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Objective System Analysis of Macroeconomic Systems

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A non-traditional criterion can be applied to the solution of the problem of the single matrix model choice by sorting-out many matrix models-candidates (the OSA algorithm - Objective System Analysis). Using the OSA algorithm on the sliding interval of time, we can evaluate the change of the diversity of a complex economic macrosystem. As an example, the intervals of more and less intensiv development of the DDR economic system are shown.

1. Introduction

Constantly increasing consideration is being given to the modeling of macroeconomic systems of the regional, national and global scales during the last decades. A great variety of methods and models are used for this purpose (sometimes very complex and sophisticated) (LEONTYEFF, [2],DADAYAN,[1]). Main difficulties in constructing such models are related to the fact that they comprise a great quantity of variables but time series describing these variables are rather limited.

To solve many modeling and forecasting problems for complex (large-scale) dynamic systems using short samples, the Group Method of Data Handling (GMDH) developed in the V. M. Glushkov Institute of Cybernetics of the Ukrainian SSR Academy of Sciences has been successfully used during two last decades. The method and examples of its application for identification and forecasting of complex technical and environmental systems are described in many of books and articles (e. g. IVACHNENKO, A. G. et al. [4], IVACHNENKO, A. G., [3], IVACHNENKO, A. G., MULLER, J. A., [5], IVACHNENKO, A. G., STEPASHKO, V. S. [6], IVACHNENKO, A. G., YURACHKOYSKI, Yu. P., [7], FARLOW, S. E., [8], IVACHNENKO, A. G., KOZUBOVSKI, S. F., [9], etc.).

The GMDH was also successfully used for modeling some laws governing the United Kingdom and German Democratic Republic economics. In this case, one of the GMDH algorithms was used - the Objective System Analysis (OSA) (IVACHNENKO, A. G. et al. [11], IVACHNENKO, A. G., [12]). As distinct from traditional GMDH algorithms (combinatorial, iterative, multiplicative ones) sorting out (sifting) vector models, in which a model corresponds to one equation, the sorting-out of matrix models is carried out in the OSA algorithms and the model is searched for in the form of a system of equations.

2. An Example: Analysis of GDR Economic System

The present report describe an application of the OSA algorithm for self-organization of forecasting models. As an example, the economic system of GDR is used. Models in the form of polynomials are synthesized - the analogs of differential equations.

The initial data array (Table.1.) comprises 25 variables:

Table 1. Initial Data for Modeling GDR Economics

Vari-ables	Years																			
	1962	1963	1904	1905	1966	1907	1968	1909	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
x\	1	0.749	0.421	0.431	0.497	0.508	0.284	0.310	0.375	0.445	0.340	0	0.121	0.217	0.271	0.282	0.314	0.315	0.314	0.301
x_2	0	0	0	0	0	0.005	0.132	0.197	0.197	0.197	0.295	0.394	0.390	0.339	0.387	0.354	0.413	0.581	0.781	1
x_3	0	0.012	0.023	0.047	0.085	0.120	0.160	0.200	0.250	0.297	0.342	0.398	0.449	0.527	0.602	0.070	0.762	0.854	0.934	1
x_4	0	0.102	0.245	0.254	0.254	0.254	0.373	0.373	0.373	0.373	0.462	0.699	0.715	0.750	0.794	0.847	0.902	0.947	0.980	1
x_5	0	0.063	0.125	0.188	0.250	0.418	0.583	0.750	0.875	1	0.938	0.875	0.730	0.573	0.468	0.375	0.313	0.310	0.303	0.300
x_6	0.344	0.435	0.595	0.763	0.779	0.840	0.870	0.931	0.931	0.931	0.939	0.946	1	0.939	0.847	0.824	0.695	0.527	0.374	0
x_7	0	0.027	0.058	0.094	0.135	0.179	0.222	0.208	0.318	0.371	0.422	0.469	0.521	0.579	0.650	0.720	0.779	0.839	0.920	1
x_8	1	0.955	0.909	0.804	0.773	0.082	0.636	0.545	0.500	0.455	0.409	0.304	0.318	0.273	0.182	0.136	0.091	0.045	0	0
x_9	1	0.903	0.840	0.719	0.700	0.770	0.821	0.845	0.847	0.833	0.787	0.702	0.579	0.419	0.262	0.138	0.053	0.012	0	0.005
x_{10}	0.267	0.092	0	0.010	0.006	0.054	0.058	0.150	0.242	0.212	0.242	0.393	0.007	0.840	0.830	0.834	0.998	1	0.709	0.850
x_{11}	0	0.019	0.074	0.059	0.105	0.138	0.138	0.192	0.260	0.295	0.375	0.401	0.575	0.587	0.717	0.781	0.857	0.895	0.930	1
x_{12}	0	0.013	0.039	0.075	0.123	0.157	0.220	0.278	0.332	0.380	0.442	0.500	0.558	0.619	0.679	0.741	0.806	0.809	0.933	1
x_{13}	0	0.020	0.045	0.084	0.127	0.170	0.215	0.205	0.319	0.370	0.420	0.475	0.544	0.620	0.684	0.752	0.825	0.885	0.932	1
x_{14}	0	0.013	0.042	0.077	0.115	0.158	0.201	0.247	0.295	0.349	0.399	0.461	0.527	0.608	0.669	0.730	0.816	0.874	0.925	1
x_{15}	0	0.020	0.050	0.071	0.091	0.149	0.190	0.221	0.256	0.287	0.370	0.459	0.488	0.570	0.672	0.754	0.816	0.870	0.936	1
x_{16}	0	0.085	0.130	0.180	0.254	0.492	0.542	0.271	0.644	1	0.780	0.678	0.814	0.780	0.627	0.763	0.780	0.508	0.271	0.508
x_{17}	0	0.080	0.172	0.259	0.345	0.448	0.534	0.003	0.655	0.724	0.759	0.810	0.879	0.931	0.966	0.966	0.983	0.983	1	1
x_{18}	0	0.023	0.041	0.059	0.082	0.110	0.142	0.183	0.228	0.279	0.338	0.397	0.461	0.525	0.594	0.667	0.744	0.820	0.909	1
x_{19}	0	0.003	0.021	0.056	0.101	0.132	0.189	0.249	0.307	0.357	0.413	0.481	0.563	0.638	0.690	0.757	0.834	0.890	0.924	1
x_{20}	0.072	0.015	0	0.039	0.071	0.086	0.104	0.173	0.239	0.289	0.313	0.374	0.532	0.644	0.721	0.789	0.861	0.909	0.957	1
x_{21}	1	0.949	0.881	0.814	0.746	0.508	0.458	0.729	0.356	0	0.220	0.322	0.220	0.373	0.237	0.220	0.220	0.492	0.729	0.492
x_{22}	0	0	0	0	0	0.200	0.400	0.000	0.800	1	1	1	1	1	1	0.800	0.600	0.400	0.200	0
x_{23}	1	0.920	0.853	0.779	0.700	0.647	0.588	0.529	0.471	0.412	0.358	0.304	0.250	0,196	0.147	0.118	0.088	0.059	0.029	0
x_{24}	0.002	0	0.013	0.024	0.036	0.047	0.060	0.071	0.084	0.094	0.120	0.144	0.167	0.309	0.476	0.571	0.691	0.790	0.900	1
3*25	0	0.010	0.017	0.027	0.034	0.044	0.051	0.061	0.069	0.076	0.086	0.128	0.170	0.390	0.594	0.661	0.730	0.790	0.914	1

,x_1 - private consumption; x_2 - social consumption; x_3 - fixed capital of production sphere; x_4 - production sphere investments; x_5 — non-productive sphere investments; x_6 - fixed capital quota; x_7 - labor productivity (gross); x_8 — fixed capital coverage; x_9 - general population; x_{10} - total number of workers; x_{11} - workers of non-productive sphere; x_{12} - share of the growth of wage level in material sphere; x_{13} - gross national product; x_{14} - national production income; x_{15} - volume of foreign trade; x_{16} - share of accumulation; x_{17} - intensity of accumulation; x_{18} - share of the growth of pensions; x_{19} - real income; x_{20} - deposits at saving banks (savings); x_{21} - share of consumption; x_{22} - fixed capital quota - new assets; x_{23} - labor force; x_{24} - export prises; x_{25} - import prises.

For data normalizing, formula was used:

$$x_i^* = \frac{x_i - x_{i,\min}}{x_{i,\max} - x_{i,\min}},$$

where x_i^* is the normalized value of the i-th variable.

The results of the computing experiments using OSA algorithm are shown in Fig. 1. It is seen from the figure that the optimal complexity system of difference equations exists for each noise level. As in other GMDH algorithms, an increase in the noise level results in the shift of the minimum of the model selection criterion to the left, i.e. to the simplification of the system, to a reduction of the number of equations forming the system.

What is more, an astonishing experimental result resides in the fact that the algorithm practically never selects a system comprising more than five to six equations. This can be explained as follows: it is well known from the automatic control theory that time

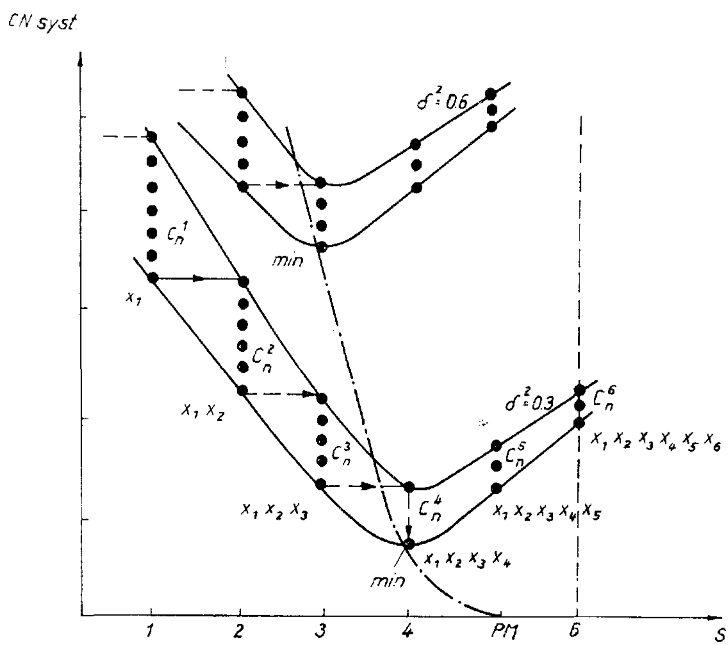

Fig. 1. CN_{syst} - system criterion, S - system complexity (number of equations in the system), PM - physical model, δ^2 - noise level

constants of individual feedback links are so different that the account of three to five time constants is sufficient *("A. Yu. Ishlinski's Rule")*. Only an inexperienced engineer can describe a control system by the equation of the degree higher than the fifth one. Similarly, five different equations of the mentioned type take upon themself the whole error variance. Computer can not play the role of the inexperienced engineer and generate too complicated system of equations comprising more than five-six difference equations of the described type.

In other words: the OSA algorithm finds sets of equations only for those variables whose behavior can be described by difference equations. The noncontradiction (minimum-of-bias) criterion(IVACHNENKO,A. G., [3]) is used in the OSA algorithm:

$$CN = \frac{\sum_1^N (\hat{q}_A - \hat{q}_B)^2}{\sum_1^N q_T^2} \rightarrow \min,$$

where q_A and q_B are the output variable values calculated from the models of the same structure whose coefficients are calculated using parts *A* and B of the initial data sample, q_T are the table values of the output variable.

3. The Results of Application of OSA Algorithm

Using the noncontradiction criterion, the algorithm has selected the following systems of equations: The best systems of the first and the second layer of selection:

$$x_{12(k)} = 2.078\, x_{12(k-1)} - 1.091\, x_{12(k-2)}$$

$$x_{7(k)} = 2.083\, x_{7(k-1)} - 1.168\, x_{7(k-2)} + 0.067\, x_{13(k-1)}$$

$$x_{13(k)} = 0.017 + 1.675\, x_{13(k-1)} - 0.625\, x_{13(k-2)}$$

The best system of the third layer:

$$x_{7(k)} = 0.032 + 1.067\, x_{7(k-1)},$$

$$x_{13(k)} = 1.903\, x_{13(k-1)} - 1.140\, x_{13(k-2)} + 0.248\, x_{18(k)},$$

$$x_{18(k)} = 1.347\, x_{18(k-1)} - 0.427\, x_{18(k-2)} + 0.224\, x_{7(k)} - 0.182\, x_{7(k-1)} + 0.085\, x_{13(k-1)}.$$

The minimum of the system criterion: $CN_{syst} = 4.52 \cdot 10^{-5}$. After the third layer, the minimum of the criterion begins increasing, therefore the sorting-out of the sets of equations terminates.

Step-by-step integration of the sets of equations has given the results presented in Table 2.

The models for other variables have been synthesized using the GMDH combinatorial algorithm COMBI with noncontradiction criterion. In this case, previous (delayed) values of the output variables and essential variables are given as arguments (initial complete polynomial was given and the COMBI algorithm has chosen only its essential terms):

$$x_{i(k)} = a_0 + a_1 x_{i(k-1)} + a_2 x_{i(k-1)} + b_0 x_{7(k)} + b_1 x_{7(k-1)} + b_2 x_{7(k-2)} + c_0 x_{12(k)} + c_1 x_{12(k-1)} + c_2 x_{12(k-2)} + d_0 x_{13(k)} + d_1 x_{13(k-1)} + d_2 x_{13(k-2)} + l_0 x_{18(k)} + l_1 x_{18(k-1)} + l_2 x_{18(k-2)}.$$

Table 2. Actual Data and Results of Forecasting of "Detailed" Variables by OSA

Variables		Years 1979	1980	1981	Forecasting error
x_7	actual	0.839	0.920	1.000	$\delta^2 = 0.31$
	forecast	0.837	0.894	0.949	
x_{12}	actual	0.869	0.933	1.000	$\delta^2 = 0.13$
	forecast	0.866	0.921	0.968	
x_{13}	actual	0.885	0.932	1.000	$\delta^2 = 0.42$
	forecast	0.897	0.967	1.038	
x_{18}	actual	0.826	0.909	1.000	$\delta^2 = 0.108$
	forecast	0.833	0.933	1.032	

The forecasting accuracy (with forecasting interval of three years — 1979...1981) is as follows:

$$\delta_1^2 = 281.15 \quad \delta_2^2 = 15.64 \quad \delta_3^2 = 0.71 \quad \delta_4^2 = 695.06$$
$$\delta_5^2 = 0.44 \quad \delta_6^2 = 0.89 \quad \delta_8^2 = 0.36 \quad \delta_9^2 = 4802.88$$
$$\delta_{10}^2 = 137.17 \quad \delta_{11}^2 = 432.20 \quad \delta_{14}^2 = 0.59 \quad \delta_{15}^2 = 42.43$$
$$\delta_{16}^2 = 71.57 \quad \delta_{17}^2 = 374.71 \quad \delta_{19}^2 = 3.93 \quad \delta_{20}^2 = 102.90$$
$$\delta_{21}^2 = 40.71 \quad \delta_{22}^2 = 0.01 \quad \delta_{23}^2 = 0.36 \quad \delta_{24}^2 = 63.45$$
$$\delta_{25}^2 = 15.30.$$

It may be concluded that only 10 of 25 variables are forecasted by means of the OSA algorithm satisfactorily and good ($\delta^2 < 1.0$). As is generally known, with $\delta^2 < 0.5$ the forecast can be considered to be good and with $\delta^2 < 0.8$ - satisfactory. With $\delta^2 > 1.0$ the forecast bears misinformation.

4. Qualitative (Fuzzy) Forecasting by OSA Algorithm Obtained with Shift of "Sliding Window" (Observation Interval)

The ordinate of the minimum of the noncontradiction criterion graph is an important index of the condition of the object being modelled which reflects the generalized level of its development (the complexity or variety level).

Applying the OSA algorithm for three basic intervals (1962-69, 1970-75, 1976-81), we can obtain a fuzzy qualitative conclusion on the trend of development of some economic system. The system perfects itself when S_{opt} increases from cluster to cluster. In the present case, we have obtained

$$S_{opt}(1962\text{–}69) = 2,$$
$$S_{opt}(1970\text{–}75) = 3,$$
$$S_{opt}(1976\text{-}81) = 3,$$

i.e., the GDR economic system has changed to a stable level of development. The value of S_{opt} is equal to the number of equations in the optimal forecasting system found by means of OSA.

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