression. The analysis reported here is an outgrowth of a recently completed, multi-disciplinary Technology Assessment of Hail Suppression (Changnon *et al.*, 1977). One phase of this assessment (and the issue considered here) addressed the question, "How can available information be used to discern the value of further research for reducing current uncertainties about hail suppression"?

This paper first describes the data needed to answer such a question, and then provides an estimate of that answer for a particular hypothetical hail suppression program. The data needed to estimate the value of additional research information can be listed in three segments. These are 1) the relationship between benefits and changes in physical factors due to hail suppression, 2) a probability distribution of the changes in physical factors caused by the contemplated research program, both before and after the proposed research, and 3) the costs, both development and operational, associated with the technology. Further discussion of the methodology described here is available in Reutlinger (1970) and Dillon (1971).

2. Benefits

A hypothetical relationship between changes in physical factors and direct benefits is depicted in Fig. 1. For the hail suppression example, it is assumed that only two physical factors, hail damage to crops and growing season precipitation, would be affected by hail suppression programs. This stipulation is justified if a program does not affect other physical factors (lightning, wind, etc.) or if such effects do not alter the direct benefits of the program in any appreciable manner. Also, for the example presented in this paper, the direct-benefits variable is restricted to net income from crop production (also a simplifying assumption).

Fig. 1 graphically relates varying levels of crop-hail damage reduction and changes in rainfall to the value of direct benefits associated with each level of these physical factors. Here movements along the AB axis relate to various reductions in crop damage due to hail, and movements along the CD axis relate to changes in hail season rainfall. The surface enclosed by points a,b,c,d completely encloses the potential net income changes brought about by the technology. For any particular outcome, with respect to reduced crop damage or changes in rainfall, a specific direct benefit level can be determined. For example, point x for crop

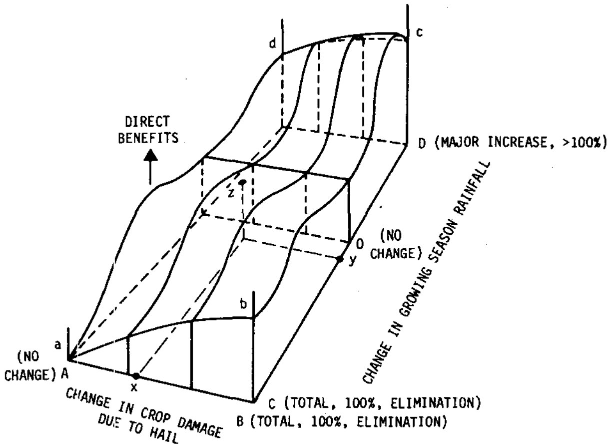

FIG. 1. Example of a relationship between changes in physical factors and direct benefits involving hail suppression.

damage (about a 20% reduction) and point y for changes in rainfall (about a 5% decrease) are uniquely associated with direct benefit level z in Fig. 1.

If we had no prior knowledge of the physical results from hail suppression, only two of the endpoints for the hail damage and rainfall variables could be specified. That would be point B, which must be a maximum of 100% signifying elimination of crop loss due to hail, and point C, which is 100% reduction in rainfall. Typically, however, prior knowledge would be available to restrain endpoints A and D as well as limiting the range of endpoints B and C. If that knowledge did not exist, or restrictive assumptions could not be made, any economic evaluation would have to stop at this point. (This discussion will be continued in the section dealing with probable outcomes.)

3. Costs

The total cost of development of a technology such as hail suppression can typically be subdivided into two portions—developmental and operational. Since development costs often occur as large expenditures before the flow of benefits commences, the time value of money must be considered.[1] This consideration is necessary to insure that the value of the flow of expected benefits has the same time dimension as do the developmental costs.

Caution must be exercised in considering the time horizon for the stream of net income benefits. If development of an improved technology is considered new knowledge which conceivably will not decay, a benefit horizon of infinite length might be considered proper. But if the net benefits are positive in each year, no matter how small, utilization of an infinite horizon will guarantee that the discounted value of the net benefits will be larger than the development costs. Therefore, a time horizon of sufficient length should be chosen to properly ascribe benefits from the future research but yet be short enough to be meaningful. Two reasonable criteria which might be considered in selecting a time horizon are 1) the length of time until a new technology would replace the one envisioned, and 2) the number of years it would take the private sector to generate the same knowledge level if the developmental research was not funded by the government.

Operational costs can often be subtracted from gross returns and thereby be captured in a net direct benefits variable—assuming the payers of those operational costs are also recipients of the benefits. If the operational costs are borne by the public sector, or in the private sector but by the individuals not receiving the benefits, a more proper profitability test would involve comparison of returns from the next best use of the monies which otherwise would be devoted to operational costs.

An additional potential cost of a new technology like hail suppression is additional expenditures or reduced benefits for individuals for whom the technology is not intended. This is the "externality" problem of economics. It is illustrated by construction of a multistory apartment building which reduces property values of the existing properties in a residential area (Henderson and Quandt, 1971). Such costs are not incorporated in this analysis. However, these costs must be taken into account if this externality problem is a significant factor.

4. Probability of occurrence

The benefit relationship of Fig. 1 cannot by itself indicate the level of benefits to expect if a particular technology is developed and made operational. The likelihood with which each physical outcome will occur both before and after the proposed research is completed is also needed, at least in a probabilistic sense.

The derivation of an expected benefit value for any innovation like hail suppression results from combining the benefits accruing from each physical outcome which the event can cause, with the likelihood that each outcome will occur. For the hail suppression example, derivation of an expected benefit value from Fig. 1 can follow a two-step sequence. First, the endpoints for the range of physical outcomes, points A and B as well as C and D, could probably be restrained to a smaller range than previously alluded to. Atlas (1977) points to a possibility whereby hail suppression efforts could inadvertently produce an increase in hail, but Changnon's review (1977) of the status of hail suppression shows that most past suppression projects have indicated either a decrease in hail loss or no change. Also the ability to totally reduce hail damage to crops may be considered to be impossible, restraining point B to some upper level (i.e., 80%, 85% or 90%). Similarly, the effect of a hail suppression program on rainfall may

[1] Here we restrict ourselves to consideration of future development expenditures only. Past expenditures are treated as fixed costs and should not affect decisions about additional expenditures.

be thought to have some reasonable outer limits (i.e., ±20%, ±30% or +20% and −50%, etc.).

But even when the endpoints of the benefit function are specified, the expected value of the program cannot be estimated until the likelihood of each physical outcome within these limits is specified. For example, one needs to know the probability P_D that each possible reduction in crop damage due to hail will occur, as well as the probability P_R that each change in growing season rainfall will occur—between endpoints A and B and C and D, respectively. If the two (or more) physical events are independent of each other, the joint probability of any benefit value can be determined by multiplying the separate probabilities, $P_{NB}=P_D P_R$. However, if the effort to change one physical factor (reducing crop-hail damage) is known to affect another physical factor (altering growing season rainfall), one joint probability distribution P_{NB} should be estimated. Changnon (1975) has shown that 25–50% of all rain change produced by hail suppression would have a detectable effect in total seasonal rainfall.

5. Value of additional information on hail suppression

The question of the value of additional information about hail suppression appears most interesting when asked regarding the aforementioned probability functions[2] P_D and P_R. A plausible setting for this question could be in response to a solicitation of public funds for research to develop more effective procedures to suppress hail. The public entity receiving such a solicitation might then quite properly ask, "What will be the payoff from this research, if it is successful?"

To facilitate discussion of the estimation procedure, a simplified circumstance is assumed to be meaningful.[3] This circumstance considers the net benefits of additional research on development of a hail suppression technology to wheat producers in northwestern Kansas, a hail-prone area. A set of expected net benefits for several assumed levels of hail suppression effectiveness was calculated (Table 1) and expressed as net income per acre of wheat production. The endpoints of the benefits distribution have been restrained to be from no change in crop-hail damage to an 80% reduction, and to a ±10% change in growing season rainfall. These extremes (endpoints) closely match those in the future scientific models developed in TASH (Changnon *et al.*, 1977). The restriction of benefits to net income from wheat production is not meant to describe the entire net benefits potentially available from hail suppression, but rather to serve as an example of the estimation process in an area where one crop dominates agriculture production and where hail loss is large.

TABLE 1. Net income per harvested acre from wheat production in northwestern Kansas assuming several levels of hail suppression effectiveness.

Percent reduction in crop damage due to hail	Percent change in growing season rainfall	Average net income ($) per harvested area*
	−10	21.56
0	No change	24.58
	+10	27.31
	−10	22.60
20	No change	25.74
	+10	28.47
	−10	24.34
50	No change	27.35
	+10	30.11
	−10	25.98
80	No change	29.11
	+10	31.88

* These income estimates are based on an economic analysis of the potential value of hail suppression to wheat producers. A description of the derivation process used, as well as estimates for other regions, is given by Potter (1976).

The net income estimates of Table 1 range from a low of $21.56 per acre to a high of $31.88 per acre. The operational costs variable was accounted for by deducting an assumed cost of $1 per harvested acre as payment for the suppression program for each income estimate. This is a much higher cost than currently charged for hail suppression operational projects, but it is a realistic future cost (Changnon *et al.*, 1976).

Given the net benefits associated with various physical outcomes (Table 1), the likelihood that each of the various physical outcomes will occur, both before and after the proposed experiment and research, has to be specified. One possible source of this information regarding hail suppression is the evaluations of previous experiments relating to this technology, but no scientific concensus has formed regarding their interpretation. Since no universally accepted probability function now exists for hail suppression, a decision maker in a federal support agency must develop and use a subjective likelihood function. Since this subjective likelihood function will probably be quite influential in the decision to fund or not fund future research, efforts should be made to seek out and quantify this probability function.

One possible situation to consider is that the present-day technology is ineffective. One can assume that no change in hail damage rainfall (row 2 of Table 1) will occur with 100% probability and all other outcomes in Table 1 would have 0% probability. Another possible assumption, and the one used in this example, was that

[2] The same process as will be discussed for the probability distribution could be easily transferred to the net benefit or cost variables if these variables were the source of greatest uncertainty.

[3] The problem setting here is one of proposed research to develop a new (or significantly improved) technology. Alternatively a proposal might attempt to generate "better" estimates of the effectiveness of a presently available technology. This latter situation involves estimation of the maximum benefit available if the proposed research rectifies an otherwise wrong decision. Such a procedure is defined by Reutlinger (1970) and an illustration to agriculture is provided by Havlicek and Seagrave (1962).

TABLE 2. Hypothetical probability distributions before and after proposed research is completed.

Percent reduction in crop damage due to hail	Percent change in growing season research	Distribution felt to be correct before research is completed (prior probability)	Possible distributions after research is completed Outcome 1	Outcome 2	Outcome 3
	−10	0.083	0.0	0.0	0.0
0	No change	0.083	0.0	0.125	0.0
	+10	0.083	0.0	0.125	0.0
	−10	0.083	0.111	0.0	0.0
20	No change	0.083	0.111	0.125	0.0
	+10	0.083	0.111	0.125	0.0
	−10	0.083	0.111	0.0	0.0
50	No change	0.083	0.111	0.125	0.250
	+10	0.083	0.111	0.125	0.250
	−10	0.083	0.111	0.0	0.0
80	No change	0.083	0.111	0.125	0.250
	+10	0.083	0.111	0.125	0.250
Relative likelihood that a particular distribution will occur if the research is completed (expressed as probability)			0.20	0.70	0.10

each of the 12 possible outcomes of Table 1 is expected to occur with equal probability. The resulting likelihood function is presented in the third column of Table 2 where each physical outcome is given an 8.3% chance of occurring.

The expected value of the uncertain present-day technology ($E[V_{PD}]$) was calculated using the net benefit estimates listed in Table 1 and the "prior probabilities" given in column 1 of Table 2 (where each prior probability is equal to 0.083); the calculation is as follows:

$$E(V_{PD})=\sum_{i=1}^{12}(0.083NB_i)= 26.58 \text{ per harvested acre,} \tag{1}$$

where NB_i is the ith net income estimate of Table 1.[4]

If the proposed research is relevant to the wheat producing area of northwestern Kansas, for example, the technology could apply to an area encompassing approximately 1 700 000 acres of wheat (U. S. Census Bureau, 1971). Here a 12 000 mi^2 area is being considered. This means that the expected net income from altered wheat production with the 12 equally uncertain hail suppression technology levels is $45.2 million in this area. This estimate of annual net income can be compared with the possible outcomes that could be derived from the added research.

Three plausible modification outcomes, based on current results and expected improvements (Changnon *et al.*, 1976), have been postulated for this paper and arbitrarily assigned different likelihoods of occurrence. These modification levels appear in Table 2. The first level, labeled Outcome 1, represents only modest success from the experiment (20–80% reductions in hail damage with ±10% rainfall changes). This is proposed as a worst outcome. The expected value of this outcome is $27.29 per harvested acre or $46.4 million for the area. This estimate results in a net benefit for the area's farmers of $1.2 million annually compared to the present technology.

A result with more substantial success is Outcome 2. Here, although the range of hail reductions is not restrained, the possibility of reductions in hail season rainfall is eliminated. Using this assumption and an equally likely probability distribution for the remaining eight physical events, the per acre expected net income is $28.07. This translates to an expected income of $47.7 million for the area's wheat producers, a net benefit of $2.5 million yearly.

Outcome 3 is a case that might exemplify a major technological breakthrough from the future research. The only physical events assumed to exist are 50 and 80% reductions in crop-hail damage coupled with no change or a 10% increase in hail season rainfall. The expected income value is $29.61 per acre, $3.03 more than the pre-experiment expected value. The annual net benefit to the area's wheat growers is $5.2 million for this outcome.

To this point, three net benefit levels ranging from $1.2 million to $5.2 million per year have been defined. However, before such benefits can be compared with

[4] Eq. (1) relates to the situation where 12 discrete coefficients are assumed to adequately describe the net benefit function. If continuous functions were assumed to more properly describe the net benefit and probability functions, the proper calculation would be

$$E'(V_{PD})=\int_C^D\int_A^B P_RP_Df(NB)dDdR, \tag{2}$$

where $f(NB)$ describes the net benefits accruing from any physical outcome.

their costs, one expected benefit figure has to be derived. Subjective beliefs as to likely results must be utilized for this derivation. Presumed subjective estimates have been converted to a probability framework, as shown in the last line of Table 2, to illustrate this point.[5] These probabilities indicate that if future research is conducted, Outcome 1 for example is expected with 20% probability. Given these probabilities, the expected net annual benefit associated with this research project is

$$EV=0.2\times\$1.2 \text{ million}+0.7\times\$2.5 \text{ million} +0.1\times\$5.2 \text{ million}=\$2.5 \text{ million}. \quad (3)$$

The final step in this example involves comparing the stream of these future benefits with their associated development costs. For this example, operational costs of the hail suppression technologies are assumed to be paid by the individuals receiving the technology's benefits, the area farmer. Therefore, the operational costs have been deducted from the net benefit estimates of Table 1.

For purposes of illustration only, we also assume that the research effort (regardless of the outcome) is expected to be completed after five years of research costing $3 million per year. Further, we assumed that a 25-year period is proper for the resulting technology. Since such a technology is unlikely to "wear out," the 25-year period would be justified 1) if a new technology could be expected to replace it after this period, or 2) if it is reasonable to expect that in 25 years the commercial sector could have developed such a technology in absence of the proposed development effort. Given this assumption, the forthcoming income stream was estimated to generate benefits of $62.5 million over a 30-year period [annual benefit from Eq. (3) times 25] at a cost of $15 million over a 5-year period. But because these estimates involve differing time periods, they cannot be compared without further adjustment.

The present value concept was used for standardizing future benefit and cost streams.[6] Basically, this concept tries to determine what amount of money one would take—today—in place of a future stream of income. This concept is

$$PV=\sum_{i=1}^{N} E(V)_i/(1+r)^i, \quad (4)$$

where $E(V)_i$ is an expected monetary value (either cost or benefit) in the ith year, r is the social discount rate, and N the number of years relevant for the cost or benefit in question.

The expenditure stream for development costs assumed in this example ($3 million per year for 5 years) was converted to a present value figure, using a 10% social discount rate in the present value computations:

$$PV_{DC}=\frac{\$3\,000\,000}{(1.1)^1}+\frac{\$3\,000\,000}{(1.1)^2}+\frac{\$3\,000\,000}{(1.1)^3}+\frac{\$3\,000\,000}{(1.1)^4}+\frac{\$3\,000\,000}{(1.1)^5}=\$11\,372\,359. \quad (5)$$

The discounted total, $11.4 million, reveals that converting future development costs to their present value apparently reduces the magnitude of these costs. Of course, this apparent reduction to present value does not change the expected expenditure pattern of $3 million per year for 5 years.

A similar calculation was done for the stream of future benefits. The benefits from the research were $0.0 for the 5 years the research was being conducted and then $2.5 million per year for the next 25 years. When converted to present value terms, the discounted value of that income stream is $14 090 000.

Although the present value of the expected stream of net benefits is still greater than the present value of the expected stream of development costs, conversion to a present value basis has reduced the ratio of benefits to costs from $62.5 million/$15 million (~4:1) to $14.1 million/$11.4 million (1.2:1). The sharp reduction in the benefit estimate for the present value figure occurs because of the longer period over which the benefits occur (30 years) and the assumption that no benefits accrue in the first 5 years when the research is being conducted.

6. Expansion to a larger scope

The example chosen was set in somewhat realistic current conditions to show how to estimate the value of future research before it is conducted. This example is strictly proper only if the funds pertain to the hypothetical experiment and its results are specific only to an area of northwestern Kansas. But such a circumstance is unlikely. A more likely situation would have experimental results applicable to a much larger geographic area and possibly to much of the Great Plains region. Transferability of physical results of storms, therefore, must be considered. (Are the storms in Kansas like those in Montana and Texas?) Also an expanded, more complex economic analysis would be needed.

First, per acre net income estimates for several commodities would need to be developed for the varying soils and climates of the entire region affected. Second, benefits would accrue to consumers of farm products in

[5] The probabilities used in this example were chosen to be illustrative of values needed in the technique being presented. They are not intended to indicate actual estimates of the success of hail suppression and use of different values could certainly affect the estimated value of the expected net annual benefit.

[6] The present value concept involves converting future monetary values to their current value. The driving force behind this concept is the idea that a sum of money to be received in some future period generally does not have the same usefulness to each of us as that same sum of money would have if we were to receive it today.

addition to (or possibly instead of) farm producers. The second issue arises because of the price-depressing effects of the additional production caused by hail suppression activities when carried on in very large regions such as the Great Plains wheat area. Analytical procedures which can overcome these difficulties are available.

7. Summary

A hopefully realistic example of the value of results to be expected from a hypothetical 5-year experiment (at $3 million cost per year) to a 12 000 mi² area in Kansas revealed a benefit-cost ratio of 1.2:1. This example illustrates three important facts about hail suppression research and development efforts.

1) It is apparent that the results of an experiment must have wider application than the tested Kansas area of 12 000 mi² in order to have a sizeable benefit/cost ratio. Thus it is important to establish the areal representativeness and transferability of any experimental area's weather conditions and modification techniques. A key question that must be answered is, "Where do experimental results from a site like northwestern Kansas extend"? Hence, a well-designed, site-specific national experiment should also be doing research sufficient to answer this question.

2) A detailed economic evaluation of the impact of hail suppression is needed for all areas and all crops. This allows a better estimate of the total impacts and value of a hail suppression technology with transferability.

3) The entire process demonstrated by this economic procedure rests on the best possible scientific estimates (subjective likelihood function) of the existing status of hail suppression, and to a lesser degree on estimates of experimental periods and costs plus area of transferability. If the value of new information about hail suppression generated by future research is to be properly estimated, three estimates are needed. First, the outer-bounds of the possible modification of hail and other associated weather conditions, like rain, need to be set, Second, various reasonable combinations of possible outcomes (−20% hail with 0% rain change) need to be estimated; and finally, estimates of the likelihoods of these outcomes need to be made. All of this calls for an in-depth assessment of findings from previous and existing programs before research monies are expended to develop new technologies.

The quantification process just described may, in itself, have substantial value. Thus development of these coefficients may provide insights as to where greatest uncertainties exist, and, if a particular proposal must rely on unreasonably favorable assumptions (with regard to value of benefits or their probability of occurrence), this reliance should be made more apparent by the process described in this paper.

The authors would like to stress that although a benefit/cost ratio was determined in this paper, the magnitude of this ratio (relative to a value of 1.0) is only a part of a larger evaluation of proposed research alternatives. The broader test, with regard to development costs, is that of "opportunity cost." This process compares the discounted stream of net benefits from investing funds to develop one innovation, such as hail suppression, with the discounted net benefits those funds could earn in their next best use. Determination of benefits from the best alternative use may be difficult, but is necessary to make a proper comparison—whether public or private monies are involved.

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