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Structural management models of technological innovations

Vladislav Gusev*

Institute of Control Sciences by V.A. Trapeznikov of the Russian Academy of Sciences, 65, Profsouznaya str., Moscow, 117997, Russia

Abstract. In order to define the parameters of structural innovations of the technological core of the economic system, a formalized criterion of the effectiveness of these innovations has been proposed, a model of the technological core has been developed, as well as mathematical methods of its analysis. The developed model uses the cross-sectoral balance sheet of the national accounts of the economy. The analysis of the model consists in calculating the preferred structure of the technological core and calculating plans for its phased development.

1 Introduction

The development of the economic system over the long term is always linked to qualitative changes in the composition and organization of its basic component, the technological nucleus, which includes all significant economic activities and changes. While the traditional economy has the characteristic of sustainability, the development process has been unsteady. Innovation is a prerequisite for development. For example, according to Joseph Schumpeter [1], a useful innovation or technology, while gaining popularity, initially unsettles the system, allowing for the greatest profit until it reaches the whole system, when there is a new equilibrium state at which profit becomes minimal. And that brings new innovation, and so on.

Innovation can range from the introduction of new technologies based on previously unknown phenomena and principles to structural changes in the technological core within existing, traditional technologies. The latter type of innovation is possible when the proportions of economic activities do not provide sufficient macroeconomic indicators, such as those of comparable but more successful countries. In this sense, one can speak of the imbalances of the technological core. In addition to comparative analysis, these imbalances can be determined by analyzing the mathematical model of the technological core of the economy and determining its optimal structure.

The introduction of structural innovation is countered by the stability of the established structure of the technological core. This sustainability is due to the routine nature of business, the absence or inefficiency of large-scale investment projects. Overcoming the persistence of existing imbalances and moving towards a more forward-looking structure requires certain structural innovations supported by project investment activities. As a result of their implementation, the system becomes a new stable state with preferred macro characteristics.

Defining the parameters of the structural innovations of the technological core of the economy requires formalizing the criterion of the effectiveness of these innovations, developing a model of the technological core, as well as mathematical

* Corresponding author: gusvbr@mail.ru

methods of its analysis. The model is consistent with the System of National Accounts and is based on a cross-industry balance sheet. The analysis of the model consists in calculating the preferred structure of the technological core and determining the parameters of the stability of its states.

2 Materials and Methods.

2.1 Structural Innovation Performance Indicators

The effectiveness of structural innovation can be measured by the relative value added of these innovations per unit of direct cost. This makes it possible to use as a measure of the efficiency of the technological core of the economy; its productivity - the share of value added per unit of direct cost. Using a closed-loop input-output model of the Leontiev type [2], the productivity of the technological core of the economic system shall be determined by analogy with the efficiency factor in the technique as $\pi = Y/Z$, where Z is the intermediate input, Y is the value added (GDP), V - gross output. Denote material intensity $a = Z/V$, gross output $V = Y + Z$. Then:

$$\pi = (V-Z)/Z = 1/a - 1.$$

Since different states of the economic model have different levels of productivity, the choice of the most productive model can be considered.

The productivity potential of the technological core of an economic system is defined for the economic model as:

$$\pi^{*} = \max_{V,Z} \pi .$$

The multipurpose production model [3] defines the output multiplier (the indicator of the productivity of the economic system) as a function of the structural proportions of output and prices of output and service industries. The maximization of this output-to-input ratio determines a balanced output-to-price structure that corresponds to a reproduction regime, where growth shares for all products and services are the same.

It is assumed that Z_{ij} is the direct input of industry j on output of type i products or services, V_j is the output of products and services of type j. On the basis of these data a_{ij} - the coefficients of unit input are calculated:

$$a_{ij} = Z_{ij} / V_j ,$$

which form a process matrix A.

The input-output model can be represented by the following ratio:

$$Z_i(t) = \sum_{j=1}^{n} Z_{ij} = \sum_{j=1}^{n} a_{ij} V_j(t),$$

or

$$\mathrm{Z} = \mathrm{AV} ,$$

from where the stationary reproduction process can be represented by a ratio:

$$V_i(t) = \gamma_i \sum_{j=1}^{n} a_{ij} V_j(t),$$

where γ_i is a multiplier of the output of the industry i, which denotes the excess of industry output over inputs. Denote γ - the minimum by industry multipliers:

$$\gamma = \min_i \gamma_i .$$

The formulation of the optimization problem for the output structure vector V with the minimum output multiplier maximum criterion γ is as follows:

$$\max_{V_i} \gamma$$

with technological restrictions on production:

$$\mathrm{V} \geq \gamma \mathrm{AV} .$$

This task allows defining the equilibrium system of releases.

In target setting, when final consumption, exports and accumulation are formally part of an activity, the stationary regime allows a change in the share of output in those areas. Otherwise, the values $\gamma_i - 1$ are the shares of output of industries used for final consumption, exports and savings. To maintain these shares equal to the reference values $\overline{\gamma_i} - 1$, where:

$$\overline{\gamma_i} = V_i(t0) / \sum_{j=1}^{n} a_{ij} V_j(t0) / \max_j \gamma_i$$

the optimization problem for the release structure will take the form of:

$$\max_{V_i} \gamma,$$

with condition

$$V_i(t) \geq \gamma \cdot \overline{\gamma_i} \sum_{j=1}^{n} a_{ij} V_j(t), \text{ or}$$

$$\mathrm{V} \geq \gamma \overline{\mathrm{A}} \mathrm{V} ,$$

where

$$\overline{\mathrm{A}} = \mathrm{diag}(\overline{\gamma}) \mathrm{A} .$$

Statement 1. If the matrix A is square, the solution to the problem of finding an equilibrium output system is its eigenvector.

The release growth condition is:

$$\mathrm{V}(t) \geq \mathrm{V}(t-1) .$$

The measure of productivity can be derived from this objective as:

$$\pi = \gamma - 1$$

and represents the share of value added in the value of intermediate consumption under the equilibrium technological development of the economic system. In equilibrium mode we have:

$$a = 1/\gamma .$$

Computation of the eigenvector of the matrix corresponding to the maximum eigenvalue λ, which ensures the stable equilibrium state of the technological core, can be done by the iterative method.

Statement 2.

Let A be a non-negative matrix whose maximum modulo eigenvalue is λ, |λ|<1. The eigenvector x of this matrix satisfies the equation:

$$A\,x = \lambda\, x.$$

The eigenvector x with a modular maximum eigenvalue is searched by an iterative procedure:

$$\lambda^k = \|Ax^k\| / \|x^k\|,$$

$$x^{k+1} = \lambda^k A x^k$$

where k is the iteration number. Procedure breakers are conditional by

$$\|x^{k+1} - x^k\| < \varepsilon,$$

where ε is the given computational accuracy (ε=0.001). The eigenvalue λ of A is estimated as:

$$\lambda = \lim_{k\to\infty} \lambda^k$$

and the eigenvector x

$$x = \lim_{k\to\infty} x^k.$$

This result shows that the inertial process of reproduction of the technological nucleus has a stable equilibrium with a fixed point equal to the eigenvector x .

2.2 Method of evaluation new technologies by productivity index

Since

$$V_i(t) = Z_i(t) + C_i(t) = \sum_{j=1}^{n} a_{ij} V_j(t) + C_i(t),$$

where $C_i(t)$ is the final consumption of the service , the unit cost factors are calculated by the formula

$$a_{ij} = Z_{ij} / V_j = Z_{ij} / (Z_j(t) + C_j(t)).$$

The new technology with number ν adds to the cross-sectoral balance sheet:

- a new line of its costs for other services and industries;
- a new column of this technology in other industries and final consumption.

Then the performance criteria of the new technology will be the fulfillment of inequalities:

$$\pi^{\nu}(t) \ge \pi(t),\ t = 1,2,..,T.$$

$$\pi^{\nu}* > \pi*$$

2.3 Conversion of Output Indices

When the output volumes change, the unit cost estimates a_{ij} change too. In order to capture the results of the change the volumes V_i in the previous cycle, the direct cost factors are converted:

$$\overline{a_{ij}} = a_{ij} \cdot V_i / V_j$$

The transformation operations of the process matrix in current prices to the matrix in relative prices and vice versa are considered.

We denote D – diagonal matrix with diagonal $V_1, V_2, .. V_n$:

$$D = \mathrm{diag}(V);$$

C is a diagonal matrix with a diagonal $1/V_1, 1/V_2, .. 1/V_n$;

then $\overline{A} = DAC$.

Statement 3. If all $V_i \ne 0, i = 1,..,n$, then a transformed matrix with coefficients $\overline{a_{ij}} = a_{ij} \cdot V_i / V_j$ has the same eigenvalue as matrix A, and the eigenvector is equal to the original one up to the multiplier D .

Let us call this process matrix transformation D a deformation transformation. To move to the prices on a relative scale (in proportion to the prices), the eigenvector of outputs V^0 on an absolute scale is used by deforming the process matrix:

$$A^1 = C^0 A^0 D^0, \text{ where } D^0 = \mathrm{diag}(V^0),\ C^0 = (D^0)^{-1}.$$

In this case, the eigenvector of the process matrix becomes unit after deformation. The eigenvalue will be maintained and the eigenvector $v*$ of the matrix A^1 in relative scale can be converted to absolute scale by conversion:

$$V* = \mathrm{diag}(V^1)\, v*.$$

In the calculation of values V_i , the values are interpreted as volume indices of the services to be performed, and the limitations on them in the assumption of non-discharge are in the form of

$$V_i(t) \ge 1, i = 1,...,n.$$

2.4 Indicative projection of structural innovation

It is not possible to instantly implement a change in the structure of the releases, making them equilibrium. In order to determine the most rational plan for the development of the industry, the following local objective may be used:

$$\max_{V_i} \gamma,$$

technological restriction on production:

$$V_i(t) \ge \gamma \sum_{j=1}^{n} a_{ij} V_j(t),$$

and the condition $\theta > 1$ of the output growth at a rate of one stroke:

$$V_i(t) \le \theta \cdot V_i(t-1), i = 1,...,n.$$

By repeating the procedures for finding an optimal solution and converting the matrix of direct costs from tact to bar, we get an indicative multi-stage plan-forecast of the joint development of branches of the technological core of the economy. The indicative plan calculation procedure uses absolute and relative output values. If V^1 - current price vector, then in the first step the process matrix deformation is used to shift to relative output v^1 :

$$A^2 = \mathrm{diag}(V^1)^{-1} A\, \mathrm{diag}(V^1),$$

the corresponding conversion is reversed for intermediate computing v :

$$V = \mathrm{diag}(V^1)\,v\,.$$

Then the problems of finding a vector of relative volumes of output are solved:

$$\max_{v^i} \gamma$$

with technological constraint:

$$v^k \geq \gamma^k A^k v^k,$$

and the condition of relative output growth $\theta, \theta > 1$ at one stroke rate:

$$I \leq v^k(t) \leq \theta \cdot I,\ k = 1,2..,$$

where I is the unit vector. Then the following statements can be used to calculate the indicative projection plan for joint industry development.

Statement 4. The sequence V^i for a finite number of bars goes to the proper vector of process matrix A, and the evaluation γ^i goes to the proper number of that matrix.

Note. When converting process matrix A with matrix deformation $D = \mathrm{diag}(v^*)$, the solution to the planning problem becomes trivial: $v = cI$, where $c \geq 1$. That is, when achieving technological equilibrium, the structure of the output does not change further.

Statement 5. If there is a solution to local problems at $i \geq 1$, the quantity of indicative releases in absolute units of the following type can be obtained:

$$V^i = \prod_{j=i}^{1} \mathrm{diag}(v^j) \cdot V^0\,.$$

Statement 6. If for all steps the coefficient is constant, the relative increase in output from a certain clock becomes equal. This property is similar to the central property of optimization models of economic dynamics [4].

If x - the resulting eigenvector, then for y≠x the value of the estimate $a = \|Ay\| / \|y\|$ can be reduced, this corresponds to an increase in the productivity estimate π.

In order to find an output vector that maximizes the productivity of the technological kernel, we will apply a gradient descent procedure. Let A be a positive matrix with non-negative components. Express material content *a = Z/V* in terms of the technology nucleus model:

$$a = \frac{\|Ax\|}{\|x\|},$$

where the vector norm is calculated as the average:

$$\|x\| = \sum_{i=1}^{n} x_i / n\,.$$

Productivity assessment can be presented as:

$$\pi = 1/a - 1\,.$$

Statement 7.

We denote I - unit vector, E - diagonal unit matrix, h - step value, Minimization procedure:

$$\min_{x_0 \leq x \leq x_1} a(x)\,.$$

The gradient descent method is:

$$x^{k+1} = \max(x_0, x^k + h\frac{(aE - A^T)I)}{\|x\|},$$

where k is the iteration number.

The choice of the step h determines the speed of convergence of the process: the more it is the greater the speed of convergence. However, infinite enlargement does not accelerate convergence.

The process of optimizing the output structure produces a sequence of incremental assessments of the productivity of the technological core, accompanied by a sequence of increments in the output of certain industries. At the same time, the increase in output from other industries does not lead to an increase in productivity assessment. The rate of convergence depends on the size of the step h: first, when the step is increased, the speed is increased.

2.5 Expenditure accounting for non-critical, but significant industries

We consider a list Ξ of activities of significance for the state, but with small values of equilibrium indices of output and not belonging to the whole «bottleneck» (non-critical, relevant branches: science, culture, social sphere, safety, ecology): $i \in \Xi$.

An additional constraint to the indicative planning task is:

$$V_i(t) \geq \xi_i V_i(t-1),\ i \in \Xi,\ 1 \leq \xi_i \leq k\,.$$

Fig. 1 shows the dependence of the output of the three branches (computing, communications, education) on the cost of research with the optimal output distribution.

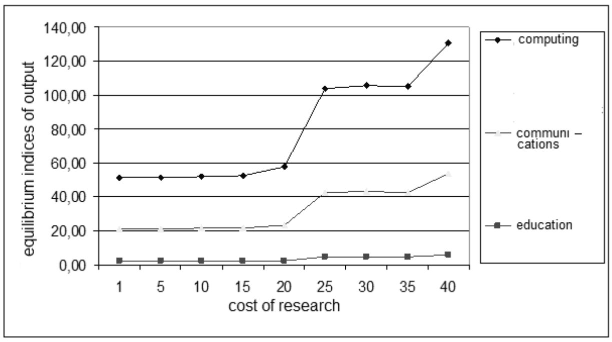

Fig. 1. Impact of research expenditure on technological equilibrium

This correlation shows that the multiplication of research costs across a wide range has little impact on the equilibrium of inputs and outputs in other industries. The swings at the 20 and 35 levels are explained by the reserve of the industry's imperfections and by the fact that only a 20- and 35-fold increase in the cost of science, respectively, could change the structure of other industries output and require a further increase in the gross output of the economy as a whole.

3. Results. Calculation of the projection plan

The following is a graph of the evolution of the productivity factor of the technological core in the balancing of output at successive stages of indicative planning, where the lower bound of the ratios of output was 1 and the upper limit of the variation in the ratios of output was $\Delta\theta = 1.5$ to the stage.

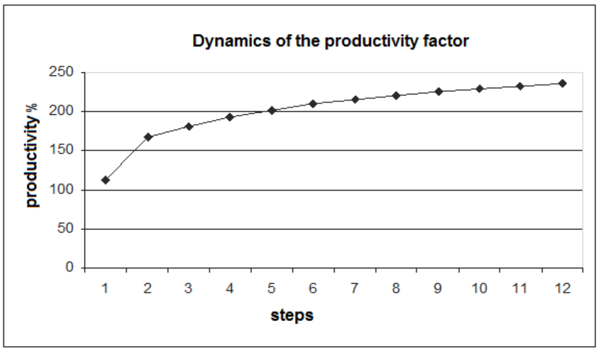

Fig. 2. Changes in the productivity factor of the technological core by optimizing the production proportions at successive stages of indicative planning.

The following is a graph of the indicative development of the proportions of output of some industries in solving the problem at successive stages of indicative planning for data on the Russian economy.

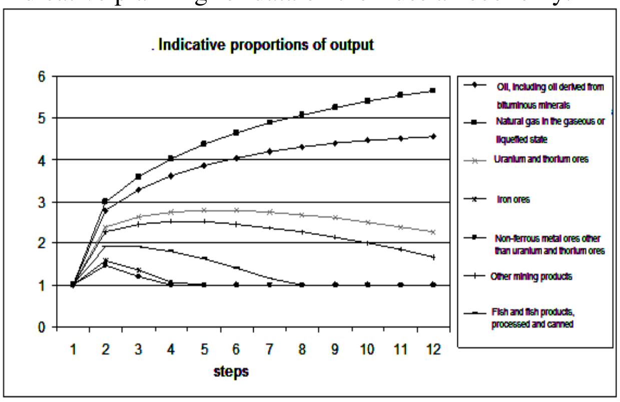

Fig. 3. Indicative development of proportions of output of some industries at successive stages of indicative planning for data on the Russian economy.

Figures 2 and 3 demonstrate the central characteristic of the [4] development model of the technological core of the Russian economy, namely, that output reaches a constant level with sufficient time of operation.

Conclusion

Despite its high potential for development, the modern economy of the Russian Federation is facing crisis phenomena. At the macro level, these include low GDP growth, the economy's critical dependence on oil and gas exports, exchange-rate volatility and undervaluation, a small share of manufacturing, dependence on external sanctions, and poor governance. These factors contribute to the under-realization of the potential of the technological core of the economy [5]. The results show the possibilities for improving the economy's efficiency, based on a gradual change in the structure of its technological core. Based on Rosstat's data, possible growth in economic productivity could be more than doubled. The practical realization of this possibility should be linked to the formulation of strategic plans for the development of the economy. And, in addition to the selection of priority areas for the development of the technological nucleus, it requires the application of adequate methods for forecasting multisectoral dynamics. This takes into account all major aspects of economic activity: stock formation, accumulation, final consumption of the State and households, export-import flows [6, 7]. Planning at a new level also involves appropriate institutional arrangements [8].

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