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SENSITIVITY ANALYSIS AND RISK ANALYSIS IN EVALUATION OF IRRIGATION PROJECTS: A CASE STUDY OF THE MAHAVILLACHCHIYA SCHEME

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ABSTRACT

Any cost-benefit analysis requires an array of assumptions about data, which are less reliable than one would like, and many value judgements. Sensitivity analysis and risk analysis techniques are used in this study to examine uncertainty and risk. This paper indicates the relevance of sensitivity analysis and risk analysis in the appraisal of projects and the importance of calculating both the net present value (NPV) and the internal rate of return (IRR) in feasibility studies. It also suggests that single point estimates may lead one to take a too optimistic view of rates of return of the more expensive physical work options and a too pessimistic view of rates of the less expensive management options.

INTRODUCTION

There is a considerable number of parameters which ultimately determine the incremental gross costs and benefits, and incremental net benefits of projects. By definition present investment yields its returns only as the future unfolds; hence the results of all investments are inherently uncertain.

There will be elements of uncertainty with respect to the data used in the cost-benefit analysis even if the best estimation techniques are used in deriving the future values of data. This uncertainty emanates from the fact that the data are estimated values and not the actual values, and some parameters used in the analysis are not mean values. Besides the uncertainties inherent in the data used in a project appraisal, there are several other uncertainties which cannot be visualised in advance, like a natural calamity, important technological innovations and a changed pattern of demand for a project output. The former type of uncertainty (data deficiencies) is sometimes referred to as 'risk' to distinguish from the 'uncertainty' on account of unexpected events. According to some scholars (Marglin 1967; Reutlinger 1970) if the occurrence of future events is subject to a degree of uncertainty and if information regarding the probability distribution of the values of the parameters is available, the situation is referred to as a case of 'risk'. There are two techniques for the examination of 'uncertainty' and 'risk' viz. sensitivity analysis and risk analysis respectively. Sensitivity analysis involves the application of possible values for those parameters which are considered to be important for the success or failure of the project. Although this method provides useful information about the range within which returns may vary, it does not measure the likelihood of the occurrence of any particular value of probability distribution. Risk analysis, unlike sensitivity analysis, involves the selection of a range of possible values for each major variable and an estimation of the probability of each value occurring. This paper presents an empirical illustration of the standard techniques of sensitivity analysis and risk analysis using a major irrigation project as a case study. This paper is thus an applied study and not a theoretical or conceptual discussion of the two techniques (Vithanage 1982).

The Setting

The government of Sri Lanka began in 1976 to modernize five large reservoir irrigation schemes with the World Bank aid. They represent some 180 similar irrigation schemes in Sri Lanka, serving a total cultivated area of about 400,000 acres, in the North Central Province of the dry zone. This paper is based on one of these schemes, namely, Mahavillachchiya scheme, the first tank which has been modernized under the project. Mahavillachchiya scheme is located 18 miles north-west of Anuradhapura. The average annual rainfall in the area is close to 55 inches. The scheme covers an area of 4,200 acres of which 2,600 acres are irrigable. The land alienated in the scheme generally comprises of 3 acres of irrigable and 2 acres of unirrigable land per farm household. A field survey was conducted during the period between October 1976 and June 1977 using a stratified random sample in the project area. In this survey, farm records were maintained for fifty farmers during the *Maha* 1976/77 and single-shot interviews were carried out in *Yala* 1976 with 150 farmers. In a second survey, in May 1980, sixty households were interviewed. Supplementary data on this scheme have been extracted from other studies, conducted in the area by Jogaratnam 1968; Suraweera 1974; Russell 1979; and Foster 1980.

The main components of the tank modernization civil engineering work were lining of all irrigation canals and field channels, installation of regulators in all canals and field channels, desilting and enlarging the entire water conveyance system and excavation of drains to improve the drainage. There are several alternative ways of dealing with modernization. In this paper six alternatives have been examined. They are (a) canal lining, (b) piple lines, (c) the cleaning and maintenance of gravel canals by direct labour, (d) compaction of soil in beds and banks of canals by direct labour, and (e) appointment of a project manager for integrated rural development. The last three alternatives are mutually compatible. Therefore, these three alternatives can also be treated as one combined alternative. In this paper, thus six alternatives were examined. The expected returns from these alternatives are derived using a set of parameters whose values were the 'best estimates' available at the time of making the projections (Table 1). This paper examines the uncertainty and risk involved with the above identified alternatives using sensitivity and risk analyses.

Table 1—DATA VARIATIONS OF AREA IRRIGATED WITH POSSIBLE ALTERNATIVES

	mean area with a 10% probability (acres)	a 60% prob. (acres)	a 30% prob. (acres)	*mean area*[a] (acres)	*mean*[b] *area (excl. 1975)* (acres)	*best guessed estimate*[c] (acres)
A. 1966–76 period ...	0	2582	3918	2724	3027	2600
B. With possible alternatives						
1. Canal lining ...	1288	4834	5200	4364	5200	4834
2. Pipe lines ...	1386	5200	5200	4568	5200	5200
3. Cleaning channels	992	3722	5200	3720	4332	3722
4. Soil compaction	1004	3765	5200	3746	4382	3765
5. Project manager ...	969	3635	5200	3670	4231	3635
6. Combined programme	1093	4102	5200	3941	4775	4102

Note: a. mean area of the period 1966–76; b. mean area of the period 1966–76 excluding 1975; c. with a 75 percent probable rainfall exceedance expectancy.

SENSITIVITY ANALYSIS

Sensitivity analysis involves the application of possible values for those parameters which are considered to be important for the success or failure of a project. This technique provides useful information about the range within which returns may vary with changes in the value of any variable applied. In sensitivity analysis, the values of the chosen variables are changed one at a time, holding all the other variables at their best estimate values and calculating the extent to which the net present value (NPV) or the internal rate of return (IRR) is affected.

The extent to which values of the chosen variables will be changed for testing the sensitivity, will depend on the value judgement of the appraiser. In the traditional approach or 'playing safe' method, allowance is made for risk by purposefully underestimating the benefits and overvaluing the costs by giving a lower percentage value and higher percentage value of the chosen variables respectively, or using the maximum and minimum possible values of the variables. This approach may be useful in small scale projects or when no alternative projects are available. A major drawback of the 'playing safe' approach is that it may become overconservative, standard and mechanized, and may eliminate some projects which may be potentially profitable. The tendency to 'play safe' may be influenced by the subjective assessment of the likely benefits to the investor, which may in some cases prove to be quite wrong. More detailed techniques of assessing risk, involved in project investments are used in this paper.

Although sensitivity analysis could be used to find out the degree of change in the values of NPV and the IRR in relation to change in all the variables, in a project there are often few variables which particularly influence the final results. Although there are some small items which jointly make up a large proportion of the project costs or benefits, a lot of computational work is required to handle all these small items. The three important variables, on which the success of the possible alternatives largely depends are (i) area irrigated, (ii) time required for full development and yields at full development, and (iii) the costs of construction, operation and maintenance. Possible values and probabilities of these variables, based on past experience at Mahavillachchiya colonisation scheme and in other irrigation schemes, are applied to the parameters of the economic cost-benefit analysis.

a. *The area irrigated*

The best estimated values of the area irrigated with the possible alternatives were based on a 75 percent probable rainfall exceedance expectancy. Using data on the area cultivated during the period 1967 to 1976 and the best estimated areas irrigated with the possible alternatives, further possible values and probabilities of the area irrigated with the alternative options have been derived (Table 1), subject to the maximum area irrigable of 2,600 acres in each season. The mean value of the area irrigated annually during the period 1966–1976 can be taken as a possible estimate. However, considering the extraordinary drought that prevailed during the period 1973 to 1975 and the inflow of drainage water from the Mahaweli river development scheme, since 1976, a mean value for the area irrigated excluding the zero acreage in 1975 was calculated as a more appropriate estimate.

b. *Yields at full development and time required for full development*

The average yied of 78.8 bushels of paddy per acre at full development in 1990 was used as the best estimate. This was based on the average yield of 49.1 bushels of paddy per acre in 1979/80. However, according to the survey data, nearly 40 percent of farmers have harvested less than 26.8 percent of the average yield (Table 2). Furthermore, many farmers, at present have little experience in cultivating pulses in paddy fields. It is, therefore, assumed that farmers will harvest only 75 percent of the best estimated average yield.

A longer time than expected for the attainment of full benefits of the project would clearly affect the NPV and IRR. If about 12 years were taken instead of 10 years to reach full agricultural development, the present value of total incremental gross benefits at 12 percent discount rate of all possible alternatives would be reduced by 21 to 27 percent.

Instead of using both variables separately for the sensitivity analysis, it is assumed that the anticipated total present value of gross benefits at 12 percent discount rate will be reduced by 25 percent due to delays in implementation.

c. *The costs of construction, operation and maintenance*

The delays in calling for tenders and contract procedures, the shortage of qualified irrigation engineers and the farmers' reluctance to forego their *Yala* cultivation have doubled the total project cost of canal lining programme in the Mahavilachchiya tank modernization project. These shortcomings are prevalent in other irrigation schemes also and according to the Irrigation Departmental officers, actual costs exceed or equal estimated costs in almost all projects undertaken by them. The possible values and probabilities given by these officials for the ratio of actual cost to estimted cost are given in Table 2. The weighted average of the ratio of actual cost to estimated cost i.e. 1.675 was used for the sensitivity analysis tests.

d. *Results of the sensitivity analysis tests*

The rsults of all the sensitivity analysis tests discussed in the preceding sections are summarised in Table 3. Although some of the alternatives would clearly not be viable on the basis of the changes in the assumptions, the sensitivity analysis tests make no difference to the accept/reject decisions regarding the viability of the combined programme.

When the mean value of area, excluding 1975, is used as the area irrigated, the area irrigated in *Yala* is increased with all alternatives other than the pipe line option, under which the maximum area would be irrigated in *Yala* even at a 75 percent probable rainfall exceedance expectancy. All alternatives other than the pipe lines and combined programme are highly sensitive to this assumption (Cols. 2 and 6 in Table 3).

Other than with cleaning channel and a project manager options, the areas cultivable with other options are lower than the best estimated values with the assumption of unweighted average value. The net present values of the pipe line and canal lining options fall below zero with this test (Table 3). These two options are highly sensitive to increases in project costs as compared to other options due to their high early costs (Figure 1). Except for the combined programme, all other options become economically unviable when the present value of total gross benefits is reduced by 25 percent with lower crop yields and delays in uptake (Table 3 and Figure 2). The combined programme is only moderately sensitive to changes in benefits and costs as compared with other options. Thus, even if the project total benefits fell below the best estimate by 25 percent the project remains viable.

RISK ANALYSIS

Although sensitivity analysis provides useful information about the range within which returns may vary and variables which particularly influence the final results, it neither measures the likelihood of the occurrence of any particular value or probability distribution nor gives the probability distribution of IRR and NPV. Risk analysis, on the other hand involves the selection of a range of possible values for each major variable and an estimation of the probability of each value occurring. The purpose of the risk analysis is to eliminate the need for restricting one's judgement to a single optimistic, pessimistic, or 'best' evaluation, by carrying throughout the analysis a complete judgement on the possible range of each variable and on the likelihood of each value within this range. At each step of the risk analysis these judgements are combined at the same time as the variables themselves are combined. As a result, the product of the analysis is not just a single value of the decision variable, but a judgement on the likelihood of each value within this range. In risk analysis the single point estimates (or best estimates) are replaced by an estimated probability distribution.

Table 2—DATA VARIATIONS OF YIELDS, PRICES, TIME NEEDED FOR FULL DEVELOPMENT AND COSTS WITH POSSIBLE ALTERNATIVES

	Possible and Probability Values				
	1	2	3	4	5
A. Yields at full development					
1. 1979/80 *Maha* paddy yields (bu./ac.)	30.6	38.5	49.1	60.0	70.0
2. Probability (%) ...	17	22	30	20	11
3. Estimated yields in 1990 (bu./ac.)	49.09	61.76	78.8	96.29	112.34
B. Project Costs					
4. Range of ratio of actual costs to best estimate ...	<0.90	.91–1.50	1.51–2.20	2.21–2.75	2.76–3.25
5. Ratio of actual costs to best estimate, which is used in the analysis ...	<0.50	1.0	2.0	2.5	3.0
6. Probability (%) ...	0	50	25	15	10
C. Prices					
7. Paddy price, cif Colombo (US $/metric ton)	260	265	314	363	368
8. Probability (%) ...	10	15	50	15	10

Source: a. Rows 1 & 2, Farm Survey, May 1980; b. Row 3, based on row 1; c. Rows 4 & 6, Construction Branch, Irrigation Department and Mahaweli Development Board; d. Cols, 2 & 3 of row 7, IBRD, Commodities and Export Projection Division's publications (1979) e. Col. 1 of row 7. Department of Customs (Dec. 1980). Customs Returns, Colombo.

Table 3—SUMMARY OF THE SENSITIVITY ANALYSIS RESULTS WITH THE PARAMETERS OF THE ECONOMIC COST-BENEFIT ANALYSIS

	Best guessed estimates ('000 Rs.)	*With mean area (excl. 1975)* [a] ('000 Rs.)	*with unweighted average area* [b] ('000 Rs.)	*With increased costs* [c] ('000 Rs.)	*With reduced yields* [c] ('000 Rs.)	*percentage change in NPV & IRR* [d]			
						With mean area (excl. 1975) [a]	*With unweighted average area* [b]	*With increased costs*	*With reduced yields*
	(1)	(2)	(.3)	(4)	(5)	(6)	(7)	(8)	(9)
A. NPV									
1. Canal lining	3317	8353	–3740	–511	–13248	152	–113	–213	–499
2. Pipe lines	6998	6998	–3539	–46358	–13034	0	–51	–765	–286
3. Cleaning channels	2726	6155	2726	2303	–2317	126	0	–16	–185
4. Soil compaction	2158	5741	2032	882	–3111	166	–6	–59	–244
5. Project Manager	–1040	1606	258	–1629	–4687	154	25	–57	–351
6. Combined programme	23049	30684	21033	21938	11822	33	–9	–8	–49
B. IRR									
1. Canal lining	12.8%	13.6%	11.0%	7.1%	8.8%	6	–14	–45	–34
2. Pipe lines	13.4%	13.4%	11.2%	11.9%	9.5%	0	–16	–11	–29
3. Cleaning channels	16.2%	20.5%	16.2%	15.5%	7.9%	27	0	–4	–51
4. Soil compaction	15.2%	19.7%	15.0%	12.4%	6.6%	30	–1	–18	–57
5. Project Manager	10.5%	14.1%	12.1%	9.8%	<5%	34	15	–7	
6. Combined programme	>30%	>30%	>30%	>30%	>30%				

Note: a. mean area of the period 1966–76 excluding 1975; b. mean area of the period 1966–76; c. see sections on yield at full development and cost of construction
d. percentage change in NPV and IRR over best estimated values.

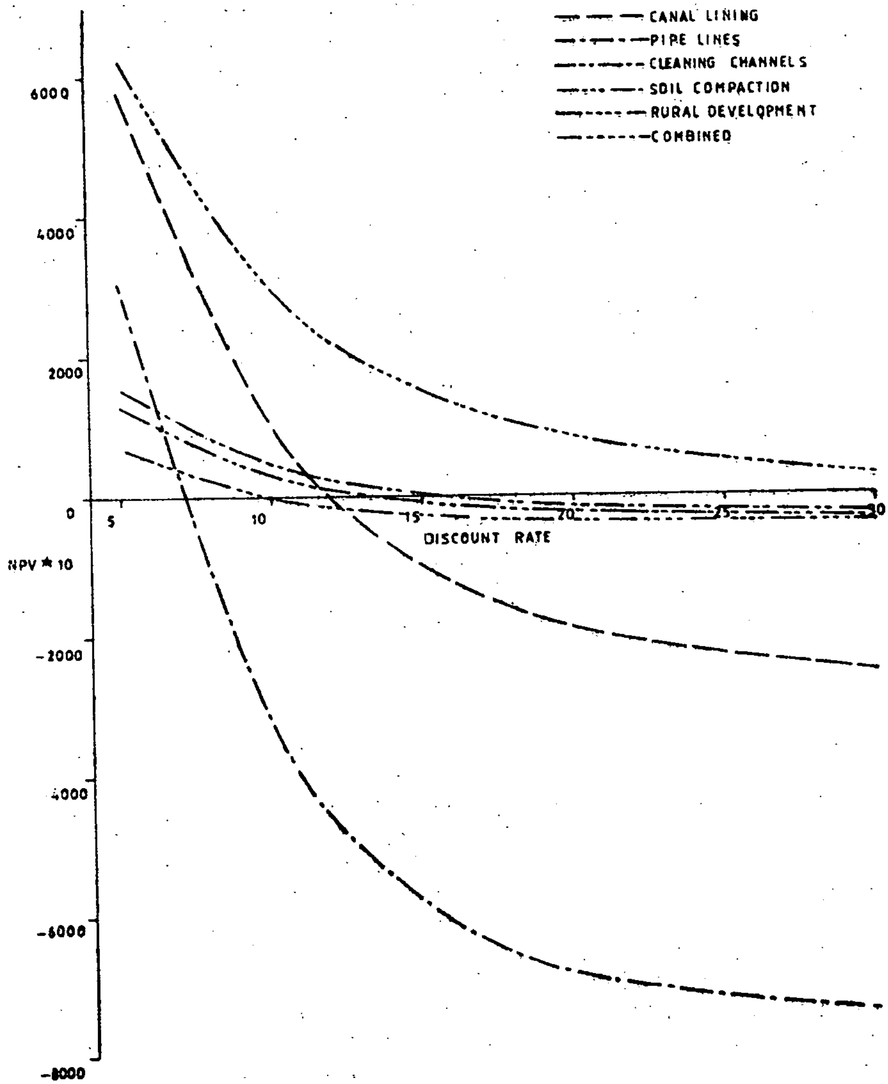

Fig.1 Choice between possible alternatives with increased project costs

The main advantage of applying risk analysis is that this method gives the most likely or average outcome as well as the extent of the riskiness of a project. It is necessary to know the riskiness of various projects and also the specific sources of risks in order to make at least an informed judgement about the likely joint outcomes from a total investment programme. One may wish to have a project with a lower mean IRR and invariably a positive rate of return instead of a project with higher mean IRR but with the possibility of a realised negative rate of return. With risk analysis, not only are the conclusions presented by appraisers less limited, but also the supporting material is quantified in an easily comprehensible, standardized form. Even if one is interested only in a single-point estimate and not the entire probability distribution, it will be desirable in some circumstances to do a risk analysis in order to avoid consistant errors of estimation. In general, when an aggregate measure is the (weighted) sum of many different variables or the product of variables, the simple aggregation of the modal values will not give an accurate estimate of the true mode of the aggregate measure (Reutlinger 1970). In some cases, errors are also incurred when the means of the probability distribution of several elementary events are being aggregated to estimate a mean of the aggregate. Since non-linear functions, used in economic projections, are frequently convex, the likely bias from neglecting proper probability analysis will be an overestimation of benefits. Risk analysis can also be used to examine whether to undertake a marginal project, how to handle a project with unusual uncertainties, how to settle on the best combination of specification in a single project, and how to identify a project with only minimal information (Pouliquen 1970).

Possible values and probabilities of the major variables, used in the economic cost-benefit analysis, including the area irrigated, time required for full development and yields at full development, and the costs of construction, operation and maintenance are applied to the parameters of the risk analysis. Possible values and probabilities for paddy and pulse prices are also included. The Prosper package of International Computers Limited (1970), has been used for the calculation. It performs a specified number of runs, selecting forecasts each time from the ranges supplied means of a Monte Carlo random number selection technique.

a. *Possible values and probabilities of the major variables*

Using the data on the areas cultivated during the period 1967 to 1976, and the best guess estimated areas irrigated with the possible alternatives, further possible values and probabilities of the area irrigated with the alternative options have been derived subject to the maximum area irrigable of 2,600 acres in each season (Table 1). Derivation of area irrigated during water deficiency periods is based on an 'extensive margin' approach. A water deficiency can in principle be met (i) through the 'extensive margin, by reducing the area irrigated while maintaining an optimum rate of water application implying a proportional reduction in output, or (ii) through the 'intensive margin' by a lower rate of water application on a given area, resulting in lower yields per acre, or (iii) through some combination of these two alternatives. The 'extensive margin' approach is used as data are difficult to find regarding the precise response function of yields to sub-optimal water applications.

Possible values and probabilities for yields at full development are based on the 1979/80 survey of the Mahavillachchiya scheme (Table 2). The gowth rate of the average paddy yields of the whole scheme does not need to be equal to the growth rates of average paddy yields for different farm groups. As none of the possible alternatives provides facilities directed towards specific farm size groups, it seems reasonable to assume that the growth rates of crop yields of the whole scheme will not differ from the growth of crop yields on farms in the different size groups.

Possible values and probabilities for the costs of construction, operation and maintenance are besed on data given by the officials of the Department of Irrigation and the Mahaweli Development Board.

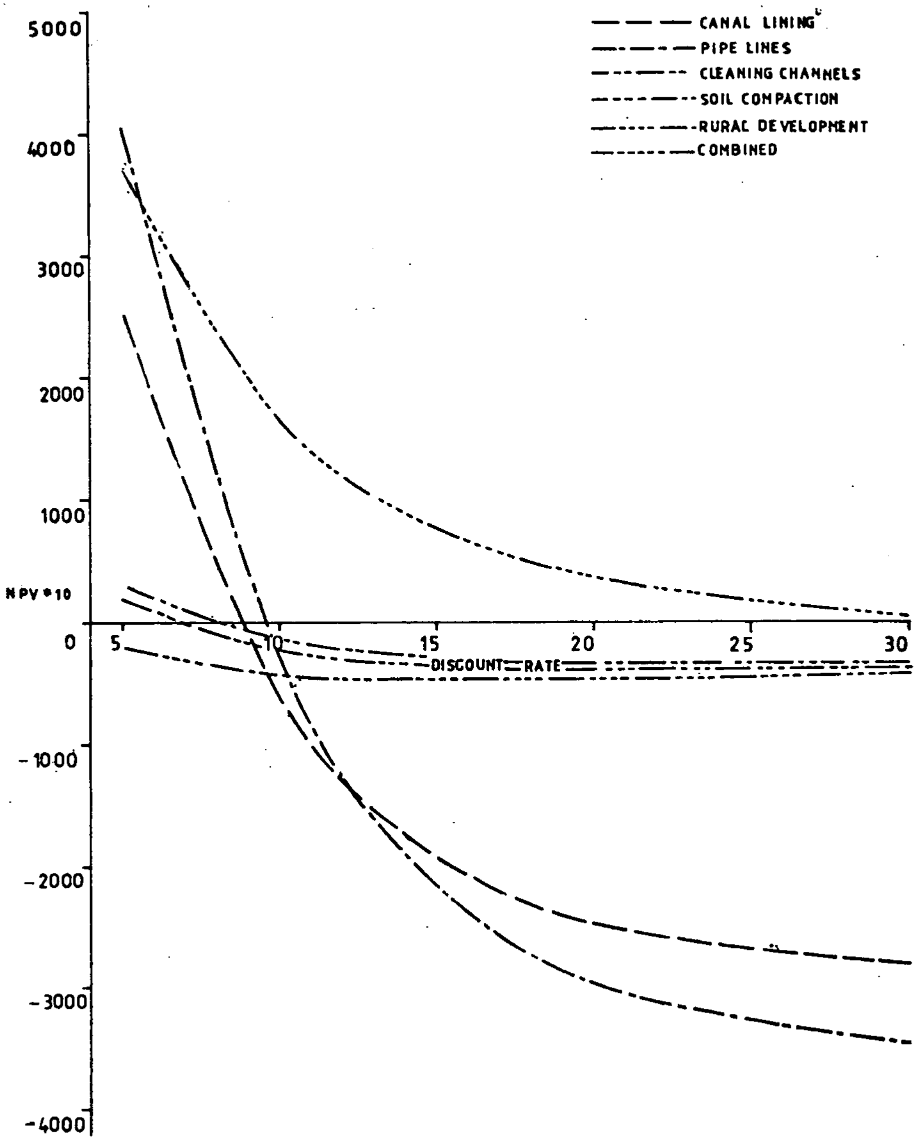

Fig.2 Choice between possible alternatives with lower crop yields and delays in uptake

It is very difficult to make predictions of possible values and probabilities about the future course of 'world' prices for agricultural products, given the inherent volatility of markets in these products and the unpredictable nature of government intervention in such markets. Furthermore, as a result of the relatively thin international rice market (less than 3 percent of the world production is traded), international rice prices are very volatile. Price variability in this study is, therefore, arbitrary. Assuming a isosceles tringale distribution for rice prices, and using 1990 and 1985 prices as projected by the World Bank, the actual 1980 price, and subjective judgement, possible values and probabilities for rice prices are derived (Table2).

b. *Results of the risk analysis tests*

The results of the risk analysis tests are summarised in Table 4 and Figures 3 and 4. The introduction of a range of values and probabilities for the major variables leads to a wide distribution of the possible IRRs for each of the alternatives. The options involving canal lining and pipe lines have mean IRRs below 12 percent; the appropriate discount rate and the combined programme have the highest mean IRR. There is at least a 50 percent probability of the IRRs of all options other than canal lining and pipe lines being above 12 percent.

The introduction of risks lowers the mean values of the IRR of canal lining and pipe lines, and raises those of cleaning channels, soil compaction and project manager options (Table 4). The reduction in the mean IRRs of former two options is due to the fact that the maximum area would be irrigated in *Yala* even at a 75 percent probable rainfall exceedance expectancy and to high early costs. The possibility of increasing area irrigated in *Yala* and low early costs of the latter three options have increased their mean IRRs with risk analysis. The results suggest that with single-point estimates a too optimistic view may have been taken of rates of return of the more expensive physical work options or hardware (physical work) options and a too pessimistic view may have been taken of rates of return of the less expensive software (management) options. Although the mean IRRs of cleaning channels, soil compaction and project manager options are higher than the canal lining and pipe lines, the chances of getting high negative rates of return with former three options are, greater when compared with the latter two options. If a decision maker is reluctant to take the chance of getting high negative rates of return, canal lining and pipe lines are more attractive than cleaning channels, soil compaction and project manager options in spite of lower expected mean IRRs.

Table 4—SUMMARY RESULTS OF THE RISK ANALYSIS RESULTS [a]

	Mean value of IRR (%)	*Probable exceedance expectancy values of IRR (%)* at 50%	at 75%
1. Canal lining	7.36 (12.63)	7	0
2. Pipe lines	8.34 (9.75)	7	1
3. Cleaning channels	28.76 (39.66)	28	12
4. Soil compaction	28.66 (47.74)	24	6
5. Project manager	26.54 (42.86)	24	6
6. Combined programme	36.54 (23.63)	36	16

Note: a. with 500 runs; standard deviations are in parentheses.

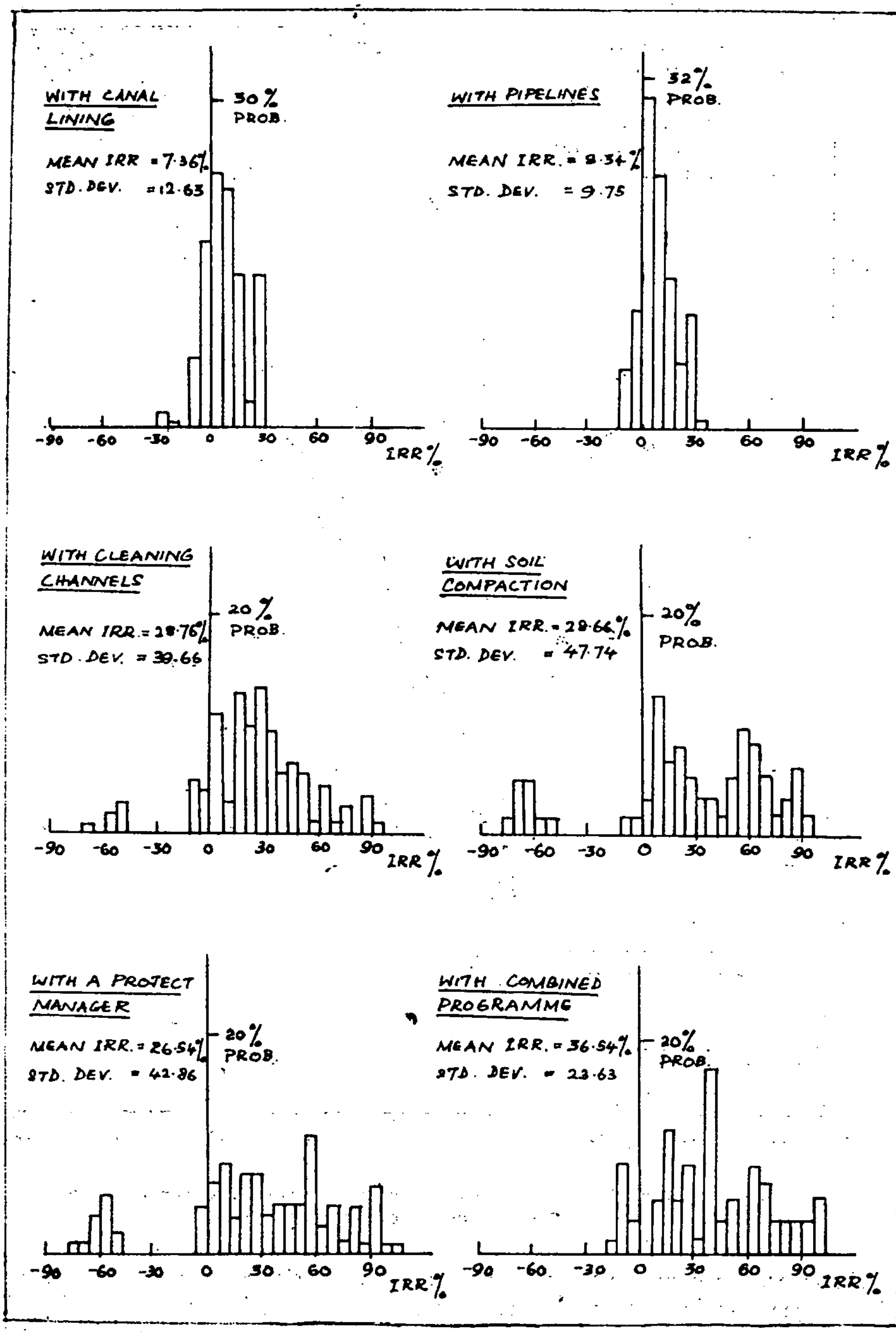

Fig.3 Distributions of internal rate of return with each Possible alternatives

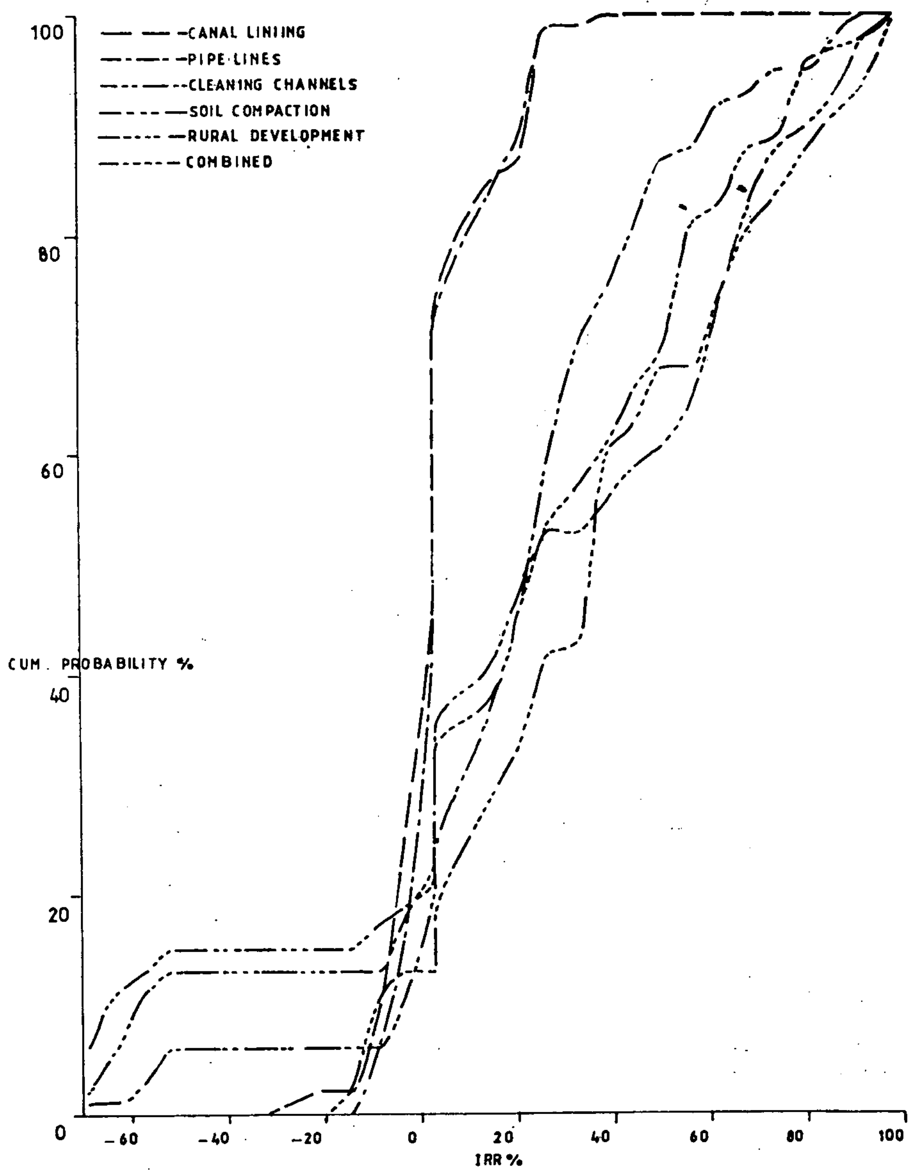

Fig.4 Cummulative probability distribution of internal rate of return with each possible alternatives

However, the combined programme, should be selected not only because the IRR is highest against other options but also the chances for getting negative rates of return are lower. Except for the combined programme, all other possible alternatives, have mean IRRs either equal to 12 percent or below 12 percent at a 75 percent exceedance expectancy.

DISCUSSION

This paper has so far attempted to show the relevance of sensitivity analysis and risk analysis in the appraisal of projects. Any cost-benefit analysis requires an array of assumptions about data which are less reliable than one would like, and many value judgements. The researcher's estimates concerning data and his value judgements may not be those of everyone. To a large extent, the task of a cost-benefit analyst is to provide the decision maker with the needed information to find out how his differences of view over values and data should affect his decision. This involves open statements of the assumptions made and the application of sensitivity analysis and risk analysis for the important variables.

The sensitivity analysis of this study also shows the importance of calculating both the NPV and the IRR in feasibility studies. The results of sensitivity analysis indicate that the NPV is generally more sensitive to variations in the parameters of economic cost-benefit analysis than the IRR. But this could well be reversed in other projects. This depends upon the shape and elasticity of the net present benefit and net present cost curves and their relationship to each other and, in turn, depends, in part, upon the timing of the benefits and costs. It is, therefore, desirable to derive both the NPV and the IRR in feasibility studies.

The risk analysis of this study also suggests that with single point estimates a too optimistic view may have been taken of rates of return of the more expensive physical work options or hardware options and a too pessimistic view may have been taken of rates of return of the less expensive software options.

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