

CAHIER DU LAMSADE

Laboratoire d'Analyse et Maîtrise des Systèmes pour l'Aide à la Décision

(Université Paris IX Dauphine)

Equipe de Recherche Associée au C.N.R.S. N° 656

An approach to solving multiple criteria
macroeconomic policy problems and an application

N° 12-1978

H. WALLENIOUS*
J. WALLENIOUS**
P. VARTIA***
janvier 1978



48E1206

- * University of Helsinki, Consultant to the Confederation of Finnish Industries.
- * Consultant to the Confederation of Finnish Industries.
- * Research Institute of the Finnish Economy.

The authors wish to express their thanks to the Confederation of Finnish Industries for the extensive support provided during the study.

1540952

RESUME

Dans ce cahier, les auteurs présentent une approche multicritère et interactive pour résoudre des problèmes de politique économique utilisant des modèles économétriques.

A l'opposé des méthodes classiques d'optimisation, il n'est pas nécessaire d'obtenir de la part du décideur, une fonction de préférence explicite.

La première partie de l'étude relate une expérience d'utilisation de cette approche avec trois décideurs de haut niveau. La méthode utilisée était celle de GEOFFRION et les réactions furent favorables, l'un d'entre eux souhaita même une poursuite de l'expérience à la Confédération des Industries Finlandaises. En raison de quelques difficultés rencontrées par les décideurs las de l'utilisation de la procédure de GEOFFRION, c'est la méthode de ZIONTS et WALLENIOUS qui fut utilisée en version time-sharing sur UNIVAC 1108. Le modèle tourne ainsi depuis un an et a permis la simulation des conséquences de certaines décisions gouvernementales majeures.

SUMMARY

In this paper we propose an interactive multiple criteria optimization approach to solve problems associated with macroeconomic policy. In contrast with classical optimization methods no explicit knowledge of the decision-maker's preference function in terms of the objectives is required. The first part of the study consists of an experiment to test the applicability of the approach to economic policy. Three high-level knowledgeable decision-makers participated in it and used the GEOFFRION multiple criteria method to solve the problem. The reactions of the decision-makers were favorable and one of them expressed his willingness to continue the implementation work at the Confederation of Finnish Industries. Because the decision-makers experienced some difficulty in using the GEOFFRION procedure, the ZIONTS and WALLENIOUS method was implemented for the UNIVAC 1108 time-sharing system as well. The system has now been used for one year for optimizing economic policy and simulating the impact of certain major governmental decisions.

PLAN

1 - INTRODUCTION	p. 1
2 - AN INTERACTIVE MULTICRITERION OPTIMIZATION APPROACH TO MACROECONOMIC POLICY FORMULATION	p. 3
3 - PROBLEM REPRESENTATION	p. 6
4 - AN APPLICATION	p. 8
4. 1. Description of the economic situation	p. 9
4. 2. An experiment	p. 11
4. 3. Application at the confederation of finnish industries	p. 15
USE OF THE MODEL FOR OPTIMIZATION PURPOSES	p. 17
USE OF THE MODEL FOR SIMULATION PURPOSES	p. 20
5 - CONCLUSION	p. 23
APPENDIX : A MODEL OF THE FINNISH ECONOMY	p. 24
REFERENCES	p. 31

AN APPROACH TO SOLVING MULTIPLE CRITERIA MACROECONOMIC POLICY PROBLEMS AND AN APPLICATION

In this paper we propose an approach to solving multiple criteria macroeconomic policy problems and report on an application using an existing econometric model.

1. Introduction

During the past few decades efforts have been made to develop econometric models for analyzing macroeconomic policy problems in several countries. Typical policy problems are, for instance, whether and by how much different categories of taxes and other income transfers should be increased or decreased, what kind of exchange rate policies should be followed, etc. The value of a simultaneous equation econometric model lies in the fact that it helps to account for the complex interrelationships existing among different variables and sectors of the economy. Once such a model has been constructed, a computer simulation approach can be used for generating and comparing different policies and for choosing a policy considered to be the best among the alternatives. This approach does not require an explicit preference function of the decision-maker, but his preferences are implicitly present in the selection of the alternative policies on the basis of the values of the target variables. Computer simulation is, however, an inefficient method of finding

the best policy decisions and optimization models have been proposed as an alternative for solving these problems. In the optimization approach a preference function is optimized subject to a set of constraints which represent economic interrelationships among the variables and describe the possible values of the instrument variables (=decision variables, parameter variables, parameters). The purpose of the optimization process is thus to select the best solution (in terms of an overall preference function) from the set of feasible solutions in an efficient way.

Recent advances in multiple criteria optimization have made it possible not to require explicit knowledge of the decision-maker's preference function in terms of the objectives prior to solving the problem. Instead, as we shall demonstrate in this paper, the decision-maker's preferences can be identified by a procedure which simultaneously leads to choosing an "optimal" solution. The practical value of an optimization procedure depends, of course, on the ability of the underlying model to describe the phenomena under study, i.e., the word optimum refers to the mathematical "play process" and not necessarily to the "real process". In order to have a realistic formulation of a macroeconomic policy problem we have in the following resorted to an existing econometric model developed by one of us. A further version of this model is presently used by the Research Institute of the Finnish Economy for analyzing and forecasting short-term fluctuations in the Finnish economy. A linear version of this model was modified

into a linear optimization model involving multiple objectives by allowing certain instrument variables to vary within a feasible range each. The optimization model was used for solving an actual decision problem of the Finnish economy and subsequently implemented at the Confederation of Finnish Industries.

The paper consists of five sections. In §1 we have outlined the problem. In §2 we describe some previous research on the problem and propose an approach to solving multiple criteria macroeconomic policy problems. In §3 we describe the problem representation and the underlying econometric model. In §4 we discuss an application of the optimization approach in practice. Conclusions of the paper are presented in §5. A description of the model employed is given in an appendix.

2. An Iterative Multicriterion Optimization Approach to Macroeconomic Policy Formulation

Let us assume that we have a linear macroeconomic model with estimated deterministic equations of the structural form

$$y = \hat{A}y + \hat{B}x,$$

where y is an n -vector of endogenous variables including the target variables, and x is an m -vector of predetermined (=lagged endogenous and exogenous) variables. The corresponding reduced form is given by

$$y = (I - \hat{A})^{-1} \hat{B}x = \hat{\pi}x.$$

Usually the exogenous variables also include a number of instrument variables which may take values from given intervals $[x_i^a, x_i^b]$, $x_i^a < x_i^b$. For the other predetermined variables $x_i^a = x_i^b$; that is, their values are fixed and the interval is reduced to a point. If the decision-maker had an explicit preference function $U(y): R^n \rightarrow R$ defined on the values of the endogenous variables (the values of some y_i 's may, of course, have no effect on the value of U , i.e., he need not be directly interested in all endogenous variables) we would have a standard optimization problem

$$\begin{aligned} (A) \quad & \text{Maximize } U(y) = U(\hat{\pi}x) \\ & \text{subject to } x \in X = [x_1^a, x_1^b] \times \dots \times [x_m^a, x_m^b]. \end{aligned}$$

Assuming that U fulfilled certain regularity conditions the problem could be solved by standard optimization methods. However, difficulties arise because the preference function is known seldom, if ever. In fact, even the existence of the preference function, and at least its time invariance, can be discussed.

Many previous approaches to optimizing macroeconomic policy problems exist. They include the classical studies of Tinbergen (20,21), Theil (19) and Van den Bogaard and Theil (22) as well as applications of linear programming and its

variations by Eckaus and Parik (3), Kornai (12), MacEwan (15), Roskamp (17), Spivey and Tamura (18), Van Eijk and Sandee (23), Zeleny and Cochrane (30), among others. An interview approach to identifying a decision-maker's preference function has been developed by Frisch (7,8). For some related research see Johansen (10,11). The use of optimal control theory has been proposed by Chow (1), Pindyck (16) and Livesey (13,14). An extensive survey of the theory of quantitative economic policy is provided by Fox, Sengupta and Thorbecke (6). Until recently, however, relatively little has been done in trying to use such methods in practice.

The approaches discussed above can all be criticized on the score of the assumption that the decision-maker is able to construct an overall preference function carried over the time period for which he is planning. Recent research in multiple criteria decision-making suggests that this assumption can be relaxed by using iterative procedures if the decision-maker is able to provide certain local information about his preferences at each cycle.

Such approaches have been developed, among others, by Geoffrion, Dyer and Feinberg (9) and Zionts and Wallenius (31). Using either of the approaches a sequence of target vectors $y, \{y^1, y^2, \dots, y^N\}$, is generated, which the decision-maker can influence in accordance with his preferences, such that for all $k \in \{1, \dots, N\}$: $y^k = \hat{\pi} x^k$, $x^k \in X = [x_1^a, x_1^b] \times \dots \times [x_m^a, x_m^b]$. The process is terminated for some N , when the decision-maker

does not want to change y any more. Such y^N is called the optimal target vector, $y^N = \hat{y}$, and it satisfies $\forall k: 1 \leq k \leq N: \hat{y} \succ y^k$; that is, y is preferred to alternative solutions. If certain assumptions concerning the stability and form of the decision-maker's preference function U are made, it can further be shown that this procedure leads to an optimal solution of the maximization problem (A). For this to be true the preference function need not be a linear function of the instrument variables. It suffices that the relationship is concave. As such formulation (A) is, of course, more general than the linear programming formulation, which assumes that we can estimate (e.g. by employing fictitious questions) the decision-maker's preference function and that it is linear. (A) is also more general than the approach proposed by Spivey and Tamura (18) or Theil (19).

3. Problem Representation

In this section we provide a brief description of the problem. A summary of the model currently employed is given in an appendix to this paper and more detailed information may be found in Vartia (24). The model is constructed using the Dutch short-term annual model as a starting point and adapted to the circumstances prevailing in Finland (see e.g. Verdoorn, Post and Goslinga (26)). As usual with short-term models, the emphasis is on the demand side and no explicit production function is included in the model. The model is based on

annual percentage changes and consists of 13 behavioral equations for the volumes and prices of the main expenditure categories, for imports, labor input, unemployment and the wage rate. In addition, the model has a number of equations defining other endogenous variables. The exogenous variables of the model include usual policy variables, such as incidence of indirect taxes, income transfers, public expenditure and changes in the exchange rate, which were taken as instrument variables for the problem. Neither monetary policy instruments nor an endogenous block for the public sector have been incorporated in the model. The model has been estimated using data for the years 1951-1970.

The econometric simulation model was expanded to an annual optimization model involving multiple objectives by taking some of the endogenous variables as target variables and by allowing certain instrument variables to vary within feasible bounds. For target variables we selected four traditional aggregate variables relating to the internal and external equilibrium of the economy: the percentage change in gross domestic product, unemployment, the rate of inflation (measured by consumer prices) and the balance of trade¹⁾. Values for the lagged endogenous and fixed exogenous variables were obtained from the latest "Economic Prospects in Finland", ETLA (4), and they were kept up-to-date to reflect the situation in the Finnish economy each time the model was used. In the earlier experiments bounds for the instrument variables were determined by us. When the optimization model was used on a more permanent basis, it

was natural to let the decision-maker himself determine the bounds defining the set of feasible solutions.

A linear version of the model presented in (24) was used in the application. Nonlinear models have often to be linearized, because linear systems allow of much easier estimation and solution techniques. However, in our case little was lost by linearizing the model, since the difference between the two versions concerns only a number of definitional equations which in the original version incorporate certain cross products.² We also emphasize that, although our model is linear in percentage changes of variables, it is, obviously, nonlinear in terms of the absolute values of the variables. Different versions of the model have been used at the Research Institute of the Finnish Economy for a period of three years for forecasting and analyzing economic fluctuations, and the results have been found useful. For additional tests of the accuracy of the model we refer to (24).

4. An Application

We performed a first test of our multiple criteria approach to solving an actual decision problem of the Finnish economy in February 1976. The experiment was successful and one of the decision-makers participating in it expressed his willingness to continue the implementation work at the Confederation of

Finnish Industries to install the optimization model as a more permanent decision-making tool. For that purpose a one-year project was initiated in the fall of 1976. In this section we describe the results of the experiment as well as our experience of using the optimization model at the Confederation of Finnish Industries.

4.1. Description of the Economic Situation

We initially provide a brief description of the economic situation in Finland at the time of our study. Finland was one of the few market economies where production did not decline during the recent deep international recession (the volume of GDP at market prices rose by 4.7 % in 1974 and by 0.1 % in 1975) and where the employment situation remained fairly good until the end of 1975 (the unemployment rate averaged 1.7 % in 1974 and 2.2 % in 1975). This was due to the strong investment activity which was to a large extent financed with foreign capital. As a consequence the country's foreign indebtedness grew quickly and rose to about a fifth of the annual gross domestic product by the end of 1975. Simultaneously the sharp rise in commodity prices had amounted to an inflationary impulse, which continued as a strong internal wage-price spiral. The rate of inflation as measured by consumer prices was 18 % in 1974 and 17.4 % in 1975, year-on-year.

At the beginning of 1976 the continuing growth of foreign indebtedness was generally regarded as Finland's most difficult problem. To achieve the central goal of external equilibrium, it was considered advisable to strongly reduce the rate of inflation and thus ensure competitiveness in foreign trade - even at the cost of lower production and higher unemployment. Since the controlling of inflation was also necessary in itself, not many were in favor of improving price competitiveness by altering the international value of the Finnish currency in 1976, as this would have affected the rate of inflation unfavorably.

The measures to control inflation and decrease the trade deficit were moderately successful during 1976. However, the inflation rate was still above ten per cent and the trade deficit more than four billion Fmk. Simultaneously, the employment situation worsened and the unemployment rate averaged 4.1 % in 1976 and despite of a cautious optimism at the beginning of 1977 continued to increase becoming the most pressing problem of the Finnish economy. To attempt to improve competitiveness in foreign trade the Finnish currency was devalued in the spring 1977 and a program to stimulate the economy was announced in the summer. See also section 4.3.

A linearized version of the model presented in Vartia (24) was modified in the manner described above, so as to obtain an optimization model, and this together with the Geoffrion method assuming a monotonic preference function and a linear constraint set was implemented for the UNIVAC 1108 time-sharing system at the Helsinki School of Economics.³ Some parameter values of the model were also changed so as to better reflect the current economic situation.⁴

Three high-level knowledgeable decision-makers participated in the experiment. They were 1) the Chief of the Bank Inspectorate, an ex-Cabinet Member, 2) the Deputy Managing Director of the Confederation of Finnish Industries and 3) a Director of the Bank of Finland. The purpose was to evaluate the applicability of our approach to macroeconomic policy formulation. Each of the decision-makers was familiar with the general characteristics and scope of the econometric model upon which the study is based. We discussed various aspects and explained the major features of our approach and the use of the method. After the starting solution the decision-maker was expected to provide two kinds of information at each cycle concerning his preferences: 1) An estimate of his marginal rates of substitution between the objectives determining the "best" direction of search. 2) Resolution of a step-size problem determining how much of a change to make. For a more complete treatment of the method the reader is referred to Geoffrion, Dyer and Feinberg (9).

In an earlier work one of us had discovered that the Geoffrion, Dyer and Feinberg (9) method was relatively difficult to use (see Wallenius 27)). This was why we decided to assist the decision-makers in several ways. A variant of the original method designed to help the decision-makers to estimate their marginal rates of substitution described in Dyer (2) was implemented. We also presented the decision-makers with a number of examples computed using different responses generated by us.

A summary of the results of the test is given in Table 1. For some additional details see (29). We note that two of the decision-makers wanted the gross domestic product to grow from the preceding year, but the third was content with a decrease in its value, since this made a considerable reduction in trade deficit possible. The resulting unemployment rates represent in each case increases on the previous year's figure. The rates of inflation chosen by the three persons were close to each other and not far from the absolute minimum inflation achievable. The "optimal" balance of trade deficits varied considerably among the three persons but promised in each case an improvement on the preceding year's Fmk 7.75 billion.

Table 1: Summary of the Results of the Iterative Decision-Making Procedure for 1976

Cycle	Criteria ¹⁾			
	GDP increase, %	Inflation, %	Unemployment Rate, %	Trade Deficit Billions Fmk.
	(7.18)	(8.16)	(1.88)	(1.21)
First Decision-Maker				
1	-2.74	8.16	3.28	2.24
2	0.57	9.00	2.81	5.27
3	1.81	8.88	2.64	6.54
Second Decision-Maker				
1	-2.74	8.16	3.28	2.24
2	-0.37	8.27	2.95	4.55
3	0.17	8.29	2.88	5.08
Third Decision-Maker				
1	2.00	10.00	2.50	6.50
2	-1.39	8.69	3.06	3.46
3	-1.39	8.69	3.06	3.46

1) "Utopian" solutions obtained with one-at-a-time optimization are given in parentheses under each criterion.

Some Reactions of the Decision-Makers

The decision-makers considered the results yielded by the model and the relationships among the objectives realistic at the time the tests were performed, with the possible exception that the unemployment rate and the rate of inflation, were, in their opinion, somewhat low when fixed values were given for the other objectives. This can at least in part be explained by the fact that the model was not used for forecasting but for optimization purposes, and the feasible

region of the decision variables may not have corresponded exactly to the one thus considered relevant in the current economic situation. The decision-makers seemed to appreciate the interactive processing mode providing rapid feedback and were satisfied with the way the Geoffrion method worked, with the exception that the estimation of the marginal rates of substitution among the objectives (despite the assistance provided) was not considered simple enough.

The advantages of the optimization framework were considered to be the following:

1. The model would provide information about the relationships between the objectives and between the objectives and policy instruments.
2. The decision-makers would better learn their preferences in terms of the objectives.
3. The optimization framework would indicate which are feasible and which are infeasible targets for economic policy.

Also, the possibility of using this kind of "policy formulation game" as a pedagogic instrument for different groups of decision-makers was considered a fruitful application.

4.3. Application at the Confederation of Finnish Industries⁵

Our intention was to implement the optimization model as a more permanent decision-making tool at the Confederation of Finnish Industries. The Confederation of Finnish Industries does not have the authority to implement the results but as an interest group of various industries it can influence the economic policy pursued. Our involvement in the project terminated by writing a detailed user's manual (28) and by teaching some persons at the Confederation of Finnish Industries to use and update the system, so that its future use is no longer necessarily dependent on us. Prior to the application some of the equations had been reestimated and the model extended with an additional behavioral equation. In addition, net income transfers were disaggregated into a number of components, public expenditure was decomposed into public consumption and investment and total investment into private and public sector investment. The values of the predetermined variables were updated in the fall of 1976 and in the spring of 1977 in accordance with the latest "Economic Prospects in Finland", ETLA (4). In its present form the periodic updating of the model involves some labor, but it could easily be automatized so that the computer would do most of the routine work.

In the initial stages of the project we used the Geoffrion, Dyer and Feinberg method (9), but because the decision-makers experienced some difficulty in using it we subsequently

switched to the method developed by Zionts and Wallenius (31). Both methods are fully interactive and the system allows the user to execute programs in a conversational manner. In the Zionts and Wallenius method the decision-maker is only requested to provide answers to yes and no questions regarding certain tradeoffs that he likes or dislikes. His answers are used to construct sets of consistent weights for the objectives and to find the associated Pareto-optimal solutions. If such solutions are not appealing, the method generates efficient neighboring solutions and poses them to the decision-maker for his evaluation.⁶ The procedure is terminated when a reasonably good solution has been found. Two versions of the method were programmed: one assuming linear preferences and another assuming concave preferences in terms of the objectives.⁷ Because there was no reason to believe that the decision-makers' preferences would be linear the more general version was used most of the time. No test of concavity of the preference function was made. It is, however, a common assumption in economic theory and seemed reasonable in our context as well. For further details the reader is referred to (31).

The model naturally generates economic forecasts when fixed values are given for all exogenous variables and various test runs are performed to assure the user of the realism of the results. The model has also been used for investigating the impact of certain major governmental policy decisions in 1977 with given fixed instrument variables. When the model is used for optimization purposes, it is important that the specification of the bounds of the instrument variables by

the decision-maker corresponds to the relevant region in the current economic situation. In practice a reasonable approach seems to be to start with loose bounds and, as new information becomes available, modify the feasible space accordingly. Furthermore, different aspects of the system such as the problem representation and the important characteristics of the method were discussed in small groups before the optimization procedure was used in practice.

Use of the Model for Optimization Purposes

The Geoffrion, Dyer and Feinberg method (9) was used in the testing phases by us and later by one of the directors of the Confederation of Finnish Industries. Since the results were similar to those reported earlier in this paper, we only describe the experiences gained in using the Zionts and Wallenius procedure (31). The Zionts and Wallenius procedure was used individually by half a dozen persons including a director and a number of economists of the Confederation of Finnish Industries. The idea was that by using the model the persons involved should learn something about the interconnections of the objectives and the instruments and about their preferences in terms of the objectives. Although the work is still in process, it seems that we have made progress and that the decision-makers did learn something by using the system and analyzing the results.

Representing a first application of the general version of the Zionts and Wallenius optimization procedure, the tests provide us with some useful information about its performance. The procedure seemed generally to function well, its ease of use was appreciated and it was not sensitive to inconsistent responses by the decision-maker. On average, approximately four question sessions and ten responses were required for finding the neighborhood containing the optimal solution. The cost of a run was of the order of US \$25. As the decision-maker's preferences were nonlinear in general, the method found a solution within some neighborhood of an optimum. In the tests it sometimes happened that some of the solutions neighboring to the optimal solution were relatively far from each other and it was thus necessary to use further optimization to find the optimal solution. It seemed sufficient to perform this further optimization by visualizing the neighborhood in which the true optimum was located and letting the decision-maker select the most preferred solution from this neighborhood. No sophisticated search methods were used but, if desired, could relatively easily be incorporated. An example of the use of the Zionts and Wallenius optimization procedure, performed in early 1977, will now be presented.

An initial solution was determined by using arbitrary weights for the objectives. The result, provided in terms of the objectives and the instrument variables, is presented in Table 2. In addition, the user was provided with a complete

Criteria:	Solution 1	Proposed Tradeoff 1	Solution 2	Proposed Tradeoff 2	Proposed Tradeoff 3	Proposed Tradeoff 4	Solution 3
GDP, %	2.73	.2005	.0728	.2053	.2501	-.3139	3.90
INFLATION, %	10.24	.1925	-.2202	.1925	.0031	.0242	9.18
UNEMPLOYMENT, %	4.75	-.0333	-.0109	-.0333	-.0394	.0486	4.57
TRADE DEFICIT, Billions Fmk	1.46	.1013	.0388	.1013	.2634	-.3130	2.48
Decision-Maker's response:		"NO"	"YES"	"PREFERRED"	"NO"	"DON'T KNOW"	"NO"
Instruments:		U T N I O T I N D E V A L U A -	U I N N I D I T I R D E C T R E A X E S		U T N I O T I N D E V A L U A -	U P I U N U R I B L E I C N C R X P A E S N E I -	U D N I R T E C T I N C T R A E S S E I N
PUBLIC CONSUMPTION, %	2.0			2.0			2.0
PUBLIC INVESTMENTS, %	2.0			2.0			2.0
PUBLIC EXPENDITURE, %	2.0			2.0			2.0
INDIRECT TAXES, %	11.0			6.5			6.5
DIRECT TAXES of households, %	3.5			2.0			2.0
OTHER INCOME TRANSFERS to the public sector, %	0.2			0			0
INCOME TRANSFERS to households, %	1.5			2.5			2.5
DEVALUATION, %	0			0			0
							"NOT PRE-FERRED"
							"PRE"

list of the values of the other variables and, if desired, the associated aggregate balance of resources and expenditure at each iteration. The next step requires the decision-maker to respond to certain efficient tradeoff questions concerning feasible changes in the values of the objectives. More specifically, the decision-maker was asked whether he was willing to accept an increase in GDP of .2005 %, an increase in inflation of .1925 %, a decrease in unemployment of .0333 %, and an increase in trade deficit of Fmk .1013 billion corresponding to a unit devaluation of the currency. The response was negative. The second question corresponding to a unit decrease in indirect taxes involved an increase in GDP of .0728 %, a decrease in inflation of .2202 %, a decrease in unemployment of .0109 %, and an increase in trade deficit of Fmk .0388 billion. The trade was found attractive. A solution consistent with these two responses was generated and posed to the decision-maker for his evaluation. (See Table 2). The solution essentially promised an increase in GDP and decreases in inflation and unemployment at the expense of an increase in trade deficit and implied decreases in indirect and direct taxation and other income transfers to the public sector. The general version of the Zionts and Wallenius procedure requires a strict utility increase at each iteration and thus the decision-maker was asked to compare the first and the second solution. The latter solution was found more appealing and the process was continued from there. Three questions as described in Table 2 were posed to the decision-maker, but none of them was liked. However, some doubt was expressed about the fourth

question and the decision-maker was advised to respond "I don't know." Obviously, the solution consistent with the three most recent responses remained unaltered. In such a case we generate neighboring solutions to the previous solution corresponding to yes and I don't know responses. This time there was only one such solution providing a slight improvement in GDP at the expense of a corresponding increase in trade deficit (solution 4), which meant an increase in public expenditure. The new solution was not only preferred to the previous solution, but it was also considered satisfactory by the decision-maker. After evaluating the neighboring solutions the process was terminated by printing the associated aggregate balance of resources and expenditure. By comparing the optimal solution with the starting solution we can see that by increasing public investment and income transfers to households and decreasing indirect and direct taxes of households GDP can be increased and the inflation and the unemployment rates decreased at the expense of an increment of a billion Fmk in trade deficit. No devaluation would be required.

Use of the Model for Simulation Purposes

The model can flexibly be used for simulating the impact of major economic policy decisions by giving fixed values for the instrument variables . Thus e.g. when the Finnish

currency was devalued in April 1977 by 5.7 %, the impact was simulated using the model for the year 1977. Simultaneously it was investigated which effects a larger devaluation would have had. In the following we report in more detail on the results of a simulation run performed after the Government had announced in June 1977 a program for the stimulation of the growth of the economy. These results were used as one source of information in evaluating the effectiveness of the proposed measures.

The program consisted of the following measures, among others, to be implemented in the fall:

- 1) The turnover tax and some other indirect taxes will be reduced by Fmk 240 million.
- 2) Exports will be subsidized by Fmk 20 million.
- 3) Income transfers from the public sector to households will be increased by Fmk 28 million.
- 4) Employers' contributions to social security will be reduced by Fmk 138 million.
- 5) Funding of industrial investments will be increased by Fmk 350 million.
- 6) Governmental share of the capital stock of certain public companies will be increased by Fmk 30 million.

From Table 3 we see that the main effects were those on investment, imports and private consumption. GDP was estimated to grow by about 0.5 %, but the trade deficit

would at the same time increase by Fmk 500 million. The program does not seem to have any major impact on the employment situation, nor does it increase exports much.

Table 3: Changes in the Aggregate Balance of Resources and Expenditure Due to the Governmental Program to Stimulate the Economy

	Annual Change (percentage)			Absolute Changes
	Vol.	Price	Value	Billions Fmk.
GDP (mp)	0.9	0.8	1.7	1.9
IMPORTS	0.7	4.5	5.2	1.6
TOTAL RESOURCES	0.9	1.6	2.5	3.5
EXPORTS	0.3	4.1	4.4	1.3
INVESTMENTS	0.8	1.2	3.0	0.6
- private	0.9	1.4	3.3	0.6
- public	0	0.3	0.3	0
CONSUMPTION	0.8	1.0	1.7	1.3
- private	0.9	0.9	1.9	1.1
- public	0	0.8	0.8	0.2
INVENTORY CHANGES			0.3	0.3
TOTAL DEMAND	0.9	1.6	2.5	3.5
TRADE DEFICIT				0.5
UNEMPLOYMENT (%)				-0.2

would at the same time increase by Fmk 500 million. The program does not seem to have any major impact on the employment situation, nor does it increase exports much.

Table 3: Changes in the Aggregate Balance of Resources and Expenditure Due to the Governmental Program to Stimulate the Economy

	Annual Change (percentage)			Absolute Changes
	Vol.	Price	Value	Billions Fmk.
GDP (mp)	0.9	0.8	1.7	1.9
IMPORTS	0.7	4.5	5.2	1.6
TOTAL RESOURCES	0.9	1.6	2.5	3.5
EXPORTS	0.3	4.1	4.4	1.3
INVESTMENTS	0.8	1.2	3.0	0.6
- private	0.9	1.4	3.3	0.6
- public	0	0.3	0.3	0
CONSUMPTION	0.8	1.0	1.7	1.3
- private	0.9	0.9	1.9	1.1
- public	0	0.8	0.8	0.2
INVENTORY CHANGES			0.3	0.3
TOTAL DEMAND	0.9	1.6	2.5	3.5
TRADE DEFICIT				0.5
UNEMPLOYMENT (%)				-0.2

In this paper we have described work in process to implement an optimization model for formulating macroeconomic policy decisions in Finland. One of three experienced decision-makers who experimentally used the model to solve the problem for 1976 felt that the approach would be valuable in providing decision-makers with relevant quantitative information and was willing to continue and finance the implementation work at the Confederation of Finnish Industries. The system has now been used for one year for optimizing economic policy and simulating certain major governmental decisions. It is also expected that the system will be used in the future. It has been agreed, among other things, that a seminar will be arranged in the near future by the Confederation of Finnish Industries at which some leading Finnish decision-makers will be invited to use it.

If the system described in this paper is used for regular problem solving, it can still be further developed. E.g. the graphical mode of operation may be the way interactive systems will be used in the future. The adoption of such technology would involve changes in the computer implementation. The time horizon in the application was one year, but plans have been made to extend it because the consequences of policy formulation for one year are perceptible also in the longer run. In addition, the econometric model upon which this study is based is subject to revisions and further development.

Appendix: A Model of the Finnish Economy

In the following list of variables all exogenous variables are underlined. Unless otherwise stated, capital letters stand for value and small letters for volume. Absolute variables are denoted by the symbol ($\sim$); all other variables denote percentage changes from the previous year. Because no confusion is expected to arise, the subscript t denoting time has been dropped. Thus, for instance, C_t is abbreviated C and C_{t-1} (the lagged value) C_{-1} .

CONSUMPTION

c, C	total consumption
cpr, Cpr	private consumption
<u>cg</u> , Cg	public consumption
pc	price of total consumption
$pcpr$	price of private consumption
pcg	price of public consumption

INVESTMENTS

i, I	total investments
ipr, Ipr	private investments
ias	private investments in housing
$iasc$	other private investments
<u>ig</u> , Ig	public investments
N	inventory changes
pi	price of total investments
$pipr$	price of private investments
pig	price of public investments

FOREIGN TRADE

Imports	m, M	total imports
	mg, Mg	commodity imports
	ms, Ms	imports of services
	pm	price of total imports
	pmg	price of commodity imports
Exports	mw	weighted growth of industrial production in ten OECD countries (export demand variable)
	x, X	total exports
	xE, XE	bilateral commodity exports
	xg, Xg	commodity exports
	xgw, Xgw	multilateral commodity exports
	xs, Xs	exports of services
	px	price of total exports
	$pxcom$	price of competing exports
Others	pxg	price of commodity exports
	$\tilde{E}$	trade deficit
	S	factor income from abroad (net)

SALARIES

H	wage increases exceeding profitability
k_1	effects of employers' contribution to social security
W	total wage bill (inc. social security)
Ws	total wage bill (exc. social security)
wI	wage rate

LABOR INPUT

aII	total labor input
$\tilde{U}$	unemployment rate

INCOME VARIABLES

K	profit margin
NI	national income
<u>0</u> ₁	public sector income from property and enterprises
WZD	disposable income of households
Z ₁₀	nonlabor income

SAVING

0₄ corporate saving

TAXATION 0₃ direct corporate taxes

0₅ direct taxes of households

Ti indirect taxes minus subsidies

TiDN incidence of indirect taxes minus subsidies

INCOME TRANSFERS

0₆ other income transfers from households to the public sector

0₇ income transfers from the public sector to households

0₈ income transfers of households abroad

0₉ income transfers from abroad to households

0₁₀ net income transfers of households

OTHERS

d, D total demand

dn, DN total demand minus inventory changes

pdn price of total demand minus inventory changes

F depreciation

g, G public expenditure

pg price of public expenditure

0₂ interest on public debt

y, Y gross domestic product at market prices

yn gross domestic product minus inventories

py price index of gross domestic product
Ynfc net domestic product at factor prices

Desiderata:

1. Change in the volume of gross domestic product (y) as big as possible.
2. Inflation (pc) as small as possible.
3. Unemployment rate ($\tilde{U}$) as small as possible.
4. Trade deficit ($\tilde{E}$) as small as possible.

Behavioral equations:

Domestic expenditure:

1. $cpr = .365(WZD - pcpr) + .435(WZD - Cpr)_{-1} - 2.407\tilde{U} + 2.389$
2. $iasc = 3.111\Delta yn_{-3/4} + .527Z_{10} + .487Z_{10-1} - .573pipr - .916$
3. $N = .321\Delta dn_{-1/2} + .037\Delta pmg - .369N_{-1} + .695$

Foreign sector:

4. $xgw = 2.338mw - .520(pxg - pxcom) - .828(pxg - pxcom)_{-1} - .308(pxg - pxcom)_{-2} - 3.172$
5. $mg = 1.924dn + 3.074N + .594(py - pmg)_{-1/3} + .334\Delta dn - 3.868$

Labor input and unemployment:

6. $aII = .549y + .060y_{-1} + .049K - .881$
7. $\tilde{U} = -.287aII + \tilde{U}_{-1} + .679$

Wages and prices:

8. $wI = .562pcpr + .9(y - aII)_{-1/2} - .846\tilde{U} + .4(wI - .562pcpr + .846\tilde{U})_{-1} + .074$

10. $pcg = .757H + .060pmg + .090pcg_{-1} + 2.486$
11. $pipr = .363H + .255pmg + .155pipr_{-1} + 1.086$
12. $pig = .812H + .208pmg + .136pig_{-1} - .254$
13. $pxg = .189H + .780pxcom + .069pmg + .3(pxg - .189H - .069pmg)_{-1} - .297$

Definitional equations: +)

14. $Cpr = cpr + pcpr$
15. $Ipr = ipr + pipr$
16. $ipr = (tiasc/tipr)_{-1}iasc + (tias/tipr)_{-1}ias$
17. $G = (tCg/tG)_{-1}Cg + (tIg/tG)_{-1}Ig$
18. $Xgw = xgw + pxg$
19. $Mg = mg + pmg$
20. $D = (tCpr/tD)_{-1}Cpr + (tIpr/tD)_{-1}Ipr + (tDN/tD)_{-1}N + (tG/tD)_{-1}G + (tX/tD)_{-1}X$
21. $DN = (tCpr/tDN)_{-1}Cpr + (tIpr/tDN)_{-1}Ipr + (tG/tDN)_{-1}G + (tX/tDN)_{-1}X$
22. $dn = (tcpr/tdn)_{-1}cpr + (tipr/tdn)_{-1}ipr + (tg/tdn)_{-1}g + (tx/tdn)_{-1}x$
23. $DN = pdn + dn$
24. $H = wI - (y - aII)_{-1/2}$
25. $W = Ws + kI$
26. $K = pdn - (tWS/tDN)_{-1}wI - (tTi/tDN)_{-1}TiDN - (tM/tDN)_{-1}pm$
27. $Ws = aII + wI$
28. $WZO = (tW/tWZO)_{-1}W + (tZ_{10}/tWZO)_{-1}Z_{10} + [(tW + tZ_{10})/tWZO]_{-1}O_{10}$

+) The symbol t in the definitional equations is used to indicate the absolute value of the variable.

$$31. x_g = (t_{xgw}/t_{xg})_{-1} x_{gw} + (t_{xE}/t_{xg})_{-1} x_E$$

$$32. x = (t_{xg}/t_x)_{-1} x_g + (t_{xs}/t_x)_{-1} x_s$$

$$33. X_g = (t_{Xgw}/t_{Xg})_{-1} X_{gw} + (t_{XE}/t_{Xg})_{-1} X_E$$

$$34. X = (t_{Xg}/t_X)_{-1} X_g + (t_{Xs}/t_X)_{-1} X_s$$

$$35. X = x + p_x$$

$$36. m = (t_{mg}/t_m)_{-1} m_g + (t_{ms}/t_m)_{-1} m_s$$

$$37. M = (t_{Mg}/t_M)_{-1} M_g + (t_{Ms}/t_M)_{-1} M_s$$

$$38. y_n = (t_{dn}/t_{yn})_{-1} d_n - (t_m/t_{yn})_{-1} m$$

$$39. d = (t_{cpr}/t_d)_{-1} c_{pr} + (t_{ipr}/t_d)_{-1} i_{pr} + (t_{dn}/t_d)_{-1} N + (t_g/t_d)_{-1} g + (t_x/t_d)_{-1} x$$

$$40. y = (t_d/t_y)_{-1} d - (t_m/t_y)_{-1} m$$

$$41. Y = (t_D/t_Y)_{-1} D - (t_M/t_Y)_{-1} M$$

$$42. Y = p_y + y$$

$$43. Y_{nfc} = (t_Y/t_{Ynfc})_{-1} Y - (t_F/t_{Ynfc})_{-1} F - (t_{Ti}/t_{Ynfc})_{-1} Ti$$

$$44. NI = (t_{Ynfc}/t_{NI})_{-1} Y_{nfc} + (t_{Ynfc}/t_{NI})_{-1} S$$

$$45. Z_{10} = (t_{NI}/t_{Z_{10}})_{-1} NI - (t_W/t_{Z_{10}})_{-1} W$$

$$46. c = (t_{cpr}/t_c)_{-1} c_{pr} + (t_{cg}/t_c)_{-1} c_g$$

$$47. i = (t_{ipr}/t_i)_{-1} i_{pr} + (t_{ig}/t_i)_{-1} i_g$$

$$48. C_g = c_g + p_{cg}$$

$$49. I_g = i_g + p_{ig}$$

$$50. C = (t_{Cpr}/t_C)_{-1} C_{pr} + (t_{Cg}/t_C)_{-1} C_g$$

$$51. I = (t_{Ipr}/t_I)_{-1} I_{pr} + (t_{Ig}/t_I)_{-1} I_g$$

$$52. C = c + p_c$$

$$53. I = i + p_i$$

$$54. G = g + p_g$$

$$55. O_{10} = -O_1 + O_2 - O_3 - O_4 - O_5 - O_6 + O_7 - O_8 + O_9$$

$$56. \tilde{E} = \tilde{M}_{g-1} + \frac{M_g}{100} \tilde{M}_{g-1} - \tilde{X}_{g-1} - \frac{X_g}{100} \tilde{X}_{g-1}$$

$$57. g = (t_{cg}/t_d)_{-1} c_g + (t_{ig}/t_g)_{-1} i_g$$

In order to take into account the effect of eventual exchange rate changes on exogenous foreign trade variables the following equations were used (variables with the bar represent forecast values of the exogenous variables excluding the effect of exchange rate changes):

$$58. \text{ pm} = \overline{\text{pm}} + \text{De}$$

$$59. \text{ pxcom} = \overline{\text{pxcom}} + \text{De}$$

$$60. \text{ pmg} = \overline{\text{pmg}} + \text{De}$$

$$61. \text{ Ms} = \overline{\text{Ms}} + \text{De}$$

$$62. \text{ Xe} = \overline{\text{Xe}} + \text{De}$$

$$63. \text{ Xs} = \overline{\text{Xs}} + \text{De}$$

References

- (1) Chow, G. C., "Optimal Control of Linear Econometric Systems with Finite Time Horizon", International Economic Review, 13, February 1972.
- (2) Dyer, J. S., "A Time-Sharing Computer Program for the Solution of the Multiple Criteria Problem", Management Science, Vol. 19, No. 12 (August 1973), pp. 1379-1383.
- (3) Eckaus, R. S. and Parik, K. S., Planning for Growth, MIT Press, Massachusetts, 1968.
- (4) "Economic Prospects in Finland", Research Institute of the Finnish Economy, (ETLA), Bi-Annual Publication, Helsinki.
- (5) Economy-Wide Models and Development Planning, (eds.) C. R. Blitzer, P. B. Clark and L. Taylor, Oxford University Press, 1977.
- (6) Fox, K., Sengupta, J. and Thorbecke, E., The Theory of Quantitative Economic Policy with Applications to Economic Growth, Stabilization and Planning, 2nd ed., Amsterdam, 1973.
- (7) Frisch, R., "Numerical Determination of a Quadratic Preference Function for Use in Macroeconomic Programming", Giornale Degli Economisti e Annali Di Economica, 1961.
- (8) Frisch, R., "Cooperation between Politicians and Econometricians on the Formalization of Political Preferences", Reprint Series No. 90, University of Oslo, Institute of Economics, 1972.
- (9) Geoffrion, A., Dyer, J. S. and Feinberg, A., "An Interactive Approach for Multicriterion Optimization with an Application to the Operation of an Academic Department", Management Science, Vol. 19, No. 4 (December 1972), pp. 357-368.
- (10) Johansen, L., "On the Optimal Use of Forecasts in Economic Policy Decisions", Journal of Public Economics, 1, April 1972.
- (11) Johansen, L., "Establishing Preference Functions for Macroeconomic Decision Models", European Economic Review, Vol. 5, 1974, pp. 41-66.
- (12) Kornai, J., Mathematical Planning of Structural Decisions, Amsterdam, 1967.
- (13) Livesey, D. A., "Optimizing Short-Term Economic Policy", Economic Journal, Vol. 81, 1971, pp. 525-546.
- (14) Livesey, D. A., "Feasible Directions in Economic Policy", Paper presented at the European Meeting of the Econometric Society, Helsinki, August 23-27, 1976.
- (15) MacEwan, A., Development Alternatives in Pakistan, Harvard University Press, Cambridge, Mass., 1971.

- (16) Pindyck, R. S., Optimal Planning for Economic Stabilization, North Holland Publishing Company, Amsterdam, 1973.
- (17) Roskamp, K., "Multiple Fiscal Policy Objectives and Optimal Budget: A Programming Approach", Proceedings of the Leningrad Congress, International Institute of Public Finance, Paris, 1971.
- (18) Spivey, W. A. and Tamura, H., "Goal Programming in Econometrics", Naval Research Logistics Quarterly, Vol. 17, No. 1 (March 1970), pp. 183-192.
- (19) Theil, H., Optimal Decision Rules for Government and Industry, Rand McNally & Co., Chicago, 1964.
- (20) Tinbergen, J., On the Theory of Economic Policy, Contributions to Economic Analysis, North Holland Publishing Company, Amsterdam, 1952.
- (21) Tinbergen, J., Economic Policy, Principles and Design, North Holland Publishing Company, Amsterdam, 1956.
- (22) Van den Bogaard, P. J. M. and Theil, H., "Macrodynamic Policy-Making: An Application of Strategy and Certainty Equivalence Concepts to the Economy of the United States 1933-1936", Metroeconomica, Vol. 11, 1959.
- (23) Van Eijk, C. J. and Sandee, J., "Quantitative Determination of an Optimum Economic Policy", Econometrica, Vol. 27, 1959.
- (24) Vartia, P., An Econometric Model for Analyzing and Forecasting Short-Term Fluctuations in the Finnish Economy, Helsinki, 1974.
- (25) Vartia, P., "Malli ei ole mekaano", Kansantaloudellinen Aikakauskirja, 1975: 1, pp. 66-70.
- (26) Verdoorn, P. J., Post, J. J. and Goslinga, S. S., The Re-Estimation of the Annual Model, Central Planning Bureau, the Hague, 1970.
- (27) Wallenius, J., "Comparative Evaluation of Some Interactive Approaches to Multicriterion Optimization", Management Science, Vol. 21, No. 12 (August 1975), pp. 1387-1396.
- (28) Wallenius, H. ja Wallenius, J., "Talouspolitiikan optimointisysteemi: ekonometrisen malli, menetelmä ja kaytto", Confederation of Finnish Industries, July 1977.
- (29) Wallenius, H., Wallenius, J. and Vartia, P., "An Experimental Investigation of an Interactive Programming Approach to Solving Macroeconomic Policy Problems", forthcoming in Operational Research '78, (ed.) K. B. Haley.
- (30) Zeleny, M. and Cochrane, J. L., "A Priori and A Posteriori Goals in Macroeconomic Policy Making", in Multiple Criteria Decision Making, ed. Cochrane, J. and Zeleny, M., Columbia, South Carolina, 1973.
- (31) Zionts, S. and Wallenius, J., "An Interactive Programming Method for Solving the Multiple Criteria Problem", Management Science, Vol. 22, No. 6 (February 1976), pp. 652-663.

- 1 At the end of 1975 the Economic Council, chaired by the Prime Minister, set these four objectives as the most important criteria in evaluating macroeconomic policy decisions in Finland in 1976.
- 2 Equation (14) of the original model, for instance, reads
$$Cpr = cpr + pcpr + 0.01cpr \times pcpr$$
, for which the first two terms with small changes in cpr and $pcpr$ give a reasonably good approximation. For different versions of the model see Vartia (24).
- 3 The Geoffrion method was implemented using a linear programming algorithm in which case the direction-finding problem always generates a corner solution. One of the reasons for using the Geoffrion method in the experiment was that we had available a workable computer program embodying the method.
- 4 For methods of manipulating the solutions of the model and for ways of combining outside information with an existing model, see Vartia (24,25).
- 5 As consultants to the Confederation of Finnish Industries Hannele and Jyrki Wallenius assume the responsibility for the results reported in section 4.3, but wish to thank the Research Institute of the Finnish Economy for making the model available. During the project we were responsible directly to the Deputy Managing Director.

6 A definition of an efficient neighboring solution and the procedure for identifying them is given in (31).

7 The necessary FORTRAN programs were developed by Mr. Matti Sihto, Helsinki Technical University.