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SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT OF RUSSIAN REGIONS: A TYPOLOGICAL ANALYSIS, 2012—2024

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Contemporary geoeconomic transformations have heightened the need for spatial analysis of the sustainability of scientific and technological development across Russian regions, particularly in light of the strategic transition from import substitution to technological sovereignty. This study examines typological differences in the level and dynamics of scientific and technological activity of Russian regions between 2012 and 2024, identifying territories that have consistently demonstrated strong performance and are therefore capable of serving as centres for national technological policy amid changing external conditions. The analysis applies hierarchical cluster methods to longitudinal data on regional scientific and technological inputs (staff, funding) and outputs (performance). The extended temporal scope enables the identification of stable regional dynamic profiles, revealing structural distinctions and long-term developmental trajectories. This approach is especially relevant today, as national scientific and technological development increasingly depends on domestic resources, capabilities and competencies. The study establishes a typology of regions, with a core group distinguished by substantial resource concentration and persistently superior performance. It is concluded that the analysis of spatial and temporal dynamics enables the identification of regions that demonstrate resilience to external shifts and have the capacity to contribute to the implementation of a long-term state strategy in science, technology and innovation.

Keywords:
scientific and technological development, spatial typology, import substitution, economic security, technological sovereignty, external relations, technology import, exclave, Kaliningrad region

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Introduction and problem setting

Russia's current public policy has focused on finding ways towards national technological independence [1][1] and establishing a solid R&D framework for sustainable development. Achieving this agenda requires participation from both the real sector of the economy and universities. The international context also necessitates addressing this problem, particularly as sanctions have reduced international trade opportunities and limited the possibility of purchasing hi-tech solutions abroad. In 2012, Russia was listed as an import partner by 158 countries and as an export partner by 43.[2] By the end of 2024, the number of such states had decreased by 40 % for both trade directions.[3]

Although the above does not imply a complete severance of international economic ties, it elucidates the diminution of direct contacts, stressing the actual restructuring of the composition and structure of logistic chains in technological, research, commercial and industrial interactions. However, for example, the dynamics of Russia's imports of research services over 2012—2024 also show an almost identical decline of 43 %,[4] suggesting a similar trend in both the changing opportunities for importing and in the volumes of Russia's technology imports under agreements with other countries. Access to the actual data has been suspended since 2022,[5] but the volume of funds previously allocated for the acquisition of foreign technologies was considerable and broadly comparable to total federal budget expenditure on science, amounting to roughly 60 % in 2019—2021.[6]

Thus, alongside the search for priority directions for investment in the development of domestic technologies, changes in external economic relations raise the issue of utilising funds that require partial reallocation.

At the same time, the problem area of efficient spending and distribution of financial resources across the country's regions is shaped by two factors:

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[1] 2030 Concept for Technological Development, approved in 2023. Order of the Government of the Russian Federation dated 20.05.2023 № 1315-r (as amended on 21.10.2024), URL: https://www.consultant.ru/law/hotdocs/80349.html (accessed 15.05.2025).

[2] Trade Data, 2025, *UN Comtrade*, URL: https://comtradeplus.un.org/TradeFlow (accessed 16.08.2025).

[3] The Russian Federation is directly indicated as a partner (as of August 2025).

[4] Russia's Interntional Trade in Services within the Structure of the Expanded Classification of Services, 2025, *Bank of Russia*, URL: https://cbr.ru/statistics/macro_itm/external_sector/ets/ (accessed 16.08.2025).

[5] Payments for Technology Imports under Agreements with Foreign Countries Since 2017, 2017, *Unified Interdepartmental Statistical Information System*, URL: https://www.fedstat.ru/indicator/58697 (accessed 17.08.2025).

[6] Payments for Technology Imports under Agreements with Foreign Countries Since 2017, 2017, *Unified Interdepartmental Statistical Information System*, URL: https://www.fedstat.ru/indicator/58697 (accessed 17.08.2025) ; Annual Report on the Execution of the Federal Budget, 2025, *Ministry of Finance*, URL: https://minfin.gov.ru/ru/perfomance/budget/process/otchet/ (accessed 17.08.2025).

1) disparities in the development of Russian regions;[1]

2) the need to maintain a balance between the level of investment and the results achieved, the returns generated, and the objectives set, for example, within the framework of technological development.[2]

This context calls for determining the specific position of each region[3] within the functioning of the country's research and technological subsystem. This is essential for the effective allocation of existing and future funding across regions, with a greater likelihood of securing returns on these investments. Determining a region's position is also necessary to assess the degree of regional differentiation by analysing key indicators of RTD levels, based on the construction of a typology of Russian regions according to this parameter. This paper presents such a study, using data covering 13 years, from 2012 to 2024 inclusive.

The time interval selected by the authors is limited to 2012—2024, as during this period the country, and consequently regional economies, encountered three 'transition points' to new operating conditions[4] (Fig. 1).

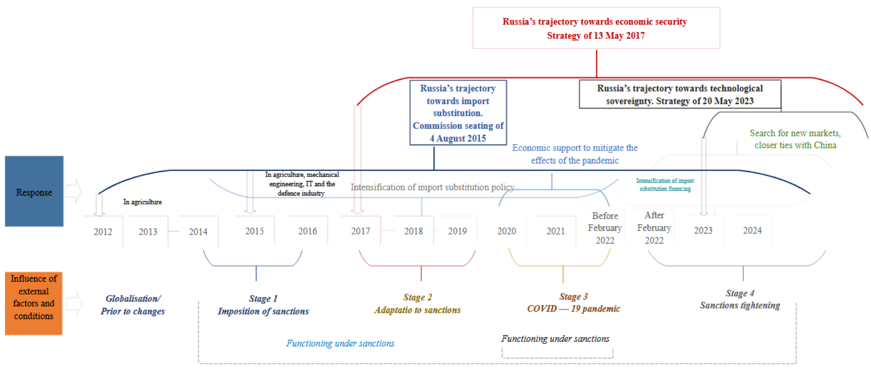

Fig. 1. Intensification of national development trajectories under external factors and conditions

This study aims to develop a robust typology of Russian regions for the period 2012—2024 by clustering key statistical indicators that capture the resource and performance dimensions of regional research and technological subsystems. The objective is to identify pillar regions for advancing research and technological development in accordance with current state policy.

The research hypothesis posits that pillar regions exhibit the highest levels of development of their research and technological subsystems over an extended

[1] Spatial Development Strategy of Russia with Outlook to 2036 (Order of the Government of the Russian Federation dated 28.12.2024 № 4146-r), URL: https://www.consultant.ru/document/cons_doc_LAW_495567/ (accessed 17.08.2025).

[2] Strategy for the Scientific and Technological Development of the Russian Federation (approved by Presidential Decree of 28.02.2024 № 145), URL: https://www.consultant.ru/document/cons_doc_LAW_470973/ (accessed 17.08.2025).

[3] Taking into account the data available for Russian regions.

[4] 1) March 2014; 2) March 2020; 3) February 2022.

period and show limited sensitivity[1] to changes in external factors and economic conditions. This is particularly important for ensuring the sustainability of the country's research and technological development, achieving technological sovereignty and addressing economic security objectives by concentrating research and technological activity in these pillar regions.

To some extent, the geographical connectivity of Russia's regions mitigates regional development disparities. In this regard, particular attention is paid in this study to examining the performance of the research and technological subsystem of the Kaliningrad exclave, one of Russia's regions most sensitive to external conditions [2]. This allows for an assessment of the prospects for achieving the region's research and technological development objectives under new conditions.

Theoretical framework

Differentiating regions according to indicators of the level of their research and technological development and innovation potential [3] has been the subject of prolonged scientific discussion. This stems from the fact that such a distribution serves as a fundamental condition for implementing virtually any national economic development strategy that assumes the independence of the domestic technological framework (Fig. 2).

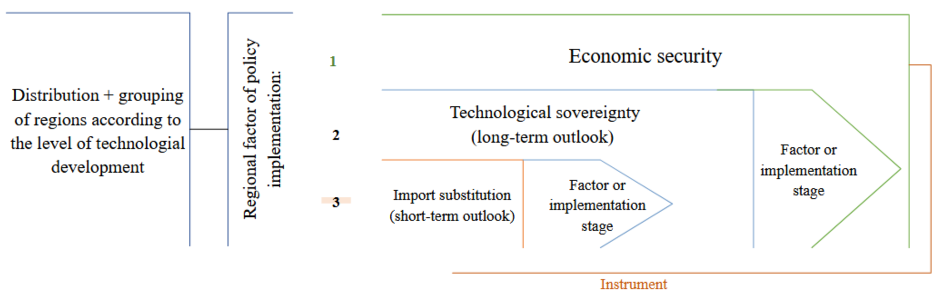

Fig. 2. Grouping of regions by the level of research and technological development as a prerequisite for devising and implementing various types of development strategies

Compiled based on data from [1; 5; 7; 9; 11; 15; 21].

Research interest in indicators, criteria, and the essential conditions for classifying regions by the level of R&D and utilising the results of such classification is generally linked to a transition to a new avenue of national policy, often driven by external factors or expectations of their future change [2; 4—6] (see Fig. 1).

[1] In most cases, the level of sensitivity is below average or they adapt swiftly to changing conditions.

Currently, the contribution of each region to the country's economic security as the 'protection of the economy from external challenges and threats' [7],[1] including those arising from high dependence on external partners, their resources, personnel and technologies [8—10], seems crucial. Thus, differentiation of regions by R&D level is primarily used to address issues of research and technological [9; 10] and innovation security [11—13], the latter incorporating a research and technological component [13]. Although research and technological activity (RTA) is significant for all aspects of security, not all regions need to attain high levels of R&D indicators; rather, they should operate in balance and complementarity to ensure the fulfilment of national objectives.

Russia's current transition from import substitution to technological sovereignty[2] [5], which can be seen as a shift in priorities from the use of tactical measures to long-term development requiring either an existing or rapidly developed domestic R&D framework (Fig. 2), underscores the urgency of identifying regions where such a framework is already functioning, as well as those where its development would be most appropriate.

The term 'technological sovereignty' is interpreted in the literature in various ways, ranging from an emphasis on state independence in the technosphere and the protection of national interests to its understanding as the ability to maintain agency in global technological chains without pursuing autarky [4; 14; 15].

A consensus exists in distinguishing between sovereignty and import substitution: the former entails the creation and control of critical domestic technologies, while the latter merely replaces imports without ensuring competitiveness.

In Russia, the updated Strategy for Research and Technological Development has formalised the priorities and mechanisms for implementing R&D policy. Yet, institutional barriers persist, including misalignment of priorities and low absorptive capacity of the economy for innovation. Without addressing these issues, even large-scale support from the state does not lead to a sustained reduction in technological dependence. General scholarly consensus holds that the key drivers of sovereignty include investment in R&D and human capital, the development of institutions and infrastructure, and network-based forms of cooperation. At the same time, the sovereignisation of critical technologies may temporarily reduce efficiency, but, in the long term, it lowers the risks of external pressure [16—18].

Serving as the foundation for economic security [9], the research and technological component underpins and determines the capacity to achieve national technological sovereignty.

Various assessments of the research and technological subsystem, including ranking-based approaches, are used to evaluate the state of the national research and technological framework at a given point in time, to identify potential sources of technological breakthroughs and to turn to advantage the most

[1] Strategy for the Scientific and Technological Development of the Russian Federation (approved by Presidential Decree of 28.02.2024 № 145), URL: https://www.consultant.ru/document/cons_doc_LAW_216629/ (accessed 11.08.2025).

[2] Note that transiting to technological sovereignty is being considered by many technologically advanced nations.

favourable conditions for adopting new technologies. For example, a scientific report by researchers from the Institute of Economics of the Russian Academy of Sciences, which focuses on the spatial aspects of innovation and research and technological development in Russia [19], brings together seven regional rankings based on research and technological indicators, along with an equal number of methodologies for assessing the innovation potential of the country's regions. Natalia Volkova and Evelina Romanyuk, within their research and technological development (RTD) ranking, featuring 28 indicators grouped into four categories, also note the 'increased relevance of producing research RTD rankings under anti-Russian sanctions, as a result of which access to international technology has been blocked for the country' [20, p. 50].

Among existing rankings, particular attention should be accorded to studies produced by the Higher School of Economics National Research University, which, for more than a decade, has systematically differentiated Russian regions for a range of purposes, taking into account the availability of primary statistical data. The research and technological potential of regions was presented as a standalone block until 2019 and has since been incorporated into the Regional Innovation Development Ranking (RIDR). The first edition of the ranking (2012) was based on 35 indicators, whereas the current tenth iteration, published in July 2025,[1] relies on an original methodology comprising 51 indicators (the sixth, 2019, edition included 53 indicators).The ranking draws on data from around 20 different databases and information platforms. In addition, the authors of the Higher School of Economics methodology acknowledge that the normalisation methods they employ enable comparisons between regions but do not allow for comparisons over time.

On 28 October 2024, the *RIA Rating e*conomic research centre presented another ranking of regions by R&D level.[2] This ranking draws on Rosstat data and comprises 19 aggregated indicators characterising various components of research and technological activity, funding volumes, search for innovation and related aspects. In addition, for two consecutive years — 2022 and 2023 — the Ministry of Education and Science has published a national ranking of the research and technological development of Russian regions. The 2022 ranking comprised 33 indicators, while the 2023 edition included 43 indicators grouped into three categories.[3]

Substantial differences in the methodologies used to compile these rankings significantly hinder direct comparisons and the assessment of changes, even over a single year. For instance, the positions of 22 Russian regions shifted by several dozen positions within one year (Table 1). This raises the question of the extent to which such results reflect not only rapidly changing conditions in the regions but also revisions to the evaluation criteria.

[1] Since 2012, the ranking has been produced by the Institute for Statistical Studies and Economics of Knowledge Higher School of Economics national research university.

[2] Ranking of Regions by Scientific and Technological Development, 2024, *RIA Novosti*, URL: https://ria.ru/20241028/razvitie-1979499343.html (accessed 22.09.2025).

[3] National Ranking of the Regions of the Russian Federation, 2025, *Ministry of Education and Science*, URL: https://minobrnauki.gov.ru/action/stat/rating/ (accessed 12.09.2025).

Table 1

Data on rankings and classifications of Russian regions by research and technological development indicators[1]

Region	Ranking						Differentiation	Clustering			Performance within robust typology	
	Ranking by the Ministry of Education and Science (environment for RTD)			RIA Rating (RTD) Rosstat			Differentiation of regions (2017—2021) / 40 indicators (31 indicator in category 1)	According to 2022 data: 29 / 31 indicators		According to data from 2012—2024 / 4 indicators		
	Ranking in 2022	Ranking in 2023	Change in a region's position (2023 compared with 2022)	Ranking in 2022	Ranking in 2023	Change in a region's position (in 2023 compared to 2022)	Region group by differentiation	Region's group by initial indicators (29)	Region's group by new indicators (31)	Regio s group within robust typology: 2012—2024	Variability from 2012—2024, %	Region type
Moscow	1	1	0	1	1	0	1	1	1	1	33	Pillar
St Petersburg	3	2	–1	2	2	0	1	2	2	1	17	Pillar
Republic of Tatarstan	2	3	1	3	3	0	1	2	2	1	15	Pillar
Nizhny Novgorod region	9	6	–3	4	4	0	1	2	2	1	21	Pillar
Moscow region	4	7	3	5	5	0	1	2	2	1	19	Pillar
Tomsk region	6	4	–2	14	13	–1	1	2	2	1	20	Pillar
Sverdlovsk region	7	9	2	10	10	0	1	3	3	1	20	Pillar
Chelyabinsk region	10	22	12	16	20	4	1	2	3	1	192	Pillar
Perm Krai	25	13	–12	7	8	1	1	3	3	1	45	Pillar
Voronezh region	24	21	–3	21	18	–3	1	3	3	1	40	Pillar
Novosibirsk region	5	5	0	13	16	3	1	2	2	1	24	Pillar
Krasnoyarsk Krai	21	23	2	22	22	0	2	3	3	1	44	Pillar

[1] For cluster analyses, a region group (1-2-3-4-5) corresponds to the cluster number (C1-C2-C3-C4-C5). For differentiating subjects, a region group corresponds to the assigned region type (1(I)-2(II)-3(III)-4(IV)). A detailed table with the results of the grouping is provided. Azhinov, D. 2025, Ratings and groupings of Russian regions by the level of scientific and technological development, *Mendeley Data*, vol. 1, doi: 10.17632/95pkdj68ht.1.

Continuation of Table 1

Region	Ranking						Differentiation	Clustering			Performance within robust typology	
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Samara region	20	10	−10	6	6	0	2	3	3	1	26	Pillar
Ulyanovsk region	11	16	5	9	9	0	2	3	3	1	31	Pillar
Yaroslavl region	45	18	−27	18	21	3	2	3	3	1	48	Pillar
Kaluga region	33	27	−6	20	15	−5	2	2	3	1	36	Pillar
Tyumen region	12	12	0	11	7	−4	2	3	3	1	72	Pillar
Penza region	32	38	6	27	27	0	2	3	4	1	28	Pillar
Republic of Bashkortostan	8	8	0	12	12	0	2	3	3	2	18	Promising: Tier I
Rostov region	15	17	2	15	14	−1	2	3	3	2	35	Promising: Tier I
Saratov region	48	40	−8	36	33	−3	2	3	3	2	53	Promising: Tier I
Belgorod region	18	11	−7	24	23	−1	2	3	4	2	33	Promising: Tier I
Khabarovsk Krai	36	47	11	28	29	1	2	3	4	2	64	Promising: Tier I
Omsk region	14	19	5	17	17	0	2	3	3	2	143	Promising: Tier I

Republic of Udmurtia	37	30	−7	25	26	1	2	4	4	2	94	Promising: Tier I
Tver region	31	32	1	40	40	0	2	4	4	2	52	Promising: Tier I
Vladimir region	39	43	4	30	25	−5	2	3	3	2	33	Promising: Tier I
Tula region	16	25	9	8	11	3	2	3	3	2	38	Promising: Tier I
Republic of Chuvashia	35	29	−6	26	31	5	2	4	4	2	65	Promising: Tier I
Volgogad region	43	45	2	33	34	1	3	4	4	2	53	Promising: Tier I
Ryazan region	29	35	6	23	24	1	3	4	4	2	40	Promising: Tier I
Republic of Mordovia	17	14	−3	19	19	0	3	3	4	2	23	Promising: Tier I
Novgorod region	30	57	27	29	32	3	3	4	4	2	69	Promising: Tier I
Khanty-Mansi Autonomous Okrug	47	66	19	45	41	−4	3	4	4	3	36	Promising: Tier II
Murmansk region	40	48	8	31	28	−3	3	3	4	3	127	Promising: Tier II
Republic of Komi	44	46	2	61	64	3	3	3	4	3	95	Promising: Tier II
Republic of Karelia	28	34	6	63	53	−10	3	3	4	3	121	Promising: Tier II
Smolensk region	65	80	15	50	52	2	3	3	4	3	60	Promising: Tier II
Magadan region	68	73	5	68	67	−1	3	4	4	3	331	Promising: Tier II

Continuation of Table 1

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	Ranking in 2022	Ranking in 2023	Change in a region's position (2023 compared with 2022)	Ranking in 2022	Ranking in 2023	Change in a region's position (in 2023 compared to 2022)	Region group by differentiation	Region's group by initial indicators (29)	Region's group by new indicators (31)	Regio s group within robust typology: 2012—2024	Variability from 2012—2024, %	Region type
Republic of Buryatia	58	70	12	59	50	−9	3	5	5	3	73	Promising: Tier II
Sakhalin region	64	50	−14	65	63	−2	3	4	5	3	150	Promising: Tier II
Leningrad region	75	51	−24	37	36	−1	3	3	3	3	76	Promising: Tier II
Kamchatka Krai	62	65	3	64	65	1	3	4	4	3	76	Promising: Tier II
Sevastopol	66	26	−40	60	62	2	3	5	5	3	47	Promising: Tier II
Kaliningrad region	22	24	2	56	51	−5	3	4	4	3	82	Promising: Tier II
Krasnodar Krai	34	53	19	46	48	2	2	3	3	4	153	Promising: Tier III
Stavropol Krai	23	42	19	44	45	1	2	4	4	4	26	Promising: Tier III

Altay Krai	46	39	−7	51	54	3	2	3	3	4	22	Promising: Tier III
Kemerovo region	13	15	2	55	56	1	2	4	4	4	90	Promising: Tier III
Lipetsk region	60	69	9	42	47	5	3	3	4	4	66	Promising: Tier III
Ivanovo region	27	36	9	52	60	8	3	4	4	4	118	Promising: Tier III
Yamalo-Nenets Autonomous Okrug	80	54	−26	49	49	0	3	3	4	4	274	Promising: Tier III
Astrakhan region	55	59	4	66	70	4	3	4	5	4	82	Promising: Tier III
Orenburg region	42	44	2	47	55	8	3	4	4	4	49	Promising: Tier III
Tambov region	50	33	−17	54	42	−12	3	3	4	4	42	Promising: Tier III
Vologda region	70	41	−29	35	38	3	3	4	4	4	102	Promising: Tier III
Oryol region	69	64	−5	62	57	−5	3	4	4	4	67	Promising: Tier III
Bryansk region	57	63	6	48	44	−4	3	4	4	4	96	Promising: Tier III
Amur region	67	72	5	70	68	−2	3	4	4	4	31	Promising: Tier III
Republic of Mari El	49	37	−12	39	43	4	3	4	5	4	117	Promising: Tier III
Kurgan region	71	58	−13	57	58	1	3	4	4	4	49	Promising: Tier III
Republic of Kabardin-Balkaria	56	78	22	72	74	2	3	5	5	4	55	Promising: Tier III
Pskov region	73	68	−5	67	69	2	4	4	5	4	63	Promising: Tier III

The end of Table 1

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Kostroma region	76	56	−20	69	66	−3	4	3	4	4	91	Promising: Tier III
Republic of Dagestan	61	79	18	73	76	3	3	5	5	5	86	Developing
Republic of Crimea	51	55	4	53	61	8	3	5	5	5	108	Developing
Republic of North Ossetia-Alania	78	71	−7	74	71	−3	3	4	5	5	71	Developing
Zabaikalsky Krai	72	74	2	80	80	0	4	4	5	5	63	Developing
Republic of Kalmykia	81	76	−5	78	81	3	4	5	5	5	89	Developing
Republic of Khakassia	59	62	3	82	84	2	4	4	5	5	129	Developing
Republic of Karachay-Cherkessia	63	61	−2	81	79	−2	4	3	5	5	104	Developing
Republic of Ingushetia	83	83	0	85	85	0	4	5	5	5	97	Developing
Republic of Chechnya	79	77	−2	83	77	−6	4	5	5	5	168	Developing
Republic of Altay	84	81	−3	79	75	−4	4	5	5	5	74	Developing
Republic of Adygea	54	75	21	71	73	2	4	5	5	5	73	Developing
Republic of Tyva	74	67	−7	77	78	1	4	5	5	5	258	Developing

Compiled based on rankings, results of region differentiation [22] and clustering [14].

Rankings should, where possible, be applied independently, with a clear indication of their source, to facilitate clarification of the methodological basis of each study and the set of indicators considered. For example, in the 2023 RTD ranking by the Ministry of Education and Science, the Kaliningrad region occupies 24th place, whereas in a similar RTD ranking[1] compiled by RIA Rating, it ranks 56th.

As a hierarchical list of achievements, any ranking represents a 'snapshot,' even though it is based on real data obtained with some delay.

Another possible approach to classifying regions based on assessing their achieved or potential RTD level is through various groupings, such as classifications or clusterings. Among the results of such groupings, notable examples include: a typology of regions by their predisposition to RTD, comprising nine indicators divided into social, production and institutional blocks, based on data for 2015—2019 [21]; differentiation of regions for implementing regional science, technology and innovation policies, comprising 40 indicators divided into three categories, based on the ranking of Russian regions for 2017—2021 [22]; and a recent cluster-based assessment of regions' contributions to national technological sovereignty. This latter assessment uses indicators grouped into four blocks — capabilities, infrastructure, performance and digitalisation — based on 2022 data in two variants: the original, comprising 29 indicators, and a revised version with 31 indicators [14]. Modifications to some indicators and the inclusion of new ones were partly necessitated by the unavailability of certain data due to sanctions [14].

There is an evident trend towards both a greater number of indicators and increased complexity in the assessment methods employed. However, this approach, particularly when one of its objectives is to track changes over time, may lead to misleading conclusions, partly due to the increasing complexity of the model and the potential subjectivity of expert judgments.

A small number of key indicators provides a clearer, more focused picture, reduces the costs of data collection and processing, and makes results more accessible to both experts and policymakers. In this study, we focus on assessing the feasibility of using multifactor models comprising several dozen indicators. The words of the naturalist Hans Selye might be invoked here: 'You could never learn what a mouse is like by carefully examining each of its cells separately under the electron microscope any more than you could appreciate the beauty of a cathedral through the chemical analysis of each stone that went into its construction' [23]. Moreover, this work will adhere to the principle of 'reasonable sufficiency of empirical material' [24] in forming the research framework.

At the core of the proposed measures is the fact that research and technology require substantial investment and time [25]. Accumulating necessary infrastructure and creating favourable conditions for the development of science and innovation in a region is typically a lengthy process, where impressive achievements and breakthrough technologies certainly play a role [26], yet repetition and consistency

[1] It is considered similar based on the name of the ranking.

of progress are equally important. It is only through the latter that regions can establish a foundation for sustainable research and technological and, ultimately, socio-economic development, as well as form an effective institutional research infrastructure. Studies based on data from a single year or short time periods generally cannot capture long-term trends or the stability of processes occurring in regional RTD. Therefore, this study focuses on a 13-year interval and, as noted above, covers at least three transition points to new economic conditions:

1) 2012—2016 (including the transition point of 2014);
2) 2016—2021 (transition point 2020);
3) 2021 to the present[1] (transition point 2022) (see Fig. 1).

This approach allows for the assessment of the possible responses of each region's research and technological subsystem to changing conditions, as well as the formulation of final typology results relying on a relatively stable structure of regions within each established cluster, given the diversity of external factors operating over the period.

Data and methods

Hierarchical cluster analysis was employed to construct a robust typology of regions by the level of research and technological development for 2012—2024. The procedure included preliminary data standardisation and the application of agglomerative hierarchical clustering, with clusters identified using a reduced dendrogram cut-off threshold [27].[2] All calculations were performed using the Python 3.11 programming language and the following libraries: Pandas 2.2.2, NumPy and Scikit-learn 1.4.2.

A key methodological feature of the approach is clustering based on temporal trajectories. Each observation is represented not by a single indicator value but by a multi-year sequence of values across all four indicators simultaneously. As a result, the Euclidean distance between regions reflects the similarity of their multi-indicator, multi-year profiles: regions that are close in terms of both levels and dynamics (trajectory shape) are grouped within the same dendrogram branches and, at a given cut, within the same cluster. This technique enhances the robustness of the typology to short-term fluctuations and makes it possible to identify 'structural' similarities between regions, one that persists over an extended observation period.

[1] In this work, to 2024 inclusive.

[2] Clustering was carried out in two stages: first, the indicators were prepared with consideration of the long time scale; second, agglomeration was performed using Ward's method in the Euclidean space of standardised indicators. The code imports four input files. Since each source file contains multi-year series for 2012—2024, their integration produces a wide matrix in which each row represents a region and each column represents a specific indicator in a specific year. Thus, each region is represented by a complete time trajectory for all four indicators rather than by single-year values. This approach ensures clustering based on a dynamic profile, capturing stable or shifting regional characteristics over the long observation interval rather than a momentary state.

Empirically, the study relies on statistical data that reflect only the key characteristics of the functioning of regional research and technological subsystems, enabling a focus on the most significant aspects of their RTD. The selection of indicators was driven by the need to capture both resource- and outcome-related components of the research and technological subsystem, the availability of comparable regional data over a sufficiently long period (2012—2024) to identify long-term trends and assess the stability of processes taking place in regional RTD (Fig. 3).

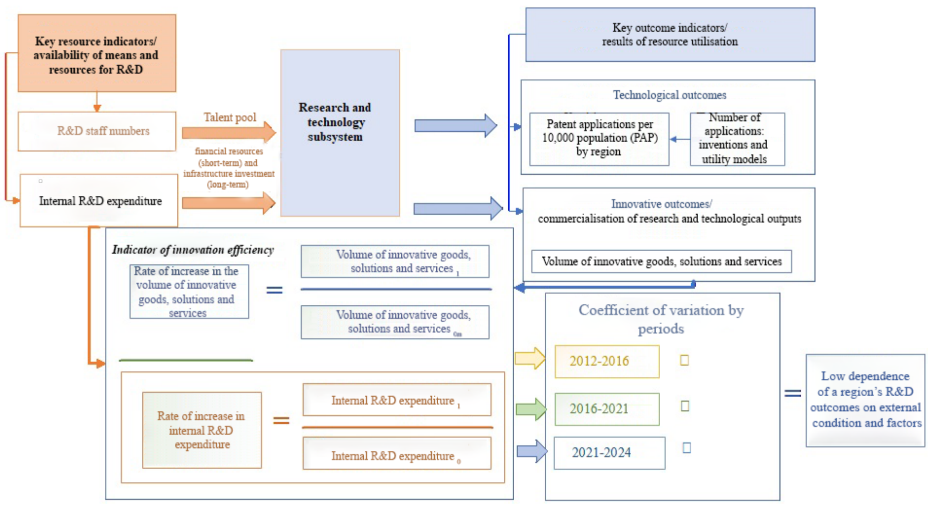

Fig. 3. Relationship between resource and outcome indicators used to assess the RTD level in regions[1]

Compiled based on data from: Statistical Information on the Use of Intellectual Property Objects] 2025, *Federal Institute of Industrial Property*, URL: https://www1.fips.ru/about/deyatelnost/sotrudnichestvo-s-regionami-rossii/statisticheskaya-informatsiya-ob-ispolzovanii-intellektualnoy-sobstvennosti.php?sphrase_id=9130 (accessed 02.06.2025).

[1] Human resources analysis reflects the density of human capital engaged in the creation of new knowledge and technologies. An increase in the number of research personnel indicates the formation of advanced development territories, whereas a decline calls for adjustments to regional and federal R&D support measures.
Internal expenditures on R&D characterise the concentration of financial resources in a region. High values indicate a well-developed research and innovation infrastructure, while low values signal risks of technological lag.
The number of patent applications per 10,000 population shows the intensity of creating and protecting new technical solutions. Its growth reflects a favourable innovation environment and cooperation between research and business, whereas low values indicate structural barriers and weak incentives for patenting activity.
The volume of innovative goods, solutions and services is a composite indicator of research and technological development performance, reflecting the scale of implementation and the degree of commercialisation. High values may indicate a well-established innovation ecosystem, while low values suggest insufficient integration of science and business and weak demand for innovation.

Logarithmic transformation was performed on all the indicators prior to conducting cluster analysis. Information sources for regional RDT analysis were open-access data from 2012—2024.[1] Comparability per 1,000 population was ensured by using demographic data.[2] Analysing key indicators of RTD made it possible to determine the position of each region[3] in Russia's research and technological subsystem, which is treated as part of the manufacturing system, as discussed in detail in the authors' previous works, for example, in [28]. The presented clustering of regions, based on data over an extended period,[4] is aimed at developing a stable typology of regions, including the identification of pillar regions among them.

The study's central hypothesis posits that pillar regions — those demonstrating the highest levels of development in their research and technological subsystems over an extended period — are either only moderately dependent on changes in external factors and economic conditions or adapt to them rapidly. Consequently, an additional indicator is employed after clustering to assess the extent of regional RTD's dependence on external factors and conditions. Here, the degree of dependence of regional RTD on external conditions is evaluated through the variability of the innovation performance indicator (for details, see the calculation procedure in Fig. 3). It is assumed that regions exhibiting a low level of dependence on external factors and conditions demonstrate stable innovation performance results across all three time stages, including the 'transition points', which, in turn, may indicate a high degree of autonomy independent of external context. The stability of the achieved results was assessed by calculating the coefficient of variation at each time stage. Regions with low variability in innovation performance are considered less dependent on external conditions.

This study assumes that regions with lower dependence on external factors and conditions have exhibited stable innovation performance — interpreted as the outcome of research and technological activity — across all three periods, including the transition points. This may indicate a high degree of autonomy from

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[1] Science, Innovation and Technology, 2025, *Rosstat*, URL: https://rosstat.gov.ru/statistics/science (accessed 02.06.2025) ; Statistical Information on the Use of Intellectual Property Objects, 2025, *Federal Institute of Industrial Property*, URL: https://www1.fips.ru/about/deyatelnost/sotrudnichestvo-s-regionami-rossii/statisticheskaya-informatsiya-ob-ispolzovanii-intellektualnoy-sobstvennosti.php?sphrase_id=9130 (accessed 02.06.2025).

[2] PPopulation Census, 2020, *Rosstat*, URL: https://rosstat.gov.ru/perepisi_naseleniya (accessed 02.06.2025).

[3] Due to the lack of date, the analysis does not cover Chukotka autonomous okrug, the Jewish autonomous region, Nenets autonomous region, the Kherson region, the Zaparozhye region, the Lugansk People's Republic and the Donetsk People's Republic. To ensure comparability and dataset completeness, lacking data for the city of Sevastopol and the Republic of Crimea for 2012 and 2013 were replaced with 2014 data.

[4] The GDP deflator was used to ensure comparability of financial indicators over a long period.

the external context. The stability of achieved results was assessed by calculating the coefficient of variation for each period; regions with low variability in innovation performance were considered less sensitive to external conditions.

Clustering over a long-term period based on regional research and technological activity makes it possible to construct a robust typology of regions. An extended typology, combined with calculations of variability in innovation performance across different periods, enables the identification of regions with consistent performance under varying conditions and, therefore, lower sensitivity to corresponding changes.

Results

Clustering led to the identification of five regional clusters distinguished by levels and rates of growth in research and technology. Figure 4 shows the results of hierarchical clustering.

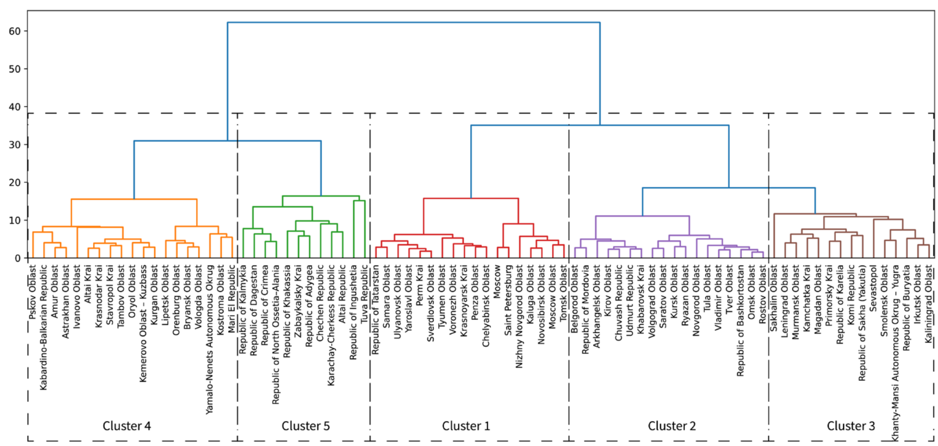

Fig. 4. Hierarchical clustering dendrogram (Ward's method)

Cluster 1, which comprises 18 'pillar regions', constitutes the core of Russia's research and technological system. The average values of all four indicators significantly exceed the national level, and, over 2012—2024, the cluster exhibited sustained growth accompanied by a relative reduction in intra-cluster heterogeneity. The cluster brings together the country's largest research, educational and industrial centres, attracting research talent and continuously expanding their R&D efforts. For most regions in this group, a moderate growth rate combined with the maintenance of leading positions is typical, indicating a transition to a stage of sustainable technological leadership.

Cluster 2, which includes 18 'tier I promising regions', occupies an intermediate position between the core and the periphery. Indicators of R&D personnel availability and internal expenditure approach those of the 'pillar regions', whereas invention and innovation output remain moderate. At the same time, this group demonstrates the highest compound annual growth rates (CAGR) across a number of indicators, particularly the volume of innovative goods and R&D expenditure, indicating a gradual narrowing of the gap with the leaders.

Cluster 3, comprising 15 'tier II promising regions', corresponds to an intermediate level of development. Average indicator values remain below the national figures, although growth rates in certain areas, particularly innovation output, are comparable to those observed in Cluster 2 regions. Growth is accompanied by high variability, reflecting heterogeneous initial conditions and a sporadic pattern of technological renewal. Geographically, this group predominantly comprises industrial regions with emerging research and educational centres and distinctive niches.

Cluster 4, which includes 18 'tier III promising regions', is characterised by relatively low average values across all indicators and pronounced intra-group differentiation. Several regions exhibit short-term spikes in inventive activity or innovation output, reflecting sensitivity to local factors such as the presence of flagship enterprises, participation in federal programmes or the development of university initiatives. Despite isolated successes, overall growth rates remain lower than in the higher-level clusters, confirming a persistent lag in key RTD parameters.

Cluster 5, consisting of 12 'developing regions', occupies the lowest positions across all indicators. These regions are marked by minimal levels of research personnel and R&D expenditure, low inventive activity and limited innovation output. Nonetheless, between 2012 and 2024, some regions displayed relatively high growth rates in specific indicators, attributable to the low-base effect and the implementation of individual RTD projects. High intra-cluster dispersion reflects the presence of isolated growth points amid generally weak R&D infrastructure.

A comparative analysis across four indicators reveals several discernible patterns. First, human capital remains a key marker of sustainable technological leadership: the availability of research staff is the most stable indicator over time and clearly differentiates the clusters. Second, R&D expenditure shows the sharpest polarisation between the top and bottom groups, with the 'runner-up clusters' (tiers I—II) demonstrating faster growth rates. Third, inventive activity is highly volatile and sensitive to institutional changes. Finally, innovation output reveals divergent trajectories: for the 'pillar regions' it is high and stable, whereas for the 'runner-up' regions growth rates are high but absolute volumes remain moderate.

Thus, the analysis confirms the existence of a hierarchically organised and spatially differentiated structure of Russia's research and technological development, in which the 'pillar' and 'tier I promising' regions form the core of the national research and technological space, while the remaining clusters represent zones of transformation and catch-up growth (Fig. 5).

Fig. 5. A choropleth map of RTD cluster distribution across Russia

The persistence of positive trends from 2012 to 2024 suggests a gradual narrowing of the gap between the upper and middle groups, although peripheral regions remain at the stage of developing the basic infrastructure and human capital required for integration into the national research and technological system.

It should be noted that the conducted clustering and dynamic analysis not only captures the current state of regional research and technological systems but also helps identify avenues for spatially targeted regional policy.

The Kaliningrad region in the robust typology of regions

The exclave of Kaliningrad is a border and coastal region of Russia [29]. The region's economy is — or was, since data on the region's international trade have not been published since 2022 — among the most open to international connections of all Russia's regions. At certain periods, imports substantially exceeded the region's GRP (for example, 1.6-fold in 2014) [2]. This indicates a relatively higher degree of the exclave's dependence on changes in external conditions compared with other regions across the country [30].

In the Ministry of Education and Science ranking, which evaluates the conditions for conducting RTD, the Kaliningrad region dropped two places in 2023,[1] from 22nd to 24th. In the RIA Rating ranking, which covers funding volumes, inventive activity, and RTD performance according to Rosstat data, the region likewise fell, from 51st to 56th place. Overall, both rankings indicate a general decline in the region's performance. According to the RTD components analysed using different ranking methodologies, the region's potential — measured in terms of conditions for RTD created by authorities and

[1] As of September 2025, the ranking for 2024 has not yet been published.

environmental parameters for knowledge-intensive business — is approximately 2.3 times greater than its actual performance under unfavourable conditions (56th in performance versus 24th in conditions).

Moreover, the unfavourable conditions for knowledge-intensive activity do not currently allow for a significant increase in the Kaliningrad region's R&D expenditure, since the exclave's share of total R&D expenditure in Russia was 0.13 % in 2012 (7.7 times lower than 1 %) and 0.16 % in 2024 (6 times lower than 1 %). According to the typology results for 2012—2024, the region is classified in Cluster 3 ('tier II promising regions') and has not yet joined the 'pillar regions' that could serve as a reliable platform for implementing current national policy objectives.

Furthermore, the baseline RTD variability for the Kaliningrad region across periods corresponding to the transition points is as follows: 1) 92 % in 2012—2016; 2) 100 % in 2016—2021; 3) 64 % in 2021—2024. Thus, in each period it exceeded not only the 33 % threshold regarded as the boundary of stable change but also the national average of 79 %, except for 2021—2024. The region's RTD is characterised by high sensitivity to external changes, whereas the dynamics of the region's indicators are largely divergent compared with the Russian average (Fig. 6).

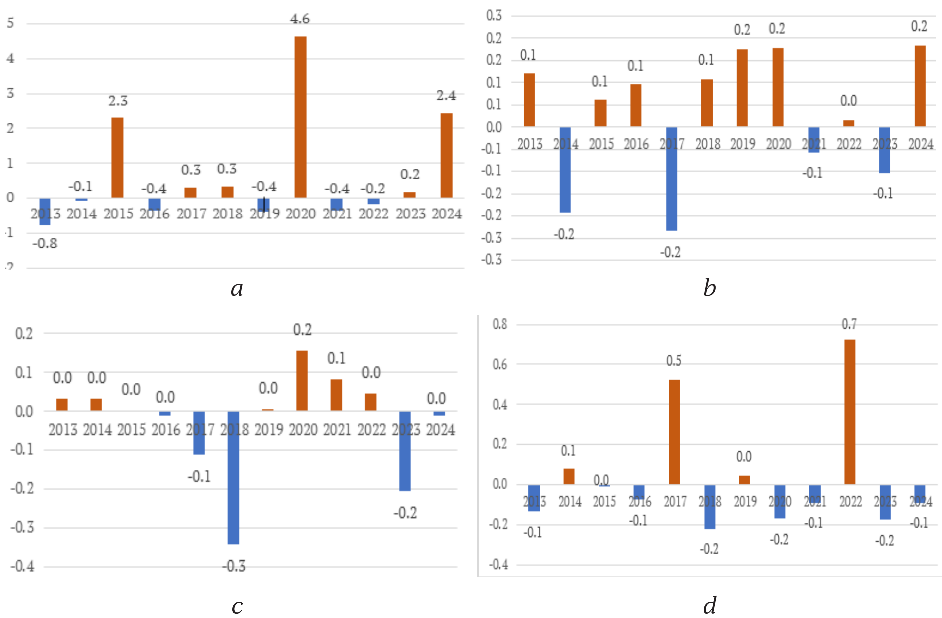

Fig. 6. Difference between the growth rates of key RTD indicators in the Kaliningrad region and Russia, percentage points;
a) volume of innovative products; b) internal R&D expenditure;
c) number of personnel engaged in research; d) patent applications per 10,000 population

Calculated based on Rosstat data.

R&D funding in the region, with an average annual growth rate of 112 % over 2012—2024, has increased slightly faster than the national average of 109 %. This figure slightly exceeds the average official inflation rate of about 7 %.[1] Over the period, the efficiency of research and technological activity in the Kaliningrad region has changed markedly relative to national indicators, or 'returns on innovation investment', assessed here as the ratio of innovative output to internal R&D expenditure, roubles per rouble.

At the beginning of the period under consideration, the region's performance amounted to less than one rouble of innovative output per rouble invested in research, corresponding on average to 17 % of the national level (Fig. 7). After 2020, the return on invested funds consistently exceeded unity, reaching 84 % of the national level in 2021—2024 and surpassing it by 64 % in 2024, with a return of 8 roubles per rouble compared with the national average of 5 roubles per rouble. Over the same period, internal R&D expenditure increased by only 14 %. This may be interpreted as evidence of the region's RTD capabilities, provided that funding volumes are sufficient to achieve the planned outcomes.

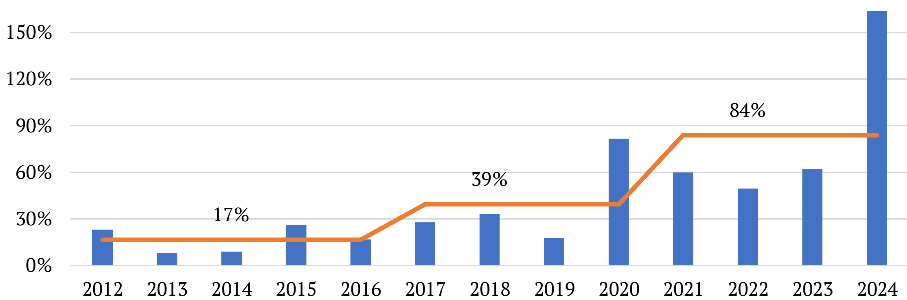

Fig. 7. Contribution of the Kaliningrad region to the national total return on expenditure in terms of innovative output, %

Calculated based on Rosstat data.

Results of current rankings and groupings (typologies and clustering) of Russian regions according to RTD

The relevance of assessing the actual and/or potential contribution of regions or regional groups to general economic security objectives, technological sovereignty as a key component, the consistency of the country's research and technological development, and understanding the hierarchy of regional performance based on RTD indicators prompts a summary of the specific outcomes of the most pertinent studies on the topic, including the present one (see Table 1).

[1] Key Rate of the Bank of Russia and Inflation, 2025, *Bank of Russia*, URL: https://cbr.ru/hd_base/infl/?UniDbQuery.Posted=True&UniDbQuery.From=17.09.2013&UniDbQuery.To=22.09.2025 (accessed 22.09.2025).

The diversity of rankings, each emphasising different aspects of regional RTD, has been noted above, with a comparison of the robust typology results and current research and technological development rankings revealing several fundamental discrepancies stemming from differences in methodological approaches.

First, several regions exhibit high variability in their ranking positions, reflecting the sensitivity of rankings to changes in the combination of indicators and normalisation methods. For example, the Sverdlovsk, Samara and Nizhny Novgorod regions can shift by dozens of positions across different rankings, whereas in the multi-year cluster analysis, they consistently fall within the leading groups (clusters 1 and 2).

Second, some regions show a marked gap between the assessment of enabling conditions (according to the Ministry of Education and Science ranking) and actual RTD outcomes (according to RIA Rating and the robust typology). For example, the Kaliningrad region, despite high institutional environment scores, maintains moderate performance levels in multi-year dynamic profiles, falling within cluster 3.

Third, several regions that sit high in annual rankings due to individual large projects or short-term increases in funding (e. g., the Republic of Sakha [Yakutia], Krasnodar Krai, Khanty-Mansi Autonomous Okrug) exhibit considerable instability in their indicators when trajectories over 2012—2024 are considered, preventing them from entering the upper clusters of the robust typology.

Finally, 'covert leader' regions have been identified: those whose ranking positions remain average, but whose long-term stability and high intensity of research and technological activity per 10,000 population place them in the 'pillar regions' group, most notably, the Penza region. These discrepancies highlight that rankings primarily capture the momentary state of regional RTD, whereas stable multi-year profiles, which underlie the proposed typology, make it possible to reveal structural stability, tracing the patterns of changes and regions' ability to retain performance levels regardless of external shocks and methodological adjustments. Accordingly, ranking assessments and regional hierarchies in RTD are not planning instruments, especially not for long-term purposes, nor are they intended as such.

Another approach to classifying regions involves grouping them according to specified criteria, primarily based on whether the values of the indicators under consideration fall within certain author-defined thresholds. Vladimir Byvshev et al. [22] present results of regional differentiation for more targeted regional policy in RTD, drawing on regional ranking assessments for 2017—2021.[1] However, the time interval is considered in the aggregated format as the sum of scores across rankings over five years.[2]

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[1] The journal publication appeared on 30 September 2024 and examines data for Russian regions from 2017—2021, which reduced the period of result relevance.

[2] It should be noted that the classification of regions into groups was performed independently by the authors of this study, taking into account the boundaries of the aggregated ranking, as study [22] considers not only R&D indicators but also spatial and administrative-historical factors.

Despite differing initial assumptions and study periods, the regions [22] were classified as 'advanced' based on 40 indicators[1] (group 1 within the differentiation). They are fully included in cluster 1 of the four-indicator robust typology, which is significant for the present study.

Let us consider the results of region clustering as a final basis for comparison. One of the most relevant studies as of October 2025 is a 2024 work [14] offering two clustering variants for assessing the contribution of regions to the country's technological sovereignty. The first variant is based on a set of 29 indicators, while the second relies on 31 indicators. The authors of the study [14] note that the indicator system was modified due to the unavailability of certain data under sanctions (for example, data on regions' international trade), which necessitated the search for alternatives. The challenges of ensuring valid comparisons of grouping results over extended periods with a large number of indicators involved have already been discussed. In contrast to the present study, the mentioned work [14] employs the iterative *k*-means method for clustering. Unlike Ward's method, *k*-means requires the number of clusters to be specified in advance, which may result in the formation of suboptimal clusters. Moreover, according to [14], the first cluster consists of a single region, Moscow.

Let us employ the results of differentiation and clustering of regions (see Table 1) to verify the basic hypothesis of the present study. The hypothesis posits that regions with the most developed research and technological subsystems[2] also exhibit stable rates of innovative activity, which in this study is interpreted as a high degree of independence from changes in external factors and economic conditions (Table 2).

Table 2

Indicators of the variability of innovative activity growth rates relative to internal R&D expenditure growth rates according to the results of region grouping and clustering by RTD levels

Group of regions	Robust clustering (2012—2024)	Clustering according to 29 indicators [14]	Clustering according to 31 indicators [14]	Regional differentiation [22]
	Average variation in regional innovation performance within a group / cluster, %[3]			
1	41	33	33	40
2	65	43	19	60
3	111	71	65	94
4	84	90	87	110
5	110	103	100	—
Difference in variability between the utmost groups / clusters	2.7-fold	3.1-fold	3-fold	2.2-fold

[1] In addition to R&D indicators, the authors in [22] use indicators from the socio-economic, spatial, and administrative-historical categories.

[2] The authors consider this circumstance using different basic premises and methodologies.

[3] To allow for comparability of the results for 2012—2024.

Indeed, across all available studies, regions in groups 1 and 2, which exhibit the highest RTD performance, consistently show the greatest stability of change rates or the lowest variability, compared with other groups identified in various studies, despite differences in their initial premises. As noted above, establishing necessary infrastructure and creating favourable conditions for the development of research and the generation of innovations in a region is typically a lengthy process, in which the repeatability and consistency of progress are particularly important, as clearly demonstrated by 'pillar regions' (cluster 1) and 'tier I promising regions' (cluster 2). Let us compare regional ranking and clustering results (based on two groups of indicators) with those obtained in this study through the typology of regions for 2012—2024,[1] taking into account the constraints imposed by differing study periods. This comparison aims to assess the feasibility of using only key indicators to allocate regions by RTD performance. For the rankings, the ordinal position of each region in the respective year is used, while for the typology of clustering results, the ordinal position of each region is similarly employed, as presented in [14] according to the innovation index (RTD index)[2] (Table 3).

Table 3

Results of producing a typology of Russian regions by RTD indicators

Intra-group difference	RTD rankings				Clustering			
	19 indicators		19 indicators		29 indicators		31 indicators	
	According to RTD ranking, 2022	Percentage from the total number of regions %	According to RTD ranking, 2023	Percentage of the total number of regions %	Based on the initial clustering data, 2022	Percentage of the total number of regions %	Based on the new clustering indicators, 2022	Percentage from the total number of regions %
−3					1	1		
−2					5	6	4	5
−1	16	20	15	18	12	15	14	17
0	51	62	52	63	45	55	47	57
1	14	17	15	18	13	16	13	16
2	1	1			6	7	3	4

[1] Results of clustering-based classification of regions for 2012—2024: cluster 1: 18 regions; cluster 2: 18; cluster 3: 15; cluster 4: 19; cluster 5: 12.

[2] The results of classification based on the composite ranking for differentiating regions in study [22] are not included, as the evaluations there are based not only on R&D indicators but also on a range of socio-economic indicators.

The end of Table 1

Intra–group difference	RTD rankings				Clustering			
	19 indicators		19 indicators		29 indicators		31 indicators	
	According to RTD ranking, 2022	Percentage from the total number of regions %	According to RTD ranking, 2023	Percentage of the total number of regions %	Based on the initial clustering data, 2022	Percentage of the total number of regions %	Based on the new clustering indicators, 2022	Percentage from the total number of regions %
3							1	1
Total number: from −1 to +1	81	99	82	100	70	85	74	90

The average number of indicators used to accurately distribute regions by RTD level in the presented rankings and clustering results is 25. At the same time, using only the key indicators made it possible to achieve complete group correspondence for an average of 59 % of regions. A further 94 % of all regions fall within adjacent groups, that is, within the range of −1 to +1, providing a sufficiently relevant basis for their use and enabling the monitoring of regional progress in achieving RTD goals solely on the basis of key indicators, which are available for regular monitoring.

Conclusions

The findings of this study present a comprehensive picture of the spatial structure of research and technological development across Russian regions over an extended period, from 2012 to 2024. The hierarchical clustering method applied to multi-year data allows regions to be assessed not by single-year indicator values, but by their consistent temporal trajectories. This approach enabled the formation of a typology reflecting not only the current position of regions, but also the degree of stability of their research and technological potential under varying external economic conditions.

Clustering identified five stable groups of regions differing in the level and pace of research and technological development. At the top of the hierarchy are the ‘pillar regions’, which comprise the core of the national research and technological system as they concentrate human, financial, and institutional resources. These territories exhibit high and consistent performance across all key indicators and the lowest sensitivity to external changes, confirming their role as spatial anchors of the country's technological sovereignty. Tier I promising regions form the contour closest to the core of the research and technological space: they advance rapidly, exhibiting high growth rates in innovation activity indicators and gradually closing the gap with the leaders. Tier II and III territories display average or below-average indicator values. However, they show significant growth potential and the greatest variability in results, indicating scope for development under sufficient government support. Developing regions occupy the periphery of the national system, often remaining dependent on external factors and limited in resources, yet even among them, certain territories show signs of local advancement in research and technology.

Of particular significance is the comparison of the cluster-based typology with contemporary groupings and rankings of research and technological development, which reveals a pronounced convergence of approaches. Over 90 % of regions remain in similar groups regardless of assessment methods. This demonstrates that the use of a limited set of key indicators — staffing, expenditure, patent applications per 10,000 population and innovative output — adequately captures both the actual position of regions and the dynamics of their research and technological development.

These findings have practical relevance for spatially oriented research and technological policy implementation. Long-term clustering makes it possible to identify regions with proven robustness in research and technology and relatively low dependence on external factors, which may be regarded as pillar territories in pursuing state policy on technological sovereignty. For tier II and tier III regions, the priority lies in strengthening human capital and infrastructure capacity, whereas for peripheral regions the key task is integration into interregional and network-based forms of cooperation to compensate for limited internal resources. These issues are expected to be addressed in subsequent studies.

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