Computer analysis of innovation indicators of the chemical complex of Russia

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ABSTRACT

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, etc.). For the purposes analysis we developed the Innov-Chem 1.0 analytical information system. 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. As the database for our studies, we used the information about innovation activities from 1995 to 2015 collected by 165 leading companies of the chemical and petrochemical industries in their annual statistical reporting forms (4-Innovation) submitted to the Russian Ministry of Industry.

KEYWORDS

System analysis, factor analysis, innovative resources, statistical information, information technologies, chemical and petrochemical industry.

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 [1]. In connection with this, the goal of our 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 1995 to 2015, as well as the estimation of the main trends of innovations, features, and tendencies of innovation activities.

STRUCTURE OF BASIC INNOVATION DEVELOPMENT PARAMETERS OF COMPANIES IN CHEMICAL AND PETROCHEMICAL INDUSTRIES

The complexity and variety of corporate innovation activities determine the scientific and practical importance of the problem in the systematization of the objects under economic analysis, as well as methodological approaches to their studies. Because at any moment of time the innovation activity of a business subject may be characterized by a different degree of intensity, different potential resources, and a different level of financial results from the projects realized in the past, we propose to apply the system approach and follow the principles forming a balanced set of parameters.

At the initial stage the innovation analysis was conducted for individual sectors of chemical and petrochemical industries: phosphoric industry [2, 3], tire industry [4], the synthetic rubber industry [5], the industry of polymers and plastics [6, 7]. As the database for our studies, we used

the information about innovation activities from 1995 to 2015 collected by 165 leading companies of the chemical and petrochemical industries in their annual statistical reporting forms (4–Innovation [8]) submitted to the Russian Ministry of Industry (Figure 1).

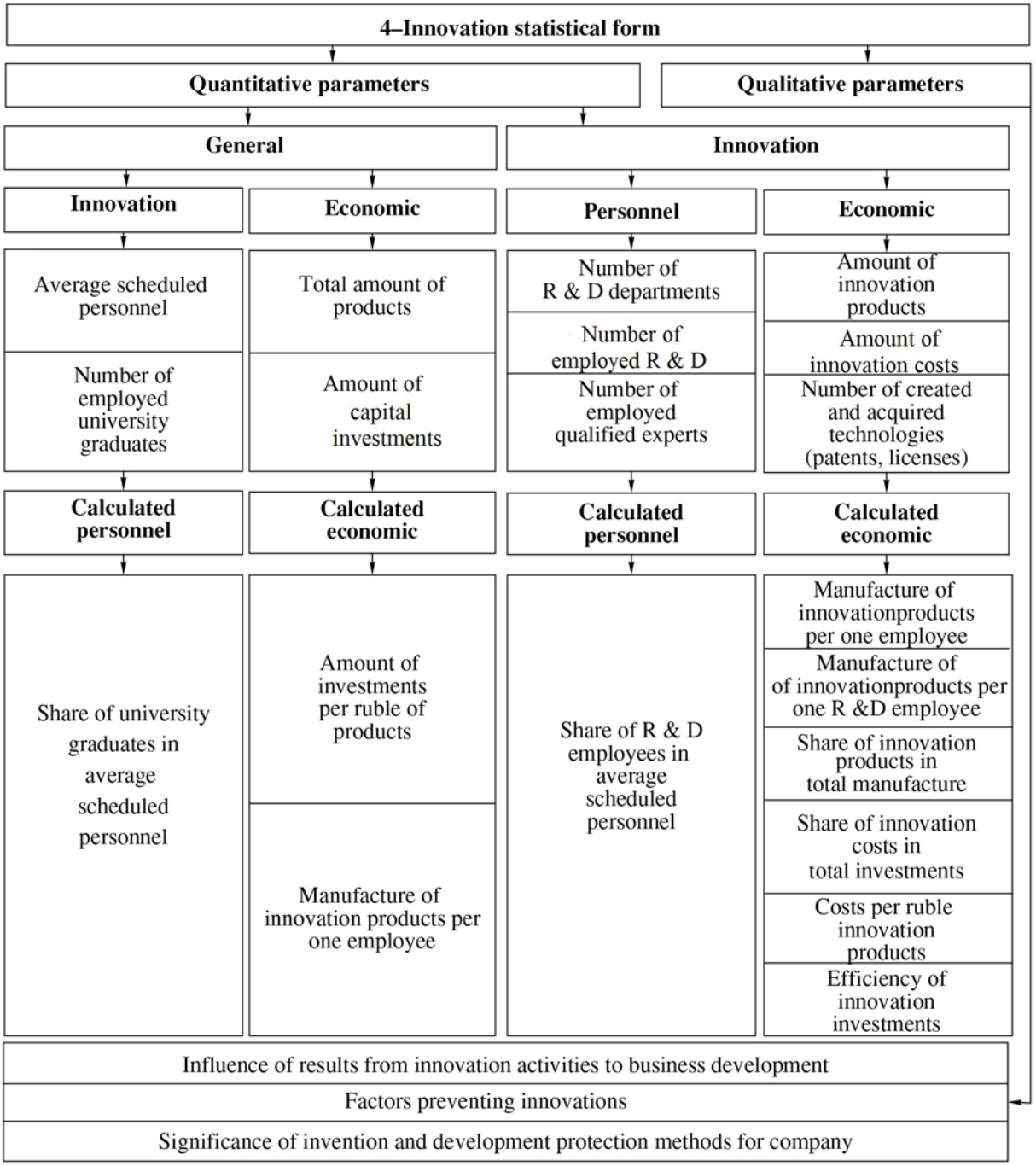

Figure 1. Structure of basic innovation development parameters of companies in chemical and petrochemical industries.

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 aspects of the innovation process. 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 1995 to 2015; 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.

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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), etc.

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).

We also considered factors preventing investments. For comprehensive study of the innovation processes, our 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.

THE SYSTEM ANALYSIS OF INNOVATION DEVELOPMENT IN LEADING CHEMICAL AND PETROCHEMICAL COMPANIES

Our 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 2000, their number decreased almost by 30% in 2015 (in 1995, 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 1995 to some 4% in 2015.
Our structural analysis of innovation products (Figure 2) showed sharp changes in the category of newly introduced products from 10% in 1995 to 80% in 2005. As compared to 1995, the share of upgraded products decreased by more than three times from 62 to 19% in 2015.

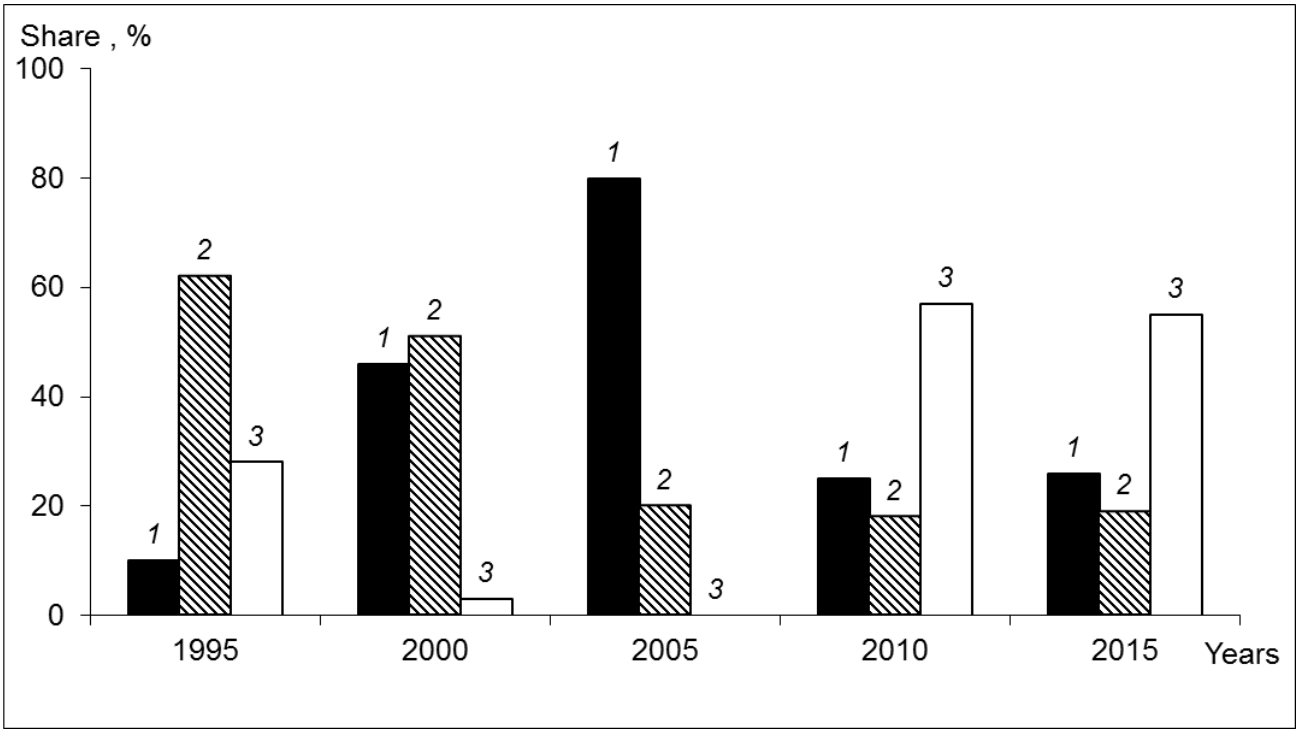

Figure 2. Structure of manufactured innovation products (%): 1– newly introduced; 2– upgraded; 3– miscellaneous

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 1995 to 4.3% in 2015. The lowest level of this parameter (1.4%) was recorded in 2005.
In the structure of technological innovation costs (Table 1), the major share was attributed to machine and equipment acquisition costs (68.5%) in 2015 and to research and development costs (50,1%) in 1995. For these ten years, 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, %	1995	2000	2005	2010	2015
Research and development of new products	50,1	26,3	12,8	15,3	5,2
Acquisition of machines and equipment	26,4	40,1	53,1	62,3	68,5
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	20,1	17,9	10,8	12,3	24,8
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	12,4	19,3	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 2015, i.e., lower by 25.5% than the level of 1995. 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 2015. The share of credits and borrowed funds in the innovation costs increased from 6.7% in 1995 to 32.2% in 2015.

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 per cent 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, etc.
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 2015 was only 0.004 for the innovatively active companies in the chemical industry.

By 2015, the general structure of corporate innovation activities underwent some changes as compared to 1995. 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, %	1995	2000	2005	2010	2015
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	0,0	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	0,0	12,9	14,7

Note a crucial change in the distribution by innovation types for five years. While product innovations (including the development and introduction of technologically new and technologically upgraded products) prevailed in the total volume of innovation products in 1995, practically all the corporate innovation activities in 2015 included the development and introduction of technologically new or significantly improved methods, including product delivery methods (Figure 3).

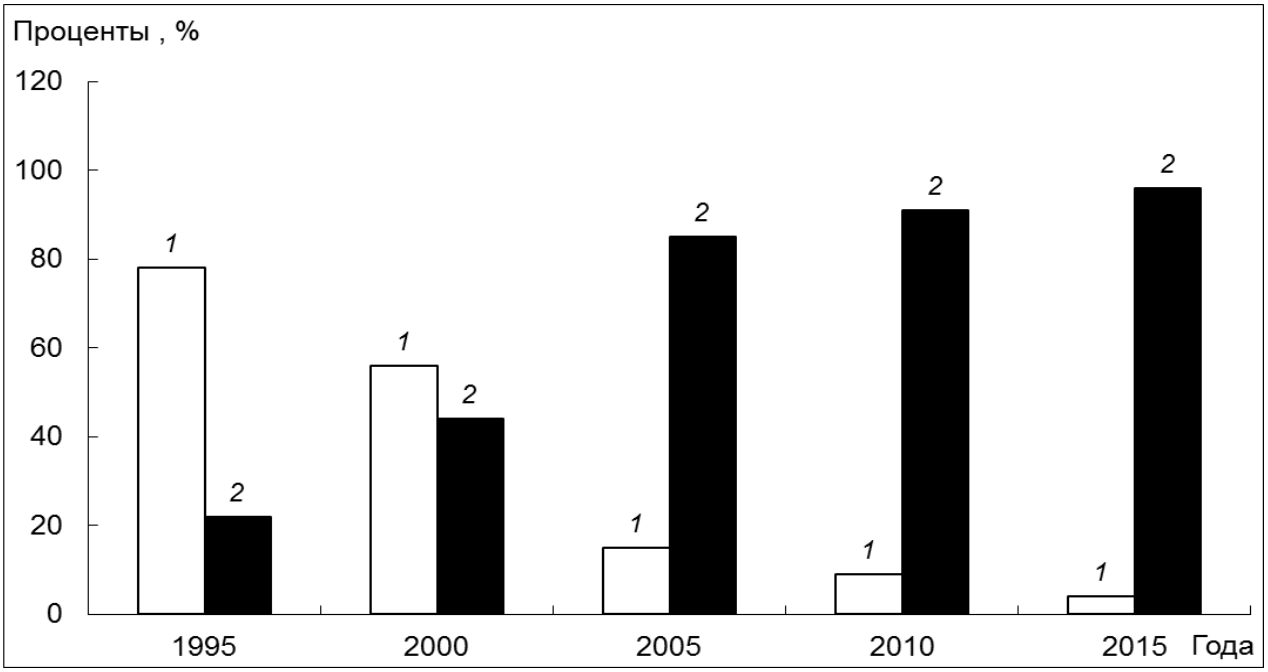

Figure 3. Distribution by innovation types in total volume of innovation products (%): 1– products; 2– processes

From 2000 to 2015, the innovatively active companies reduced their technological exchange. In 2015, the share of companies taking part in joint projects amounted to 17.9% of their total number (Table 3). The highest activity with respect to this parameter was recorded in 2005. For these 15 years, the number of joint projects decreased by 11 times. The same situation was observed for companies acquiring new technologies. The number of such companies and their acquired technologies decreased by 31.4% and 9 times, respectively, for these 15 years.

Table 3. Share of companies participating in joint R & D projects and acquiring new technologies

Corporate activities, %	2000	2005	2010	2015
Joint projects of research works	32,0	58,3	19,2	17,9
Acquisition of new technologies	44,0	33,3	14,9	12,6
Acquisition of invention patents	26,0	48,7	31,7	24,0
Purchase of patents for industrial models	0,0	33,3	7,5	4,1

The highest activity in the acquisition of invention patents and industrial models was demonstrated by companies in 2005. One half of the studied companies acquired invention patents in 2005. By 2015, this parameter sharply decreased (Table 3).

In 2015, the major partners of the studied companies in the implementation of their joint projects were research organizations collaborating with 68% of companies. The second position is taken by providers of equipment, materials, components, and software (45%). The vast majority of companies implemented their joint projects with domestic partners.

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. To our surprise, 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 4) 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 4).

Table 4. Rating list of results from innovation activities

Results of innovation activities, %	2000	2005	2010	2015
Improvement of working conditions	0,0	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	0,0	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

Our 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 per cent manufacture of chemical and petrochemical products, and some other factors.

Factor analysis [9] allows to estimate the degree of connection between main types of innovation costs and results of innovation activities in the sphere 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).

The qualitative parameters of innovation development are as follows: factors preventing innovations, the effect of results from innovation activities on the development of companies, and significance of invention and development protection methods for companies. They are represented in 4–Innovation forms with respect to their effect as one of four grades: 3 – high, 2 – middle, 1 – low or insignificant, and 0 – no effect. Averaging these grades enables the calculation of the value of a certain parameter for comparative analysis.

For example, we give the calculation of such a qualitative parameter as factors preventing innovations for all 165 companies. Decomposition of seventeen factors (4–Innovation statistical form) is provided in three information sections: economic, industrial, and other causes. The rate of each factor was calculated as the average grade for all the companies (Table 5).

Table 5. Rating list of factors preventing innovations of companies in chemical industries

Factors preventing innovations, grades	2000	2005	2010	2015
Economic factors				
Deficit of own funds	2,53	2,74	2,34	2,29
Lack of governmental support	2,21	2,15	1,74	1,57
Low demand for new products	1,63	1,58	1,49	1,42
High cost of innovations	2,13	2,29	2,08	1,98
High economic risk	2,31	1,51	1,67	1,42
Long repayment terms of innovations	1,74	1,94	1,71	1,68
Industrial factors				
Low innovation potential of company	1,41	1,29	1,33	1,35
Lack of qualified personnel	1,02	1,24	1,04	1,07
Lack of information about new technologies	1,21	1,32	1,27	1,31
Lack of information about markets	1,24	1,51	1,31	1,28
Lack of corporate reception of investments	1,02	1,27	1,08	1,13
Lack of cooperation opportunities	1,18	1,28	1,26	1,26
Miscellaneous causes				
Low consumer demand for new products	1,04	1,25	1,06	1,02
Imperfect innovation laws	1,52	1,76	1,42	1,35
Uncertain terms of innovation process	1,07	1,27	1,15	1,19
Undeveloped innovation infrastructure	1,33	1,43	1,34	1,27
Undeveloped market of technologies	1,35	1,52	1,32	1,48

As a result of this calculation (Table 5), the highes effect on innovation activities was produced by economic factors. The most significant hindrances for innovations included the deficit of own funds and high cost of innovations. In addition, companies referred to such essential hindrances of innovations as their long repayment terms. The effect of such a factor as governmental financial support decreased from 2000 to 2015, evidencing the growing opportunities of companies using other sources for innovation costs.

The industrial factors preventing innovations (Table 5) were estimated far lower by companies. Here, they noted primarily the low corporate innovation potential and lack of information about markets and opportunities for cooperation with other companies and research organizations.

For the purposes of computerized analysis of innovation development in the leading chemical and petrochemical companies, we developed the Innov-Chem 1.0 analytical information system (Figure 4). 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 [10].

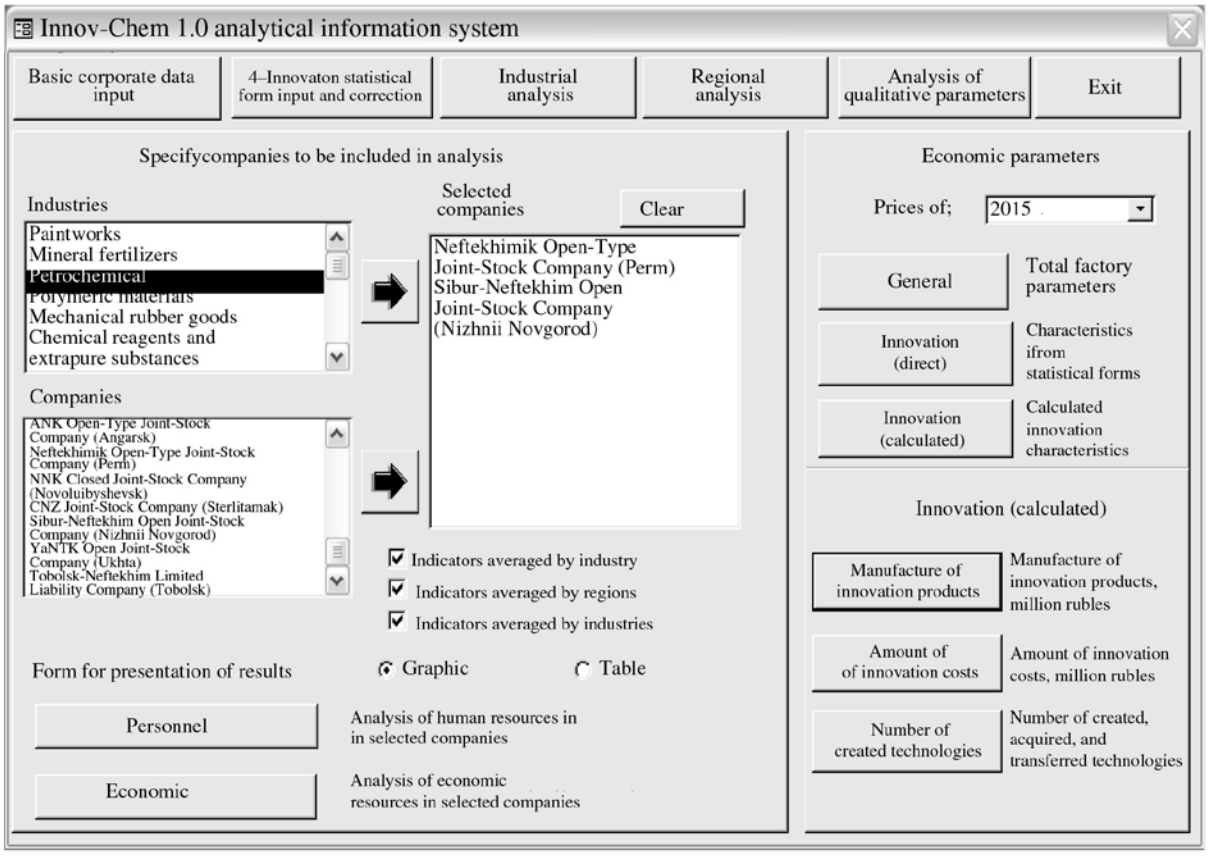

Figure 4. Analytical information system user interface for analysis of information resources of private and public companies in the chemical industry

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 paintworks, mineral fertilizers, petrochemical (Figure 4), etc. 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 (Table 5), etc.

CONCLUSION

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 (1995 to 2015) 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 2015 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.

This work was supported by Russian Foundation for Basic Research, the project 16-07-00823.

REFERENCES

1. Bessarabov, A. M., Kvasyuk, A. V., Kochetygov, A. L., System analysis of innovation activities by leading companies of the chemical industry (1995 to 2007), *Theoretical Foundations of Chemical Engineering*, Vol. 43, No. 4, pp 444-452, 2009.
2. Bessarabov A., Bulatov I., Kochetygov A. and Kvasyuk A. The system analysis of phosphoric industry waste utilization based on CALS-technologies // *Chemical Engineering Transactions*, Vol. 18, pp 327-332, 2009.
3. Bessarabov A., Bulatov I., Kvasyuk A., Kochetygov A. Utilization of waste for large capacity productions of phosphorus-containing products based on the system analysis // *Clean Technologies and Environmental Policy*, Vol. 12, No. 6, pp 601-611, 2010.
4. Kvasyuk A.V., Kochetygov A.L., Yagudin S.Yu., Bessarabov A.M. Computer analysis of innovation development of the leading enterprises of the tire industry (1995-2005) // *Oil refining and petrochemistry*, No. 7, pp 8-14, 2008 (Russia).
5. Bessarabov A.M., Kvasyuk A.V., Kochetygov A.L. System analysis of innovative resources of research and production complex of synthetic rubber // *Industrial production and use of elastomers*, No. 3, pp 3-9, 2010 (Russia).
6. Bessarabov A.M., Kvasyuk A.V. and Zaikov G.E. 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 (Volume 2): Nova Science Publishers, Inc. New York*, pp 249-256, 2012.
7. Bessarabov A.M., Zaikov G.E, Kvasyuk A.V. System analysis of innovative resources of polymer and plastics industry (1995-2009) // *News of higher educational institutions. Chemistry and chemical technology*, Vol. 55, No. 3, pp 95-100, 2012 (Russia).
8. Gorodnikova, N., Gokhberg, L., Ditkovskiy, K., et al., *Indicators of Innovation in the Russian Federation: 2017, Data Book*, National Research University Higher School of Economics, Moscow, Russia, 2017.
9. Bessarabov, A., Kvasyuk, A., Cybernetic researches in technology of chemical reagents and high-purity substances, *Clean Technologies and Environmental Policy*, , Vol. 17, No. 5, pp 1365-1371, 2015.
10. Bessarabov, A., Kvasyuk, A., Zaremba, G., Trokhin, V., Vendilo, A., System researches of chemical industry of Russia, *10th European Congress of Chemical Engineering, ECCE–10*, Nice, France, September 27th – October 1st, 2015, pp 1246-1247.