A SYSTEM APPROACH TO ASSESSING THE EFFECTIVENESS OF REGIONAL INNOVATION SYSTEMS IN THE CONCEPT OF STATISTICAL SUSTAINABILITY

Marat Rashitovich Safiullin1, Sergey Valentinovich Chekhlonin2, Anna Vladimirovna Aksyanova3*

1Vice Rector for Economic and Strategic Development, Doctor of Economics, Professor. Kazan Federal University, Russia, 2Institute of Management, Economics and Finance, Department of Production Economics, Kazan Federal University, Russia, 3Professor, Department of Business Statistics and Economics, Kazan National Research Technological University, Russia.

Email: aksyanova-anna@yandex.ru

Article History: Received on 01st October 2019, Revised on 30th November 2019, Published on 05th December 2019

Abstract

Purpose: The paper deals with the assessment and analysis of regional innovation systems. It is noted that the quantitative criterion of innovation effectiveness as the degree of influence of resources spent on obtaining the target result is practically not used in the analysis of the development of regional economic systems.

Methodology: The issues of quantitative measurement of the effectiveness, performance, and sustainability of the regional innovation system development are considered. According to the methodology proposed by the authors based on an assessment of the materiality and sustainability of statistical relationships between factor and result indicators of innovation activity, a multidimensional statistical analysis concerning the development of the Russian Federation regions by the level of innovative activity was carried out.

Result: The principle of division of the space formed by innovative activity features according to their functional significance in the system is formulated. A method of identifying sustainable relationships between elements of a regional innovation system within the process approach concept has been tested. Special groups of factors that have a statistically significant effect on innovation activity are identified. Methods for calculating effectiveness and performance indexes in categories of statistical variation are proposed. The differentiation of regions by the innovative development determinants is revealed. The conclusions about the feasibility of applying the presented methodology for a reliable assessment of the effectiveness of regional innovation system development are made.

Applications: This research can be used for universities, teachers, and students.

Novelty/Originality: In this research, the model of A system approach to assessing the effectiveness of regional innovation systems in the concept of statistical sustainability is presented in a comprehensive and complete manner.

Keywords: Innovation Effectiveness, Regional Innovation System, A System of Indicators for Assessing the Effectiveness, Effectiveness, and Sustainability of Innovation at the Meso Level.

INTRODUCTION

The main indicator and drive for competitiveness in the global economic and socio-political space is the level of development and integration of innovations in all areas of activity. In the conditions of heterogeneity of economic development, it becomes important to develop tools for assessing the effectiveness of innovation systems at the meso-level.

The index of effectiveness as a ratio of the result obtained to the resources expended should be the main target criterion for the development of an innovation system in the national economy.

The sustainable economic growth strategy is always associated with the identification of key factors and the quality of its achievement; therefore, it becomes relevant to measure the excess of the results obtained over the resources spent.

METHODS

Historically, there have been several interpretations of the effective business activity concept. So, D. Ricardo determined the activity is effective where the results exceeded the resources expended (David Ricardo, 2019). V. Pareto considered performance effectiveness through the prism of production capabilities. In his theory, effectiveness is a state in which all production capabilities are fully utilized, and in order to increase the production of one good, it is necessary to reduce the production of another (Manual of political economy, 1971). G. Kleiner classified effectiveness as a target category, as the degree of compliance of the results obtained with the goals set, as a technological category, where the level of intensity of resources conversion into the final product is determined, and as an economic category, as a ratio of profits to expended resources (Kleiner, 2002).

From the point of view of modern statistical accounting, the effectiveness of innovation activity is strictly formalized and is determined by a wide range of normatively established indicators grouped into the following blocks (National Innovation System and State Innovation Policy of the Russian Federation, 2009; Revisiting the National innovation system in developing countries, 2017):
-The system of higher and postgraduate education;
-Research and Development;
-Scientific research financing sector;
-Business sector;
-Innovative infrastructure.

The ratio of R & D costs to GDP is one of the main indicators which are most frequently encountered in the statistical records practice and characterizes the national innovation system at all. It should be noted that, in accordance with the position of the World Bank, the use of this indicator is incorrect since it does not reflect the level of effectiveness of national innovation systems and the social rate of return (Brundenius, Gokhberg, Goransson, et al. 2011).

RESULTS AND ITS DISCUSSION

To implement the quality assessment of the regional innovation system (RIS), taking into account the related performance indicators, performance, and sustainability, in accordance with the approaches (Prokopenko, 2014; Kiselev, 2015), the authors proposed a comprehensive methodology. It is based on the principle of separation into two classes with respect to the system of the "innovation production" process which is based on the innovation activity initiation source (input or resource indicators) and target (desired) states at the exit from the system (output indicators). Recognizing the differentiation of innovation activity sources and the different "quality" of the innovation resource base in a variety of input factors, three integrated groups of indicators were identified by researchers: institutional, personnel, and costly resource indicators. Hekkert, M. P., Suurs, R. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. (2007).

Table 1: The system of innovation indicators

| No | Name of the indicator                              | Designation |
|----|---------------------------------------------------|-------------|
|    | I. Institutional resource indicators              |             |
| 1  | Scientific research and development organizations, pcs. | I₁         |
| 2  | Institutions leading the training of graduate students, pcs. | I₂         |
|    | II. Human resource indicators                     |             |
| 3  | The number of personnel engaged in research and development, pers | I₃         |
| 4  | Number of researchers with scientific degrees, pers | I₄         |
| 5  | The share of personnel engaged in research and development in the total number of the working-age population in the region, % | I₅         |
|    | III. Cost Resource Indicators                     |             |
| 6  | Domestic costs of research and development, mln.  | I₆         |
| 7  | The cost of technological innovation, mln.        | I₇         |
|    | IV. Target indicators                             |             |
| 8  | Innovative activity of organizations, %          | I₈         |
| 9  | Share of the volume of innovative goods, works, services in GRP, % | I₉         |
| 10 | The ratio of the number of used advanced production technologies to the total number of enterprises and organizations, % | I₁₀        |
| 11 | The ratio of the volume of innovative goods, works, services to the cost of technological innovation, % | I₁₁        |

In accordance with the above description of the RIS assessment, the effectiveness of the system was determined by correlating the actual performance with the baseline: Leydesdorff, L., & Zawdie, G. (2010).

\[ I^k_l = \frac{I^{act}_l}{I^{base}_l} \]  

Or

\[ I^k_l = \frac{I^{act}_l}{I^{base}_l}, \quad \chi^k_2 = \frac{I^{act}_2}{I^{base}_2}, \quad \chi^k_3 = \frac{I^{act}_3}{I^{base}_3}, \quad \text{etc.} \]

To obtain a generalized performance indicator for each group, the geometric mean for the values was used: \[ I^k \] :
Where

\( n \) - The number of indicators

Evaluation of effectiveness is presented everywhere as the difference between the standard deviation of the effectiveness of resource and target characteristics:

\[
I_{EFF} = \frac{1}{n} \sum_{k=1}^{n} (1 - |\sigma_{\text{actual}} - \sigma_{n}|)
\]  

Where \( n \) is the number of groups by resource indicators

As was indicated earlier, in this system of assessment, three groups of resource indicators were conditionally identified: personnel, institutional, and cost. However, the proposed method provides for the possibility of changing the number of typological groups, as well as the number of indicators included in them.

To calculate standard deviations for each group, both \( \sigma_{\text{target}} \) and \( \sigma_{n} \), the formula was used: Hekkert, M. P., & Negro, S. O. (2009).

\[
\sigma = \sqrt{\frac{1}{n} \sum (I_{k}^n - 1)^2}
\]  

Further, the impact of each group of resource indicators on the target was evaluated, that is, the “response” of the target indicator group to changes in resources was quantified. This “response” can be measured using the coefficient of determination between the geometric average indicators for each resource group relative to the target group.

\[
R^2 = \frac{\delta_t^2}{\delta_i^2 + \delta_t^2}
\]

Where \( \delta_t^2 \) - an intergroup dispersion by groups of deviations, by a group of average geometric deviations, and by a group of target indicators.

\( \overline{\sigma_t^2} \) - The average variance of intra-group variances by target indicators.

To determine the scatter of data by target indicators, a sample of values was generated \( I_{k}^n \times \) for the number of periods \( N \). \( I_{k}^n \) was distributed into groups and periods \( N \) according to the Sturgess formula. On the basis of the groups obtained, an analytical grouping table was constructed, including the values for the corresponding periods \( I_{k}^n_{\text{target}} \).

A further calculation stage is associated with the use of an analysis of variance to establish the closeness of the relationship between the factor and result indicators. The group and total averages were calculated as weighted averages, accordingly Hekkert, M. P., & Negro, S. O. (2009).

\[
\bar{x}_i = \frac{\sum x_i \times n_i}{\sum n_i}
\]

Where \( n_i \) the number of is values in the group \( i \).

Further, the intergroup variance was determined, characterizing the degree of dependence of the resultant feature on the factor feature levels:

\[
\delta_i^2 = \frac{\sum (\bar{x}_i - \bar{x})^2 n_i}{\sum n_i}
\]

To determine the average of intra-group dispersions by target indicators \( \overline{\sigma_t^2} \), the standard deviation of the target indicator \( I_{\text{target}}^n \) was calculated proceeding from the average for the target indicator group \( x_t \):

\[
\sigma_t^2 = \frac{\sum (I_{\text{target}}^n - \bar{x}_t)^2}{\sum n_i}
\]

The obtained values for each group \( i \) were used to calculate the average of intra-group variances by target indicators:

\[
\overline{\sigma_i^2} = \frac{\sum \sigma_t^2 \times n_i}{\sum n_i}
\]

Thus, the implementation of the above methodology makes it possible to identify the relationship between resource indicators and target indicators, as well as to determine which of the groups of resource indicators has a greater effect on the target indicators.
For approbation of the calculation methodology, the official statistical reporting data on innovation effectiveness indicators by regions of the Russian Federation for the period from 2001 to 2016 were used.

For clarity of calculations, the time course of effectiveness indicators $I_S$ and effectiveness indicators $I_{EFF}$ for the Republic of Tatarstan is given (Figure 1).

![Figure 1: Time course of RIS effectiveness indicators for the Republic of Tatarstan ($I_S$) by groups of indicators](image)

Effectiveness values for a group of target indicators and effectiveness values for a group of resource cost indicators have a large degree of variation. This is probably due to the ability to most quickly change the strategy in terms of the expenditures for innovation depending on the current economic development level in terms of territories, growth or recession phases of business cycles, creating new institutional conditions to support and develop innovative entrepreneurship.

![Figure 2: Time course of the RIS effectiveness indicator for the Republic of Tatarstan ($I_{EFF}$)](image)

Effectiveness is also characterized by a strong scatter of values (Figure 2). The maximum values are observed for 2003, 2012, and the minimum values for 2009 and 2014, they are associated with a sharp change in the effectiveness value in one or several groups of indicators of innovation activity.
An analytical grouping was built to analyze the materiality of the relationship between the resource effectiveness and target indicators (Table 2).

Table 2: Analytical grouping of resource cost indicators and target indicators

| No | Group by size | The frequency of indicators in the group | The average value of the targets in the group, $X_i$ | Intergroup variance by the target $\delta^2_i$ | Average of intragroup variances by the target, $\sigma^2_i$ | Coefficient of determination, $R^2$ |
|----|---------------|------------------------------------------|-----------------------------------------------|---------------------------------|----------------------------------|-------------------|
| 1  | 1.29 - 1.61   | 1                                        | 2.79                                          |                                 |                                  |                   |
| 2  | 1.61 - 1.94   | 2                                        | 2.00                                          |                                 |                                  |                   |
| 3  | 1.94 - 2.26   | 3                                        | 2.07                                          | 0.104                           | 0.039                            | 72.7              |
| 4  | 2.26 - 2.58   | 5                                        | 1.65                                          |                                 |                                  |                   |
| 5  | 2.58 - 2.90   | 5                                        | 1.57                                          |                                 |                                  |                   |

$$R^2 = \frac{\delta^2_i}{\delta^2_i + \sigma^2_i} \times 100 = \frac{0.104}{0.104 + 0.039} \times 100 = 72.2\%$$ (10)

In the Republic of Tatarstan, there is a significant relationship between effectiveness for a group of resource cost indicators and effectiveness for a group of target indicators. The relationship between the effectiveness in the target group indicators and the effectiveness in groups of personnel and institutional resource indicators is not significant since the coefficients of determination are 8.4 and 13.3%, respectively. It can be concluded that an innovative system has been built in the Republic of Tatarstan that allows the most efficient use of invested resources for technological innovations, research, and development. Consequently, an increase in the level of such expenses will lead to an increase in the region’s innovative potential. : Hekkert, M. P., & Negro, S. O. (2009).

CONCLUSION

For a comparative analysis of the results obtained from the evaluation of the effectiveness and the degree of connection between the resource and target indicators, three regions were randomly selected from each quadrant, pre-built to identify the positions of the Russian regions on a set of two factors - the level of innovation activity and the GRP per capita.

Table 3: Performance Indicators by Regions of the Russian Federation in 2016

| No | Region               | Quadrant | Effectiveness in the group of resource institutions indicators | Effectiveness of a group of resource personnel indicators | Effectiveness of a group of resource cost indicators | Performance by target groups |
|----|---------------------|----------|---------------------------------------------------------------|----------------------------------------------------------|----------------------------------------------------|-------------------------------|
| 1  | Ulyanovsk region    | one      | 0.36                                                          | 0.15                                                      | 0.19                                              | 1.99                          |
| 2  | Saratov region      | one      | 1.00                                                          | 0.62                                                      | 0.44                                              | 0.81                          |
| 3  | Mari El republic    | one      | 0.18                                                          | 0.05                                                      | 0.04                                              | 1.28                          |
| 4  | Republic of Bashkortostan | 2 | 1.63                                                          | 0.71                                                      | 1.22                                              | 1.36                          |
| 5  | Rostov region       | 2        | 1.70                                                          | 0.96                                                      | 1.66                                              | 1.09                          |
| 6  | Chuvash republic    | 2        | 0.36                                                          | 0.15                                                      | 0.19                                              | 1.99                          |
| 7  | Moscow region       | 3        | 4.85                                                          | 5.30                                                      | 8.89                                              | 1.17                          |
| 8  | Republic of Tatarstan | 3    | 2.29                                                          | 1.04                                                      | 2.05                                              | 2.08                          |
| 9  | Krasnodar region    | 3        | 1.87                                                          | 0.76                                                      | 0.58                                              | 0.99                          |
| 10 | Krasnoyarsk region  | 4        | 0.97                                                          | 0.70                                                      | 1.95                                              | 0.69                          |
| 11 | Samara Region       | 4        | 1.35                                                          | 0.63                                                      | 1.58                                              | 1.32                          |
| 12 | Chelyabinsk region  | 4        | 0.98                                                          | 0.98                                                      | 1.84                                              | 0.74                          |
**Figure 3:** Distribution of regions of the Russian Federation by the level of innovation activity and GRP per capita for 2016

**Source:** compiled according to Rosstat: http://www.gks.ru

Regions are divided into 4 groups according to the level of innovation activity and GRP per capita, using median values. For a comparative analysis of the evaluation results for effectiveness, performance and the degree of relation between the resource and target indicators, three regions from each quadrant shown in Figure 3, were randomly selected.

It should be noted that the maximum average performance value for the target group is observed in three regions related to quadrant 2 (table 3). This is explained by the fact that in quadrant 2 there are regions that are characterized by the innovation activity indicator which level is above the average. Thus, the regions with higher innovative activity have higher performance levels than the regions with a higher level of GRP per capita, but with a level of innovative activity which is less than the average (quadrant 4).

The Republic of Tatarstan has maximum performance in the target group in 2016 with a value of 2.08. In terms of investment volume in the development of RIS, the Moscow region leads as to all three indicators: personnel (5.30), institutional (4.85) and cost (8.89). Despite the high values of resource indicators, the target performance of the Moscow region remains at an average level (1.17), and the effectiveness indicator in 2016 reached a negative value (-4.63) (Table 4).

**Table 4:** Effectiveness Indicator by Regions of the Russian Federation in 2016

| No | Region                  | Quadrant | Effectiveness |
|----|-------------------------|----------|---------------|
| 1  | Ulyanovsk region         | 1        | 0.52          |
| 2  | Saratov region           | 1        | 0.22          |
| 3  | Mari El republic         | 1        | 0.92          |
| 4  | Republic of Bashkortostan| 2        | 0.90          |
| 5  | Rostov region            | 2        | 0.70          |
| 6  | Chuvash Republic         | 2        | 0.52          |
| 7  | Moscow region            | 3        | -4.63         |
| 8  | Republic of Tatarstan    | 3        | 0.42          |
| 9  | Krasnodar region         | 3        | 0.81          |
| 10 | Krasnoyarsk region       | 4        | 0.69          |
| 11 | Samara Region            | 4        | 0.60          |
| 12 | Chelyabinsk region       | 4        | 0.78          |
If not take into account the time lag, we can conclude that in the Republic of Tatarstan the innovation system is built more efficiently, since smaller resource investments lead to higher target indicators, which is confirmed by the presence of a significant relationship between resource and target indicators.

**Table 5: Ratio of determination**

| No | Region               | Quadrant | The ratio of determination R² against targets by costly resource indicators, % | by institutional resource indicators, % | by personnel resource indicators, % |
|----|----------------------|----------|--------------------------------------------------------------------------------|-----------------------------------------|-------------------------------------|
| 1  | Ulyanovsk region     | 1        | 57.3                                                                           | 79.1                                    | 54.5                                |
| 2  | Saratov region       | 1        | 13.8                                                                           | 33.7                                    | 5.7                                 |
| 3  | Mari El Republic     | 1        | 32.2                                                                           | 32.9                                    | 37.8                                |
| 4  | Republic of Bashkortostan | 2     | 36.1                                                                           | 74.6                                    | 3.3                                 |
| 5  | Rostov region        | 2        | 38.4                                                                           | 25.0                                    | 26.7                                |
| 6  | Chuvash Republic     | 2        | 63.5                                                                           | 75.2                                    | 50.1                                |
| 7  | Moscow region        | 3        | 58.9                                                                           | 28.0                                    | 65.5                                |
| 8  | Republic of Tatarstan | 3       | 72.7                                                                           | 13.3                                    | 8.4                                 |
| 9  | Krasnodar region     | 3        | 30.4                                                                           | 26.9                                    | 52.0                                |
| 10 | Krasnoyarsk region   | 4        | 23.1                                                                           | 7.3                                     | 36.0                                |
| 11 | Samara Region        | 4        | 14.1                                                                           | 32.9                                    | 45.0                                |
| 12 | Chelyabinsk region   | 4        | 15.2                                                                           | 45.5                                    | 41.4                                |

According to the sample of regions presented (table 5), all three regions related to quadrant 3 have a significant relationship between resource and performance indicators.

The availability of a significant relationship in one of the groups of resource indicators with a determination coefficient of more than 70% determines the appropriateness of investments in the development of the innovation system of the region in the direction corresponding to the group of resource indicators. In inter-regional comparisons, an increase in the growth rate of domestic expenditures for research and development and expenditures for technological innovations in the real sector of the economy of the Republic of Tatarstan gives a more stable and effective response to the result of innovation activities. The development of institutional conditions (expansion of the network of organizations performing research and development, as well as organizations that carry out training of graduate students) is advisable in the Ulyanovsk region, the Republic of Bashkortostan, and the Chuvash Republic.

The methodology proposed by the author will make it possible to most fully evaluate not only the performance of the created innovation system but also its effectiveness. The technique takes into account the heterogeneity of the economic space, accompanied by differentiation processes concerning the conditions for the implementation of innovation activities, and provides an assessment of the sustainability of systemic relations in innovation systems at the meso level. A key feature of the approach is to identify the most effective directions for the development of innovative activity in the context of regional groups. Due to the division of resource factors into institutional, personnel and cost-dependent, identifying the degree of influence of each group on target indicators, it becomes possible to develop a more accurate strategy for the development of the regional innovation system, taking into account its characteristics.

**ACKNOWLEDGMENT**

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

The study was carried out by a grant from the Russian Science Foundation (project No. 19-18-00202)

**REFERENCES**

1. David Ricardo, (2019). The Works of David Ricardo. With a Notice of the Life and Writings of the Author, by J.R. McCulloch (London: John Murray, 1888). 6/4/2019.
2. Manual of political economy. (1971). Front Cover. Vilfredo Pareto.Scholars Book Shelf, 1971 - Business & Economics - 504 pages.
3. Kleiner G. (2002). Performance of the transitional period mesoeconomic systems / G. Kleiner // Problems of theory and practice in management. - 2002. - №6. - pp. 24-30
4. National Innovation System and State Innovation Policy of the Russian Federation (2009). Basic Report to the OECD Review of the National Innovation System of the Russian Federation - M: Ministry of Education and Science of the Russian Federation - 2009.
5. Revisiting the National innovation system in developing countries (2017). Policy Research working paper - World Bank Group - World Bank Group. - 2017.
6. Brundenius C., Gokhberg L., Goransson B. et al. (2011). Universities in Transition. The Changing Role and Challenges for Academic Institutions. New York: Springer, 2011.
7. Prokopenko O.V. (2014). Sustainable development of an enterprise, region, and society: innovative approaches to their provision: a monograph. - Poland: "Drukarnia i Studio Graficzne Omnidium" - 2014.
8. Kiselev, S. V. (2015). Methodical Approach to Evaluating the Performance of the Institutional System of Crisis Management / S.V. Kiselev, A.V. Aksianova, A.K. Shagieva // Asian Social Scienc. - 2015 - №14. https://doi.org/10.5539/ass.v11n14p27
9. Shinkevich, M. V., Shinkevich, A. I., Chudnovskiy, A. D., Lushchik, I. V.; Kaigorodova, G. N., Ishmuradova, I. I., ... & Zhuravleva, T. A. (2015). Formalization of sustainable innovative development process in the model of innovations diffusion. International Journal of Economics and Financial Issues, 6(1), 179-184.
10. Chen, K., & Guan, J. (2011). Mapping the functionality of China's regional innovation systems: A structural approach. China economic review, 22(1), 11-27. https://doi.org/10.1016/j.chieco.2010.08.002
11. Cooke, P., & Memedovic, O. (2003). Strategies for regional innovation systems: learning transfer and applications. Vienna: United Nations Industrial Development Organization.
12. Coenen, L., & López, F. J. D. (2010). Comparing systems approaches to innovation and technological change for sustainable and competitive economies: an explorative study into conceptual commonalities, differences and complementarities. Journal of cleaner production, 18(12), 1149-1160. https://doi.org/10.1016/j.jclepro.2010.04.003
13. Oughton, C., Landabaso, M., & Morgan, K. (2002). The regional innovation paradox: innovation policy and industrial policy. The Journal of Technology Transfer, 27(1), 97-110. https://doi.org/10.1023/A:1013104805703
14. Lundvall, B. Å., Johnson, B., Andersen, E. S., & Dalum, B. (2002). National systems of production, innovation and competence building. Research policy, 31(2), 213-231. https://doi.org/10.1016/S0048-7333(01)00137-8
15. Sternberg, R. (2000). Innovation networks and regional development—evidence from the European Regional Innovation Survey (ERIS): theoretical concepts, methodological approach, empirical basis and introduction to the theme issue. European Planning Studies, 8(4), 389-407. https://doi.org/10.1080/096543100300032840
16. Lundvall, B. Å. (2007). National innovation systems—analytical concept and development tool. Industry and innovation, 14(1), 95-119. https://doi.org/10.1080/13662710601130863
17. Heekert, M. P., & Negro, S. O. (2009). Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims. Technological forecasting and social change, 76(4), 584-594. https://doi.org/10.1016/j.techfore.2008.04.013
18. Leydesdorff, L., & Zawdie, G. (2010). The triple helix perspective of innovation systems. Technology Analysis & Strategic Management, 22(7), 789-804. https://doi.org/10.1080/09537325.2010.511142
19. Heekert, M. P., Suurs, R. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. (2007). Functions of innovation systems: A new approach for analysing technological change. Technological forecasting and social change, 74(4), 413-432. https://doi.org/10.1016/j.techfore.2006.03.002