MODELING TECHNOLOGICAL RELATIONS IN THE STRUCTURE OF PRODUCTION

УДК 330.42

Vladimir P. Bozhko,
Doctorate of Economic Sciences, Professor, Moscow State University of Economics, Statistics and Informatics (MESI), Statistics and Informatics
Tel: (499) 141-28-87
E-mail: vbogko@mesi.ru

Alexandr M. Batkovsky,
Doctorate of Economic Sciences, expert, the Analytical center under the Government of the Russian Federation
Tel: (495) 940-65-05
E-mail: batkovskiy_a@instel.ru

Mikhail A. Batkovsky,
PhD in Economics, senior Researcher, the Federal state unitary enterprise «MNIIRIP»,
Tel: (495) 586-17-56
E-mail: batkovsky@yandex.ru

Alexandr N. Stiazkin,
PhD in Economics, Head of Research Division of JSC «Central Research Institute «Electronics»
Tel: (495) 940-65-85,
E-mail: stiazkin_a@instel.ru

This article describes a problem-oriented approach to the modeling of technological linkages in the structure of the production of the high-tech enterprises complex. The models of evaluation of data communications in failure and uncertainty of the initial information systems for management decision making in the operation of the strategic development of high-tech complex are developed.

Keywords: production, technological relations, operation, modeling.

Владимир Петрович Божко,
д.э.н., проф., Московский государственный университет экономики, статистики и информатики (МЭСИ)
Тел.: (499) 141-28-87
Эл. почта: vbogko@mesi.ru

Александр Михайлович Батьковский,
д.э.н., эксперт, Аналитический центр при Правительстве РФ
Тел.: (495) 940-65-05
Эл. почта: batkovskiy_a@instel.ru

Михаил Александрович Батьковский,
к.э.н., ведущий научный сотрудник, ФГУП «МНИИРИП»
Тел.: (495) 586-17-56
Эл. почта: batkovsky@yandex.ru

Александр Николаевич Стяжкин,
к.э.н., начальник отделения «ОАО «ЦНИИ «Электроника»
Тел.: (495) 940-65-85
Эл. почта: stiazkin_a@instel.ru

МОДЕЛИРОВАНИЕ ТЕХНОЛОГИЧЕСКИХ СВЯЗЕЙ В СТРУКТУРЕ ПРОИЗВОДСТВА

В статье рассмотрен проблемно-ориентированный подход к моделированию технологических связей в структуре производства предприятий высокотехнологичного комплекса. Разработаны модели оценки данных связей в условиях недостаточности и неопределенности исходной информации, предназначенные для выработки управленческих решений в процессе управления стратегическим развитием высокотехнологичного комплекса.

Ключевые слова: производство, технологические связи, управление, моделирование.

1. Introduction

The main qualitative and quantitative characteristics of the process of expanded reproduction of innovative high-tech products of the high-tech complex (HTC) are interconnected, constantly changing over time and are not always subject to formalized description because of the influence of the environment, uncertainty and risk. In most papers on strategic management of HTC, there is no comprehensive, science-based and practical and feasible tool of management, as some of its elements are designed as a general rule, at the conceptual level, are fragmented and not fully take into account the technological links in the production structure. These circumstances significantly reduce the scientific validity and practical value of the existing tools of strategic management and pose serious problems in the course of its use in the development of federal programs and strategies for the development of industries HTC.

2. The urgency of the problem

Currently, the economic theory there are four main factors of economic growth:

– increasing the available economic resources;

– forcing people to excessively hard work to the detriment of their health and needs;

– ways to improve the allocation of scarce resources;

– improvement of production technology in order to reduce the consumption of resources and producing the same volume of a large number of finished goods (products and services).

The first factor corresponds to the type of extensive growth of the economic system, the second factor is the basis of non-economic way to ensure its growth, and the third and fourth factors form the basis of its intensive growth. At the heart of the extensive economic growth of the system is used by a build-up of resources and involvement in the production of traditional, often obsolete, technology. Strong economic growth of the system is based on the introduction of a fundamentally new, more advanced technologies, methods of organization and management, more efficient use of its innovative capacity.

Most of the economic activities that in the developed countries are high technology in Russia fall into the group of medium-tech low level, indicating a low technological development of the Russian industry and the lack of investment in the development of high-tech in our country.

While highly developed countries spend a significant portion of the total revenue for the development of new products and technologies (for example, in Germany, the USA, Japan and some other countries it is approximately 3% of GDP), in our country research intensity of GDP declined from 3.7% in 1990 to 1.1% currently. This is due to the fact that in the nineties of the last century, the main focus of the investment policy of Russia was the development of export-oriented production (of the fuel and raw materials complex and production of so-called redistribution).

The basis of the economic growth of our country in this period was the rent of natural resources, which provided at least 75% of net profit. Held in Russian innovation policy was not effective because was largely declarative. It was based on the introduction of pseudo – (modification of previously developed products and technologies) and microinnovatives. The government pursued a “raw” model of economic development, which has led to a sharp increase in the dependence of economy’s Russia on world prices for oil and gas, manufacturing lagging compared with the dynamics of GDP, as well as a slowdown of technological progress in the country.

The article was developed with the financial support of RFBR (№ 14-06-00018, № 14-06-00028, № 14-06-31133).

As a result, if the U.S. share of the global knowledge-based sector has increased since 1992 from 28.1% to almost 40%, the share of Russia in this period fell from 7.3% to 1.2%. Obtaining natural resource rents, Russia began to pay more "intellect" rent to countries exporting high-tech and innovative products, as our country imported more than 90% of the necessary high-tech products (some of its species) [1].

Economic development priorities of Russia in XXI century, was the need to shift emphasis from the primary sector of the economy to increase the share of high-technology and high-tech products in total output, set first the goal of accelerated development of the high-tech complex, which is the "engine" of innovative modernization of Russia.

These circumstances require decomposition of the problem of strategic management HTC by allocating a number of private, logically interrelated problems whose solutions are the stages of management. In the process of modeling of these problems, a new object-and task-oriented economic and mathematical tools for managing reproduction of the advanced innovative products HTC is developed. It provides the ability to perform real-time multiple calculations to generate optimal management decisions in the formulation and implementation of strategies and long-term programs for the development of high-tech complex, its branches, integrated structures and enterprices. The most important element of these instruments is the models and algorithms for the evaluation of technological connections in the structure of production.

3. Economic-mathematical tools for technology connections in the structure of production

The greatest uncertainty in the management of advanced innovative products reproductions of HTC have structural and technological changes, described by the vector of final products $Bk(t)$ and a matrix of technological links between its branches (sub-branches, integrated structures, businesses) $\|z_{ij}\|_t$.

Therefore, to analyze the process to be used economic and mathematical models that identify important factors that determine the patterns, and on this basis to predict the expanded reproduction of products. Economic and mathematical models of reproduction – is homomorphic mapping it into a set of equations, inequalities, logical relations, graphs.

Data show combined elements of the relationship of the reproduction process of production, and present them in the form of a similar relationship of elements of his models. Naturally, the simulation results of the process are hypothetical in nature, despite the extensive use of real information. Therefore, they can be used as a guideline, which express the general natural tendency changes the output parameters of the process of reproduction products created HTC.

Technological structure of the production process is described by a matrix of coefficients $\|z_{ij}\|_t$, that take into account the technological links between the sectors, sub-sectors, companies, enterprises of high-tech complex and their changes that have diverse character.

Given the accelerated replacement of core technologies in HTC during its innovative modernization, it is advisable to use the matrix $\|z_{ij}\|$ in the calculations for the future only to three years, as Information about the coefficients z_{ij} «late» for several years. Therefore, from our point of view, the solution of the problem need to use a probabilistic approach. Apply with some methods for correcting the «outdated» technology factors (feasibility design, factor, statistical corrections, etc.) is not appropriate because they require a cross-sectoral balances for the previous time periods. In addition, the correction methods are not designed for significant changes in the structure of the final product vectors and technologies.

Various methodological approaches to accounting for uncertainty in the matrix of technological coefficients $\|z_{ij}\|_t$.

The simplest is to use matrixes $\|z_{ij}\|_t^{max}$, $\|z_{ij}\|_{t_{min}}^{min}$, $\|z_{ij}\|_{t_0}^{l}$, where $\|z_{ij}\|_t^{max}$ and $\|z_{ij}\|_t$, – matrixes with the maximum and minimum possible values of the coefficients, and $\|z_{ij}\|_{t_0}^{l}$ – matrix used in decision making. In this case, you can use the value of λ, which characterizes their differences and assigned (determined) by an expert. Then:

$$\|z_{ij}\|_t^{max} = (1 + \lambda_t)\|z_{ij}\|_{t_0}^{l} \text{ and}$$

$$\|z_{ij}\|_t^{min} = (1 - \lambda_t)\|z_{ij}\|_{t_0}^{l} \qquad (1)$$

In view of the multiplicity of interacting factors that can not be accurately taken into account, it can be assumed that the technological coefficients $\|z_{ij}\|$ are random variables and are subject to certain laws of distribution. Then the definition of the distribution of the output parameters of the models of the process involves the use of the distribution of probabilities for $\tilde{n}^2$ elements of matrix $\|z_{ij}\|$ with dimension $(\tilde{n} \times \tilde{n})$.

Finding the type and parameters of the laws of the relevant multi-dimensional probability distribution $\|z_{ij}\|$ is very difficult for matrixes $(\tilde{n} \times \tilde{n}) \leq 5$ even with simple (one-parameter) laws of distribution technological factors. Therefore, it is advisable to use the formula of finding mathematical expectation $M[z_{ij}]$, variance $D[z_{ij}]$, and mean-square deviation $\sigma[z_{ij}] = \sqrt{D[z_{ij}]}$, in the absence of a compelling reason for the choice of any specific density distribution of random variables z_{ij}. In this methodical approach to accounting for changes $\|z_{ij}\|_t$ in material change in production technology major challenge is to define the upper and lower bounds for z_{ij}.

We use the expression, according to which possible changes in accounting limits of each element of technological matrix $\|z_{ij}\|_t$:

$$\Delta z_{ij} \leq \frac{\Delta \nu / \nu_i}{(\max b_{ik}/\nu_i) * \nu_l + \Delta \nu_i / \nu_i * b_{ik}}, \qquad (2)$$

where: Δv_i – the change in the gross output of the i-th defense industry in capacity level of production; $\|y_{ik}\|_t = \|E^M - z_{ik}\|_t^{-1}$ – the inverse matrix of technological factors; $\|E^M\|$ – identity matrix, b_{ik} – parameters of the equation.

Then, in the case of a uniform distribution law, you can use the following expression for the mathematical expectation and variance of technological factors:

$$M[z_{ij}] = \frac{\underline{z}_{ij} + \overline{z}_{ij}}{2} \qquad (3)$$

$$D[z_{ij}] = \frac{(\underline{z}_{ij} - \overline{z}_{ij})^2}{12} \qquad (4)$$

$$D[z_{ij}] = \frac{(d_{ij})^2}{3} * (M[z_{ij}])^2, \qquad (5)$$

where: $d_{ij} = \dfrac{\overline{z}_{ij} - M[z_{ij}]}{M[z_{ij}]} = \dfrac{M[z_{ij}] - \underline{z}_{ij}}{M[z_{ij}]}$;

$\underline{z}_{ij}, \overline{z}_{ij}$ – lower and upper bound values of technological factors.

Choosing a uniform distribution law z_{ij} can be seen as a pessimistic variant, which determines much longer intervals spread of the output parameters of the process models at regular intervals spread of the initial information. Thus, the application of the Act of distribution z_{ij} creates «hard» real terms since should refuse the registration of preference (in terms of the probability density differences), some values z_{ij} in the interval $(\underline{z}_{ij}, \overline{z}_{ij})$ in front of other technological values of the coefficients. As an optimistic version of the variant that takes into account the assumption of a lower density of probability for large deviations z_{ij} on $(\underline{z}_{ij}, \overline{z}_{ij})$. For this case, you can use the beta probability distribution with density $H_{\alpha,\beta}$ for the deviations (z_{ij}):

$$H_{\alpha,\beta}(z_{ij}) = \frac{G(2+\alpha+\beta)}{G(1+\alpha)G(1+\beta)} *$$

$$* \frac{(z_{ij}-\underline{z}_{ij})^{\alpha}(\overline{z}_{ij}-z_{ij})^{\beta}}{(\overline{z}_{ij}-\underline{z}_{ij})^{1+\alpha+\beta}}, \qquad (6)$$

where: $G(l)=\int_0^{\infty} y^{l-1}e^{-y}dy$ – tabulated gamma function; α and β –parameters of the distribution, and $\alpha > 0$ and $\beta > 0$.

In this case, the numerical characteristics beta-law distribution determined according to the following expressions:

$$M[z_{ij}] = \frac{1+\alpha}{2+\alpha+\beta}\overline{z}_{ij} + \frac{1+\beta}{2+\alpha+\beta}\underline{z}_{ij} \quad (7)$$

$$D[z_{ij}] = \frac{(1+\alpha)(1+\beta)}{3+\alpha+\beta} * \frac{(\overline{z}_{ij}-\underline{z}_{ij})^2}{(2+\alpha+\beta)^2} \quad (8)$$

$$\sigma[z_{ij}] = \sqrt{D[z_{ij}]} \qquad (9)$$

Modal value z_{ij}, that z_{ij}^M is to be found by the formula:

$$z_{ij}^M = \frac{\alpha}{\alpha+\beta}\overline{z}_{ij} + \frac{\beta}{\alpha+\beta}\underline{z}_{ij} \qquad (10)$$

Beta-law distribution is given by Karl Pearson first type curve and how private limiting cases include normal, uniform, exponential, and other laws of distribution of random variables. Heuristic rationale for the choice of beta-distribution law for estimating the level of uncertainty in the technological structure of the “perturbed” reproduction innovative products linked to the concept of random variables with this law distribution on the interval (0, 1) by the following relationship:

$$\Xi = \frac{\sum_{i=1}^{m} W_i^2}{\sum_{j=1}^{m+l} W_j^2} \text{ or } \Xi = \frac{\sum_{i=1}^{n} S_i}{\sum_{j=1}^{n+l} S_j}, \qquad (11)$$

where: W_i – independent normally distributed random variables; S_i – independent random variables exponentially distributed with density $H(S) = e^{-S}$ when $S \geq 0$. or $H(S) = 0$ when $S < 0$.

However, the determination of the interval $(\underline{z}_{ij}, \overline{z}_{ij})$, of mathematic expectation $M[z_{ij}]$ or mode of the distribution law z_{ij}^M still does not allow to determine the parameters α and β of the law. Setting time characteristics $M[z_{ij}]$ and z_{ij}^M is not useful as a symmetrical distribution law beta one of the parameters is arbitrary (α or β). Therefore, you can use the special case of the beta distribution law, the subordinate the rule of “three sigma”, i.e.

$$\overline{z}_{ij} - \underline{z}_{ij} = 6\sqrt{D[z_{ij}]} = 6\sigma[z_{ij}] \quad (12)$$

For a symmetrical distribution law of the expression (12) can be represented as follows:

$$\underline{z}_{ij} = M[z_{ij}] - 3\sqrt{D[z_{ij}]} \qquad (13)$$

$$\overline{z}_{ij} = M[z_{ij}] + 3\sqrt{D[z_{ij}]} \qquad (14)$$

For our case, the characteristics of the distribution law $\underline{z}_{ij}, \overline{z}_{ij}, z_{ij}^M$ and $M[z_{ij}]$ are related as follows:

$$6M[z_{ij}] = \underline{z}_{ij} + 4z_{ij}^M + \overline{z} \qquad (15)$$

From (12) it is evident that the length of the interval $(\underline{z}_{ij}, \overline{z}_{ij})$, as in the case of uniform distribution law determines the variance of z_{ij}. However, for this beta distribution law of the variance is three times smaller than the variance of the uniform distribution law in the same range of values of technological coefficients z_{ij}, which improves the accuracy and reliability of the simulation results.

If we denote by φ the value z_{ij} relative deviations from their mathematical expectations, we obtain expressions for the lower $\underline{\varphi}_{ij}$ and upper $\overline{\varphi}_{ij}$ boundaries of these deviations:

$$\underline{\varphi}_{ij} = \frac{M[z_{ij}] - \underline{z}_{ij}}{M[z_{ij}]}, \quad \overline{\varphi}_{ij} = \frac{\overline{z}_{ij} - M[z_{ij}]}{M[z_{ij}]} \quad (16)$$

Taking into account (16), we obtain the following expression:

$$D[z_{ij}] = \left(\frac{\underline{\varphi}_{ij} - \overline{\varphi}_{ij}}{6}\right)^2 * (M[z_{ij}])^2 \quad (17)$$

Thus, the dispersion $D[z_{ij}]$ is associated with indicators of the relative accuracy of the technological coefficients z_{ij} at the appropriate time interval.

Because of the large dimension of the task may be that individually determine the accuracy values for the elements of the matrix $\|z_{ij}\|_t$ as a whole is not possible, as are computers, time, statistical and other difficulties. In this case, we propose to use the following teaching methods:

– the whole matrix $\|z_{ij}\|_t$ is characterized by a single number, namely, as an indicator of the average relative accuracy φ_{cp} set of its elements. Then, on the basis of the above relationships:

– it is possible to write the following expression:

$$\underline{z}_{ij} = (1-\varphi_{cp})M[z_{ij}] \qquad (18)$$

$$\overline{z}_{ij} = (1+\varphi_{cp})M[z_{ij}] \qquad (19)$$

$$D[z_{ij}] = \left(\frac{\varphi_{cp}}{3}\right)^2 (M[z_{ij}])^2 \qquad (20)$$

$$\sigma = \sqrt{D[z_{ij}]} \qquad (21)$$

– it is possible to limit the partition of the elements of matrix of technological coefficients Ψz_{ij}, where $\left(i, j = \overline{1,n}\right)$, on several subsets $\Psi^{(1)}z_{ij}$, where $\left(i, j = \overline{1,k}\right)$, $\Psi^{(2)}z_{ij}$, where $\left(i, j = \overline{k+1,l}\right)$, $\Psi^{(n)}z_{ij}$, where $\left(i, j = \overline{m+1,n}\right)$, for each of which is determined by the index of average relative accuracy φ_{cp_i}, $\left(i = \overline{1,n}\right)$. Such a condition is fulfiling, given the significance (importance) of each technological factor z_{ij}. In this case it is necessary to conduct a comparative analysis of inter-industry linkages and to identify the most important z_{ij} by their effect on the technological structure of the process of reproduction;

– it is possible to use the ranking of industries HTC, based on the percentage of participation of each of them in the production of the final product. In this case, all elements of the i-th line of the matrix $\|z_{ij}\|_t$ is determined by the value of the index φ_{cp_i}, where $\left(i = \overline{1,n}\right)$.

As an analysis shows of linkages and a number of matrices $\|z_{ij}\|_t$, may be cases where z_{ij} deviate from their mathematical expectations $M[z_{ij}]$ at a sufficiently small values, which is typical, as a rule, for “unperturbed” HTC development (technology does not significantly change, made the same products and etc.). In this case, the specific form of the density distribution for the elements of the matrix $\|z_{ij}\|_t$ has a significant effect on the output parameters of the process models of reproductive management of the complex high-tech products.

Considered methodical techniques allow a few times to reduce the time required for modeling for technology connections in the structure of production, and the results obtained will have acceptable accuracy [2].

4. The timing of the replacement technology used by the enterprise taking into account technological connections in the structure of production

The overall level of technology is independent (external to the enterprise) factor, where as its replacement in the enterprise need to be determined taking into account both external and internal factors. Rationale for the timing (time) change the technology used now an enterprise of HTC, is an important task of managing its development. To solve it is necessary to conduct a comparative assessment of different technologies by defining the transition point the marginal cost of production to a significant change in their volume, taking into account that the cost per unit of output should be created in addition to diminish. Therefore, the calculation of so-called «limit of technology» is based on the definition of the marginal cost of production using different technologies:

$$MC = \frac{TC}{Q}, \qquad (22)$$

where: MC – the marginal cost of production; TC – total gross costs; Q – an appropriate volume of products produced by the enterprise HTC.

At the highest according to the technology used in the company HTC, the nomenclature of its production and the scale of production, the volume of total costs per unit of output, taking into account the stages of product life cycle is minimal. Given the "diseconomies of scale", which is negative from a certain period of time, the consequences of scale, period (time) of the transition to the production costs of a significant change can be defined as follows:

$$X = MC_t - MC_{t+1} > 0 \qquad (23)$$

$$X = MC_{min}, \qquad (24)$$

where: X – the point (point in time) that defines the necessary time to replace the technology in the enterprise of HTC; MC_{min} – the minimum cost; t – point (point in time), corresponding to a certain volume of products manufactured by the enterprise of HTC; MC_t – average variable costs at point t; $t + 1 > t$ – a period of time greater than t.

Therefore:

$$X_r = ATC_t - ATC_{t+1} > 0 \qquad (25)$$

$$X_r = ATC_{min}, \qquad (26)$$

where: X_r – the point (point in time) that defines the necessary time to replace by enterprise of HTC their technologies; ATC_{min} – the average total costs; ATC_t – the average total costs at point t; t – point (point in time), corresponding to a certain volume of products manufactured by the enterprise of HTC; $t + 1$ – a period of time greater than t.

Calculation of points X and X_r subject to the minimum and average values of costs, taking into account technological factors can determine the time of replacement technologies at enterprises of HTC [3].

5. Conclusion

The above methodological approaches, models and algorithms allow a few times to reduce the time required for modeling for technology connections in the structure of production, and the results obtained have acceptable accuracy. Their use in the development of management solutions can improve the scientific validity and optimality of federal targeted programs for the development of high-tech industries complex.

References

1. The development of the theory and practice of business management high-tech complex. / Edited by Avdonin B.N., Batkovsky A.M., Bozhko V.P. – Moscow: MESI, 2013. – 366 p.

2. Batkovsky A.M. Forecasting and modeling of innovative development of economic systems. – Moscow: ontoPrint, 2011. – 202 p.

3. Batkovsky A.M. Management of innovative development of enterprises of radio electronic industry. – Moscow: ontoPrint, 2011. – 248 p.