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System Analysis of the Integration of Innovative Resources of the Leading Enterprises of the Chemical Complex

Arkadiy Bessarabov*, Vasiliy Trokhin, Galina Zaremba, Tatiana Stepanova

R&D Centre "Fine Chemicals", Krasnobogatyrskaya st., 42, Moscow, Russia
bessarabov@nc-mtc.ru

The system and factor analysis of innovation development in leading chemical and petrochemical companies was carried out on the basis of the most significant indicators. This analysis involved the whole ensemble of companies and information aspects (regional, industrial, time and others). For the purposes analysis the Innov-Chem 1.0 analytical information system has been developed. This system is a multicomponent structure consisting of several units. Such a software designing principle enables the addition and deletion of any functions to increase the system flexibility and scalability. The information about innovation activities from 2000 to 2019 collected by 165 leading companies of the chemical and petrochemical industries was used as the database for the studies. Such information about innovation activities is submitted to the Russian Ministry of Industry in annual statistical reporting forms (4-Innovation).

1. Introduction

At the present time, chemical and petrochemical companies of Russia make up one of the basic segments of Russian industry. Their successful functioning in the current market economy needs the active introduction of innovations (Gershman et al., 2017). In connection with this, the goal of this study is the system analysis of the innovation development level achieved by the leading companies of chemical industry in Russia and the dynamics of innovation indicators for the period of 2000 to 2019, as well as the estimation of the main trends of innovations, features, and tendencies of innovation activities. A similar research was conducted 12 y ago (Bessarabov et al., 2009). It used data on innovative development only until 2007. Most of the new publications describe the researches on individual innovative industries (Ribeaux et al., 2020) or innovative products (Rezende et al., 2019). A much smaller number of publications are associated with the innovative development of industry in individual countries. The analysis of the group of countries with transition economies used the Global Entrepreneurship Index (GEI), in which three components relate to innovation: technology absorption, product and process innovation (Komlósi et al., 2019). However, both in this study and in the analysis of industrial development in Ukraine (Gorova et al., 2019) or Russia (Gokhberg et al., 2019), a small number of innovative indicators is considered and information on the chemical industry is lacking. The relevance of this study is due to the fact that at present there are practically no publications on the analysis of the dynamics of the most important innovative indicators of the Russian chemical industry over the past 20 y.

2. Structure of basic innovation development parameters of companies in chemical and petrochemical industries

As the database for the studies, the information about innovation activities from 2000 to 2019 collected by 165 leading companies of the chemical and petrochemical industries has been used. Such information about innovation activities is reflected in annual statistical reporting forms "4-Innovation" (Gokhberg et al., 2019) being submitted to the Russian Ministry of Industry (Figure 1).
Such selection and analysis of the innovation development parameters for companies of the chemical industry was carried out in conditions of uncertainty caused by factors not subjected to strict quantitative estimation that determined the necessary methodological application of the system analysis to these studies. All of the statistical data were systematized and the parameters were associated in groups characterizing various

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aspects of the innovation process (Bessarabov et al., 2009). In order to provide the comparable data from studies of various innovation development characteristics, the average values and calculated parameters were used.

These studies included five main stages: to collect and process the statistical data of corporate innovation activities in chemical industries from 2000 to 2019; to form a set of parameters providing the system analysis of the corporate innovation activities in the chemical industry with the available statistical database; to study the dynamics in the main innovation development parameters; to provide complex analysis of the corporate innovation development parameters for the estimation of the level of innovation development; to reveal the main trends of innovations, features and tendencies of innovation activities, levels of corporate innovation activities, development, and potential.

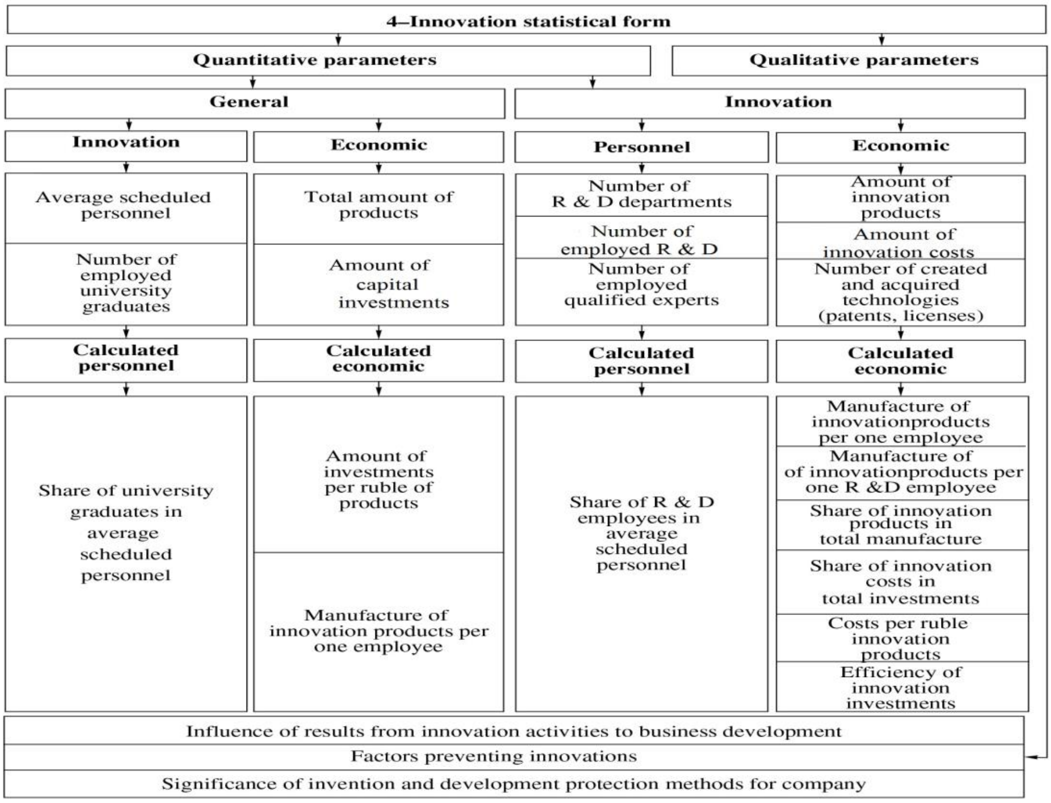

Figure 1: Structure of basic innovation development parameters of companies in chemical and petrochemical industries

As a result of this system analysis, all the direct (4–Innovation statistical form) and calculated parameters at the top hierarchical level were divided into two information groups: quantitative and qualitative (Figure 1). In turn, the quantitative parameters at a lower hierarchical level make groups of general and innovation indicators. Each of these groups is divided into personnel and economic parameters: general personnel parameters include the average scheduled personnel, number of university graduates and research and development (R&D) employees, as well as number of employed qualified experts; among the innovation economic parameters, the objects of analysis in each company included the amounts of investments and innovation costs, volumes of general and innovation products, number of created, acquired, and transferred technologies (patents, licenses) and others.

The comparative analysis of innovation activities used a set of calculated parameters based on mutual dependence and the effect of the following quantitative data: share of university graduates and R & D experts; quantity of innovation products per one employee, university graduate, and R & D expert; shares of innovation products in the total production and innovation costs in the total investments; and parameters of resource consumption for innovation products and the efficiency of innovation investments (Figure 1).

The preventing investments factors have also been considered. For comprehensive study of the innovation processes, the performed analysis included statistical data of administrative organizational changes and the expansion of the product markets, which are not attributed to the technological, but supplementing the general, description of innovations.

3. The system analysis of innovation development in leading chemical and petrochemical companies

The analysis on the current situation of the corporate innovation activities in the chemical industry using the database of “4–Innovation” forms evidences the decreasing innovation activity parameters for recent years. The corporate innovation activity level is usually defined as the ratio of innovatively active (i.e., carrying out any innovation activities) companies to the total number of companies studied for the certain period. While the ratio of innovatively active companies to the total volume of study companies exceeded 75 % in 2005, their number decreased almost by 30 % in 2019 (in 2000, all of the studied companies were innovatively active). The share of shipped innovation products in total volume also showed a trend to decrease from 20 % in 2000 to some 4 % in 2019.

The structural analysis of innovation products showed sharp changes in the category of newly introduced products from 10 % in 2000 to 80 % in 2010. As compared to 2000, the share of upgraded products decreased by more than three times from 62 to 19 % in 2019. The intensity of innovation costs, which is characterized by the ratio of these costs to the value of products shipped by innovatively active companies, decreased from 6.8 % in 2000 to 4.3 % in 2019. The lowest level of this parameter (1.4 %) was recorded in 2010.

In the structure of technological innovation costs (Table 1), the major share was attributed to machine and equipment acquisition costs (68.5 %) in 2019 and to research and development costs (50.1 %) in 2000. For these 10 y, however, the latter costs decreased almost by ten times to 5.2 %. Very insignificant funds were assigned to the acquisition of new technologies and software (0.12 to 1.65 %).

Table 1: Structure of innovation costs by activities

Parameters, %	2000	2005	2010	2015	2019
Research and development of new products	50.10	26.30	12.80	15.30	5.20
Acquisition of machines and equipment	26.40	40.10	53.10	62.30	68.50
Acquisition of new technologies	0.57	0.98	0.21	0.32	0.87
Acquisition of software	0.12	1.49	1.20	1.65	1.52
Industrial design	20.10	17.90	10.80	12.30	24.80
Personnel education and training	0.10	0.49	3.88	2.75	0.35
Marketing studies	0.14	0.30	0.37	0.25	0.05
Miscellaneous innovation costs	2.64	12.40	19.30	6.23	0.55

A company’s own corporate funds comprise the main financing source for the innovation costs. These funds include a part of the net profit and depreciation charges. Therefore, the own resources of a large company take the key role in financing the product updating process. For this reason, these sources are paid the greatest attention for estimation of the corporate innovation capacities. Their share in the total financing volume was 65.7 % in 2019, i.e., lower by 25.5 % than the level of 2000. Their financing from the federal and regional budgets was minimized for these years. At the same time, the funds for corporate innovation activities increased from other sources to 31.7 % in 2019. The share of credits and borrowed funds in the innovation costs increased from 6.7 % in 2000 to 32.2 % in 2019.

Such a decrease in corporate R& D funds was accounted for by the following circumstances:

1. Today, developments are offered to industry at the stage of technical solutions that increases the costs of the introduction and achievement of the required technical and economic characteristics. Over 70 % of inventions are targeted to maintenance and insignificant improvement of the existing technique and technologies. Introduction of such inventions gives companies no long economic effect. Most models of machines and equipment do not comply with the current quality requirements and are not provided with security documents, safety certificates, service and maintenance systems.

2. An important role is taken also by the expressed tendency of companies to the practical realization of innovations and by the relatively low capital intensity of research activities, including low salary of research personnel. This fact is evidenced by the research intensity (defined as the ratio of R & D costs to the total production costs), whose average level in 2019 was only 0.004 for the innovatively active companies in the chemical industry.

By 2019, the general structure of corporate innovation activities underwent some changes as compared to 2000. The number of R & D companies decreased by 19.5 % and the number of those acquiring new technologies decreased by 49.5 %. The number of companies acquiring machines and equipment and providing industrial design decreased by 18.1 % and 6.4 %, respectively (Table 2).

Table 2: Main innovation activities of companies in chemical industries

Number of companies, %	2000	2005	2010	2015	2019
Provided research and development	73.5	65.8	75.0	59.3	54.0
Acquired machines and equipment	60.3	76.3	62.5	64.1	78.4
Acquired new technologies	73.5	39.5	37.5	26.2	24.7
Acquired software	0	36.8	25.0	23.7	29.6
Provided industrial design	29.4	44.7	50.0	39.3	35.8
Provided personnel education and training	23.5	31.6	37.5	29.5	25.1
Provided marketing studies	16.2	31.6	0	12.9	14.7

Note a crucial change in the distribution by innovation types for 20 y. While product innovations (including the development and introduction of technologically new and technologically upgraded products) prevailed in the total volume of innovation products in 2000, practically all the corporate innovation activities in 2019 included the development and introduction of technologically new or significantly improved methods, including product delivery methods.

Analysis of the references to the innovations used by companies in their own activities showed that the most of them refer to the own corporate sources, primarily R & D departments. In addition, they widely use such data sources as product users, exhibitions, fairs, and advertising media. A certain reference role is taken by the current regulations and standards, scientific and technical literature, conferences, seminars, symposia, as well as competitors and other companies of the same industry, providers of materials, equipment, components, and software. In the opinion of company management (as expressed in 4–Innovation statistical forms), research organizations, consulting, and information companies are insignificant sources of innovation data.

For successful realization of their innovation activities, companies of chemical industries have undertaken a series of administrative organizational changes. Most often, companies developed and introduced new or essentially changed organizational structures, applied modern systems for quality control and certification of products (services), organized and improved marketing services, as well as introduced modern corporate administration methods based on information technologies. They provided protection of inventions and scientific and technological works primarily by trademark registration, nondisclosure of commercial secrets, and patenting.

The rating list of results from innovation activities calculated on the basis of the corporate estimated innovation effect to industrial development (Table 3) evidences as follows. The corporate innovation activities produced the most significant effect to retention and expansion of the traditional markets. A high rate of such results as retention of traditional markets is accounted for by strengthening positions of domestic commodity producers in the domestic market promoted by the introduction of import substituting products and improvement of product quality. The effect of innovations on the replacement of obsolete products, creation of new markets, and reduction of salary costs was estimated as insignificant by the administration of companies (Table 3).

Table 3. Rating list of results from innovation activities

Results of innovation activities, %	2000	2005	2010	2015
Improvement of working conditions	0	62.5	46.7	48.3
Reduction of environmental pollution	34.2	87.5	60.4	58.9
Reduction of energy costs	23.7	62.5	47.8	45.4
Growth of manufacturing capacities	0	50.0	72.3	70.1
Enhancement of industrial flexibility	31.6	75.0	69.8	62.7
Creation of new markets in Russia	42.1	75.0	57.2	52.8
Expansion of traditional markets	39.5	100	81.3	79.7
Expanded range of products and services	94.7	87.5	75.9	69.0
Improved quality of products and services	63.2	87.5	80.7	81.6

The results confirm the conclusions given in that the further development of chemical industries is restricted by the following factors: insufficient level of scientific and technological works and industrial introduction thereof, technological backwardness and low competitiveness of manufactured products, strengthening competition in the domestic and foreign markets, disparity of prices and rates for products of natural monopolies, high degree of physical and moral wear of equipment, deficit of investment resources, unstable supply of industry with hydrocarbon precursors (natural and liquefied gas) as the basis for 80 % manufacture of chemical and petrochemical products, and some other factors.

Factor analysis using the Pearson coefficient (Bakulina et al., 2020) allows to estimate the degree of connection between the main types of innovation costs and the results of innovation activities in the field of energy saving and resource-saving. The closest correlation to energy saving was shown for such indicators as "increasing flexibility of production" (correlation coefficient R = 0.78), the amount of expenses for production design (R = 0.61) and "improving product quality" (R = 0.52). This factor also shows the greatest influence on resource economy (R = 0.98). Indicators that have less influence are: «the value of expenses for machinery and equipment (R = 0.72) and "the growth of production capacities» (R = 0.65). The analysis of resource-saving factors on "reducing environmental pollution" was carried out. According to the results of the analysis it was established a correlation of medium strength with a factor of resource-saving (R = 0.71), and a weak correlation with energy saving factor (R = 0.05).
For the purposes of computerized analysis of innovation development in the leading chemical and petrochemical companies, the Innov-Chem 1.0 analytical information system has been developed (Figure 2). The development of algorithms and software was carried out on the basis of the Microsoft Access database management system (Eckstein and Schultz, 2017).

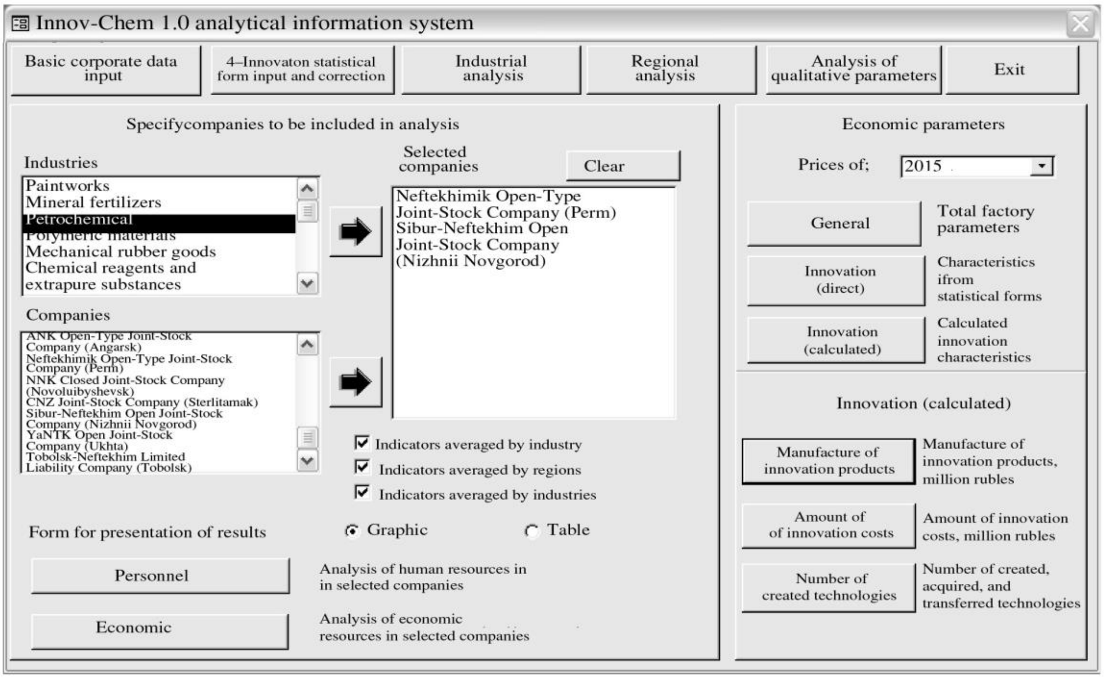

Figure 2: Analytical information system user interface for analysis of information resources of private and public companies in the chemical industry)

This system is a multicomponent structure consisting of several units. Such a software designing principle enables the addition and deletion of any functions to increase the system flexibility and scalability. The logical structure of Innov-Chem 1.0 was built on the basis of principle of maximum abstraction of its components. This approach provides flexibility, adaptability and scalability of the developed system (Date, 2015).
According to the performed functions, the system is divided into three levels: information input, data analysis and visualization. The user interface is also built in accordance with these levels. The general model of the graphical user interface of the system covers all aspects of the use of this computer system, with which the user deals with the input and output of information, the execution of control commands or individual operations.
The Innov-Chem 1.0 graphical interface is based on templates. This means that it is represented by one main form (Figure 2). This main form is a container (template) for all other forms that are subordinate to it. This software realized the mechanisms for analytical data processing, taking into account the features of specific analysis. This system enables the analysis and estimation of the corporate innovation resources by such chemical industries as polymers (Bessarabov et al., 2012), paintworks, phosphate fertilizers (Bessarabov et al., 2010), petrochemical and others. In addition, the innovation indicators can be analyzed with respect to the federal territorial affiliation of companies (subsystem of regional analysis). The subsystem of qualitative analysis considers grades in various information sections: the effect of results from information activities to corporate development, factors preventing innovations and others.

4. Conclusions

The assessment of the degree of connection between the main types of costs for innovation and the results of innovation activities has been carried out. Further research in this area will make it possible to develop an optimal strategy for the development of enterprises.
New data on the dynamics of innovative development make it possible to assess the potential of the chemical industry. This can serve as the basis for the tax and investment policies of the relevant government agencies.
The results of this computerized analysis showed that the effect of the scientific and technical component in the corporate innovation resources for the studied period (2000 to 2019) remained insufficient because the innovation processes of the recent years were not practically targeted to the improvement and enhancement of the competitiveness of the manufactured products (main parameters of development in innovation sphere fluctuated at a rather low level). Therefore, the enhancement of production volumes for the years of growth was accounted for by the reproduction of old models, rather than by updating the range of products and developing an issue of new commodities.
In conclusion, note that such a significant growth of chemical manufacture was of an extensive nature and realized primarily by loading the created capacities. The development of innovation activities by chemical companies in Russia is still complicated by maladjustment of the former system to the new conditions of business. Despite of all the aforementioned negative factors, in 2019 chemical industries became leading with respect to the dynamics of growing investments. After a long period of industrial recession, the chemical industry showed an expansion.

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References

Bakulina G., Fedoskin V., Pikushina M., Kukhar V., Kot E., 2020. Factor analysis models in enterprise costs management. International Journal of Circuits, Systems and Signal Processing, 14, 232-240.
Bessarabov A.M., Kvasyuk A.V., Kochetygov A.L., 2009. System analysis of innovation activities by leading companies of the chemical industry (1995 to 2007). Theoretical Foundations of Chemical Engineering, 43, 444-452.
Bessarabov A., Klemeš J., Zhekeyev M., Kvasyuk A., Kochetygov A., 2010. Computer analysis of waste utilization at the leading enterprises of phosphoric industry. Chemical Engineering Transactions, 21, 805-810.
Bessarabov A.M., Kvasyuk A.V., Zaikov G.E., 2012. Analysis of Innovative Resources of Russian Polymers Industry Based on the System Approach (1995-2009), Unique Properties of Polymers and Composites. Pure and Applied Science Today and Tomorrow (Vol. 2): Nova Science Publishers, Inc. New York, USA.
Date C.J., 2015. SQL and Relational Theory: How to Write Accurate SQL Code. O'Reilly Media, Sebastopol, USA.
Eckstein J., Schultz B.R., 2017. Introductory relational database design for business, with Microsoft Access. Wiley Publishing, Chichester, UK.
Gershman M., Gokhberg L., Kuznetsova T., Roud V., 2018. Bridging S&T and innovation in Russia: a historical perspective. Technological Forecasting and Social Change, 133, 132-140.
Gokhberg L., Ditkovskiy K., Kuznetsova I., Lukinova E., Martynova S., Ratay T., Rosovetskaya L., Fridlyanova S., 2019. Indicators of Innovation in the Russian Federation: 2019, Data Book, National Research University Higher School of Economics, Moscow, Russian Federation.
Gorova K., Dluhopolskyi O., Dluhopolska T., 2019. Entering in the global manufacturing outsourcing market and innovative development of the Ukrainian industrial enterprises. Economy and Sociology: Theoretical and Scientifical Journal, 2, 20-31.
Komlósi E., Páger B., Márkus G., 2019. Entrepreneurial Innovations in countries at different stages of development. Foresight and STI Governance, 13 (4), 23-34.
Ribeaux D.R., Jackes C.V., Takaki G.M.C., Medeiros A.D.M., Marinho J., Lins U., Nascimento I., Barreto G., 2020. Innovative production of biosurfactant by candida tropicalis UCP 1613 through solid-state fermentation. Chemical Engineering Transactions, 79, 361-366.
Rezende F.A.G.G., Sande D., Coelho A.C., Oliveira G.P., Boaventura M.A.D., Takahashi J.A., 2019. Edible flowers as innovative ingredients for future food development: anti-Alzheimer, antimicrobial and antioxidant potential. Chemical Engineering Transactions, 75, 337-342.