OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

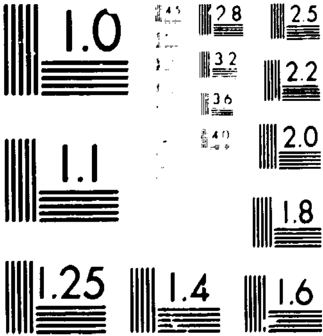
FAIR USE POLICY

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS

11385

Distr.
LIMITED

UNIDO/IS.308
16 April 1982
English

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

FLEXIBILITY AS A MAXIMAND IN INDUSTRIAL PLANNING IN THE DEVELOPING COUNTRIES*

Prepared by the

Global and Conceptual Studies Branch

Division for Industrial Studies

Special Studies in Industrialization

Working Papers

002609

* This document has been reproduced without formal editing.

V.82-24676

Table of Contents

I. INTRODUCTION

The International Development Strategy for the Third United Nations Development Decade represents a comprehensive set of quantitative and qualitative targets for accelerating the development process in the developing countries over the 1980s, including not only a 7 per cent average annual growth rate of GNP and a targeted investment level equal to 28 per cent of GDP by 1990, but also incorporating targets such as the early eradication of poverty and dependency in the developing countries.

A key role in the development plans of the developing countries is forseen for the industrial sector, where the average annual growth rate of manufacturing output is targeted at 9 per cent. Attainment of this growth rate, together with a marked increase in the share of the developing countries in the total world export of manufacturing goods, will, in turn, only be possible if the developing countries engage in a comprehensive programme of planning in the industrial sector and, most importantly, design and carry out a thoroughgoing set of planned adjustment policies for industrial restructuring.

In the contemporary world economy three realities can be seen to play a crucial role in programmes of long-term economic development, and hence will be of incisive importance in the process of industrial planning that the developing countries must engage in in their attempts to attain the targets of the International Development Strategy for the Third Development Decade. The first of these realities is the overwhelming importance of technological development in determining both the level and pattern of long-term industrialization and development; the second is the reality of environmental and social constraints on economic development and the increasing concern with the impact on the atmosphere and social environment of policies of long-term economic development; and the third is the increasing importance of the international implications of, and reactions to, industrial policy decisions made at the national level in a given country that results from the reality of the ever growing international interdependence of the industrialization process.

All three of these realities imply that the industrialization policy that the developing countries formulate today must be conceived of dynamically. Such dynamic policy making has the corollary that short-term benefits must sometimes be sacrificed in the interests of the long-term <u>flexibility</u> of policy making. The process of industrial policy making therefore acquires a new dimension: rather than selecting one 'best' set of targets and working out the optimal allocation of instruments to targets, planners and policy makers would select a number of sets of targets and correspondingly a number of sets of optimal allocation of instruments.

The optimal economic policy is then chosen on the basis of a comparison among these alternative sets of targets and instruments, using the criterion of optimal future flexibility of decision making on industrial restructuring. Basing economic decision making on the maximization of long-run flexibility may well impose the cost of short-term 'losses', in the sense that the variant chosen from the alternative sets of targets and corresponding instrument allocations may not be the one that maximizes the short-run industrial output or profitability. In this case the short-run objective will be outweighed by the long-run objective of maximum flexibility to respond to the new realities facing planners in their elaboration of the country's policy on industrial restructuring.

While the formalized models of industrial policy making and planning developed over the last two-and-a-half decades have become increasing sophisticated and in many cases also appreciably more realistic, a fundamental shortcoming of the developments to date has been the failure of the models, both for policy making in the developed capitalist countries and for planning in the developed socialist countries, to formally recognize that the nature of the environment in which industrial decision makers operate is such that they must integrally incorporate a degree of flexibility into their decision making to allow them to accomodate the uncertainty of the decision space in which they operate. This paper demonstrates how flexibility of response can be formalized in such a way as to allow the policy makers in the developing countries to choose that policy from among the set of desirable policies that simultaneously guarantees the policy makers the maximum degree of flexibility to respond to changes in technology, in the socio-political environment, in the international structure of industrial production, and to uncertainty in general in the formulation of their national policies on industrial restructuring.

II. UNCERTAINTY IN THE TRADITIONAL DECISION MAKING FRAMEWORK

In traditional neo-classical analysis the preference function of economic decision makers is specified in terms of maximizing (or minimizing) the level of given policy objectives in environments where information and knowledge are free goods. This analysis has been extended both by specifying goal functions and by introducing constraints on behavior, but the models leave little effective choice since, given data on the variables, the solutions are perfectly predictable.

Recognizing the reality of uncertainty in the decision making process creates choice. A prediction then becomes a probability rather than a certainty, and the solution set is likely to contain several solutions, each of which may be equally likely to occur. The industrial planner can now not be certain as to which solution will be the appropriate maximand for use in policy making.

A random variable could be introduced into the function which would allow for risk aversion and risk taking. In general, such models[1/] predict results different from those predicted under the certainty condition and, in the case of risk taking, several of the solutions are indeterminate. The effect of handling uncertainty in this manner is to make several alternative states of the world possible from one set of given initial conditions.

1/ I. Horowitz, "On the Theory of the Monopolistic Multiproduct Firm under Uncertainty", International Economic Review 5 (September 1964)

This paper argues that a preferable preference function for use in planning long-term industrial restructuring in developing countries under uncertainty would be one of maximizing robustness, robustness being defined as the flexibility for future policy remaining after the current decision is made. The concept of robustness is developed and presented as a quantifiable maximand giving a measurable scale for policy makers to use in making choices between alternative sets of policies for industrial development and industrial restructuring.

III. UNCERTAINTY AND FLEXIBILITY IN DECISION MAKING

Given uncertainty, policy makers make decisions under partial, ignorance. As the planning horizon is lengthened, the decision makers will have less and less information on which to base forecasts, and what information they possess will be less realistic. Under such conditions, the pursual of one maximand can foreclose (through inflexibility) many future states which may turn out to be highly desirable. A fundamental result of this fact is that a policy allowing industrial planners the freedom to pursue several alternative future economic policies on industrial restructuring may be more valuable than a maximal optimal policy in conditions where the policy makers have only imperfect information on future environmental outcomes.

The conventional way to represent policy making under uncertainty is to assume the policy makers possess knowledge of all possible outcomes without knowing the specific outcome. Based on expectations of the foreseeable outcomes, the decision maker can subjectively assign probabilities to the i outcomes such that the probabilities sum to one:

$$\sum_{i=1}^{n} p_i = 1. \tag{1}$$

The expected value of the outcomes m_i will be:

$$E(m) = \sum_{i=1}^{n} P_i m_i = \bar{M}. \tag{2}$$

Where there is no objective basis for assigning different probabilities between m_i outcomes, the decision maker gives each probability a value equal to 1/n. This represents the extreme position of maximum uncertainty given known outcomes.

To reduce the problem to one of certainty, the decision maker must deduct from the expected value $\bar{M}$ the variance of the distribution around $\bar{M}$. This gives:

$$U(M) = \bar{M} - \sigma^2 \qquad (3)$$

for the utility of the expected value to the decision maker, where U(M) is the certainty-equivalent of $\bar{M}$. Given these modifications, the certainty-equivalent values can be substituted for the known values under the perfect information assumption of general equilibrium theory. Such a procedure would, however, only be acceptable within a short-term decision-making framework in a relatively stable economic environment. Such environments have limited interest under conditions of uncertainty as the possibility of unforeseen events is ruled out and the analysis of uncertainty is reduced to a variant of risk analysis.

Introducing unforseen contingencies allows the analysis to again become interesting. The set of known future outcomes (1,2,...,n) is assumed to be a subset of all possible outcomes (1,2,...,n, n+1,...,z) and therefore:

$$\sum_{i=1}^{n} p_i < 1 \qquad (4)$$

In the short term the class of unforseeable contingencies may have a relatively low probability of occurrence, but as the policy-makers' time-horizon lengthens, the probability of unforseeable events occurring is likely to rise at an increasing rate. Thus, the above equation could be re-written as:

$$\sum_{i=1}^{n} p_i + \eta^{\beta} = 1, \qquad (5)$$

where η is a positive random variable distributed independently of p_i and β, $\beta>1$ is a time derivate such that $\partial^2\beta/\partial t^2>0$. Of course, many of these unforseen events are endogenous to the policy makers decision space.

A major objective of those charged with formulating policy on industrial restructuring in developing countries then becomes the attempt both to moderate the influence of unforseeable adverse contingencies and to generate new unforseen favourable contingencies if they are to stay in power in the long-term. Within environments incorporating a high variance in expected outcomes together with a confusion over the likelihood of unexpected future events, certainty-equivalence alone is not a viable technique for designing a policy that is desirable over the long-run.

In addition to assigning subjective probabilities to the expected outcomes, the policy makers must find a technique for withstanding the occurrence of unforseen outcomes whenever η^β is significant. Given the impossibility of compiling reliable prior estimates of η^β, the most rewarding technique is likely to be the incorporation of a maximum degree of flexibility in the formulation of the government's policy on industrial restructuring.

The retention of uncertainty as an environmental condition has major implications for the theory of planning and policy making in industry. The conventional mathematical treatment of uncertainty as a variant of risk analysis must be supplemented by a function which maximizes flexibility in future decision making. Specifically, rather than aiming at a unique and pre-determined, theoretically optimum solution, the analysis needs to require solutions which maximixe the number of future desirable options. Indeterminancy, rather than being regarded as an undesirable property (as within the convential equilibrium framework), has to be incorporated as a characteristic of the solution set in order to allow the industrial sector to attain its optimal growth path and therefore achieve its targeted industrial structure most efficiently.

IV. ROBUSTNESS AS AN OBJECTIVE

The two previous sections have emphasized the need to maximize flexibility with regard to future decisions when operating in uncertain environments, and flexibility has been suggested as an essential element for inclusion within the industrial policy makers' long-run preference function. Such a function will maximize the <u>robustness</u> of policy decisions towards industry, robustness being defined as the degree of flexibility that a decision maker retains with regard to future decisions after the initial decision has been made. It can only be ensured by the policy makers maintaining the highest possible degree of freedom of action, consistent with their given rate of time preference.

The maximizing of robustness should form the appropriate objective for policy makers in environments in which the planned path of industrial development is liable to be upset by unforseeable outcomes. When η' becomes a significant variable, the standard optimum solutions of conventional equilibrium theory are restricted in usefulness. The devising of robust solutions should allow the decision makers to strategically overcome the information gap presented by the likelihood of the occurrence of unforseen outcomes in the long-term. By pursuing robustness as an objective, the policy maker will be able to continue operating within the conventional subjective probabilistic framework while retaining a long-term strategy for coping with unforeseen contingencies.

However, if robustness is to be a purposeful maximand for decision making, it must be transformed from a qualitative concept into a quantitative measure. Precision is essential for a long-run preference function at the industry level, and decision makers must have a measurable scale as a basis for choice between alternative courses of action and hence between alternative paths for attaining the desired future industrial structure.

V. THE TECHNOLOGY OF ROBUSTNESS UNDER CERTAINTY

Simple robustness

Initially, we place the industrial sector of a national economy in a deterministic environment and assume that the policy makers have a set of $\underset{\sim}{D}$ alternative decisions which are feasible in the short-run. Of this set $\underset{\sim}{D}$ they make the decision d_i, i.e., $\underset{\sim}{D} = \{(d_i)\}$. In making this initial decision, the decision makers reduce the set $\underset{\sim}{S}$ of feasible alternative plans which could have been realized in the long-run to a subset of attainable plans $\underset{\sim}{S}_i$; i.e., $\underset{\sim}{S}_i \in \underset{\sim}{S}$.

Of the initial set $\underset{\sim}{S}$ of feasible alternative plans, a subset of $\hat{\underset{\sim}{S}}$ is currently considered 'good' by the decision makers, and the result of the initial decision d_i will be to reduce $\hat{\underset{\sim}{S}}$ to the subset $\hat{\underset{\sim}{S}}_i$ (the intersection of $\hat{\underset{\sim}{S}}$ with $\hat{\underset{\sim}{S}}_i$). Then robustness can be defined as:

$$r_i = \frac{n(\hat{\underset{\sim}{S}}_i)}{n(\hat{\underset{\sim}{S}})}, \qquad (6)$$

where $n(\hat{\underset{\sim}{S}})$ is the number of elements in $\hat{\underset{\sim}{S}}$.[2/] This, then, can be considered <u>simple robustness</u>.

The decision makers would then rank each alternative course of action falling within the set of feasible and 'good' subset which they faced according to the amount of flexibility (for future decision making) that the decision maker retained, after making the initial decision. Defining a solution to be 'good' only if it meets certain constraints (e.g., on employment or capital productivity), and then only considering as possible candidates decisions d_i those elements of $\underset{\sim}{D}$ which are both feasible and 'good', the decision maker is able to pursue a policy of multiple objective decision making: n-1 of the objectives define the 'good' subset of $\underset{\sim}{D}$, and the n^{th} objective is flexibility. In a standard mathematical programming approach this is similar to the process of multiple objective decision making with a criterion complex.[3/]

2/ J. Rosenhead, M. Elton and S.K. Gupta, "Robustness and Optimality as Criteria for Strategic Decisions", Operations Research Quarterly 23 (December 1972).

3/ P. Wiedemann, "Planning with Multiple Objectives", Omega 6 (December 1978).

By choosing the alternative decision with the greatest robustness, the decision makers would be emphasizing the long-term nature of industrial policy making and the continuous process of economic decision making. By ranking alternative initial decisions with respect to the useful flexibility which will be maintained, robustness handles the uncertainty inherent in strategic planning by stressing the importance of flexibility. It places emphasis on the continuous process of planning, and reflects the sequential nature of decision making.

Independent decision making

This formulation of robustness can be extended to incorporate the international interdependence of industrial policy making and restructuring, and therefore reflect another aspect of the complexities of the process of strategic industrial planning. Thus a decision by policy makers 1 (say, developing country 1) will affect the future flexibility of that country not only because it will exclude certain 'good' economic plans, but also because the decision will cause other countries to make reactive decisions. This set of decisions will alter the future flexibility of country 1, probably for the worse, by changing the future in which plans will be 'good' or not. The magnitude of the effect on flexibility will depend upon the degree of interdependence between the country making the initial decision and the actors which may respond. This aspect of the international interdependence of industrial policy making is particularly relevant in the framework of the long-term plans for accelerated industrialization (and the attainment of a higher share of world industrial output) of the developing countries. It also reflects the dependence of industrial restructuring in the South on industrial policy in the North.

We may designate the feasible initial decisions of country 1 by $\underset{\sim}{D}^1 = \left\{d_i^1\right\}, (i = 1, 2, \ldots, n_i)$. Then consider that there are m reacting agents (countries) j, j = 2, 3, ..., m. We may write the set of feasible responses as $\underset{\sim}{D}^j = \left\{d_k^j\right\}$, $(k = 1, 2, \ldots, n_j)$. Of these n_j possible responses, of course, only a small subset will generally be relevant at any given time.

Explicit recognition of such a response decision requires a modification of the formulation of simple robustness above. 4/ Decision d_i by developing country 1, i.e., d_i^1, now produces the set of responses $\left\{d_{k_{ij}}^j\right\}$, with $j = 2, 3, \ldots, m$. For each actor j responding to the initial decision, k_{ij} is uniquely determined by i - i.e., every major policy decision in the industrial field in country 1 generates a specific response action from every other country j. The possible future environment open to country 1 pursuant upon making decision i is then modified by the set of responses $d_{k_{ij}}^j$.

Policy makers in country 1 made decision i so as to maximize the freedom of action in the future, but the response of other agents in the environment has the effect of reducing the future flexibility of country 1 by an amount depending on the size of $d_{k_{ij}}^j$. The effect of $d_{k_{ij}}^j$ then will be to reduce $\hat{S}_i$, the subset of the desirable states which the policy makers could attain in the long-run - the alternative possible industrial structures - by an amount we could call $\hat{S}_{k_{ij}}^j$.

The reduction in the robustness of the developing country (country 1) due to the response decisions of other actors (i.e., other countries), measured relative to the original set $\hat{S}$, could then be represented by $r_{k_{ij}}^1$. Thus:

$$r_{k_{ij}}^1 = \frac{(\hat{S}_i) - \hat{S}_{k_{ij}}}{\hat{S}}, \quad j = 2, 3, \ldots, m.$$

A modified robustness score that allowed for the incorporation of the external interaction of decision maker 1 with the environment, that is $\left\{d_{k_{ij}}^1\right\}$, into the robustness measure would then be:

$$r_i^1 = r_i - \sum_{j=2}^{m} \sum_{k=1}^{n_j} r_{k_{ij}}^1 \qquad (8)$$

4/ J. Rosenhead and P. Wiedemann, "A Note on Robustness and Interdependent Decision Making", Journal of the Operational Research Society 30 (September 1979).

This interdependent robustness incorporating response decisions in a deterministic framework could also be written by expressing the result of the response set $\left\{ d^{j}_{k_{ij}} \right\}$ as a modification of the expected future environment that would have resulted in absence of the response decisions. Let us call this modified state of the future environment E_i.

To each E_i there will correspond a different set of $\hat{\underset{\sim}{S}}(E_i)$ of 'good' plans and likewise a corresponding subset $\hat{\underset{\sim}{S}}_i\,(E_i)$ of good plans can be attained after decision d_i has been made. We can then calculate an interdependent robustness score that allows for the external interaction of decision maker 1 with the environment identical to that above as:

$$r^1_i = \frac{n\left\{\hat{\underset{\sim}{S}}_i\,(E_i)\right\}}{n\left\{\hat{\underset{\sim}{S}}\,(E_i)\right\}} \qquad (9)$$

Either formulation can then be used to allow a given developing country 1 to assess the long-run implications for its industrial structure of a certain industrial policy decision d_i which is taken in the present period and then reacted to by other developing and developed countries.

VI. THE TECHNOLOGY OF ROBUSTNESS UNDER UNCERTAINTY

Simple robustness under a probabilistic framework

It is, however, often the case that the policy makers will not know with certainty all future states of the world. At the very best, industrial planners in a developing country may know each of the possible future states of the world ("possible futures") and the specific probability with which each of these possible futures can be expected to occur. For each of the multiple possible futures there will be a set of good feasible plans $\hat{\underset{\sim}{S}}$, and a subset $\hat{\underset{\sim}{S}}_i$ of good feasible plans which can be attained after decision d_i is made.

Each of these possible sets S and subsets S_i will occur with a probability p^w, where each p^w is such that $0 \leqslant p^w \leqslant 1$ and $\sum_{w=1}^{q} p^w = 1$.

Thus, simple probablistic robustness is defined as

$$r_i^w = \sum_{w=1}^{q} p^w \left[\frac{n(\hat{S}_i^w)}{n(\hat{S}^w)} \right] , \qquad (10)$$

where $\hat{S}^w$ and $\hat{S}_i^w$ refer to the set of feasible alternative plans and the subset of feasible alternative plans attainable after decision d_i in the future state w, respectively, and p^w is constrained as above.

With robustness defined for decision making within a probabilistic framework, the industrial planners can then proceed to rank possible decisions with respect to the useful flexibility that will be maintained after the decisions are made for each of the (known) multiple future environments. The decision maker can continue to pursue a policy of multiple objective decision making and maximize future flexibility of decision making concerning the future industrial structure for the developing country for each possible future state of the world.

Interdependent decision making in a probabilistic framework

By explicitly incorporating the response decision of actors j to the decision d_i of policy makers in country 1, we modified simple robustness to incorporate the modification of the flexibility of future response of country 1 effected by $\left\{ d_k^j \right\}_{ij}$. In the probabilistic framework decision d_j^i produces response d_k^j from country j with some known probability p_{ijk} ($j = 2, 3, \ldots, m$; $k = 2, 3, \ldots, n_j$).

If we assume that the responses of the other reacting countries are independent of each other, there are a very large number of combinations of responses, and each of these response decisions would generate its own future environment. For computational feasibility, we will group the combination of responses into sets based on the similarity of their effect on developing country 1. Each of the reduced number q of combinations constitutes a modification to the expected future environment of developing country 1.

Let these modified environments be $E_{i\ell}$ (ℓ = 1, 2, ...q). The probability $p_{i\ell}$ of occurence of $E_{i\ell}$ (given $d_i^{\,1}$) can be calculated from $\{p_{ijk}\}$. Then we can compute $r_{i\ell}$, the robustness of decision d_i in environment $E_{i\ell}$, by

$$r_{i\ell} = \frac{n\left\{\hat{\underset{\sim}{S}}_i \quad (E_{i\ell})\right\}}{n\left\{\hat{\underset{\sim}{S}} \quad (E_{i\ell})\right\}} \tag{11}$$

The values $(r_{i\ell})$, ℓ = 1, 2, ..., q, can then form the basis of an interdependent probabilistic robustness score:

$$r_i^{1\ell} = \sum_{\ell=1}^{q} p_{i\ell}\, r_{i\ell} \tag{12}$$

Such a probabilistic approach to uncertainty could also be applied to interdependent robustness and this requires only adept manipulation of subscripts and superscripts.

VII. ROBUSTNESS UNDER COMPLETE UNCERTAINTY

As is well known, however, in reality, the policy makers in a developing country neither operate in an environment of complete certainty nor do they ever possess a complete ordering of the probabilities of occurrence of a set of alternative outcomes. In the case of complete uncertainty where there are no known probabilities p_{ijk}, and therefore no derived probabilities p_i, robustness analysis must be further developed to reflect the correspondingly modified approach to decision making. In this new environment one would still recommend adopting that strategy yielding the highest interdependent robustness score.

This is the equivalent to maximizing the net robustness to the industrial policy maker in the developing countries and corresponds to the strategy of Maximin in game theory. In the case of complete uncertainty this could be expressed as

$$r_i^1 = r_i - \sum_{j=2}^{m} \underset{k=1}{\overset{n_j}{<}} \quad r_{k_{ij}}^1 \tag{13}$$

A realistic approximation may well be one in which not only does the decision maker have no knowledge of the probability of occurrence of the response set $r^{1}_{k_{ij}}$ - i.e., of how other countries will respond to changes in the industrial structure in developing country 1 - but not even know the set of alternative values. In this case, the equation for interdependent robustness under total uncertainty would reduce to the equation for simple robustness. But one would suggest that while the decision maker will generally not possess a complete ordering of alternatives with individually differentiated probabilities, they will also generally not consider every outcome equally probable.

The appropriate robustness maximand under uncertainty, as in a probabilistic framework would then be,

$$r_i^{1\ell} = \sum_{\ell=1}^{q} p_{i\ell}\, r_{i\ell} \qquad (14)$$

But in interdependent robustness under uncertainty, $p_{i\ell}$ would equal 1/n for all those strategies the probability of occurrence of which is completely unknown, and $p_{i\ell}$ would be greater or less than 1/n for those strategies the decision maker considers at least somewhat more likely (> 1/n) or less likely (< 1/n) to occur than those the probability of occurrence of which is totally unknown. In the case of total uncertainty this approach to decision making reduces to

$$r_i^{1} = \frac{n\left\{\hat{\underset{\sim}{S}}_i \quad (E_i)\right\}}{n\left\{\hat{\underset{\sim}{S}} \quad (E_i)\right\}} \;; \qquad (15)$$

and in the case where the decision makers felt each strategy at least minimally differentiated from every other strategy this approach reduces to:

$$r_i^{1\ell} = \sum_{\ell=1}^{q} p_{i\ell}\; r_{i\ell} \qquad (16)$$

Therefore, the probabilistic robustness maximand $r_i^{1\ell}$ applies not only to the w known future outcomes, but it also offers an approach to the handling of unforeseen contingencies without the necessity of trying to specify $r^{?}$. By attempting to maximize robustness after investigating the effects of decision d_i in the λ environments, the policy makers will have operated a strategy which will leave it with the highest possible freedom of action. In keeping its options regarding the long-term industrial structure open for as long as possible, the policy makers should be optimally located to carry out a policy of industrial restructuring in the face of unforseen events.

VIII. AN APPLICATION OF ROBUSTNESS ANALYSIS FOR THE PLANNING OF THE PROCESS OF INDUSTRIAL RESTRUCTURING IN DEVELOPING COUNTRIES

Having developed the technology of robustness at some length, it is now appropriate to demonstrate how the quantification of flexibility can serve as a useful decision-making tool for the developing countries in carrying out a national programme of industrial restructuring that is designed in full awareness of the uncertainty factor in long-term industrial planning and that is also designed in harmony with the world-wide process of international industrial restructuring.

The starting point of the analysis is the recognition of the crucial importance of technology as a pillar of economic and social development in the developing countries over the current and coming decade and of the role that technology and the new technology industries will play in the attempts by the developing countries to accelerate their development and to attain the industrialization objectives contained in the International Development Strategy for the Third Development Decade and the Lima target. The key to the full participation of the developing countries in the technological revolution as well as to the attainment of the technological transformation of the developing countries is the strengthening of their own technological capacity and the designing of a planned and co-ordinated programme of fostering the development of the new technology industries as an integral part of the long-term industrialization of the developing countries.

At the micro level this means drawing up alternative sets of plans, with alternative sets of development strategies for the establishment over, say, the next ten years of selected sub-branches of industries such as the micro-electronics or bio-engineering industries. Each alternative development strategy implies a different picture of the industrial structure that will exist in 1990, and therefore has markedly different implications for the programme of industrial restructuring that must be undertaken over the decade in the country.

Let us therefore assume that a given developing country, having assessed the human and physical capital resources and economic and social infrastructure that it can expect to be available over the period 1986-1995, and having acting on the most accurate forecasts available to it of the nature of the technology to which it will have access over the decade, elaborates a series of alternative industrial structures for the period. Each of the industrialization scenarios is planned to generate the same increment to GNP per capita over the period and differ only in their estimated total cost to the economy. For the sake of clarity in the example, it will be assumed that the existing intellectual capacity of the planning bureau in the country in question is such as to limit the number of alternative programmes for industrial restructuring to nine, with each of these involving the development of five industries (denoted by A to R).

We may now apply robustness analysis to this programme of industrial restructuring. Table 1 contains the set $\hat{\underset{\sim}{S}}$ of good solutions, so that $n(\hat{\underset{\sim}{S}}) = 9$. A traditional initial decision could well be that the programme of industrialization should contain sector A, as this sector figures in the lowest cost industrial structure. This is industrial strategy 1 on Table 1, with an estimated total cost of $780 million. If the initial decision is made for a strategy that includes sector A, however, only two of the nine possible alternative programmes of industrial restructuring (numbers one and nine) will be attainable over the plan period.

This means $n(\hat{\underset{\sim}{S}}_A) = 2$, and the robustness of strategies containing sector A is $r_A = 2/9 = 0.22$. The robustness resulting from taking each of the alternative industrial sectors as the first decision in a restructuring programme can be calculated similarly and is presented on Table 2, from which it can be seen that sector G has a robustness of 0.78 and on this criterion would clearly be the appropriate initial decision.

Robustness analysis then suggests that the apparent lowest cost structure from Table 1 would not be the best, when one took into account the possibility of disturbances entering into the long-term decision making and planning sequence. These could arise from unanticipated changes in technology, unexpected developments in the world economic environment in which the developing country must trade (and seek finance, and compete), unforseen changes in the industrial structure of other economies with which the given country has close economic relations, or changes in economic or political priorities in the national economy. The use of a robustness criterion instead of a traditional cost minimization criterion would therefore allow for and incorporate this uncertainity into the decision making process.

Table 1. Estimated Total Cost of the Programme of Industrial Restructuring*

Industrial Strategy	Elements of the New Industrial Structure	Estimated Total Cost (mil.$)
1	A B D F J	780
2	B E F G K	800
3	B C D E G	830
4	G J M N P	900
5	H L M P R	1200
6	E G H N R	1290
7	D G J K L	1380
8	B E G J M	1500
9	A B C E G	1550

* Note: The order of the elements of the new industrial structure within a given industrial strategy is not important.

Table 2. Robustness of Alternative Initial Decisions in Programmes of Industrial Restructuring

Industrial Branch	Frequency of Occurrance	Robustness
G	7	0.78
E	5	0.56
B	5	0.56
J	4	0.44
D	3	0.33
M	3	0.33
A	2	0.22
C	2	0.22
F	2	0.22
H	2	0.22
J	2	0.22
L	2	0.22
N	2	0.22
P	2	0.22
R	2	0.22

IX. CONCLUSION

This paper has re-examined the preference function of industrial planners in developing countries under the condition of uncertainty where the decision maker faces a problem of choice given the indeterminate nature of any conventional maximal solution. Traditional approaches must be supplemented by a long-run preference function which incorporates maximal flexibility for future decisions as an objective. Such an objective will orientate decision makers towards the necessity of keeping open as many options on industrial restructuring as possible as they make decisions against a moving planning-horizon.

This paper hypothesises that when faced with uncertainty, the optimum decision time-path for a developing country's industrial policy makers is one of maximizing robustness: that degree of flexibility with regard to future decisions on industrial structure which remains after a given initial decision has been made. Such a maximand emphasises the long-term nature of the industrial planning process and the continuous, sequential process of decision making on industrial restructuring.

Robustness has been presented as a long-term objective for the plans for industrialization in the developing countries under the conditions of certainty, within a probabilistic framework, and under total uncertainty. In all three approaches, the analysis presented a quantifiable function for simple robustness, where there was no environmental response to the initial decisions. This was then modified by incorporating the effect of reaction by policy makers in other developing and developed countries, giving the interdependent estimator of robustness.

Thus, robustness appears to be a purposeful maximand for decision making under uncertainty. It forms an operational objective which is consistent with industrial plans containing a disjoint set of targets. And it orients economic decision making in developing countries towards the need to keep options open so as not to foreclose desireable opportunities which were not foreseen and which may arise over the long-term process of industrial restructuring required for accelerated industrialization.