Assessment of structural changes in the spatial innovative development of Russian regions

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Abstract. The study of the effectiveness of spatial innovation development is a highly topical issue today due to the increased impact of innovation on economic growth. In order to assess the structural dynamics of regional innovative development, an analysis of the innovation indicators for Russian regions in 2010–2018 was carried out. Cluster analysis and the correlation-regression method were used to assess the structural changes in the innovative development of Russian regions. The analysis demonstrates an increased number of entities in the innovative leading region cluster by 2018, which can be considered as a positive result of innovation policy and the growth in indicators of regional innovative development. The research results can be used to develop regional innovative strategies and decision making for the further development of innovative activities.

1. Introduction
The increasing importance of innovation for economic growth in recent years in the context of the post-industrial society is one of the key factors that led to radical structural shifts in developed economies. The significance of this work is determined by the need to study the problems of the effectiveness of spatial innovation development and assess the impact of innovation policy on structural shifts and economic growth for the development of regional innovation strategies and decision making for the further innovation development.

At present, structural shifts and the optimal spatial structure of the economy are an actively discussed topic for the economy of any country, which poses a challenge to search for and study the mechanisms of influence on structural changes in order to create an effective economic setup. Structural changes in the economic system occur under the influence of various determinants. In the last half century, the process of innovation diffusion and transfer has become a decisive factor that determines the nature of technological change impact on the structural dynamics of the economy [1–4].

The systemic macroeffects of structural changes occurring under the influence of innovation diffusion are made up of structural changes expressed, first of all, by the increased indicators of the innovative goods volume in the economy, the share of high-tech products, the number of introduced patents, investment activity and financial support for innovation.

Structural shifts as a process of increasing the share of the innovation component in the economy reflect the result of innovation policy that leads to various effects. Direct effects are
immediate characteristics of innovation activity measured by such indicators as the volume of innovative products, their share in GRP, patents, R&D expenditure, and other quantitative indicators. Indirect effects resulting from knowledge spillover and innovation can be defined as effects that are not directly involved in innovation diffusion but affect the performance of agents and create prerequisites for changing the economy structure [5–6].

Structural shift mechanism studies are carried out from the standpoint of cyclical and wave dynamics, they use methods of measuring the amount and nature of structural shifts, endogenous and exogenous models, where certain factors are identified that can lead either to economic growth or to stagnation through structural shifts [7–11]. Approaches to assessing structural shifts include the calculation of various structural change coefficients and indices, the weighted mean square deviation, indicators of the change intensity in the structure and levels of specialization and diversification of the economy in dynamics [12–16].

Research focusing on the development of territories identifies innovation as the key element of the regional economic development. Structural transformation management in the context of economic and innovation space polarization should take into account spatial concentration of economic activities in the center-peripheral model and inequality of innovation development. Under conditions of high differentiation of Russian territories by the economic development level, the authors use various models for comparative analysis and distribution of regions into groups to assess the structural dynamics, from calculating relative share and descriptive statistics to mathematical methods based on differential calculus [17–19].

In our opinion, a relevant and justified tool for the analysis of such a complex phenomenon as the innovation dynamics can be a multidimensional indicator grouping that allows taking into account the weight of several variables at the same time, which was implemented in this study. We stratify regions into clusters and diagnose structural shifts in the innovation development by analyzing changes in the structure of a region set in a cluster and determine the structure stability for a cluster of leading regions through an increase in the number of leading regions.

The aim of the study is to analyze the main innovation indicators and assess the dynamics of regional innovation development. The object of the analysis is data on the main indicators of the innovation development in Russian regions for the period 2010–2018.

To achieve this goal, the tools of multivariate classification methods (cluster analysis), mathematical statistics (testing statistical hypotheses), correlation-regression analysis (Spearman’s rank correlation coefficient) and cartographic methods were used.

This study continues the scholarly discussion on the effectiveness of spatial innovation development and contributes to the search for tools for assessing regional innovation policy and the dynamics of innovative structural shifts.

The academic contribution of this research consists in the development of tools for assessing the effectiveness of spatial innovation development and in assessing the innovation efficiency of Russian regions development.

The scientific novelty of the results obtained consists in the development of a methodology for studying the processes of knowledge spillovers and innovation diffusion and their influence on the spatial development of regions. The empirical significance lies in obtaining new knowledge about the trends and dynamics of innovative structural shifts in the modern Russian economy.

2. Data and methods
Standard economic indicators do not adequately identify systemic effects of innovation diffusion impact on economy structure changes; an integral indicator is needed to assess these processes. The present study uses innovation development indicators the growth of which contributes to the innovation development of the economy and its structural changes.

To assess structural changes in regional economic dynamics and the dynamics of spatial innovation development of Russian regions, we have identified the following key indicators.
X1 – High-tech and knowledge-based industries share in GRP, %;
X2 – Share of investment in fixed assets in GRP, %;
X3 – Utilization of the results of intellectual activity, units;
X4 – Share of R&D expenditure in GDP, %;
X5 – Share of innovative goods, works, and services in GRP, %.

They characterize the innovation effectiveness and make it possible to assess the structural changes that have occurred in the innovation development of Russian regions (table 1). The relative nature of the indicators (expressed in percentage terms) provides a correct comparison of R&D performance indicators in regions of various sizes.

Table 1. Composition of clusters and the leading region group in terms of innovation

| Periods | Regions |
|---------|---------|
| 2010    | Moscow, Saint Petersburg, Moscow Region, Nizhny Novgorod Region, Perm Area, Republic of Tatarstan, Samara Region, Sverdlovsk Region, Tula Region, Tyumen Region, Chelyabinsk Region |
| 2014    | Moscow, Saint Petersburg, Krasnoyarsk Area, Moscow region, Nizhny Novgorod Region, Perm Area, Republic of Tatarstan, Sverdlovsk Region, Tula Region, Tyumen Region, Yaroslavl Region |
| 2018    | Vladimir Region, Moscow, Saint Petersburg, Irkutsk Region, Krasnoyarsk Area, Moscow Region, Nizhny Novgorod Region, Novosibirsk Region, Penza Region, Perm Area, Bashkortostan Republic, Republic of Tatarstan, Rostov Region, Ryazan Region, Samara Region, Saratov Region, Sverdlovsk Region, Stavropol Area, Tver Region, Tula Region, Tyumen Region, Udmurt Republic, Chelyabinsk Region, Yaroslavl Region |

Given the purpose of this study in terms of measuring structural shifts, we have chosen three time periods: 2010, 2014 and 2018. The choice of the first time slice was due to the “upward” wave (in N. D. Kondratyev’s terminology) and the Russian economic recovery after the 2008 global crisis which was succeeded by an economic recession by 2014. The third period of 2018 is the latest available data from official statistics [20]. The sample was formed in such a way that the current climate of innovative development is compared in our study with the pre-crisis, standard and post-crisis states. As a result, this made it possible to assess the structural changes that occurred in the innovation development in the regions of Russia under the influence of the macroeconomic background trends.

Moreover, it should be noted that a quantitative analysis of these indicators of the innovation development in Russia as a whole for 2010–2018 does not give an unambiguous answer about the nature of spatial development and their dynamics trends of innovative structural shifts (figure 1). The dynamics of the analyzed indicators demonstrates the absence of significant structural shifts. This justifies the use of the approach to cluster analysis outlined in our study to assess regional indicators of innovation development and to analyze the nature of structural changes, allows to assess spatial structural shifts in the innovation development of Russian regions.

To diagnose structural changes in the innovation activity of Russian regions, we used the cluster analysis tools and the correlation-regression method in two stages [21–26]:

1) at the first stage, from the arsenal of multivariate statistics, the cluster analysis method was applied in the form of a multivariate grouping, while Euclidean distance was used as a
distance metric [27]:

$$d_{ij} = \sqrt{\sum_{k=1}^{m} (x_{ik} - x_{jk})^2},$$  \hspace{1cm} (1)

where $x_i$, $x_j$ – the value of the variable for the $i$-th and $j$-th objects.

Ward’s method was used as a method for combining objects [28]:

$$V_k = \sum_{i=1}^{n_k} \sum_{j=1}^{p} (x_{ij} - \bar{x}_{jk})^2,$$  \hspace{1cm} (2)

where $k$ – cluster number; $i$ – object number; $j$ – feature number; $p$ – the number of features that characterize the object; $n_k$ – the number of objects in the $k$-th cluster.

2) at the second stage, to measure structural shifts and differences in the structure of clusters, the correlation-regression method was used, in particular, Spearman’s rank correlation coefficient was calculated [29]:

$$\rho = 1 - \frac{6 \sum_{i=1}^{n} (R_i^x - R_i^y)^2}{n(n^2 - 1)},$$  \hspace{1cm} (3)

where $n$ – population size; $R_i^x$, $R_i^y$ – value of ranks by variables $x$ and $y$.

The data for the analysis were obtained from Rosstat materials for 80 regions of Russia from 2010 to 2018 on the main innovative indicators. Moscow City was excluded from the analysis as an anomalous object with extremely high values. However, Moscow City is one of the most developed innovative regions and it is displayed on the map. All calculations were performed using STATISTICA statistical software package.

3. Results

The cluster analysis resulted in a tree-like diagram dividing the set of Russian regions for 2010, 2014 and 2018 into two clusters according to previously defined indicators of the innovative development level. The diagram for 2018 is shown in figure 2.

Obviously, the first group of ‘strong innovation leaders’ included the regions with the best values of innovation indicators, the second group of ‘less developed’ regions or ‘outsiders’ included the regions where the innovation indicators did not show significant dynamics.
The outcomes of changes in the structure of regional clusters are presented in figure 1 and table 2, thereby assessing the stability of the Russian region cluster structure in terms of innovation level in different time periods, and macroeconomic conditions, accordingly.

According to table 1 results, in 2010–2018 the number of regions holding leading positions in terms of the innovation development increased from 11 to 24. Thus, the improvement of indicators of the innovation effectiveness in the spatial aspect has been established. Structural changes of regional clusters are shown in figures 4–5.

**Figure 2.** Tree cluster diagram of Russian regions by the level of innovative development, 2018.

**Figure 3.** Dynamics of the number of leading regions in the leading region cluster in terms of innovation development, units.
Table 2. Intra-group averages for Russian region clusters by their innovation level

| Periods | Indicators | X1 | X2  | X3  | X4  | X5  |
|---------|------------|----|-----|-----|-----|-----|
|         | mean for cluster 1 | 24.31 | 26.22 | 823.5 | 1.89 | 7.95 |
| 2010    | mean for cluster 2  | 19.26 | 29.62 | 93.48 | 0.61 | 4.40 |
|         | \(t\)-value        | -2.86* | 0.95  | -16.34* | -4.56* | -2.31* |
|         | mean for cluster 1 | 23.99 | 25.14 | 1133.6 | 2.04 | 10.67 |
| 2014    | mean for cluster 2  | 19.86 | 26.78 | 140.00 | 0.62 | 5.87 |
|         | \(t\)-value        | -2.15* | 0.71  | -16.42* | -4.85* | -1.71** |
|         | mean for cluster 1 | 22.64 | 19.41 | 1225.79 | 1.30 | 8.46 |
| 2018    | mean for cluster 2  | 19.57 | 24.58 | 90.18  | 0.46 | 4.13 |
|         | \(t\)-value        | -2.1*  | 2.28* | -5.33* | -4.24* | -3.36* |

* – statistically significant at the 5% level;
** – statistically significant at 10% level.

Note that there are stable leader regions in all three time frames. These include Saint Petersburg, Moscow region, Nizhny Novgorod region, Perm area, Republic of Tatarstan, Sverdlovsk region, Tula region, Tyumen region.

Our study confirmed the current view that the most effective regional innovation systems are formed in the largest agglomerations with leading universities and research centers [30].

The sustainable high result of the dynamics of innovation development indicators in the listed regions is explained by several factors:

1) historically, these regions have geographical and administrative advantages, and as a result, the territorial distribution of industrial production;
2) there are established research clusters, as well as an innovative infrastructure and other conditions for innovation;
3) being large donor regions, the listed regions consolidate significant financial resources that are invested in innovation and technological development.

According to the data in table 2, the studied set of regions is satisfactorily divided into groups, as evidenced by the values of Student’s \(t\)-statistics.

If we consider the intra-group averages at three highlighted time points, then we can state the stability over time of averages for X1 (High-tech and knowledge-based industries share in GRP), X4 (Share of R&D expenditure in GDP) and X5 (Share of innovative goods, works, and services in GRP). Whereas the X2 (Share of investment in fixed assets in GRP) values for the first group decreased which is explained by the inclusion in the subgroup the regions with lower values than the leading regions’ ones. The average values for X3 indicator (Intellectual activity results use, units) are growing, which can be interpreted as a positive shift.

Using the clustering outcomes, we calculated the Spearman’s rank correlation coefficient. The group numbers were used as the data participating in the analysis (table 3).

The interpretation of the Spearman’s rank correlation coefficient in relation to structural shifts and the movement of objects from one group to another over the time interval under study is as follows: the closer the value is to unity, the more identical the structure of the studied regional clusters is, that is, there is no movement of objects and the group is stable over time. Accordingly, the closeness of the indicator to zero indicates significant changes in the structure and that the set of objects in groups is changing.

The values of the correlation coefficient given in table 3 indicate the stability of the structure and the identical content of the region groups in 2010 and 2014. But the growth of differences in
Figure 4. Structure of regional clusters by innovation level, 2014. Source: Prepared by the author.

Figure 5. Structure of regional clusters by innovation level, 2018. Source: Prepared by the author.
Table 3. Spearman coefficient values for three time frames

| Time frames                  | Spearman’s rank correlation coefficient | t-value |
|------------------------------|----------------------------------------|---------|
| 2010 year & 2014 year        | 0.79                                   | 11.35*  |
| 2010 year & 2018 year        | 0.41                                   | 6.80*   |
| 2014 year & 2018 year        | 0.35                                   | 5.80*   |

* – statistically significant at 5% level.

the structure of innovative regions in 2018 from previous time periods demonstrates an increase in the number of innovative regions-leaders in the cluster and is considered as a positive result and an the innovation indicator growth of the regions.

4. Conclusions
Summing up the study results, the following conclusions can be drawn from the innovation analysis in the regions of Russia:

1) cluster analysis and multidimensional grouping of objects according to innovation indicators showed significant differentiation of Russian regions in terms of innovation levels. Two subsets of subjects were identified: a cluster with high values of innovation indicators which is explained by the availability of resources, and a cluster with low values;

2) the use of Spearman’s rank correlation coefficient made it possible to establish the relative stability of the group population in 2014 relative to 2010 and to identify a structural shift in 2018 relative to previous time frames;

3) the study of indicator changes over time showed an increase in the group of leading regions by 2018, which was facilitated by government policy aimed at stimulating innovation and investment activities. This allows to give a positive assessment of the ongoing innovation policy in the regions of Russia in dynamics from 2014 to 2018. This fact also testifies to the effectiveness of the impact on innovative structural changes in the economy.

The results of the study will be useful to the management bodies for the balanced innovation strategy formation and adjustment. The study allows to assess the effects of innovation policy and can be used to develop directions for the state resource allocation, to adjust development goals depending on the specifics of the spatial structure of the country’s economy and to search for new sources of innovation growth.

The implementation of the formulated conclusions, concepts, developed approaches and methods will provide a sound approach to the development of recommendations to improve the efficiency of regional innovation systems and will allow developing program performance for each cluster of regions.

Further development of the research is seen in the application of econometric models to the object of study, which will reveal and measure the influence of macroeconomic factors on the innovation activity of regions.

Acknowledgments
The research was supported by Russian Science Foundation (project No. 19-18-00199).

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