One of the inherent characteristics of capital investment projects is the presence of uncertainties in estimated outlays and future benefits. The concept of sensitivity analysis in project appraisal has been recently extended to include risk analysis. The assessment of the nature and magnitude of uncertainties poses methodological problems. The complexities arising out of interdependencies among the uncertainties necessitate a formal approach to risk analysis. A methodology for assessing the uncertainties, especially when they are interdependent, is outlined here. The application of the methodology is illustrated in the context of a project financed by the World Bank.

M. Meenakshi Malya is a professor at the Indian Institute of Management, Ahmedabad. Her teaching and research interest is in Decision Analysis, Operations Research, Project Planning, and Capital Budgeting. As the chairperson of the management development programmes at the Institute, she is also involved in designing and conducting management development programmes for executives.

the analysis of a World Bank financed project. The scope of the paper is confined to the situations where non-availability of extensive past data precludes the construction of any mathematical models for forecasting.¹

**Methodology**

A five-step process of assessing uncertainties is outlined here:

1. **Deterministic modelling of the project inflows in terms of variables that affect cash flows.**
2. **Sensitivity analysis for identifying key uncertainties.**
3. **Quantification of uncertainties.**
4. **Modelling the stochastic situation.**
5. **Implications and finalizing.**

**Deterministic Modelling**

A rough analysis in terms of modelling the project inflows and outflows is the first step. The capital expenditure is estimated, the possible benefits from the project are identified, and the net present value or the rate of return is calculated to establish the dimensions of the project. This stage helps in articulating the inter-relationships among different variables that affect the cash flow and the technical aspects of the project which will result in the project benefits or affect the cost estimates. Very often, the thinking on the project is unclear at this stage, and the final analysis may well result in conclusions vastly different from the rate of return obtained at this stage.

**Sensitivity Analysis**

At this stage the magnitudes are altered purely in an *ad hoc* manner (by i 5% or say 10%) and the effect of each such change is observed on the rate or the net present value. Those variables to which the returns are sensitive are then listed for examining the uncertainty, if any, associated with them.

¹ Such forecasting models, whenever appropriate data is readily available, can be helpful and a vast amount of literature is available on these techniques.

**Quantification of Uncertainties**

**Definition**

The procedure for assessment of uncertainties begins at this stage. Each of the uncertainties that are listed will first have to be defined sharply in terms of variables which can be quantified. For instance, the capital expenditure can be one of the key variables which will affect the rate of return. The uncertainty surrounding the magnitude of capital expenditure can be defined in terms of several variables such as devaluation, project slippage, and so forth. However, these uncertainties need to be more specifically defined in terms of quantifiable measures such as "the year and magnitude of devaluation" or "the time in months by which the project will be delayed," and so forth.

**Structuring**

The next sub-step in quantifying the uncertainties is to structure them. Having defined the variables, structuring is very often necessary because rarely can the variables be assessed directly. For instance, the project slippage may have to be structured in terms of different units in the project starting later (or earlier), delay in licensing, and slippage in delivery of plant and machinery, and so forth. It will be difficult to assess directly what will be the uncertainty surrounding the total slippage in project timing whereas components may be relatively easier to handle. Similarly, cost over-runs are difficult to assess unless the over runs are structured in relation to the reasons for the same.

Two types of structuring are useful in dealing with complex uncertainties. The first is to decompose the uncertain variable into smaller, simpler components, which are easier to assess than the complex one. For instance total sales may be decomposed by possible end-users or by different territories. Thus, an uncertainty can be decomposed into causal factors or into disaggregation of its characteristics. The other type of structuring is for technical advantages in assessment. If a pair of interdependent uncertainties can be struc-
tured in terms of independent components, the task of computing the project returns is vastly simplified. For instance, if sales in two adjoining territories are interdependent, it is possible to express them in terms of the average sales and the differential sales between the two territories. If these (average and difference) are independent uncertainties and could be assessed with ease, the interdependent sales in the two adjoining territories could easily be derived. This type of structuring has been labelled as "tactical" structuring as against the first type which is a "strategic" structuring. (For details of strategic and tactical structuring with examples and a framework for structuring different types of uncertainties, see Malya Chs. 6-8.)

**Preliminary Assessments**

Having arrived at a list of specific variables to be assessed, the next task is to identify knowledgeable persons who can quantify the degree of uncertainty associated with these variables. For instance, in the World Bank project, devaluation (timing and amount) was assessed by an expert from the International Monetary Fund, whereas the equipment prices were assessed by the technical consultants on plant and machinery. The quantification of uncertainties in terms of the possible values the variables can take, along with the associated chances, is a difficult process. However, well-established routines are available to elicit such judgements. Moreover, if the problem is of importance and the involvement of the people is ensured, it facilitates the assessment process.

The most commonly used procedure is the fractile method. The assessor states values of the uncertain quantity such that the chances of the actual value being less than or equal to the stated values are respectively .01, .25, .50, .75, and .99. Other levels of fractiles may be chosen, but these five are the most commonly used and convenient ones. The advantage of the fractile method lies in its adoptability by non-technical persons. For instance, the fractile value corresponding to the level 0.50 is the median and can be assessed easily by asking the assessor to state a value such that it is as likely for the actual value of the uncertainty to be above this value as for it to be below the value. In other words, there is a 50:50 chance that the actual value may fall on either side of the stated (median) value. (For details of the fractile method, see Raiffa, pp. 161-167; and Malya, pp. 5-31 to 5-33 and 9-11 to 9-14).

**Consistency Checks**

After the preliminary quantification is done checking for consistency is essential. Along with this, any logical fallacies that may have arisen in the assessments have to be identified and rectified.

**Revision, Modification, and Refinement**

The final step in the quantification is to modify the assessments in the light of consistency checks and discuss or examine the implications of the assessments made. Quite often the implications of the first round of assessments make one realize that the articulation of uncertainties perhaps is not representative of one’s true feelings. The steps outlined in assessment and consistency checks are iterative and may have to be repeated two or three times to ensure that the decision maker is comfortable with the assessments made.

**Modelling**

Having assessed the uncertainties, the task of modelling them in relation to each other and how they affect the cash flows is the next step. This enables us to calculate the various possible consequences (net present values or rates of return) with the degree of uncertainty associated with each possibility.

**Implications and Finalizing**

The final step is to examine the implications of the risk profile of the project. One such
implication can be to decide on the magnitude of contingency funds that might be needed and provide safeguards against some of the uncertainties which can adversely affect the project. The expenditure and effort that is necessary for safeguarding will be reflected by the contribution of these variables to the overall uncertainty surrounding the project.

The World Bank Project

The government of a country had requested the World Bank for a credit of 12 million to meet the estimated foreign exchange needs for a programme to modernize the cotton ginning industry. The programme involved rehabilitating 10 existing ginneries and constructing four new ones. The ginneries, besides feeding domestic textile industry, generated substantial foreign exchange for the country through the exports of its superior grades of ginned cotton. Benefits and returns flowing from the project were therefore expected to be quite substantial. The modernization was envisaged in the blending equipment, storage, transportation, cleaning, humidifying, and pressing operations. The current manual methods would be mostly mechanized.

Existing Procedure of Project Analysis

Initially, the World Bank adopted a conventional cost-benefit analysis for the appraisal of its industrial projects. The costs—investment, operating and other expenses—were compared with the expected benefits—cost savings, increased production, quality improvement—and so forth—to determine whether or not a project should be funded. For all the costs and benefits "best" estimates were used. Risk analysis of a project, incorporating probabilistic assessments instead of using single estimates was not a common procedure. However, the bank realized the need for incorporating uncertainties in project analysis and a research team of the bank examined the implications of ignoring uncertainties. The report of the team cites two studies which indicated a larger degree of variation in the rates of returns denoting a substantial amount of risk in the projects than was originally estimated because of ignoring the uncertainties (Pauliquen).

Feasibility Report

The host country had commissioned a technical consulting firm to prepare a feasibility report and recommended the technology which would be appropriate both for rehabilitating the existing ginneries and starting new ones. A three-volume feasibility report prepared by the consultants had been submitted to the World Bank. The bulk of the report was on technical recommendations. The economic analysis of the project had been done at a very preliminary level without incorporating any uncertainties. The rate of return from the project was estimated around 8% which was low by the bank's standards for similar projects. However, scrutiny of the benefits resulted in the consultants admitting the fact that they had not quantified the substantial revenue gains from quality improvement of the ginned cotton through modernization. They revised their figures, and the rate of return was recalculated. This time it was over 41%. The World Bank appraisal team realized that there was a substantial degree of uncertainty in the project and therefore a full-fledged risk analysis was commissioned.

Identification

Based on the consultants' report and discussions with the appraisal team, the following tentative list of uncertainties was drawn up in a working paper:

2. Time schedule : delays in startups, construction, and achieving full operational capacity.
3. Size of cotton crop.
4. Operational costs : labour and maintenance.
5. Savings due to increased efficiency, improved quality, decrease in labour costs, and rents.
7. Price of oil extracted from the seeds obtained as a by-product.

3 In the interest of the host country, the identifying details have been disguised.
The interrelationships among these variables had to be understood. Since any delays in startups and construction could affect the capital costs, variables 1 and 2 were interdependent. Size of cotton crop (variable 3) could significantly affect operating costs, savings, cotton price, and capacity utilization. Variable 8 (capacity utilization), in turn, could affect variables 4 and 5.

Further discussions led the appraisal team to decide on a quick sensitivity analysis to pick out the key uncertainties. These were found out to be the size of cotton crop, increased revenues through quality improvement, capital costs, and time schedule. To this were also added the factor of inflation and possibility of devaluation.

**Definition**

The uncertainties had to be defined now in more specific terms so that the judgemental assessments could be obtained from various experts in the field. The problem of defining an uncertainty was by no means very simple. For instance, "slippage" (the time delay in the completion of the project) was a difficult variable to define. It was not clear whether the delay meant 1) the postponement of the completion of the last ginning unit scheduled to be started, 2) the slippage in the date on which all the new and rehabilitated ginneries would be fully operational, or 3) a composite picture built by estimating the time of completion of each of the 14 ginneries in the programme. Conditional on the delay, the capital expenditure pattern and capacity utilization would also vary and uncertainties in the cost and revenue estimate would be affected. Initially, definition (2) was chosen surmising that it would be the easiest one to use. However, when it came to actual assessments, it turned out that the judgements could not be made for the project as a whole and one had to consider each ginnery and adopt definition (3). This proved to be one of the most difficult and time consuming of the uncertainties to be defined, structured, assessed and modelled. Substantial cost over-runs were also noticed to be a function of the delays.

Devaluation was another factor that presented difficulties in definition and formulation. The questions that cropped up were: Could there be multiple devaluations? By how much would the currency be devalued? What is the interdependency between the year of devaluation and the amount? It was decided that an expert in the IMF would be contacted for deciding the best way to handle the uncertainty about devaluation.

The expert decided first to assess the chances of devaluation in or earlier than the years 1974, 1975, and so on. For instance, he stated that there is a 70% chance that the devaluation would occur earlier than 1980 (i.e., in 1979 or earlier). Then conditional on there being a devaluation in any year, the chances of the magnitude of devaluation was also assessed using the fractile method. This might have resulted in some oversimplification but none of the less provided insights into the possible magnitude of the impact of devaluation risk on the project. The assessments are given in Appendix I.

Though the list of uncertainties had been identified from the preliminary analysis, new sources of uncertainties cropped up later during the analysis. One of these was the uncertainty in additional costs needed for surveying and designing new constructions in the existing ginneries. Additional outturn in ginned cotton was also another variable that was included at a later stage in the analysis. It is to be observed that in practice, though an initial listing and sensitivity analysis is helpful, this list should not be held sacrosanct as the investigation proceeds. The analyst should be aware of the possibilities of new uncertainties cropping up or the initial ones not turning out to be important.

The final list of the uncertainties in the World Bank project was as follows:

1. Size of cotton crop.
2. Devaluation (timing and amount).
3. Grade improvement: Grade improvement proved to be a difficult variable to assess. It had to be structured into four components which were not mutually independent.
4. Capital cost: Again this variable presented some
difficulties. It was structured into several independent components. Its dependence on slippage also had to be modelled.

5. Slippage or timing of completion: Several independence assumptions were made. Timing affected both capital costs and capacity utilization and hence benefits and savings realized.

6. Operating cost savings per unit of cotton ginned.

7. Percentage increase in outturn of cotton lint.

Structuring

The uncertainties had to be further structured to render them into a form which would be easier to assess. The first uncertainty of crop size was decomposed into two components. The first one was assessed after consulting the past records, the current plans for cotton development and the future likelihood of more cotton cultivation through increased land being brought under the crop, better irrigation, facilities, and more intensive scientific cultivation methods. The second component was the annual percentage variation around the long-term trend. This was assessed after observing the forecast and the actuals for a number of years and discussion with the agricultural officers in different regions of the country.

Devaluation was structured in a rather simple manner by first assessing the year of a possible devaluation and then assessing the amount of devaluation. In this case, some simplifying assumptions had to be made, i.e., the two components were independent and that there would not be more than one devaluation during the first ten years of the project.

"Grade improvement" was structured into four components. The improvement in new and rehabilitated ginneries in dry and delta regions were assessed and these component variables and their interdependencies were then modelled to estimate the additional cash inflow due to quality improvement.

Capital expenditure was first decomposed by individual equipments, survey and design costs, erection costs, and so forth. Over 40 components of the variables were listed. These were then reaggregated according to 1) the nature of payment (foreign exchange or local currency), 2) type of ginnery (new or rehabilitated), and 3) whether the costs were relatively more certain or uncertain. These categories not being mutually exclusive, their interrelationships had to be further structured. The equations are given in Appendix II.

As has been mentioned earlier, the slippage in the time schedule was assessed by separately considering each unit (10 rehabilitated and 4 new ginneries) and the probable completion schedules. The major task then was to assess the effect of different completion dates on capital costs, capacity utilization, and cash inflows.

The Assessments and the Assessors

The assessments were done in several rounds, the possible values of each uncertainty were simulated and discussed with the respective assessors, consistency checks were made, and reassessments of some of the uncertainties were done. A few illustrations of the assessments obtained are given in Appendix I.

The quantification of judgement on various uncertainties had to be done by different experts in their respective fields. For instance, the capital costs were assessed by technical consultants. The devaluation, as has been mentioned, was assessed by a monetary expert. The size of the cotton crop was assessed after interviewing officials in the ministries of agriculture, irrigation, and power. The grade improvement was assessed after talking to the cotton industry federation, exporters, ginning experts, graders, and so forth. Some initial resistance to quantifying the uncertainties was encountered, but it was easily overcome once the purpose of the analysis was explained.

Modelling

A complex simulation routine was developed incorporating 30 uncertain quantities which could affect the rate of return from the project. A diagrammatic outline of the model is given in Appendix III.

Implications of the Uncertainty Analysis

A marked difference in the financial results emerged between the analyses with and with-
out the risk analysis. The rate of return calculated without the risk analysis in the consultant's feasibility report was 41.8%. This was calculated in accordance with the "traditional" bank group methodology. The risk analysis indicated an expected rate of return of 17.6%, the possible values ranging from 14% to 23%. This happened not only because of the uncertainties involved but also due to improved quality of the estimates obtained through detailed assessments. A comparison of results with and without risk analysis is presented in Table 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Estimates with conventional risk estimate (» 1,000)</th>
<th>Expected values with analysis (» 1,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>11,154</td>
<td>12,327</td>
</tr>
<tr>
<td>Completion of project</td>
<td>Mar. 1977</td>
<td>Dec. 1977</td>
</tr>
<tr>
<td>Rate of return</td>
<td>41.8%</td>
<td>17.6%</td>
</tr>
<tr>
<td>Revenue gains</td>
<td>5,267</td>
<td>2,453</td>
</tr>
<tr>
<td>Incremental after tax cash flows</td>
<td>4,442</td>
<td>2,674</td>
</tr>
</tbody>
</table>

The risk profiles (the cumulative probability distribution curves) of the internal rate of return and the net present value at 12% were also constructed. This analysis indicated that there was a 20% chance that the rate of return would be below 17%.

The analysis served the major purposes of refining the estimates, questioning the assumptions, and understanding the interrelationships.

The complex variables could not have been analysed at all without properly defining, structuring, and assessing the uncertainties and their interdependences.

Finally, this effort demonstrated the feasibility of incorporating uncertainties in conducting project appraisals, within the time and cost limits normally operative for such tasks, given the interest and enthusiasm of the appraisers and analytical help of a decision analyst.

The World Bank's report fully supported the project and was of the opinion that the project was economically sound. A direct result of the uncertainty analysis was a recommendation to increase the foreign exchange credit for capital expenditure to cover some of the possible contingencies as indicated by the magnitude of uncertainty in this variable. The appraisal team also drew the attention of the country to the possible increases in costs due to slippage and recommended that efforts be made to keep to the proposed schedule.

References


Appendix I

**Devaluation**

<table>
<thead>
<tr>
<th>Year</th>
<th>Probability of devaluation on or before the date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>.04</td>
</tr>
<tr>
<td>1975</td>
<td>.10</td>
</tr>
<tr>
<td>1976</td>
<td>.22</td>
</tr>
<tr>
<td>1977</td>
<td>.40</td>
</tr>
<tr>
<td>1978</td>
<td>.56</td>
</tr>
<tr>
<td>1979</td>
<td>.70</td>
</tr>
<tr>
<td>1980</td>
<td>.80</td>
</tr>
<tr>
<td>After 1980</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Assessment of Crop Size**

Current production: 100 = 10.2 million units

<table>
<thead>
<tr>
<th>Probability that devaluation is equal or below the parity factor</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.15</td>
<td>.01</td>
</tr>
<tr>
<td>1.20</td>
<td>.25</td>
</tr>
<tr>
<td>1.22</td>
<td>.40</td>
</tr>
<tr>
<td>1.25</td>
<td>.50</td>
</tr>
<tr>
<td>1.30</td>
<td>.75</td>
</tr>
<tr>
<td>1.32</td>
<td>.80</td>
</tr>
<tr>
<td>1.40</td>
<td>.90</td>
</tr>
<tr>
<td>1.50</td>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Amount of devaluation parity factor</th>
<th>Probability that devaluation is equal or below the parity factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.15</td>
<td>.01</td>
</tr>
<tr>
<td>1.20</td>
<td>.25</td>
</tr>
<tr>
<td>1.22</td>
<td>.40</td>
</tr>
<tr>
<td>1.25</td>
<td>.50</td>
</tr>
<tr>
<td>1.30</td>
<td>.75</td>
</tr>
<tr>
<td>1.32</td>
<td>.80</td>
</tr>
<tr>
<td>1.40</td>
<td>.90</td>
</tr>
<tr>
<td>1.50</td>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Annual variation around the average</th>
<th>Cumulative probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10%</td>
<td>0</td>
</tr>
<tr>
<td>-3%</td>
<td>.25</td>
</tr>
<tr>
<td>0%</td>
<td>.50</td>
</tr>
<tr>
<td>2%</td>
<td>.75</td>
</tr>
<tr>
<td>4%</td>
<td>.95</td>
</tr>
<tr>
<td>5%</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Appendix II

**Structuring the Capital Expenditure**

**Total Capital Expenditure**

<table>
<thead>
<tr>
<th>New Ginneries</th>
<th>Rehabilitated Ginneries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreign Expenditure</td>
<td>Local Expenditure</td>
</tr>
<tr>
<td>Foreign Expenditure</td>
<td>Local Expenditure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>More certain costs</th>
<th>Less certain costs</th>
<th>More certain costs</th>
<th>Less certain costs</th>
<th>More certain costs</th>
<th>Less certain costs</th>
<th>More certain costs</th>
<th>Less certain costs</th>
</tr>
</thead>
</table>

Vikalpa
Appendix II Contd.

The components are not independent in the stochastic sense. The variables assessed and their interrelationships are summarized in the following set of equations.

1. All the variables are in terms of factors which when multiplied by the "best" estimates in each category give the desired assessments of capital costs in each category.

2. All the following variables are mutually independent.

\[ x \] : Local cost factor of new ginneries
\[ x' \] : Additional uncertainty factor for 40% of the local cost of rehabilitated ginneries.
\[ V \] : Foreign cost factor of relatively certain items
\[ w' \] : Foreign cost factor of relatively uncertain items
\[ B_1 \] : "Best" estimates in dollars (in each year) of local costs for new ginneries
\[ B_3 \] : "Best" estimate?, in dollars (in each year) of local costs for rehabilitated ginneries
\[ B_5 \] : "Best" estimates in dollars (in each year) of foreign costs for new ginneries
\[ B_7 \] : "Best" estimates in dollars (in each year) of foreign costs for rehabilitated ginneries

The desired capital costs are:

\[ \sum \]
\[ C_t : Local costs for new ginneries \]
\[ C^\wedge : Local costs for rehabilitated ginneries \]

Foreign costs for new ginneries

Foreign costs for rehabilitated ginneries

The relationships are:

\[ C = C_j + C_o + C_8 + C_t \]

Equation (1) is self-explanatory.

Equation (2) uses the same uncertainty as in (1) for 60% of the costs and imposes an additional uncertainty for the remaining 40% of the local costs for rehabilitated ginneries as mentioned earlier.

Equation (3): 42% of the foreign costs for new ginneries are estimated to be relatively certain and 58% relatively more uncertain.

Equation (4): In the foreign cost, the relatively certain cost items comprise a slightly higher (48%) percentage for rehabilitated ginneries. In our analysis, we first modelled this part with a single vector of best estimates of capital expenditure pattern over the years, for the four groups of costs (the B's). Later, when slippage was introduced as an uncertainty, matrices (instead of vectors) of capital expenditure pattern had to be estimated.

\[ \text{In total capital costs:} \]
\[ C = C_j + C_o + C_8 + C_t \]
Appendix 111

Cotton Ginning Project Montecarlo Simulation for Project Analysis: Computer Programme Flow Chart

[Devaluation Module] [Project Slippage]

<table>
<thead>
<tr>
<th>Capital Costs Module</th>
<th>[Do Nothing Module]</th>
<th>Crop Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved [Same]</td>
<td>Improved [Same]</td>
<td></td>
</tr>
</tbody>
</table>

Exports | Local | Grade Improvement Size and Volume |

Grade Improvement Module | oPremium Drop |

Revenue due to Grade Improvement

[Capacity: Type & Region]

Breakdown Penalty | Production Capacity (Penalty) | Operating Costs | Operating Costs Savings due to Modernization | Seed |

Savings | Depreciation |

Project Benefits | Interest |

Inc. Incremental Cash Flow

20 Years

Next Year

Rate of Return

Simulation (400 Trials) Next Trial Print

* Based on the World Bank's internal appraisal report.