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Proceedings of the 3-rd
Polish-Finnish Symposium
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SUPPORTING PLANNING DECISIONS BY EXPERIMENTS WITH A COMPLEX DEVELOPMENT MODEL

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ABSTRACT
An idea of interactive procedure is presented supporting analysis and choice of aggregated development program of national economy according to preferences of a given collective of experts. The procedure has been used in experiments done with participation of 9 experts. In the experiments an aggregated complex development model KMR2 has been utilised for calculation of effects resulting form proposed and considered development programs.

Keywords: decision support systems, multiple criteria optimization, making collective decisions.

1. INTRODUCTION

Several computer experiments with a complex development model are presented in this paper. The model describes the six main branches of the economy over a period of 15 years and enables analysis of the development strategies of the national economy. By using the model it is possible to verify whether the labor force, capital, natural and energy resources are sufficient to cover the demand resulting from the assumed development programs. The programs are characterized by a number of parameters which can be considered to be the objectives of economic development. The model can be used by a group of experts who deal with national economy planning /processes/. The experts are assumed to have subjective preferences only. The experiments enable a discussion of the admissibility of the development programs and a consensus regarding experts' preferences.

2. STATEMENT OF THE PROBLEM

Optimization of long-range strategy of development (at the national or regional level) is an important part of modern methods of planning and decision making . It is connected with periodic evaluation of the past achievements and formulation of new goals for the next planning period. Each new strategy can be regarded as correction of the old one. The corrections are also necessary in the case when the experts' utility function changes during the planning periods.

These remarks indicate that the problem of optimization of development strategy can be treated as a problem of control in the system shown in Fig.1 .

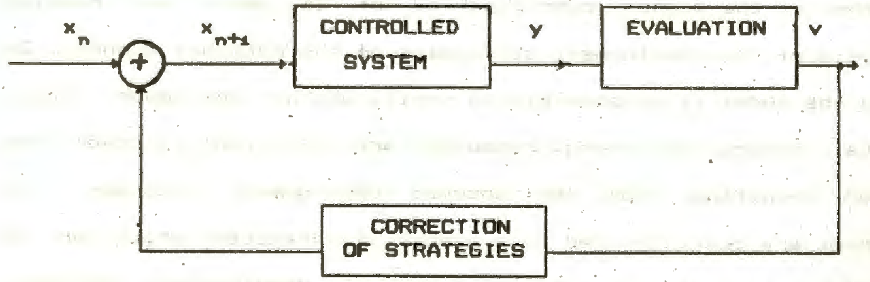

Fig. 1.

The system is controlled by the vector function

$$x(t) \equiv \{ x_1(t), \ldots\ldots x_n(t) \}, \quad t \in [0, T_p] ,$$

T_p - planning interval.

The output

$$y(t) = \{ y_1(t), \ldots y_N(t), \omega \} , \quad t \in [0, T_p] ,$$

ω - random variable ;

is observed by the decision maker who attaches an evaluation, i.e. a number v , to each particular observation.

Obviously , the relation

$$f(x) = M \{ v | x \},$$

can be regarded as the regression function.

One does not know the exact analytical form of $f(x)$ though it can be assumed that $f(x)$ is continuous and has a unique (at least in a certain domain X) maximum point $\bar{x} \in X$.

The problem boils down to the approximation of $\bar{x}$ by iterations

$$x_{n+1} = x_n + \frac{b_n}{c_n} [v_{2n+1} - v_{2n}] , n = 0,1,\ldots. \qquad (1)$$

where b_n , c_n - given "small" numbers , while $v_{2n+1}(x_n+c_n)$, $v_{2n}(x_n-c_n)$ - evaluation of output by the decision maker of the disturbed (by $\pm c_n$) strategy x_n. As shown by Kiefer,Wolfowitz (1952) and others, the process (1) converges stochastically to $\bar{x}$ (under certain regularity assumptions regarding $f(x)$ and the coefficients b_n, c_n). It should be observed that using (1) one should generally derive the direction improving utility of the experts. Such an approximation process cannot be performed in the case of a real multidimensional economy. However, it is possible to use the computerized model of the economy, avoiding in that way experiments on the "living" economy.

The main problem studied in the presented paper is the analysis of collective decision making, within a group of specialists, who observe the output y(x), corresponding to a given input strategy x, and give their evaluations v. The output y(x) is calculated by the computer using the model of the national economy. The model has been described elsewhere, see e.g. Kulikowski (1987), and is treated only very briefly here.

The model consists of several aggregated production sectors which generate the components of the national income. The sectorial productions are described by the Cobb-Douglas production functions.

It is convenient to express the dynamic processes, say f(t), in terms of the so called "rate of growth", defined as

$$\delta f = \frac{df}{dt} : f(t).$$

The sectorial production function can be written

$$\delta X_i = \mu_i + \alpha_i \delta K_i + (1-\alpha_i)\delta K_i \;, \; i = 1,\ldots n, \qquad (2)$$

where δX_i, δK_i, δL_i - the rates of growth for production, capital and labor respectively, μ_i - neutral technical progress, while α_i is a given number $(0 < \alpha_i < 1)$. It is assumed that capital is used by the economy in an optimum way, i.e. $K = \frac{\alpha}{1-\alpha}\frac{w_l}{w_k} L$, where w_l, w_k - prices of labor and capital. The relation (2) can be written

$$\delta X_i = \mu_i + z_i - \alpha_i w \;, \qquad w = \delta\left(\frac{w_k}{w_l}\right), \qquad (3)$$

where

$z_i \hat{=} \delta L_i$ - rate of growth for labor in i-th sector.

The employment rates z_i are limited by the demographic suppl

of growth $\lambda(t)$, i.e.:

$$\sum_{i=1}^{n} z_i l_i = \lambda(t) , \qquad l_i = L_i / \sum_{j=1}^{n} L_j ,$$

In planning practice, the n-1 sectorial rates of growth are

i.e.

$$\delta X_i = a_i , \qquad i = 1,.....n-1,$$

while the growth of the last sector is unconstrained.

In equation (3) the parameter w is unknown and can be derived

the capital balance equation

$$\sum_{i=1}^{n} k_i(z_i - w) = \delta R , \qquad k_i = K_i / \sum_{j=1}^{n} K_j ,$$

where δR - the growth rate of the energy and raw mat

supply, which constitute the capital.

The model operates as follows. For each strategy of develo

expressed in terms of given parameters a_i , i=1,...n-1, the

equations (3)-(6) are solved for unknown rates of employment

i=1,...n. Then the sectorial productions (X_i), capital

employments (L_i) and related economic variables are derived.

decision maker observes the computed results and changes

preferences (expressed by a_i) if necessary.

3. EXPERIMENTS

The experiments dealt with optimization of devel

strategy by a collective of specialists (experts). In this

they were scientific researchers dealing with modelling of

national economy. These experiments utilised the c development model described by Bury (1988). The model for given input quantities calculates a number of outputs characterizing the development of the economy. The input quantities can be divided into two groups: input data, constant within the experimental session, and controls.

The input data include the assumed planning interval: 1985-2000, demographical data, assumed aggregation of the economy including six sectors: agriculture, construction, fuel and energy, industry, material and nonmaterial services, initial quantities in the sectors including employment, investments, net production, energy consumption, initial gas pollution (emission) in fuel and energy as well as industry sectors, rate of debt repayments, energy conservation coefficients, labor force growth rate and others. Most of the input data have been assumed on the basis of the data of the Main Statistical Office (MSO), and on the base of the MSO prognosis. However the experiment started from a meeting of the specialists taking part in the experiment and a discussion on the input data. The rate of debt repayment calculated in per cent of national income and energy conservation coefficients in particular five years periods were assumed as the result of the discussion. The main input data are presented in table 1.

The control variables include production growth rate (in %) of the following sectors: agriculture, construction, industry (excluding the fuel and energy sector), material services, nonmaterial services. The control variables should not be considered as the desicion variables in the national economy. They are controls in the computerized model. For given controls the

Table 1. Main input data of the computerized complex development model used in the experiments.

Starting year : 1985 Planning interval : 3*5 years = 15 years

Aggregation of national economy : 6 sectors

Population growth rate : 0.0054 0.0042 0.0044 (second variant of MSO prognosis) **

Initial population - 37.3 $*10^6$

INITIAL QUANTITIES for sectors :

	AGRIC.	CONSTR.	FUEL-EN.	IND.	MAT.S.	NMAT.S
EMPLOYMENT $[10^6]$	5.121	1.282	0.609	4.390	2.840	2.82
INVESTMENTS $[10^9 zl]$	229	31.7	14.4	392	245	459
NET PRODUCTION $[10^9 zl]$	928	609	336	2274	1151	
ENERGY CONSUMP. $[10^6 tce]$	4.4	2.6	9.7	53.9	40.0	20.5

INITIAL GAS POLLUTION (EMISSION) in FUEL-ENERGY INDUSTRY

	FUEL-ENERGY	INDUSTRY
total $[10^3 t]$	*2774.9*	*2157*
SO_2	*2038*	*614*
CO_2	*142*	*1210*

RATE OF DEBT REPAYMENT	10	15	20	[% NI]
ENERGY CONSERV.COEFF.	0.0	1.0	2.0	
LABOR FORCE GROWTH RATE	0.0028	0.0064	0.0088	(**)

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other model parameters were estimated from statistical data

---

model calculates a number of outputs describing development of the economy in the assumed three five year periods. This means one set of controls defines one variant of development program.

The experiments were done according to the idea presented in point 2. The procedure was performed in several rounds. In each round, the experts had 5 test programs to evaluate and compare with one basic program. The particular test programs were generated by a small perturbation of the basic program. The perturbations were done, respectively, along the axes in the space of input variables in such a way that test program 1 (TEST1) was obtained assumming that the increase in agriculture was 0.5 % greater than in the basic one, while the other control variables were the same; test program 2 (TEST2) was obtained under the assumption that the increase in construction was greater, and so on. All of the output variables were calculated for programs generated in this way. In the first round, the basic program had been assumed on the basis of the assumptions to the National Plan for 1985 - 2000. An example of the information given to the experts is shown in table 2. The information includes : repetition of part of the input data (i.e. rates of growth for population and labor, energy conservation coefficient, assumed debt repayment [% of national income]) , control variables i.e. production growth rates for the 5 sectors , output quantities including : employment, energy consumption , investments in all 6 sectors , structure of sectorial quantities i.e. share of particular sectors in total production, employment, energy consumption and investments; growth rate of global indices : national income,

Table 2.Example of information delivered to experts in every round

	population growth rate	labor growth rate	energy cons. coefficient	debt repayment
1986 - 1990	0.54	0.28	0.00	10.00
1991 - 1995	0.42	0.64	1.00	15.00
1996 - 2000	0.44	0.88	2.00	20.00
1986 - 2000	7.16	9.25		

GROWTH RATE OF SECTORIAL INDICES [%]

	agricult.	constr.	energy	industry	mat.serv.	nm.serv
production						
1986-1990	1.25	3.05		3.22	5.86	2.2
1991-1995	1.25	3.05		3.22	5.86	2.2
1996-2000	1.25	3.05		3.22	5.86	2.2
1986-2000	28.02	62.57		66.12	128.08	
employment						
1986-1990	0.70	1.00	1.97	-0.83	1.81	0.15
1991-1995	0.52	1.40	-0.47	-0.43	2.21	0.55
1996-2000	0.82	1.56	0.07	-0.27	2.37	0.71
1986-2000	7.14	21.13	9.84	-7.46	35.47	7.21
energy consumption						
1986-1990	2.03	2.96	3.93	1.13	3.77	2.11
1991-1995	-0.25	0.63	-0.84	-1.20	1.44	-0.22
1996-2000	-1.42	-0.68	-2.17	-2.51	0.13	-1.53
1986-2000	1.04	14.44	2.21	-13.11	28.29	1.02
investments						
1986-1990	-2.75	0.44	3.75	-5.83	3.22	-2.47
1991-1995	-3.58	-2.15	-9.07	-5.66	-0.89	-3.63
1996-2000	-0.21	0.18	-1.94	-2.39	1.16	-0.92
1986-2000	-29.91	-7.95	-41.41	-55.28	17.38	-31.59

Table 2 , continued.

STRUCTURE of SECTORIAL QUANTITIES [%]

	agricult.	constr.	energy	industry	mat.serv.	nm.serv
<u>production</u>	(part of national income)					
1985	17.51	11.50	6.35	42.91	21.73	
1990	15.98	11.36	5.94	42.69	24.02	
1995	14.60	11.24	5.01	42.54	26.61	
2000	13.26	11.06	4.20	42.16	29.32	
<u>employment</u>						
1985	30.02	7.51	3.57	25.74	16.62	16.54
1990	29.71	7.78	3.87	24.33	17.88	16.43
1995	29.53	8.07	3.73	23.07	19.24	16.36
2000	29.44	8.33	3.59	21.80	20.61	16.23
<u>energy consumption</u>						
1985	3.33	1.94	7.43	41.13	30.51	15.66
1990	3.28	2.00	7.95	38.86	32.43	15.48
1995	3.26	2.07	7.65	36.71	34.93	15.39
2000	3.24	2.14	7.31	34.40	37.68	15.23
<u>investments</u>						
1985	16.74	2.31	1.05	28.58	17.90	33.42
1990	16.34	2.67	1.41	22.91	23.51	33.15
1995	16.24	2.88	0.93	19.89	27.20	32.85
2000	16.49	2.99	0.87	17.97	29.53	32.15

GROWTH RATE of GLOBAL INDICES [%]

	national income	total cons.	cons. as % NI	invest.	energy prod.	gas pollution
1986-1990	3.88	3.46	78.69	-2.33	1.82	2.97
1991-1995	3.72	3.99	84.29	-3.48	-0.42	1.65
1996-2000	3.87	3.02	86.37	-0.51	-0.44	1.81
1986-2000	69.06	62.04		-28.87	11.82	35.60

total concumption and consumption as % of national income , investments, energy production and gas pollution. All the quantities are calculated in constant prices, the growth rates in particular 5-years periods are yearly average.

The results of the experiment are given in table 3 and on the figures. The table presents evaluations of particular testing programs in four consequtive iterations, and directions generated

Table 3. Evaluation of testing programs by experts and generated directions.

	iteration 1				iteration 2			
	evaluation -1	0	+1	direction	evaluation -1	0	+1	direction
TEST1	7	2	0	-0.40	8	0	0	-0.50
TEST2	0	1	8	0.44	0	1	7	0.44
TEST3	3	3	3	0.00	5	1	2	0.20
TEST4	1	3	5	0.22	1	5	2	0.06
TEST5	2	6	1	-0.05	2	5	1	-0.06

	iteration 3				iteration 4			
	evaluation -1	0	+1	direction	evaluation -1	0	+1	direction
TEST1	5	3	1	-0.22	3	4	2	-0.03
TEST2	1	3	5	0.22	4	3	2	-0.05
TEST3	2	2	5	0.17	2	3	4	0.05
TEST4	2	4	3	0.06	3	6	0	-0.08
TEST5	3	4	2	-0.06	6	2	1	-0.14

according to the procedure. The evaluations were given by nine experts using a scale: +1, 0, -1, meaning, respectively, that a particular testing program is treated as better, the same, worse than the basic one.

The experts were also asked to verbally indicate the quantities assumed in their opinion as the most important objectives and to explain the motivations behind their evaluations. These evaluations were normalized and used with an assumed step length in the calculation of a new basic program in the next iteration. Let us observe that the normalized evaluation of the testing programs represent collective preferences of the experts. The evaluations were utilised for generation of a direction improving the collective utility in the space of the input variable, and the new basic program was obtained according to this direction. In each iteration the five testing programs were also calculated and given to the experts for evaluation. The procedure was repeated as in the first iteration. The procedure converged after four iterations. In the last iteration some of the experts reversed the direction improving their utility, some of them selected the basic program as the best one. As the result, changes in the last iteration were minimal. Also in verbal opinions the experts inicated that the procedure should be stopped.

The main results, including input variables and selected output variables are presented in figures 2 and 3. Figure 2 illustrates the changes, occuring during the experiment, of the yearly production growth rate in agriculture, construction, industry, material and nonmaterial services. In figure 3, total growth rate of production in the agriculture, construction, fuel and energy, industry and material services sectors as well as the total growth rate of the national income, consumption and gas pollution in the period 1985 - 2000 are given. The results show that during the experiment, the experts tried first of all to increase the total consumption, construction sector production and to decrease pollution (all in comparison to the initial, basic program). They slightly increased production of material services, assumed the national income and industrial production to be nearly the same as given in the basic program. They agreed to decrease the growth of agricultural production and the growth of production in the fuel and energy sector to achieve the goals set in construction, total consumption and pollution. The results should be considered as subjective for this particular collective of experts. A different collective could have different preferences, and the experiment could give different results.

4.FINAL REMARKS

An experiment has been conducted utilizing an interactive procedure supporting collective evaluation and modification and providing a choice of aggregated development programs of the national economy. The experiment made use of a complex development model. It showed that the proposed procedure can support the generation and finding of a program according to aggregated, collective preferences of the experts. The experts dealt with a vector of objectives. The utility function of the experts had not been given explicitly, and we did not try to aggregate the utilities, but rather in an interactive way to modify the basic program according to the collective preferences of the experts. Practical convergency of the procedure was observed.

5. REFERENCES

P.Bronisz.H,Bury,L.Kruś.1988,Interactive Supporting System for the Analysis of Development Strategies, proceedings of the 1st National Conference of Operational and System Research,Książ, 13-17 June, 1988

H.Bury,1988,Modified Complex Development Model-KMR2

J.Kiefer,Wolfowitz,1952, "Stochastic Estimation of the Maximum of a Regression Function", Annals of Math.Statistics, No 3, (1952)

R.Kulikowski,1987,"Modelling and Control of Complex Environmental, Economic and Social Development ",Proc. of X-th IFAC Congress, Münich(1987)

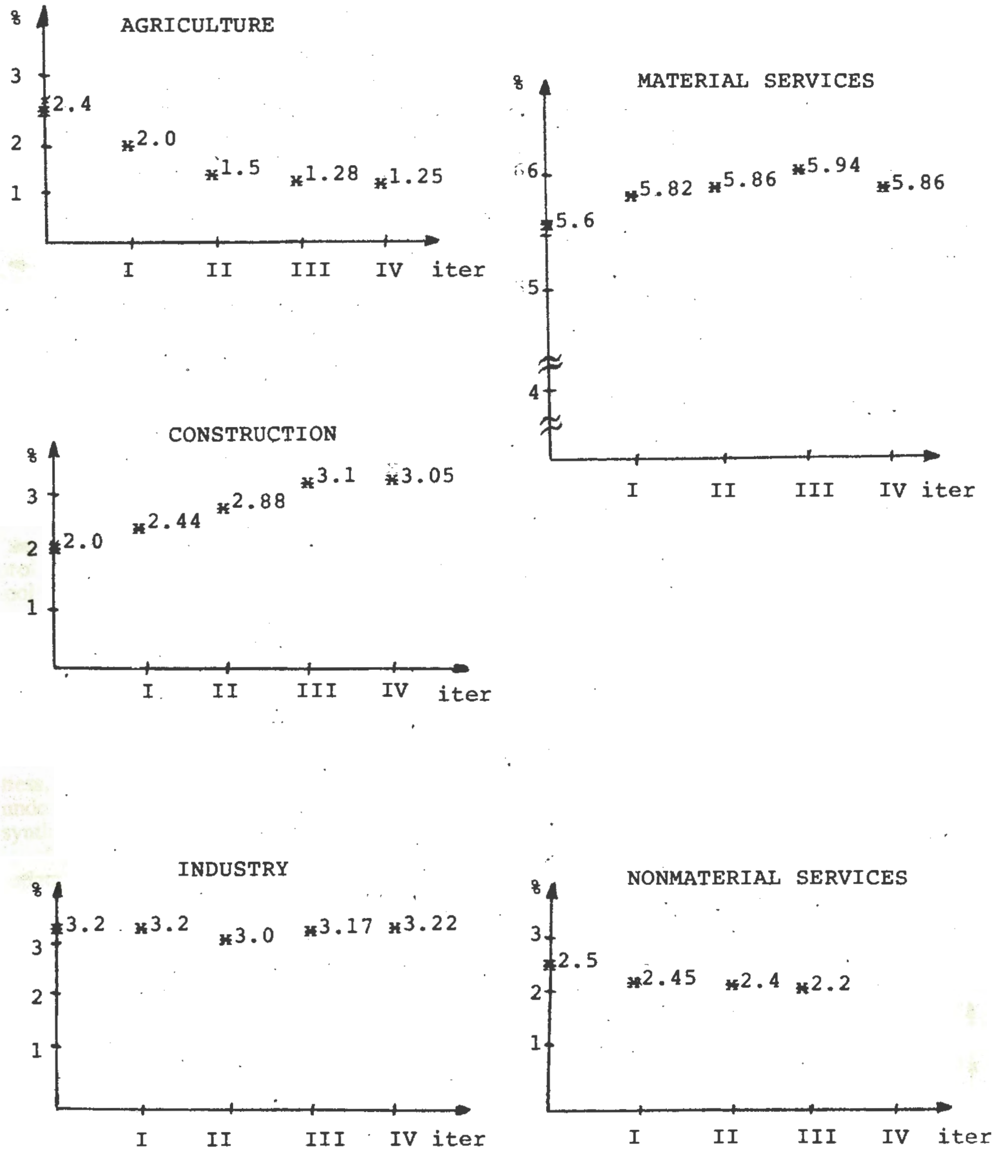
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Fig. 2.

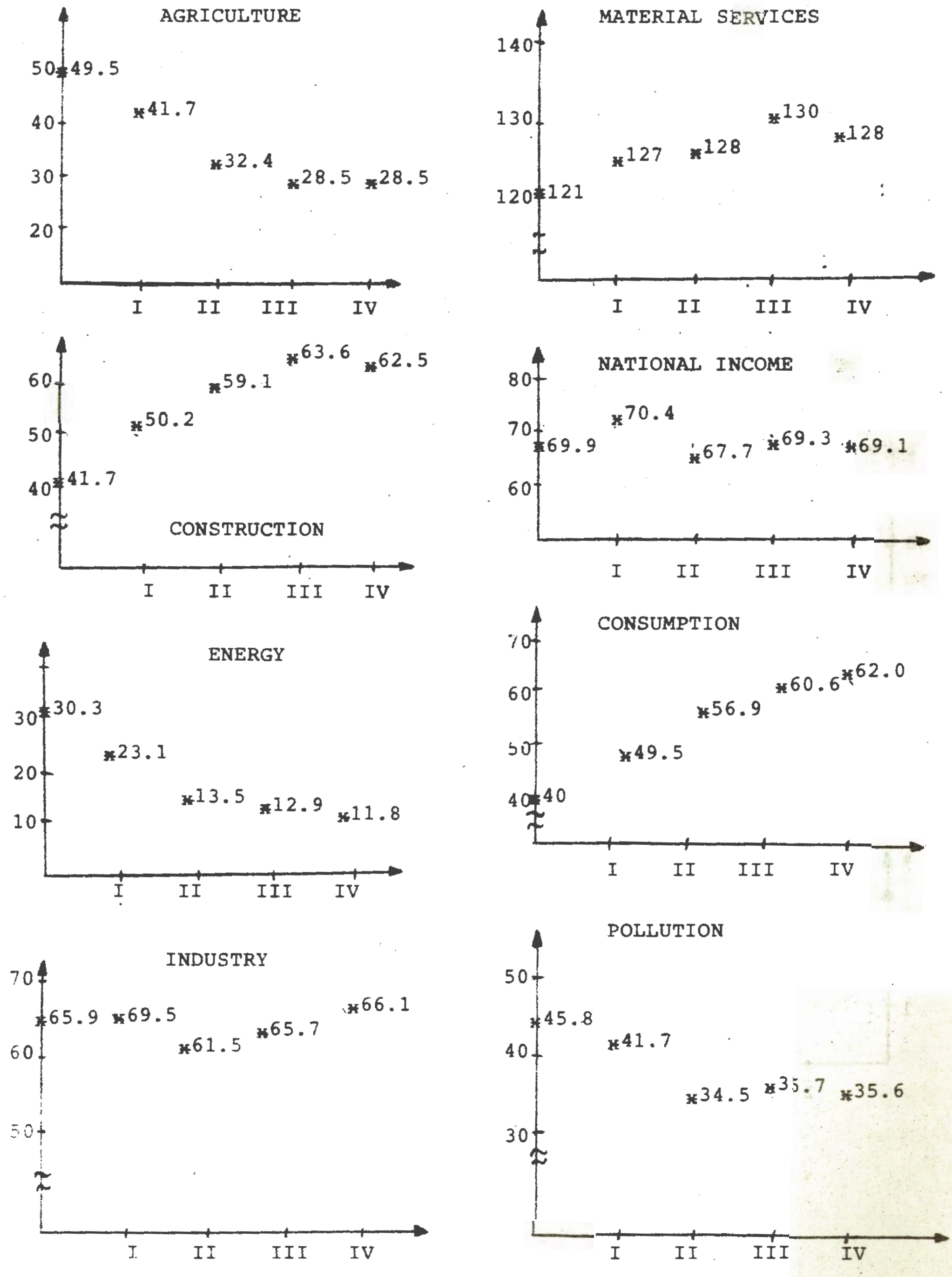
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Fig. 2