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PROBLEM OF IDENTIFICATION PARAMETERS OF ENERGY-DEPENDENT ECONOMICS

Gaiduchok Olena Vasylivna
PhD in Economics, Associate Professor of the Department of Applied Mathematics, National University "Lviv Polytechnics", Ukraine

The system model of two sector economics, in which power and production sectors acts separately, is described. Production is divided into two sectors - the first sector produced the final product, and the second sector - the energy that is required to produce the final product. The models for the sectors power are recorded. The system model as the system of differential equation is obtained. An algorithm for defining identification parameters is described. Control parameters for system model for main macroeconomic indicators are shown.

Keywords: *system model of two-sector economics, system of differential equations, identification parameters.*

Introduction. As we know, Ukraine's economy greatly depends on the supply of imported energy raw. Rising prices for energy raw leads to change in all macroeconomic indicators, including an increase in the price of goods. However, it is unknown how much the price of goods will increase at different modes of energy raw price changes. To conduct prediction of volatile economy we consider system model of two-sector economy with concretisation of the energy sector. That means the economics is modelled by systems of differential equations. When we try to do simulations and predictions based on this model, it is assumed that all involved parameters (such as coefficients of real state of economics) are known. However, first of all these parameters have to be determined. Since they are frequently hardly accessible to direct measurements, they have to be fitted from indirect measurements. This leads us to the problem of parameter identification.

Analysis of recent researches and publications. For research and forecasting future economic situation there are many methods, namely the method of time series; methods for linear and nonlinear regression analysis by simulation; econometric models. However, analysis of existing models has found that they do not implement system approach [4, 7, 9]. Specificity of system approach of building a macroeconomic model is that this approach focuses on integrity of various types of complex object relationships and brings them into a single theoretical picture. First system economic model was built in the works of Petrov [8].

Main purpose of the article. The aim of this article is to develop a methodological approach to defining the parameters of system model of economics. This approach could be used for prediction of future scenarios of economics development.

Results and discussions. Let's consider a closed economy, i.e. the economy without foreign exchange. All economic agents act on the perfect competition market. Prices for product and recourses are formed by the interaction of aggregate demand and supply of goods.

Production is aggregated into two sectors. The first sector produces end product, part of which is used as a consumer product, and others part to create capacity in both sectors. The second sector processes an energy raw (oil, gas and coal), which is spent in the first sector while producing process, and for the final consumption of population [1,6].

The production function of the first sector is represented by:

$$Y_1 = M_1 f_1\left(x_1^1, x_1^G, x_1^N, x_1^V\right), \quad x_1^1 = \frac{R^L}{M_1}, \quad x_1^G = \frac{E^G}{M_1}, x_1^N = \frac{E^N}{M_1}, \; x_1^V = \frac{E^V}{M_1} \tag{1}$$

where M_1 - power of the first sector, $f_1\left(x_1^1, x_1^G, x_1^N, x_1^V\right)$- production function of the first sector, R^L- amount of labour force, E^G, E^N, E^V - amount of raw stuff of gas, oil, and coal, x_1^G, x_1^V, x_1^N - amounts of gas, coal, oil raw stuff per unit power involved for the production of the first sector. Demand functions for labour R^d, energy E^d and function of product supply Y_1^* are provided from the conditions of maximum current income producing product:

$$\Pi_1\left(x_1^1, x_1^1, x_1^G, x_1^N, x_1^V\right) = M_1\left[p_1 f_1\left(x_1^1, x_1^G, x_1^N, x_1^V\right) - s x_1^1 - p_2^G x_1^G - p_2^N x_1^N - p_2^V x_1^V\right] \to \max_{x_1^1, x_1^G, x_1^N, x_1^V},$$

which is equivalent to equations

$$\frac{\partial f_1\left(x_1^1, x_1^G, x_1^V, x_1^N\right)}{\partial x_1^1} = \frac{s}{p_1}, \qquad \frac{\partial f_1\left(x_1^1, x_1^G, x_1^V, x_1^N\right)}{\partial x_1^G} = \frac{p_2^G}{p_1}, \tag{2}$$

$$\frac{\partial f_1\left(x_1^1, x_1^G, x_1^V, x_1^N\right)}{\partial x_1^V} = \frac{p_2^V}{p_1}, \qquad \frac{\partial f_1\left(x_1^1, x_1^G, x_1^V, x_1^N\right)}{\partial x_1^N} = \frac{p_2^N}{p_1},$$

where s- salary wage, p_1 - price of the first sector product, p_2 - price of the second sector product (correspondingly gas, oil and coal).

The total power changes could be written as

$$\frac{dM_1}{dt} = I_1 - \mu_1 M_1 \ , \qquad (3)$$

where I_1 - speed of creating new facilities.

The second sector is subdivided into three parts. The supply of raw material is represented by equations:

$$Y^G{}_2 = M_2^G f_2\left(x_2^G\right), \quad Y^N{}_2 = M_2^N f_2\left(x_2^N\right), \ Y^V{}_2 = M_2^V f_2\left(x_2^V\right), \qquad (4)$$

here M_2^G , M_2^N, M_2^V —gas / oil / coal processing power; $f_2(x_2^G)$, $f_2(x_2^N)$, $f_2(x_2^V)$ - production functions for gas, oil and coal sectors, respectively; V_E^G , V_E^N, V_E^V - the number of gas / oil / coal raw materials consumed; $x_2^G = \frac{V_E^G}{M_2^G}$ - amount of gas raw per unit of power involved in processing gas; $x_2^N = \frac{V_E^N}{M_2^N}$- amount of oil raw per unit of power involved in the production of oil products; $x_2^V = \frac{V_E^V}{M_2^V}$- amount of coal raw per unit of power involved in coal processing.

The population is divided into two groups: workers and owners. Workers and owners consume the product first sector and energy (oil, gas and coal) in fixed proportions. Employee's income is only salary, it is spent on consumption.

Energy cannot be stored, so the price of energy varies depending on the supply and demand for it. Producers create a unified system of energy supply. So when demand is lower than supply, the price of energy decreases much more slowly than it increases when supply is less than demand.

Based of the above reasons (as well as the results of [2,3,6]) the closed system of functional differential equations for the power sector and capital markets and the prices of basic products sector wages, prices of gas, oil and coal is obtained (process is fully presented in the [3]):

$$\frac{dM_2^G}{dt} = I_2^G - \mu_2^G M_2^G; \qquad \frac{dM_2^N}{dt} = I_2^N - \mu_2^N M_2^N; \qquad \frac{dM_2^V}{dt} = I_2^V - \mu_2^V M_2^V;$$

$$\frac{dK_1}{dt} = \frac{k_1 k}{\xi^*} M_1 f_1\left(x_1^1, x_1^G, x_1^N, x_1^V\right) - \left(1-k_1\right)\mu_1^* K_1 + k_1\left(\mu_{2,G}^* K_2^G + \mu_{2,N}^* K_2^N + \mu_{2,V}^* K_2^V\right);$$

$$\frac{dK_2^G}{dt} = I_2^G p_2^G b_2^G - \mu_{2,G}^* K_2^G; \qquad \frac{dK_2^N}{dt} = I_2^N p_2^N b_2^N - \mu_{2,N}^* K_2^N; \tag{5}$$

$$\frac{dK_2^V}{dt} = I_2^V p_2^V b_2^V - \mu_{2,V}^* K_2^V; \qquad \frac{dp_1}{dt} = -\alpha_1 \frac{Q_1}{M_1} p_1;$$

$$-\frac{k_1}{p_1}\left(\mu_1^* K_1 + \mu_{2,G}^* K_2^G + \mu_{2,N}^* K_2^N + \mu_{2,V}^* K_2^V\right) - \frac{p_2^G b_2^G I_2^G + p_2^V b_2^V I_2^V + p_2^N b_2^N I_2^N}{p_1} - \qquad ;$$

$$\frac{dp_2^G}{dt} = -\alpha_2\left(M_2^G f_2\left(\frac{V_E^G}{M_2^G}\right), M_1 x_1^G + \frac{c^{L,G} s \min\left\{M_1 x_1^1, P_0^A U e^{\lambda_p t}\right\} + c^{0,G} c^0 p_1 M_1 f_1}{p_1 + c^{L,G} p_2^G}\right) \times$$

$$\frac{dp_2^N}{dt} = -\alpha_2\left(M_2^N f_2\left(\frac{V_E^N}{M_2^N}\right), M_1 x_1^N + \frac{c^{L,N} s \min\left\{M_1 x_1^1, P_0^A U e^{\lambda_p t}\right\}}{p_1 + c^{L,N} p_2^N} + \frac{c^{0,N} c^0 p_1 M_1 f_1}{p_1 + c^{0,N} p_2^N}\right) \times$$

$$\times\left(1 - \frac{M_1 x_1^N + \dfrac{c^{L,N} s \min\left\{M_1 x_1^1, P_0^A U e^{\lambda_p t}\right\}}{p_1 + c^{L,N} p_2^N} + \dfrac{c^{0,N} c^0 p_1 M_1 f_1\left(x_1^1, x_1^G, x_1^V, x_1^N\right)}{p_1 + c^{0,N} p_2^N}}{M_2^N f_2\left(\dfrac{V_E^N}{M_2^N}\right)}\right) p_2^N;$$

$$\frac{dp_2^V}{dt} = -\alpha_2\left(M_2^V f_2\left(\frac{V_E^V}{M_2^V}\right), M_1 x_1^V + \frac{c^{L,V} s \min\left\{M_1 x_1^1, P_0^A U e^{\lambda_p t}\right\}}{p_1 + c^{L,V} p_2^V} + \frac{c^{0,V} c^0 p_1 M_1 f_1}{p_1 + c^{0,V} p_2^V}\right) \times$$

$$\times\left(1 - \frac{M_1 x_1^V + \dfrac{c^{L,V} s \min\left\{M_1 x_1^1, P_0^A U e^{\lambda_p t}\right\}}{p_1 + c^{L,V} p_2^V} + \dfrac{c^{0,V} c^0 p_1 M_1 f_1\left(x_1^1, x_1^G, x_1^V, x_1^N\right)}{p_1 + c^{0,V} p_2^V}}{M_2^V f_2\left(\dfrac{V_E^V}{M_2^V}\right)}\right) p_2^V;$$

$$\frac{\partial f_1\left(x_1^1, x_1^G, x_1^V, x_1^N\right)}{\partial x_1^1} = \frac{s}{p_1}, \qquad \frac{\partial f_1\left(x_1^1, x_1^G, x_1^V, x_1^N\right)}{\partial x_1^G} = \frac{p_2^G}{p_1},$$

$$\frac{\partial f_1\left(x_1^1, x_1^G, x_1^V, x_1^N\right)}{\partial x_1^V} = \frac{p_2^V}{p_1}, \qquad \frac{\partial f_1\left(x_1^1, x_1^G, x_1^V, x_1^N\right)}{\partial x_1^N} = \frac{p_2^N}{p_1}.$$

Since this system of nonlinear differential equations has a quite sophisticated look, it is difficult to investigate analytically its stability. In previous works [2] we have shown the stability of the solution as the results of computer simulation. It is proved that for the some set of identification parameters the solution is stable.

In order to reduce the discrepancy between experimental and numerical development, a parameter automatic identification procedure from rheological test is formulated as an inverse problem. The direct model, which permits to simulate the large strain behaviour during the rheological test, is a Finite Element Code [5] The inverse problem is formulated as finding a set of rheological parameters starting from a known constitutive equation. The goal is to compute the parameter vector which minimizes an objective function representing, in the least square sense, the difference between experimental and numerical data. The high nonlinearity of the problem to be solved requires the use of an accurate evaluation of the sensitivity matrix by analytical differentiation of governing equations with respect to the parameters.

Identification system parameters are chosen as a solution of inverse problem. This means that projected solutions of the system should be to some extent similar to the real dynamics of the appropriate values of Ukraine in the last 10 years.

Based on the above statements the identification parameters of the system model are defined: b_1, b_2 – capital intensity per unit (for the first and second sector, respectively); μ_1, μ_2 – the rate of disposal capacity due to deterioration of assets; λ – growth rate of labour supply; δ – time constant which characterise the relaxation of changes in the share of investment; p_E – the price of energy; μ_1^*, μ_2^* – write-off rate of production equipment; k – price of gold (or currency) in gross domestic product; ξ^* – provision of bank reserves; Δ – time scale wages in the labour market; η – cost of gross domestic product, consumed by the owners; c^L – energy consumption per unit of product 1st sector.

Conclusions and further researches directions. In this article we investigated the problem of defining identification parameters for system model for energy dependent economics, which can be modelled by systems of partial differential equations. System identification system parameters are chosen as a solution of inverse problem. After defining parameters, this model enables the mathematical description of the entire economy as a whole, that is, change in any input would change all the original results.

That is system model allows someone to build the system forecasts, make certain assumptions about the economy over time, check the results of the theory in the system, not on the real economy (use simulation modelling).

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ПРОБЛЕМА ІДЕНТИФІКАЦІЇ ПАРАМЕТРІВ ЕНЕРГОЗАЛЕЖНОЇ ЕКОНОМІКИ

Гайдучок Олена Василівна
кандидат економічних наук, доцент, доцент кафедри прикладної математики, Національний університет "Львівська політехніка", Україна

Описано системну модель двохсекторної економіки, у якій виділяється енергетичний сектор. Виробництво поділяється на два сектори - перший сектор виробляє кінцевий продукт, а другий сектор - енергію, необхідну для отримання кінцевого продукту. Змодельовано потудності енергетичного сектору. Отримано системну модель енергозалежної економіки у вигляді системи диференціальних рівнянь. Описано алгоритм для визначення параметрів ідентифікації. Наведено параметри керування системною моделлю для основних макроекономічних показників.

Ключові слова: *система модель двохсекторної економіки, система диференціальних рівнянь, параметри керування.*

ПРОБЛЕМА ИДЕНТИФИКАЦИИ ПАРАМЕТРОВ ЭНЕРГОЗАВИСИМОЙ ЭКОНОМИКИ

Гайдучок Елена Васильевна
кандидат экономических наук, доцент, доцент кафедры прикладной математики, Национальный университет "Львовская политехника", Украина

Приведена системная модель двухсекторной экономики, в которой выделяется энергетический сектор. Производство делится на два сектора - первый сектор производит конечный продукт, а второй сектор - энергию, необходимую для получения конечного продукта. Смоделирован мощности энергетического сектора. Получена системная модель энергозависимой экономики в виде системы дифференциальных уравнений. Описан алгоритм для определения параметров идентификации. Приведены параметры управления системной моделью для основных макроэкономических показателей.

Ключевые слова: *системная модель двухсекторной экономики, система дифференциальных уравнений, параметры управления.*