KNOWLEDGE AND INNOVATION DYNAMICS OF THE NORTHWEST RUSSIA UNDER GEOPOLITICAL CHANGES

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Over the past 25 years, Russia has faced several economic and geopolitical challenges, including the 2008 global financial crisis, sanctions imposed in 2014, and the COVID-19 pandemic. To remain resilient in the face of these challenges, Russia needs to adopt a flexible development strategy and transition to a new path of development. This transition requires the development of new knowledge-intensive industries, expansion into promising markets, strengthening trade and economic partnerships, and achieving technological sovereignty. This study examines the innovation system in Northwest Russia and identifies factors that are critical for its sustainability and innovation security in the face of geopolitical instability. The study uses an integrated approach to trace the knowledge production and innovation process from research findings to the commercialization of new technologies. The study finds that there are strong correlations between innovation activity and R&D investment, patent activity, and the number of innovative organisations. The study also identifies three types of regional innovation systems in Northwest Russia: core, semi-periphery, and periphery. The nature of the regions' involvement in R&D determines the dynamics and specialization of their publications and patents. The study also finds that there is a positive correlation between the volume of innovative products and quantitative factors in the functioning of subsystems involved in knowledge generation and innovation. Finally, the study examines the geography and structure of the international research network that the regions of Northwest Russia had formed by 2022. It shows that the geopolitical transformation requires a significant part of cooperation ties with unfriendly countries to be restructured.

Keywords:
geography of knowledge, geography of innovation, innovation process, scientometrics, publications, R&D, patents, innovations, Northwest Russia, scientific cooperation

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Introduction and Problem Statement

Innovations serve as a catalyst for the reorientation of industrial and technological structures [1; 2], playing a pivotal role in the restructuring of a regional economy and its adaptation to rapidly changing circumstances [3]. During times of crisis, regions that embrace innovative advancements tend to be more successful in navigating the aftermath of shocks. They leverage accumulated internal resources and experience to devise ingenious solutions to external challenges [4; 5]. Assessing the consequences of the 2008—2009 global economic crisis, reports from the governments of certain developed countries underscore the critical importance of innovation for economic recovery post-recession. Regions with higher innovation potential demonstrated greater resilience in withstanding the crisis [3].

In 2022, Russia faced increased sanctions from unfriendly countries (see Russian Federation Government Directive № 430-r of 5 March 2022). They prohibited the export of a wide range of goods and technologies to Russia, suspended software sales and maintenance and technical support services, and restricted access to various online resources and digital systems. The 'cancel culture' targeting Russia has diminished its opportunities for international research collaboration.

The rupture of scientific and technological ties exacerbated the problem of technological dependence, i.e. basing critical national infrastructure and production on foreign technologies. In May 2023, the Russian government adopted the Concept of Technological Development until 2030. According to the document, the primary goal for the next decade is to attain the nation's technological sovereignty. It requires moving into an innovation-driven economy by creating conditions for the sustainable development of production systems. Thus, this study aims to assess the scientific and innovative dynamics of regional development in Northwest Russia in the context of geopolitical changes.

The research object is the regions of the Russian Northwestern Federal District, commonly referred to as Northwest Russia. This choice is determined by their significant role in the innovative development of the country, territorial proximity to the EU countries and associated higher geopolitical pressure. The St. Petersburg-Pribaltic region, characterized by advanced industry and innovation leadership, has traditionally been the front runner in 'accepting' and 'transmitting' external innovations [6]. Current processes are steadily changing the capabilities, external relations and functions of Northwest Russia since it is here that the 'fragility' of cross-border interactions (resulting from the geopolitical and geoeconomic reformatting of the Eurasian space) is most clearly manifested [7].

The St. Petersburg agglomeration and the surrounding regions are expected to be the first to feel the consequences of the crisis [8]. Considering the spatial diffusion of the coronavirus infection in the Russian part of the Baltic macroregion, by parity of reasoning, we assume that St. Petersburg, the Leningrad and Kaliningrad regions (areas with high permeability) will undergo the most profound structural changes, and the Novgorod and Pskov regions — the smallest [9]. At the same time, path dependence, which is especially strong in long-settled areas, can hinder accelerated modernization and adaptation [10].

Theoretical framework

The concept of development trajectories provides the framework for studying growth opportunities against the background of crisis phenomena. There are different pillars of a region's transformation: from sectoral modernization and diversification to the emergence of new activities [11]. The article [12] proposes four directions of regional development through adopting a new industrial path: a) the transformation of the current structure; b) the development of related activities based on accumulated capabilities; c) the transfer and consolidation of industries from outside; d) the emergence of entirely new activities based on advanced technologies, scientific discoveries, business models and innovations.

While *sustainability* means the preservation of the current level of well-being and natural resources for future generations [13], *resilience (*flexibility, sturdiness) refers to a regional economic system's response to crises. Bristow and Healy describe economic resilience as the ability of regions to withstand and/or recover quickly from shocks [3]. The main factors of resilience, or *shock resistance*, include economic diversification and high innovation potential [14].

There are three approaches to the conceptualization of resilience [15].

(1) The ability to return to pre-shock conditions. The level of resilience shows how quickly the system can recover from shocks while retaining its structure and functions [16]. The basis is the idea of the immutability of a current development path, including partial absorption of shocks without significant changes in its structures [17].

(2) Adaptation, reorientation and structural changes in response to a crisis [18]. 'Evolutionary resilience' suggests the emergence of new ways of development as a result of a continuous process of adaptation, regardless of the frequency of shocks [19].

(3) Ability to make the transition to a new sustainable path characterized by a more effective and fair use of resources [20, p. 15]. The idea of 'transformational resilience' suggests that the crisis can not only lead to structural transformations but also become a 'window of opportunity' for a change in the development trajectory [21]. In contrast to a transformative capacity, which shows the ability

of a system to reconfigure in response to future challenges [22], resilience reflects the extent to which shocks can be harnessed to initiate or accelerate radical changes.

Evolutionary economic geography, which considers the development trajectories of countries and regions of the world [23], increasingly supports the view that regions' ability to innovate beyond the existing paradigm underlies resilience [24]. Asheim and Herstad [25] note that innovation is a key factor in economic restructuring, resilience and sustainable development. Technological innovations help to overcome inertia and leave long-established development paths [26].

The relationship between innovation and resilience is complex [3; 27]. A developed innovation system makes it easier for a region to adapt and overcome crises. However, literature [28; 29] provides evidence that innovation activity is more susceptible to the negative impacts of crises and other destabilizing factors. In a period of uncertainty, innovative companies, especially small and medium-sized ones [30], tend to curtail investment projects and reduce their R&D spending, focusing on current activities.

The consequences of the 2007—2008 crisis, the 2020—2021 Covid recession, and the current geopolitical tensions around the situations in Ukraine and Taiwan bring out the low resilience of many created regional innovation systems (for example, in the EU countries). There is a need to shift to challenge-oriented innovation systems better adapted to dealing with shocks [31].

Methods and Materials

Methodological aspects of the innovation assessment

A regional innovation system relies on two interrelated subsystems: knowledge production and innovation. The knowledge production subsystem serves as an indicator of the technological potential of the region, influencing the level of a region's economic complexity. This, in turn, reflects the innovativeness and manufacturability of goods produced and exported by the region. The development of this subsystem is a precondition for innovative and technological changes in high-tech and capital-intensive production [32].

The basis for distinguishing the two subsystems is the difference in understanding the essence of inventions and innovations. According to Schumpeter's approach [33, p. 66], innovations are 'new combinations' of products, processes, production methods, markets, organizational forms or resources. Inventions become innovations only when adopted into practice as part of the innovation process. The idea of the innovation process as linear and sequential, with R&D leading to innovations, is very rough since not all innovations require investment in research and development [34]. An example of the practical diversity of non-linear technological development strategies is open innovations [35]. Many innovations are not patented, much R&D does not lead to innovations and not all patented products are brought to the market [36].

Different degrees of novelty distinguish adaptive, incremental, and breakthrough innovations. The diversity of innovation types is reflected in the assessment indicators. Innovation indicators can rely on data on research and development, scientific publications, patents, innovative products and processes [36; 37]. The most common are patent- and R&D expenditure statistics [36; 38]. Less common indicators for assessing scientific, technological and innovative potential include [39; 40] the number of computers with Internet access, the share of organizations with a website, the share of Internet users, the number of subscriber devices for cellular communication, the number and volume of between academia, industry and government, the number of students in natural science, mathematics, engineering and medicine, salaries of R&D personnel, the availability of research infrastructure.

Patent statistics have been used to measure R&D output since the middle of the twentieth century [41]. Their limitation is the fact that they reflect inventions rather than innovations. Their strength is that they include only new inventions, not moderate changes in existing technologies [36].

The limitations of using expenditure on R&D as an indicator [42] arise from the fact that the commercialization of the outcomes is not guaranteed. R&D is an input factor for innovation [35]. The amount of expenditure on R&D does not reflect the economic value of the innovation and or the product's technological complexity. Despite these limitations, data on R&D and patents serve as the basis for innovation statistics [43—45].

Another approach to assessing innovation activity is a literature-based innovation output analysis (LBIO), which has become widespread due to digitalization. A scientific literature analysis does not capture all aspects of innovation or replace other indicators, rather it serves as a valuable addition to them [42], being a relatively reliable way to measure the 'radicality' of the innovations generated.

Thus, each indicator captures an aspect of the scientific and innovative process: *R&D* — investments in new developments; *scientific publications* — the effectiveness of the knowledge production system; *patents* — novelty; *innovation* — commercialization of technologies.

Study design

The first stage involves the assessment of scientific activity in Northwest Russia. Indicators for the analysis are the number of commissioned and performed R&D projects and expenditure on R&D by performers and consumers (total and per project). The considered period is 2019—2021. The share of the Northwest regions in the total performed and commissioned R&D in Russia allows us to assess the size of their scientific systems. This and other indicators in absolute values provide the basis for a comparative assessment of the role of considered regions in the national and district's scientific space.

Accounting for particular fields of knowledge of performed R&D projects in a region allows one to identify its specialization. For each region, we calculate coefficients of scientific specialization according to the following formula

$$KS_{ja} = \frac{S_{ja}/S_{jtotal}}{S_a/S_{total}}, \quad (1)$$

where KS_{ja} is the coefficient of scientific specialization of the region j in the field of knowledge a; S_{ja} is the volume of R&D performed in the region j in a field of knowledge a; S_{jtotal} is the volume of R&D performed in the region j in all fields of knowledge; S_a is the volume of R&D performed in the country in a field of knowledge a; S_{total} is the volume of R&D performed in the country in all fields of knowledge. KS_{ja} above one shows the region's specialization in a particular field of knowledge.

The second stage is an assessment of the effectiveness of the scientific systems of the considered regions through publication and patent statistics analysis. It includes determining their contribution to the total volume of Russian publications in the Scopus database in 2018—2022. A rank method allows for a structural assessment of knowledge areas in regional publication portfolios.

To assess the impact of geopolitical changes on the publication landscape in the regions, we determine the share of their publications co-authored by representatives of 'unfriendly', 'friendly', and 'neutral' countries. The Russian Federation Government Directive №430-r of 5 March 2022 (with amendments) provides the list of unfriendly countries. Friendly ones include those with which the cooperation continues and there are no flight restrictions. The rest of the countries are neutral.

Formula 2 computes coefficients of inventive specialization in subject areas for each of the regions based on data related to issued patents, encompassing inventions, industrial designs, and utility models

$$KP_{ja} = \frac{P_{ja}/P_{jtotal}}{P_a/P_{total}}, \quad (2)$$

where KP_{ja} is the coefficient of inventive specialization of a region j in a subject area a; P_{ja} is the number of patents in the region j in a subject area a; P_{jtotal} is the number of patents in the region j in all subject areas; P_a is the number of patents in the country in a subject area a; P_{total} is the number of patents in the country in all subject areas. KP_{ja} above one shows the region's inventive specialization in a particular subject area.

The third stage is the assessment of the relationship between scientific and innovative activity in the regions in 2019—2021. A correlation analysis assesses the strength of the correlation between the indicators using the Cheddock scale. The evaluation was performed in the StatTech v.3.1. software environment.

To build correlation dependencies, we use the following innovation indicators: the number of organizations engaged in innovation activities, the volume of innovative goods, works, and services, and innovation expenditure. Research activity indicators include the number of performed R&D projects, the number of patents issued, and the number of publications in the Scopus database.

All indicators by regions are weighted according to Formula 3

$$Y_{norm} = \frac{Y_i}{Y_{max}}, \qquad (3)$$

where Y_{notm} is the weighted value of the indicator for region i; Y_i is the absolute value of the indicator for region i; Y_{max} is the maximum absolute value of the indicator in the considered regions (in this study, for all indicators, this is St. Petersburg). Thus, during the correlation and regression analysis, we use not absolute values of the indicators but the relative ones, reflecting the gap between each region and the leader. This approach is consistent with the logic of the comparative cross-regional assessment used in the previous stages of the analysis.

To avoid distortions in the calculation of dependencies, we exclude St. Petersburg from the analysis due to its extremely high values of indicators compared to other regions. Using the linear regression method, we built regression models capturing the relation between the volume of innovative products in 2021 and the factors influencing the functioning of the knowledge generation and innovation subsystems in 2019–2021. Comparing 2021 data with 2019 and 2020 data allows for taking into account the time lag in the scientific and innovative process.

Data sources and methods

The study relies on several data sources

The data source in the first stage was the Unified National Information System for Civil Research, Development and Engineering (EGISU NIOKTR — *Rosrid.ru*). Out of the data on 150 thousand R&D projects downloaded and compiled, only projects launched in 2019—2021 were selected. The array of information included project titles and abstracts, keywords and subject categories, the amount and source of funding, customers and performers.

In the second stage, the authors selected enterprises from the SPARK-Interfax database using the primary national registration numbers (OGRN) of consumers and performers. There are over 15 thousand Russian enterprises participating in R&D.

The third stage involved the creation of a database of publication activity in the Northwest regions. The source of information on publications was the *Scopus online database (Scopus.com)* by Elsevier. It contains 1.95 million Russian publications published since 1864, including 1.16 million publications published since 2010. Scopus overlaps with coverage of other databases (for example, Web of Science). It also forms the basis of the Russian RSCI Core — the highest quality part of publications by Russian researchers [46].

To determine publication activity for each region, the authors used complex search queries taking into account spelling variations of the names of the regions, their cities, and major organizations. The source of information on the organizations was the Russian Index of Research Organizations (RIRO).

The search was limited to three types of publications: ra — research articles; re — review articles; cp — conference proceedings. Information was collected through the Scopus API using program code written in Python (in the IDE PyCharm environment). Subsequent validation of the information was carried out selectively, by manual Scopus queries. The covered period is 2018—2022.

The fourth stage was collecting patent statistics. The open data sets of Rospatent contain information about all inventions, utility models, and industrial designs registered in Russia. Downloaded data supplemented by information found using a patent registration number search service formed the database of all patents registered and re-registered in 2019—2021. The array included information about the authors and patent holders, the region of registration and the subject category.

In the fifth stage, a database of 2019—2021 innovation statistics by region was formed using Rosstat data. The authors obtained aggregate data on companies' innovation expenditure, the volume of innovative goods, works and services, and the number of organizations engaged in innovation activities combined with OKVED2 (i.e. industry type).

Research results

Dynamics of scientific activity

Northwest Russia has significant scientific and technological capabilities, which makes it a national-scale knowledge generator. In 2019—2021, its regions accounted for 14.3 % of all R&D performed in Russia and 11.7 % of the total expenditure on R&D. Less often, the regions acted as customers of R&D activity.

The scientific landscape here is heterogeneous. The city of St. Petersburg is the leading centre. Figure 1 reflects the differences in the number of projects and the amount of expenditure on purchased and performed R&D among the regions. St. Petersburg leads by far. It has 15.6 times more performed R&D and 6.8 times more commissioned R&D than the Vologda Region occupying the second place, 22.4 times higher expenditure on performed R&D, and 10.6 times higher on commissioned R&D than the Leningrad region and the Republic of Karelia.

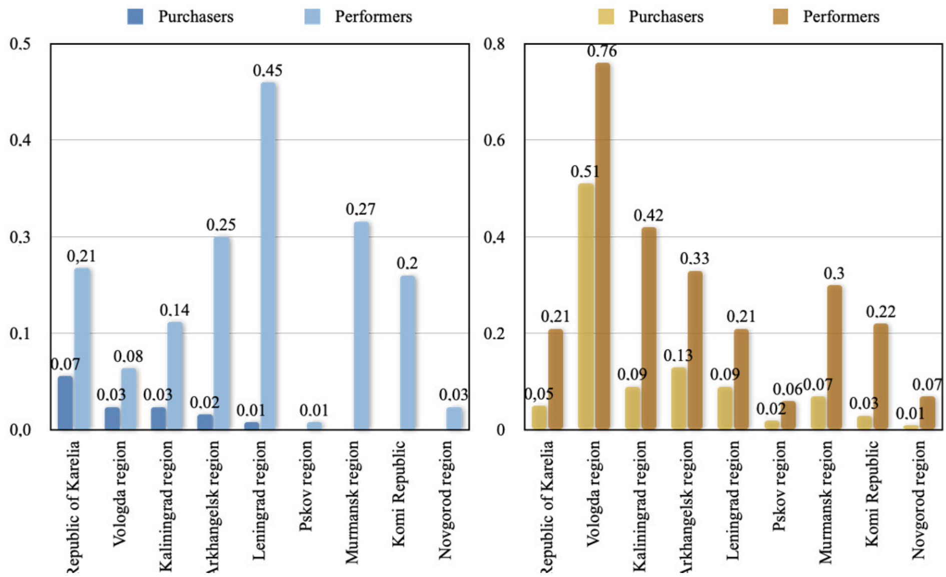


Fig. 1. Geographical distribution of R&D projects and total expenditure on R&D by performers and purchasers by regions of Northwest Russia, 2019—2021, % of the national total

Note: Figure 1 does not show St. Petersburg; its share in the national R&D is 3.47 % by purchasers and 11.77 % by performers; its share of national expenditure on R&D is 0.69 % by purchasers and 10.05 % by performers.

Source: developed by the authors based on EGISU NIOKTR.[1]

The Vologda, Kaliningrad, Arkhangelsk and Murmansk regions are leading in the geography of research projects in the Northwestern Russia. However, the Leningrad region shows the highest expenditure on R&D and, thus, it has the largest projects. The average cost of a performed project in the Leningrad region is 38.4 million roubles, the Republic of Karelia comes second with 17.9 million roubles (less than the national average of 18.2 million roubles). The Pskov and Vologda regions show the lowest expenditure on a performed project in 2019—2021 (about 2 million roubles).

[1] Analytical open data, 2023, *EGISU NIOKTR*, URL: https://rosrid.ru/analytics (accessed 02.08.2023).

The regional average expenditure on a commissioned project ranges from 25.5 million roubles (the Republic of Karelia) to 94 thousand rubles (Komi Republic), while the overall average in the Federal District is 3.6 million roubles. In general, all the regions have more R&D performed than commissioned. The gap in the number of projects ranges from 1.6 times (the Vologda region) to 9.5 times (the Novgorod region) with an average difference of 3.4 times. The differences in total expenditure on R&D by performers and customers are more dramatic. This is especially true for Komi Republic (1,389 times), Novgorod (556 times), Murmansk (103 times), Leningrad (48 times) regions, to a lesser extent for the Kaliningrad (five times), Vologda (three times), Pskov (two times) regions and the Republic of Karelia (three times). This indicates the shift from the absorption of scientific knowledge towards its production and the external management of the scientific agenda of the Northwestern regions.

Figure 2 shows the differences in commissioned and performed R&D in the regions.

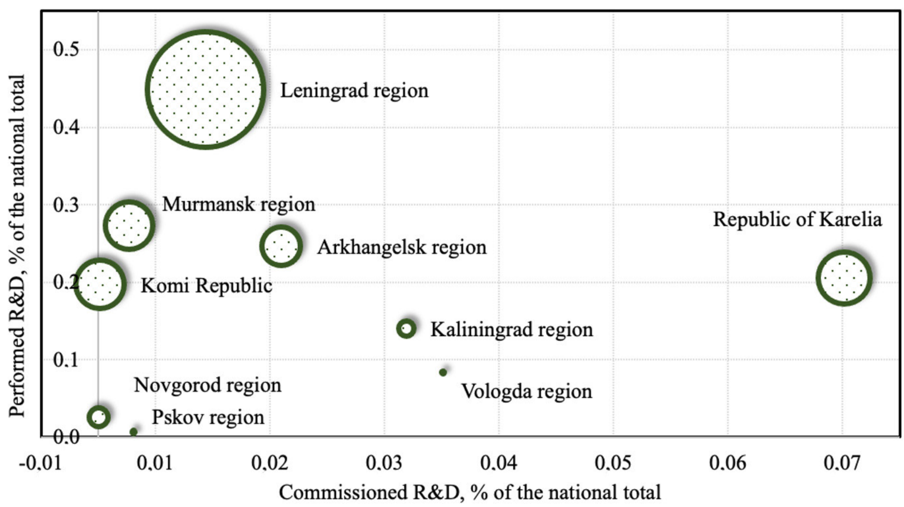


Fig. 2. The regions of Northwest Russia by R&D performed and commissioned in 2019–2021, % of the national total

Note: A circle diameter shows the average expenditure on a performed R&D project. The chart does not show St. Petersburg, whose share of national expenditure on R&D is 0.69 % for those commissioned and 10.05 % for those performed.

Source: developed by the authors based on EGISU NIOKTR, *Rosrid.ru data*.[1]

In general, there are three large groups of regions distinguished by their involvement in research activities:

[1] Analytical open data, 2023, *EGISU NIOKTR*, URL: https://rosrid.ru/analytics (accessed 02.08.2023).

Group 1 — the core, including St. Petersburg and the adjacent Leningrad region, which are far ahead of other subjects of the Federal District in terms of performed R&D, while being purchasers of R&D.

Group 2 includes the Murmansk, Arkhangelsk, Kaliningrad regions and the Republic of Karelia. These regions are the semi-periphery of the scientific space of Northwest Russia, as their R&D indicators are average.

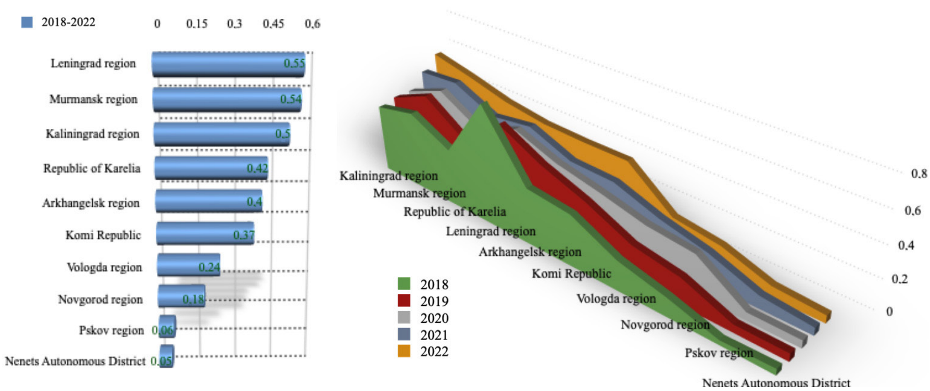
Group 3 unites the regions with the lowest numbers of performed and commissioned research projects (Komi Republic, Vologda, Novgorod and Pskov regions), or ‘the periphery’.

Appendix 1 provides the results of a rank assessment of the diversity of R&D performed in the regions of the Northwestern Russia. Ranks were calculated using the formula (1) relying on the coefficient of scientific specialization.

In 2019—2021, the broadest research agenda was in St. Petersburg, the Vologda and Kaliningrad regions — 45, 38 and 31 fields of knowledge. The Pskov and Novgorod regions performed R&D on the smallest number of fields of knowledge — 14 and 18, respectively. In the periphery group, the top 5 fields of knowledge for performed R&D include mainly social sciences and humanities. The semi-periphery shows a combination of social and humanitarian knowledge and natural sciences as leading in scientific specialization. The first group, the core of the research specialization has mainly natural-scientific direction.

Effectiveness of research systems

The assessment of research and development effectiveness includes the analysis of publication and patent activity indicators. Figure 3 shows the regions distributed by their share in the total number of Russia-affiliated papers indexed in the Scopus database in 2018—2022.



a *b*

Fig. 3. Share of the regions of Northwest Russia in publications in 2018—2022, %

Note: The average St. Petersburg share of the national total is 15.3 %.

Source: developed by the authors based on Scopus data.[1]

[1] Scopus, URL: https://www.scopus.com/ (accessed 11.07.2023).

The results of the assessment of the publication activity of the regions of Northwest Russia correspond to the results of the analysis of their involvement in research and development activities. The leaders in the total number of publications in the leading international journals are the subjects of the first group — St. Petersburg (90.1 thousand units) and the Leningrad region (3.2 thousand units). They are followed by the regions of the second group, the semi-periphery of the scientific space of the North-West of Russia: the Murmansk, Kaliningrad, Arkhangelsk regions and the Republic of Karelia. Their shares range from 0.4 to 0.54 %. The regions in the periphery group have the lowest number of publications indexed in the Scopus database — less than 0.4 % of the Russian total in the considered period. The smallest numbers are observed in the Pskov region (329 publications) and the Nenets Autonomous District (295 publications), which is 10 and 11 times less than in the Leningrad region. In 2018—2022, the district leader had 305.6 times more publications indexed in the Scopus database than the outsider.

The dynamics of publication activity in the regions of Northwest Russia differ over the years (Fig. 3*b*). In the first group, St. Petersburg demonstrates a fairly stable annual number of publications (about 18 thousand). The five-year increase was 5.6 %. The Leningrad region, on the contrary, shows a significant curtailment of publication activity in the studied period. This is the only region showing a decline in the annual number of publications: the 2022 figures show a 37.2 % on 2018.

All regions of the second group saw an increase in the total number of publications in the Scopus database. The five-year growth ranged from 20.8 % in the Murmansk region to 50.8 % in the Kaliningrad region. The major breakthrough in the group occured in 2019 compared to 2018 (and the Kaliningrad region in 2021 compared to 2020). In 2022, three out of four regions in this group reported a decline in publication activity compared to 2021. For instance, in the Arkhangelsk region, the number of publications in 2022 increased by 3.4 % compared to the previous year, but before that, the trend was negative for two years.

The regions of the third group, characterized by low baseline numbers in 2018, also showed an increase in publications over five years. The Pskov region gained the largest growth (189 %) due to a small annual number of publications (from 27 in 2018 to 78 in 2022). In general, these regions show the strongest positive dynamics from 2018 to 2020 (the Pskov region in 2021, as well). After that, the annual growth rate reduced. By 2022, it had become negative in some regions.

The regions were ranked not only by R&D but also by the number of publications indexed in the Scopus database in 2018—2022 by fields of knowledge (Appendix 2). The publication profile of the first group regions largely coincides with the national one. The dominant fields include physics, astronomy, engineering, and materials science. Chemistry, biochemistry, genetics and molecular biology are also significant in the Leningrad Region, and medicine and computer science are important in St. Petersburg. In the Leningrad region, the fields of knowledge of the publications are less varied compared to St. Petersburg.

The second group of regions show a steady range of publications by fields of knowledge. Earth and planetary, environmental, agricultural and biological sciences have a significant role in their structure (in addition to the Russian top-five fields of knowledge).

In the third group, papers on social sciences and humanities have a significant weight in the structure of the publications, along with natural science. The Novgorod, Pskov regions and the Nenets Autonomous District presented publications in the smallest number of fields (among the other subjects of Northwest Russia).

Figure 4 presents the shares of international co-authorship of scientific publications in the North-West. St. Petersburg and the Leningrad Region have the largest share compared to the Russian Federation (19.0 % and 1.8 % respectively). In the second group, the value of this indicator ranges from 0.4 to 0.7 %, while in the third group, it is 0.2 % or less. Figure 4 shows the distribution of the regions of Northwest Russia by the level of scientific cooperation in publications.

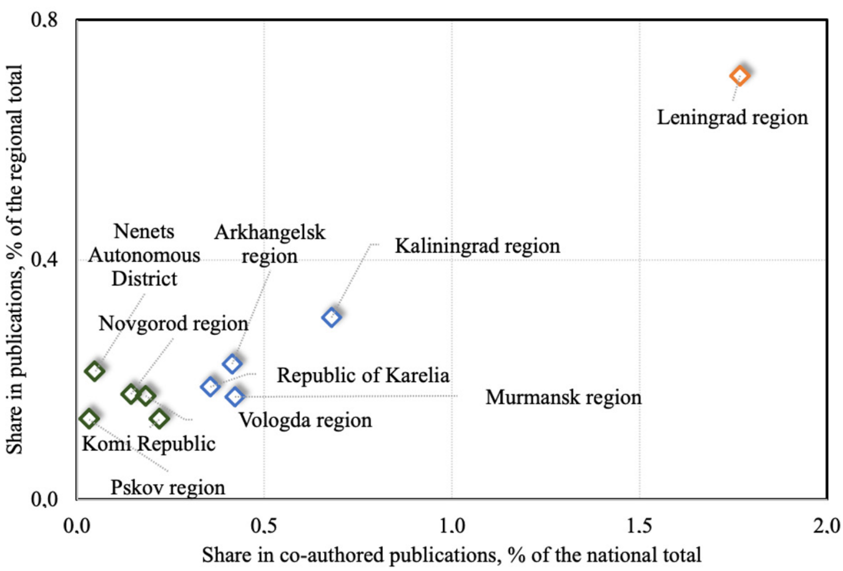


Fig. 4. Regions of Northwest Russia by share of publications in 2018—2022, %

Note: the graph does not represent St. Petersburg, which has 19.0 % of Russian publications co-authored with at least one non-Russian researcher, and 0.27 % of the total number of publications in the region. The first group is orange diamonds, the second is blue diamonds, and the third is green diamonds.

Source: developed by the authors based on Scopus data.[1]

[1] Scopus, URL: https://www.scopus.com/ (accessed 11.07.2023).

The geography of scientific collaboration of the subjects of Northwest Russia in 2018—2022 was diverse (covering 168 countries). After 2022, the geopolitical vector in scientific ties of Russian regions changed: some broke, while others received an additional impetus for development. Appendix 3 shows the countries — scientific partners of the subjects of Northwest Russia in the period from 2018 to 2022 distributed by the categories of 'unfriendly', 'friendly', and 'neutral'.

St. Petersburg and the adjacent Leningrad Region jointly had the widest geography of scientific ties (159 countries) compared to the other groups. However, given a considerable variety of contacts, the largest share of the publications in 2018—2022 was co-authored with researchers from unfriendly countries. The top 25 countries by the number of joint publications include 20 unfriendly (Germany, USA, France, Great Britain, Italy, Finland, Poland, Spain, Switzerland, Czech Republic, Netherlands, Australia, Sweden, Austria, Japan, Canada, Greece, Ukraine, Portugal, South Korea) and five friendly (China, Brazil, India, Belarus, Turkey) countries.

The regions of the second group have a somewhat more modest geography of scientific relations — from 88 (the Murmansk region) to 116 (the Kaliningrad region) countries. These regions' scientific collaboration with Western countries was stable until 2022. In the top 25 countries by the number of joint publications, friendly and neutral countries accounted for only seven in the Arkhangelsk, five in the Kaliningrad, three in the Murmansk regions, and four in the Republic of Karelia. Countries neighbouring these regions (Poland, Finland, Norway) accounted for a significant share of publications co-authored by at least one non-Russian researcher.

The regions of the third group had the least varied scientific relations: from 21 to 59 partner countries. Only Komi Republic stands out. Its researchers published joint publications with authors from 87 countries. However, in 2018—2022, in these regions, the Western European vector also prevailed over the eastern and southern ones. In the top 25 countries by the number of joint publications, friendly and neutral countries accounted for eight in the Vologda, five in the Novgorod and Pskov regions, four in the Nenets Autonomous District, and two in Komi Republic.

Another indicator of the effectiveness of scientific activity is inventive activity closely linked to innovation. As in the case of publications, St. Petersburg occupies a leading position in the Federal District in the absolute number of patents issued. The Vologda region (the second place) has 50 times fewer patents (in 2020 — 65 times fewer). Figure 5 shows the change in patent activity in the subjects of Northwest Russia in 2019—2021. Most regions saw a decrease in the annual number of patents issued, except for the Pskov region, which showed growth, and the Murmansk region and the Republic of Karelia having no stable dynamics.

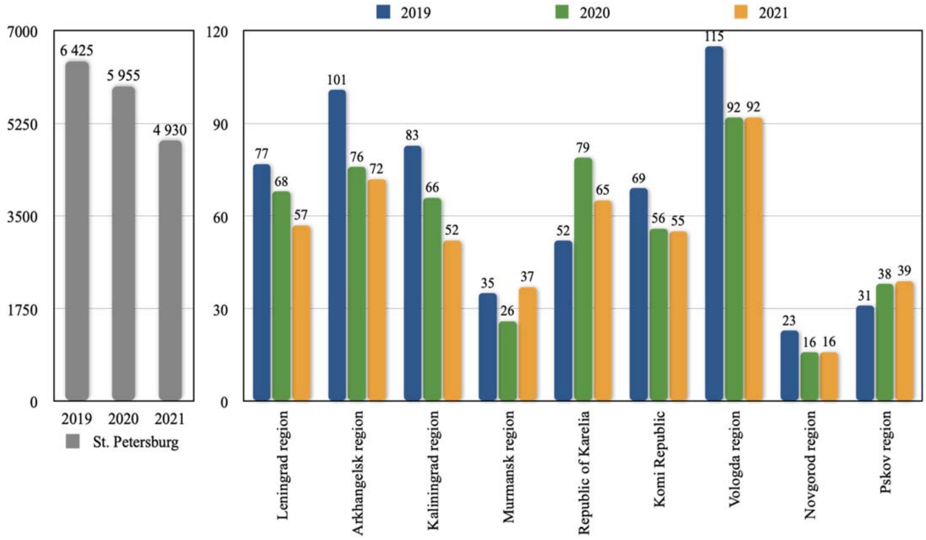


Fig. 5. Patents issued in the regions of Northwest Russia, 2019—2021

Source: developed by the authors based on Rospatent data.[1]

In most regions of Northwest Russia, inventions prevail in issued patents (Fig. 6). In 2019, their share ranged from 52.2 % in the Novgorod region to 80.7 % in the Kaliningrad region. In 2021, compared to 2019, there were significant structural shifts in patent types towards a decrease in the share of inventions in seven out of ten regions under study. Only the Leningrad, Vologda and Novgorod regions saw an increase in patents for inventions in 2021 compared to 2019 (15.7 %, 2.8 %, 10.3 % respectively). The most significant redistribution of patent types occurred in the Republic of Karelia: the share of inventions decreased from 59.6 % to 33.8 %, and utility models increased from 36.5 % to 52.3 %.

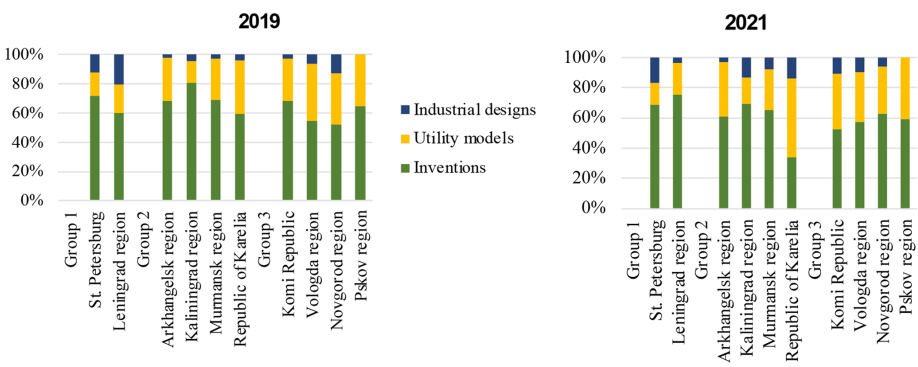


Fig. 6. Patents granted in the regions of Northwest Russia by type, in 2019 and 2021

Source: developed by the authors based on Rospatent data, Openstat.rospatent.gov.ru.[2]

[1] Patent search, *Rospatent,* URL: openstat.rospatent.gov.ru (accessed 02.08.2023).

[2] Ibid.

Among the 82 fields of knowledge in which the subjects of Northwest Russia issued patents, there are 38 most actively developed specializations (with a coefficient of inventive specialization above three in at least one of the regions — Appendix 4). The regions of the periphery and semi-periphery (excluding the Komi Republic and the Vologda region) strongly focus on particular fields of knowledge, while the core regions have broader inventive competencies.

Relation between research and innovation

To assess the relationship between the research and innovation subsystems in Northwest Russia, the authors conducted a correlation analysis of the indicators of patent, publication, research activity and the generation of innovative products. It established a close and statistically significant relationship between the volume of innovative goods, works, and services and the amount of R&D performed in the regions. The correlation coefficient between these indicators was 0.867 (at $p = 0.001$) in 2020 and — 0.721 in 2021 ($p = 0.019$). The tightness, according to the Cheddock scale, is high. The results also show a positive correlation between innovation and patent activity in the regions, however, it has a one-year lag. There was a statistically significant correlation between the number of patents issued in 2019 and the volume of innovative goods, works, and services in 2020 ($p = 0.048$). There was no significant correlation between the indicators of publication and innovation activity in the regions.

The number of organizations carrying out innovative activities positively impacted the volume of innovative products in subsequent years. There was a strong correlation between these indicators in 2019—2020 — 0.818 ($p = 0.004$). In 2021, it slightly weakened — to 0.709 ($p = 0.022$), but remained strong.

The linear regression method was used and a regression model was built to assess the relation between the volume of innovative goods, works, and services produced in the subjects of Northwest Russia in 2021 on the quantitative factors of the functioning of the knowledge generation subsystem (R&D, inventive and publication activity) in 2019—2021. The number of observations was nine. Table 1 presents the results of the regression analysis.

Table 1

The results of the regression analysis of the volume of innovative products in 2021 and the factors influencing the functioning of the knowledge production subsystem

Indicator	B	SE	t	p
Intercept	–0.029	0.038	–0.755	0.475
R&D performed in 2019	4.476	1.701	2.632	0.034*

Note: * — differences in indicators are statistically significant ($p<0.05$).

Source: developed by the authors using StatTech v.3.1.6.

The result of the econometric analysis was the linear regression equation

$$Y_{2021\_Innovations} = -0.029 + 4.476 * X_{2019\_R\&D}, \quad (4)$$

where $Y_{2021\_Innovation}$ is the volume of innovative goods, works, and services in 2021, $X_{2019\_R\&D}$ is the volume of R&D performed in 2019.

An increase in the $X_{2019\_R\&D}$ indicator by 1 is expected to increase the $Y_{2021\_Innovation}$ indicator by 4.476. The obtained regression model has a correlation coefficient of $r_{xy} = 0.705$, which is strong, according to the Cheddock scale. The resulting model is statistically significant ($p = 0.034$) and explains 49.7 % of the observed variance in the volume of innovative goods, works, and services in 2021.

Table 2 shows the results of the assessment of the dependence of the volume of innovative products produced in the regions in 2021 on the quantitative factors of the functioning of the innovation generation subsystem conducted similarly.

Table 2

The results of the regression analysis of the volume of innovative products in 2021 and the factors influencing the functioning of the knowledge production subsystem

Indicator	B	SE	t	p
Intercept	–0.014	0.015	–0.921	0.393
The volume of innovative goods, works, and services	0.888	0.133	6.693	< 0.001*
Innovation expenditure in 2019	0.339	0.122	2.777	0.032*

Note: * — differences in indicators are statistically significant ($p < 0.05$).

Source: developed by the authors using StatTech v.3.1.6.

The following linear regression equation describes the observed relationship between the indicators

$$Y_{2021\_Innovations} = -0.014 + 0.888 * X_{2020\_Innovations} + 0.339 * X_{2019\_Expenditure}, \quad (5)$$

where $Y_{2021\_Innovations}$ is the volume of innovative goods, works, and services in 2021, $X_{2020\_Innovations}$ is the volume of innovative goods, works and services in 2020, $X_{2019\_Expenditure}$ is the volume of innovation expenditure in 2019.

An increase in $X_{2020\_Innovations}$ by one is expected to lead to an increase in $Y_{2021\_Innovations}$ by 0.888; an increase in $X_{2019\_Expenditure}$ by one is expected to lead to an increase in $Y_{2021\_Innovations}$ by 0.339.

The obtained regression model has a correlation coefficient of $r_{xy} = 0.705$, which is very strong according to the Cheddock scale. The model was statistically significant ($p = 0.001$) and explains 89.0 % of the observed variance in the volume of innovative goods, works, and services in 2021.

Discussion and conclusions

Geopolitical shifts in the system of international relations in recent years have demonstrated the need for countries to ensure technological sovereignty and innovative security [47]. This is relevant for Russia, which, being involved in a hybrid confrontation with Western countries, is under significant direct and secondary sanctions pressure. The dominance of foreign technologies in its innovative and technological development has led to Russia's high dependence on foreign partners. Its new national targets include import phase-out with at least 75 % of high-tech products being local. The research considers responding to macroeconomic and geopolitical challenges within the framework of transformational resilience. The latter is associated with the search for development opportunities during the crisis through changing an old trajectory.

The study assesses the scientific and innovative potential of Northwest Russia and the impact of external and internal turbulence on it. The study relies on information on R&D, patent and publication activity, as well as statistics on the innovation activity of enterprises from 2019 to 2021, for some indicators — up to 2022. All regions of Northwest Russia were divided into three groups: the core (St. Petersburg in conjunction with the Leningrad region), the semi-periphery (Murmansk, Arkhangelsk, Kaliningrad regions and the Republic of Karelia) and the periphery (Komi Republic, Vologda, Novgorod and Pskov regions).

The results show that, firstly, the regions of Northwest Russia are connected within the framework of the national system of scientific knowledge redistribution. Regional actors perform R&D on external requests and act as purchasers of projects on topics of interest. The regions have more R&D performed than commissioned, which reflects the high level of their research and technological development. However, in some cases, it can indicate the ignorance of regional organizations about localized competencies that allow performing complex projects, or the discrepancy between the specializations of the scientific and innovation subsystems of the regions. This imbalance results in reduced effectiveness of network interaction in spite of a high 'institutional density' [48]. Expanding interregional cooperation by increasing the supply of R&D services to new markets can facilitate the use of the regions' capabilities and increase their innovative capacities by attracting additional funding.

Secondly, the subjects of Northwest Russia have different research specializations. The analysis of the subjects of the performed R&D and indexed scientific publications demonstrates the prevalence of natural science in the 'core' regions and social sciences and humanities in the 'periphery'. In some cases, this difference can hinder the development of collaboration due to the lack of non-territorial proximity [49]. However, this is needed for radical innovations, whose prerequisite is 'unrelated variety' [50]. The research in 'open innovation' [51] shows that it is the adoption of secondary results and related technologies 'from the open market' that allows for breakthrough innovations. A profound shift in the peripheral group towards social and humanitarian research can indicate weak innovation activity in these regions. Thus, there is a need to increase the connectivity between science and business, including through the promotion of entrepreneurial universities and small innovative enterprises.

Thirdly, after 2019, most regions of Northwest Russia show a decrease in the annual number of patents and publications. The analyzed indicators do not immediately reflect the difficulties faced by the regional innovation systems, as patent registration and publication indexing are delayed (the lag is a year or more). We can assume that the decrease in the productivity of the scientific systems of the regions of Northwest Russia in 2021—2022 is associated with previous factors, including the COVID recession [52], increased sanctions pressure, destabilization of financial markets and general uncertainty caused by the armed conflict on the border with Ukraine. Given the transformational course of national policy and the impossibility of returning to the pre-crisis state, the transition to a new development path can be accompanied by a further decrease in the productivity of research and innovation subsystems of the studied regions.

Fourthly, in 2021, compared to 2019, there were significant structural shifts in patent types towards a decrease in the share of inventions in most regions. This is important, given the difference between the invention, utility model and industrial design.[1] The share of R&D results (creation of new products and technologies) is decreasing, while there is growth in the modernization of devices and technologies already on the market and appearance.

Fifthly, until 2022, the regions of Northwest Russia actively integrated into international scientific and innovative processes. Interregional relationships had been developing for many years, including within Russia—EU cross-border cooperation programs [53]. The analysis of the geography of publications prepared in Northwest Russia shows that, before Russia's turn to the East, the

[1] Invention and utility model or industrial design — which is better to patent? 2023, *Guardium,* URL: https://legal-support.ru/information/faq/patent/izobretenie-i-poleznaya-model-ili-promyshlennyi-obrazec-chto-luchshe-patentovat (accessed 14.08.2023).

key partners were institutions in unfriendly countries. Moreover, there is a regularity: the higher the region's scientific and innovative development level, the wider its international scientific collaboration network. The importance of contact with technology leaders is confirmed by the cases of post-colonial countries [54], which, after gaining independence, pursued protectionist policies (import phase-out, strict regulation of technology import and participation in international projects). Nevertheless, sanctions pressure and the cancel culture indicate the need to diversify international partnerships. The reorientation to China, India, Iran, Brazil and other friendly countries is of current interest. This will ensure the possibility of entering international technology and innovation markets and accessing information resources, equipment and consumables.

Future research should assess the role of foreign innovations in the domestic economy to contribute to a fuller understanding of the current situation through the lens of technological sovereignty. Another research avenue is the assessment of the territorial distribution of the innovation process stages, which requires the development of a methodology for identifying cause-effect relationships. One of the questions to answer is which R&D has contributed to the results presented in publications or formed the basis of patents, which became innovations.

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