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Quantitative Studies of the Regions Innovative Development Based on the Triple Helix Econometric Model

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ABSTRACT
The examination of the Triple Helix Econometric Model within regional innovation systems offers a valuable perspective on enhancing the dynamics and synchronization between different stakeholders in the economic framework. This model underscores the critical role of collaboration between the University, Industry, and Government, alongside other crucial entities, in steering both the trajectories of innovation and the broader economic growth. This holistic view addresses the strategic alliances that foster technological advancement and regional economic expansion.
The article explores the applications of econometric analysis and quantitative approaches in assessing the innovative development of regions, guided by the Triple Helix model. It employs a specialized software created in Python to facilitate this analysis. The study leverages a dataset sourced from official innovation-focused government websites, comprising 18 essential statistical indicators pivotal for fostering regional innovation economies. The findings from the econometric computations align closely with the economic activity rankings provided by the National Research University "Higher School of Economics," corroborating the effectiveness of the software in addressing econometric problems. This validation highlights the software's potential in analyzing the collaborative dynamics among Universities, Industry, and Government within the Triple Helix framework.
The suggested software facilitates an in-depth analysis and evaluation of the innovation sector across different economic and political entities. It serves experts in scientific projects, innovation management, and economic development, along with regional analysis hubs and research institutions that scrutinize and track economic patterns within territories.
This study enhances the functional aspects of the economy by employing quantitative techniques to address real-world problems associated with the growth of regional innovation economies. It does so through the utilization of econometric methods applied to the Triple Helix Theory Model, which integrates industry, academia, and government to foster economic development..
Keywords: Triple Helix framework; stakeholders; innovation growth; statistical measurement system; quantitative analysis; Python programming environment; innovation performance index

INTRODUCTION:

The contemporary economic landscape is significantly shaped by intellectual capital, where predicting and managing trends in innovation are critical components. In the Triple Helix Model (TH model), each Helix symbolizes a unique process, distinguished by its specific traits and distinct measurement indicators that assess its performance and impact.

The concept of a tripartite model for fostering innovation gains consensus for involving essential contributors to economic growth. This model emphasizes collaboration between academic institutions focused on research, industries involved in manufacturing marketable products, and government bodies that regulate the marketplace.

The Triple Helix Model, formulated by Henry Etzkowitz and Loet Leydesdorff, is a globally recognized framework (Etzkowitz, 2003; Etzkowitz, Leydesdorff, 1995; 1996) utilized across a spectrum of disciplines such as artificial intelligence, political science, sociology, corporate ethics, university education, spatial economics, and managerial behavior. It serves as a tool for professionals to explore synergistic relationships and foster innovation within their respective fields (Cai, Etzkowitz, 2020).

Numerous scholarly articles focus on the Triple Helix (TH) model from both domestic and international researchers. For instance, several studies have explored different aspects of foreign innovative evolution using the

TH model (Botot, Satinski, 2011; Borisoglebskaia, Mikhailov, 2016; Klimenko et al., 2021; Kovalev, Iankhai, 2021; Prikhodko et al., 2021). E. Zashchitina's research (Zashchitina, 2023) highlights a comprehensive analysis of the Triple Innovation Helix, illustrated with examples from Central Asian nations, and discusses the key components that shape a national innovation system in light of evolving models of innovation.

The Triple Helix model shows the perspective of universities, industry, and government interaction. This model is useful for understanding entrepreneurship, the changing dynamics of universities, innovation, and socio-economic development. Currently, the profile journal Triple Helix publishes such studies on the concept of the Triple Helix as theory, measurement and empirical research in all aspects of the interaction between universities, industry and government (Triple Helix Journal. https://brill.com/thj).

This international publication publishes the results of scientific research by innovative scientists from various countries on university transformation, knowledge capitalization, translational research, complementary activities, intellectual property, knowledge and technology transfer, as well as the international foundations and dimensions of Triple Helix relationships, their impact on social, economic, political, cultural, medical and environmental aspects.

Scientific publications on the adaptation of the Triple Helix model in the regions of Russia can be found in the materials of publications by Russian scientists in recent years (2020-2024) (Zoidov and Rastegaev, 2024; Volkova and Sekerin, 2023; Dremova and Jamaldinova, 2022; Egorov and Vasilyeva, 2022; Naumova and Sokolova, 2022; Udaltsova and Krutskikh, 2021; Leshchev and Khrustalev, 2021; Artemova, 2020; Baymuratov et al., 2020; Batrakova, 2020; Opryatova, 2020).

The issues of applying the Triple Helix model in the Russian innovation system have been considered in detail since 2008 from the works of the authors I. Dezhina (Dezhina and Kiseleva, 2008; Dezhina, 2011), E. Babkina (Babkina and Sergeev, 2011), A. Ivanova (Ivanova et al., 2011), E. Monastyrsky (Monastyrny and Uvarov, 2011), N. Smorodinskaya (Smorodinskaya, 2011), P. Drobot (P. Drobot and D. Drobot, 2017) and the so-calledWinner of the award named after T. Suslovoy (Suslova, 2011). It should be noted that the first translated publications of the founder of the Triple Helix model, Henry Itzkowitz, were published in Russia in 2010-2011 (Etzkowitz, 2011; 2010).

It is important to recognize that establishing a Triple Helix in Russia, at both the national and regional levels, necessitates a unified approach among all innovation stakeholders: Government (at federal and regional tiers), Academia, and the Private Sector. Currently, not all Russian regions are equipped to adopt the TH model; its effective deployment demands collaborative efforts from educational and scientific institutions, regional industries, and government bodies. Furthermore, to catalyze innovation in industrial areas, it is essential to implement holistic incentives at all administrative strata while ensuring that the interests of all involved parties are considered (Naumova, Sokolova, 2022).

There are a limited number of studies that investigate the quantitative analysis of synergy levels among Triple Helix model entities, mainly using publication metrics (Nurutdinova, Dmitrieva, 2018; Leydesdorff, Etzkowitz, 2003; Mêgnigbêto, 2018; Leydesdorff et al., 2015) and data from high-tech sectors (Leydesdorff, Park, 2014). Econometric evaluations have been performed on the connection between innovation indicators and national statistics (Istomina et al., 2018). The complexity of interactions within the Triple Helix framework has so far precluded a standardized approach for assessing these dynamics (Popodko, Nagaeva, 2019). This is due to the absence of a robust economic model to handle intricate relational analyses within the framework. Consequently, it is crucial to advance methodologies for examining interactions and developmental patterns within the Triple Helix configuration and applying these insights to evaluate innovation quantitatively (Drobot, P., Drobot, D., 2017).

The examination of literature by both international and domestic scholars indicates a significant gap in the availability of practical frameworks for measuring Regional Innovative Development (RID) according to the Triple Helix (TH) theory, with the notable exception being the simulation model that delineates interactions between TH entities (Ivanova & Leydesdorff, 2014). Addressing this deficiency, the authors introduce a numeric methodology for assessing RID utilizing a refined econometric version of the TH model (Egorov, Pospelova, 2024; Egorov et al., 2019; 2021). This advanced econometric model employs the latest econometric techniques suitable for precise numerical analysis and forecast modeling. Within this structure, the university is pivotal, functioning as both a generator of knowledge and innovative concepts and as a custodian of intellectual property, ripe for commercial exploitation. This commercial potential attracts the active participation of the Government, which provides policy-based support, and the Industry, driven by the pursuit of profit. Establishing such a collaborative framework necessitates persistent and coordinated efforts to ensure the effective functioning of the regional innovation system, focusing on fostering robust ties among the principal actors of the innovation landscape, thereby catalyzing the birth of new industrial sectors.

The implementation of the Triple Helix model in numerical simulations encounters specific challenges predominantly due to the intricate nature of the interactions it attempts to model. Analyzing the characteristics of complex social and economic systems poses considerable difficulties, in stark contrast to physical systems where solutions are more readily attainable. Therefore, the incorporation of empirical data is crucial. This includes the quantitative measurements and statistical evaluations of the three primary agents within the Triple Helix framework.

MATERIALS AND METHODS

Dedicated Python-based software has been created to conduct quantitative assessments and analyze regional

innovation progress utilizing the Triple Helix econometric framework (Egorov and Pavlov, 2025).

This application facilitates automation in analyzing and creating consolidated measures derived from a complex multi-variable framework. It enables detailed assessments concerning the level of scientific, technical, and innovative activities within various Russian regions by integrating metrics that are categorized into three principal domains: scientific research and educational endeavors (A), business innovation processes (B), and the effectiveness of regional government policies aimed at fostering an innovative economic environment (C).

The application was developed in Python, utilizing libraries such as pandas, numpy, openpyxl, and tkinter. It operates independently from external databases, instead processing input data directly from an Excel spreadsheet filled with regional statistics. Its design emphasizes straightforward deployment and user-friendliness. Additionally, the structure is scalable, facilitating the incorporation of new metrics into the framework without altering the core algorithm.

Primary roles of the program encompass this specific process:

1. Choosing a .xlsx database file containing annual data, regional information, specific indicators, and their associated values.

2. The algorithm executes computations, utilizing the absolute figures derived from the statistical records concerning actors in sections A, B, and C.

3. The peak values are derived from actor metrics.

4. Normalization to unity, which involves scaling the raw data values for each actor by dividing each value by the maximum value found in that actor's respective data row.

5. Computation of average scores derived from normalized metrics related to the actors' quantitative assessments.

6. Standardizing average measurements.

7. Consolidation of normalized scores for entities A, B, and C followed by computation of their composite index.

8. Creating a histogram to represent the ranking based on the Regional Innovative Development Index (RIDI).

9. Compilation of average metrics for entities A, B, and C and determination of their respective percentages in contributing to the overall RIDI value.

10. Development of regional distribution graphs illustrating the actors' inputs.

11. Production of metrics in standardized units followed by the development of a pie chart illustrating their allocation for a chosen year.

12. Development of an Excel spreadsheet (.xlsx format) incorporating finalized data, along with visual elements such as graphs and pie charts for data representation.

The selection of the year, region, or absolute values from statistical datasets for each designated area hinges on the objectives of the research.

This software tool is primed to underpin the creation of a Regional Information and Analytics System (RIAS), which will enable thorough assessments and oversight of innovation engagement among economic entities, utilizing the Triple Helix framework that comprises both a database and an analytical module. Integrating this RIAS into local governance mechanisms is expected to enhance the caliber of both information and methodologies used in examining innovative progress, thus aiding in the formulation of sound and effective management policies.

The primary methodologies adopted for this investigation included both comparative and correlation analysis. Sources of data encompassed a variety of governmental websites, including the Federal State Statistics Service (Rosstat), the Unified Interdepartmental Statistical Information System (EMISS), the Federal Service for Intellectual Property (Rospatent), and the Treasury. The framework of metrics integrated three distinct segments corresponding to the actors of the Triple Helix model: University, Industry, and Government. This model incorporated 18 pivotal statistical indicators deemed critical for the progression of regional innovative economies. The comparative aspect of the study involved analyzing the TOP-10 ranking of Russian Federation regions—excluding Moscow and Saint Petersburg—relative to the Russian Regional Innovation Index (RRII) for the year 2021, which the NRU HSE Institute for Statistical Studies and Economics of Knowledge (ISSEK) constructed. This index is based on 55 indicators, which are organized into 15 detailed segments and subdivided into five thematic areas (HSE ISSEK, 2024).

Table 1 presents a set of statistical indices that describe the capabilities of key participants in the innovation process (University, Industry, Government), encapsulating the dynamics of regional innovation growth in Russia meticulously and comprehensively:

Table 1. Triple Helix Actors System of Statistical Indicators

Indicator	Designation	Source
Actor A. University		
Proportion of organizations engaged in research and development per 1000 organizations, %	A1	Rosstat

Proportion of employees engaged into scientific research and development from the annual mean number of employees contributing to the economy, %	A2	Rosstat
Internal Research & Development costs per one employee engaged in Research & Development, mill. rub.	A3	Rosstat
Number of patents issued for inventions or utility models from the mean average of the annual mean number of those contributing to the economy, units.	A4	Rosstat
Inventive activity coefficient, %	A5	Rospatent
Number of students undertaking Bachelor's, Specialist's, Master's degree program per 1000 people	A6	Rosstat
Number of students, studying for mid-level professionals per 10000 people	A7	Rosstat
Actor B. Industry		
Degree of innovative activity of companies, %	B1	Rosstat
Proportion of companies engaged into technological innovation among the total number of studied companies, %	B2	Rosstat
Proportion of corporate expenses on the innovative activity in the total amount of shipped goods, completed work, services, %	B3	Rosstat
Proportion of innovative goods, work, services in the total amount of shipped goods, completed work, services, %	B4	Rosstat
Developed cutting-edge technology in use per 100 companies, units.	B5	Rosstat
Proportion of costs of the implementation and usage of information technology per GRDP, %	B6	Rosstat, EMISS
Correlation of export and import of technology and services of technological nature	B7	Rosstat
Actor C. Government		
Innovative activity costs share in the regional budget, %	C1	NRU HSE
Proportion of budgetary funds in the internal Research & Development costs, %	C2	EMISS
Scientific research expenses share in the consolidated regional budget, %	C3	Treasury
Higher and secondary vocational education expenses share in the consolidated regional budget, %	C4	Treasury

Section D. Indicators used to calculate relative values		
Number of companies, units	D1	Rosstat
Companies, engaged into scientific research and development, units.	D2	Rosstat
Annual mean number of employees, number of people, thousand people	D3	Rosstat
Number of employees engaged into scientific research and development, number of people	D4	Rosstat
Internal Research & Development costs, mill. rub.	D5	Rosstat
Number of patents issued for inventions or utility models, units	D6	Rosstat
Developed cutting-edge technology in use, units.	D7	Rosstat

Gross regional domestic product (GRDP), mill. rub.	D8	Rosstat
Costs of the implementation and usage of information technology, mill. rub.	D9	EMISS
Expenses in the consolidated budget of a Russian Federation subject, mill. rub.	D10	Treasury
Expenses in the consolidated budget of a Russian Federation subject on fundamental and applied scientific research, mill. rub.	D11	Treasury
Expenses in the consolidated budget of a Russian Federation subject on higher and secondary vocational education, mill. rub.	D12	Treasury

Based on the above table and the Triple Helix econometric model calculation methods proposed in the studies (Egorov, 2025; Egorov, Pospelova, 2024; Egorov, Vasilyeva, 2022; Egorov et al., 2021; 2019), the general Regional Innovative Development Index (RIDI) can be expressed through the following formula:

$$RIDI=ROOT((7/18*A)^2+(7/18*B)^2+(4/18*C)^2)) \quad (1)$$

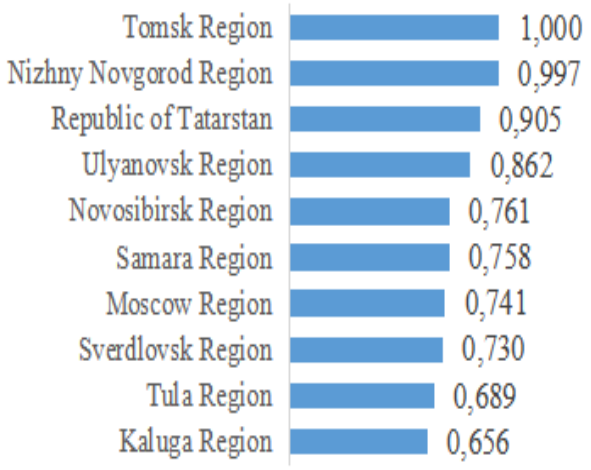
It is worth noting that the System of Statistical Indicators is to provide a comprehensive set characterization of innovation processes, encompassing all their main stages: 'Science – Innovation – Industry – Market.' The set of indicators has to be flexible, that is, capable of reflecting all changes occurring in the innovative sector of the region (including both resource-related and outcome-oriented characteristics). The number of the indicators is to be limited and aligned with the specifics of regional statistics and their capacity to enable a comparative assessment of innovation potential when broken down by territory.

RESULTS.

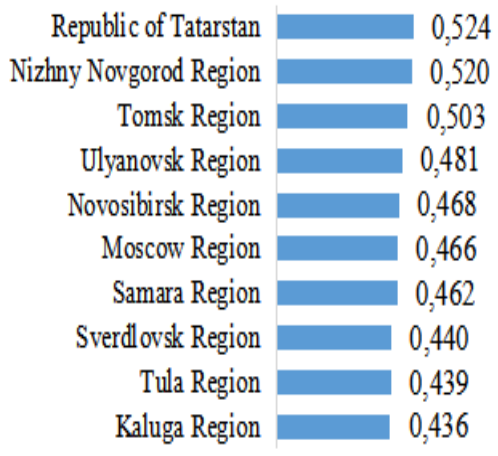
Results of the TOP-10 Russian Federation regions ranking with regards to the degree of their innovative development are shown in Figure 1.

Figure 1. Russian Federation regions innovative development ranking, 2021:

a) RIDI Numeric calculations; b) RRII values (NRU HSE ISSEK)



a)



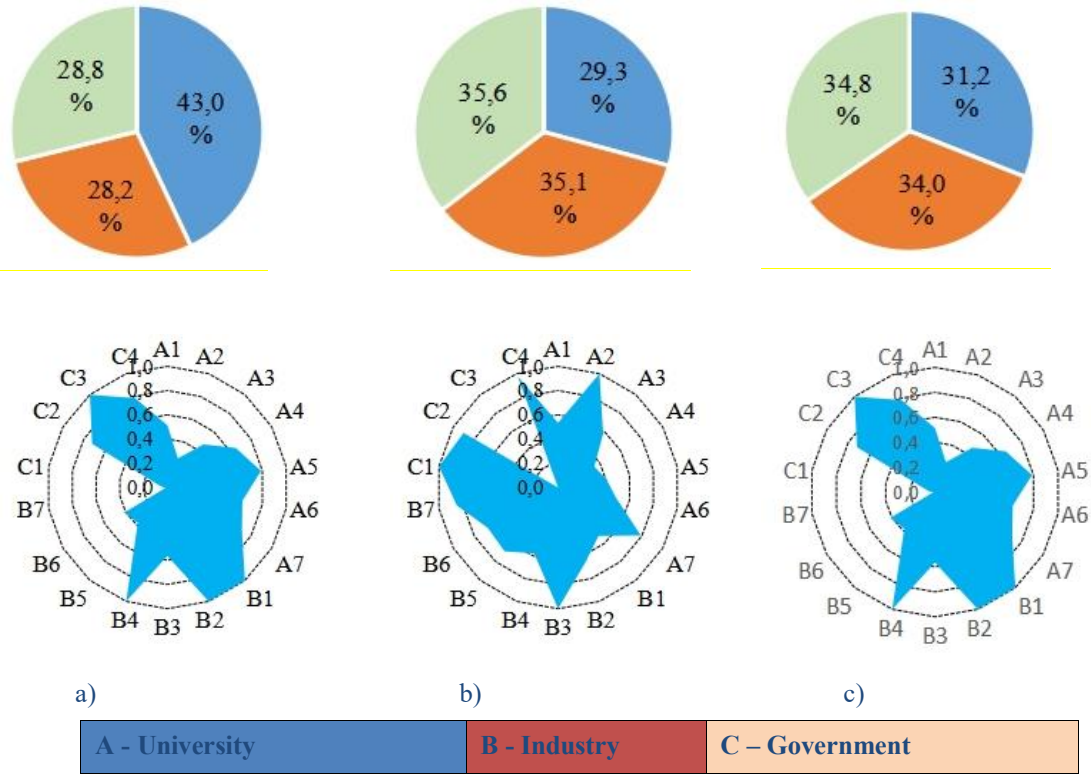
b)

As illustrated, the results of numeric calculations using the Phyton software product rather adequately reflect the results RRII of Russian Federation subjects ranking, prepared by National Research University Higher School of Economics (NRU HSE) Institute for Statistical Studies and Economics of Knowledge (ISSEK).

The developed software allows to evaluate integrative influences of the Triple Helix actors and the degree of their contribution, as well as to create innovation profiles for Russian Federation subjects, which visibly demonstrate the strong and the weak points of the influence by the University, Industry, and Government on the innovation development of the respective region. As an example, Figure 2 illustrates the indicators of the top three positions in the Russian Federation regions innovative development ranking, 2021.

Figure 2. Distribution of the contributions of the Triple Helix actors and RIDI indicators:

a) Tomsk Region; в) Nizhny Novgorod Region; c) Republic of Tatarstan



Indubitably, the general innovative development of a regional economy is affected by the TH model actors, in the integral index of the regional innovative development, whose degree is evaluated on the basis of the following formula:

$$\dot{F}=(RIDI/I_j)^2*100 \qquad (2)$$

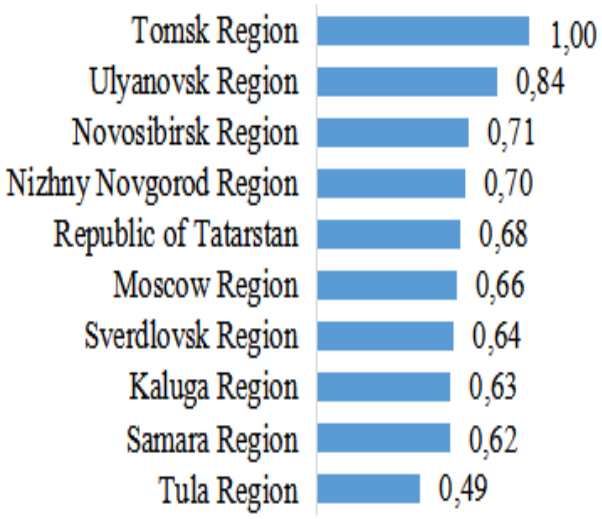
where:

F stands for Ij actor contribution degree;

Ij strands for innovation potential degree of the A, B, and C actors, respectively.

As shown by the calculation results, the degree of each Triple Helix element contribution varies by region. For example, with regards to the actor A (University), the top positions are held by Tomsk, Ulyanovsk, and Novosibirsk regions (Figure 3).

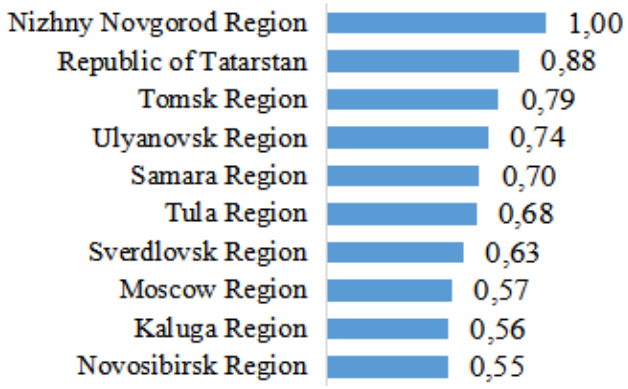
Figure 3. Actor A regional ranking: University



Note that the top position of the Tomsk region with regard to actor A is mostly based on the relatively high values of the 'Proportion of organizations engaged in research and development per 1000 organizations, %' (A1), 'Inventive activity coefficient, %' (A5), and 'Number of students undertaking Bachelor's, Specialist's, Master's degree program per 10000 people' (A6) indicators.

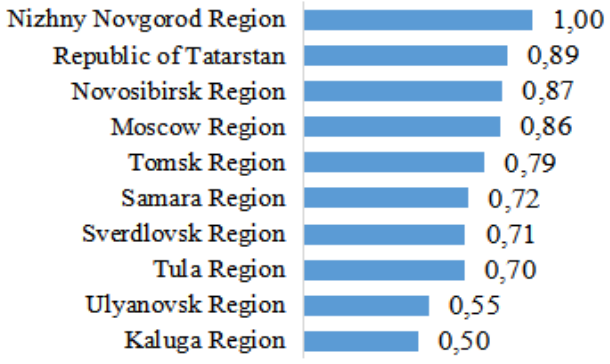
As industry rankings indicators show, the top position with regard to actor B is held by Nizhny Novgorod region, where companies' expenses on innovative activities are significant in comparison to other regions (Figure 4). In its turn, the Republic of Tatarstan has a high value for the indicator 'Proportion of innovative goods, work, services in the total amount of shipped goods, completed work, services' which characterizes the efficiency of the innovation process in companies, and Tomsk region is the leader in the 'Correlation of export and import of technology and services of technological nature' indicator.

Figure 4. Actor B regional ranking: Industry



Nizhny Novgorod region holds the 1st place in the ranking of providers of financial support of innovative activity in the region, mostly in the 'Innovative activity costs share in the regional budget' indicator (5,5%) (Figure 5). In Novosibirsk region this indicator is 3.3%.

Figure 5. Actor C regional ranking: Government



The Republic of Tatarstan's high ranking, second in this national index, largely stems from its allocation for scientific research within the consolidated regional budget at 0.134%, which outpaces nearly all other Russian regions, except the Moscow region at 0.072%. When considering budgetary allocations for internal Research & Development expenses, Novosibirsk region leads with 77.7%, surpassing its closest competitors, Nizhny Novgorod at 70.1% and Tatarstan at 56.0%.

Overall, the findings of this research corroborate the assertions made by N. Udaltsova and D. Krutskikh in their 2021 study that the Russian adaptation of the Triple Helix model is uniquely characterized by an overly pervasive governmental control over the innovation ecosystem (indicator C). This excessive legal framework imposed by the state is detrimental, stunting the growth of collaborative networks and leaving numerous aspects of this framework significantly underdeveloped. Furthermore, it is important to recognize that not every region in the Russian Federation implements the Triple Helix model, which complicates the assessment of regional innovation. Effective evaluation, therefore, demands active involvement from all stakeholders in the innovation process including universities, industries, and government bodies, as noted by Batrakova in 2020.

DISCUSSION

Therefore, employing econometric methodologies in this analysis provides insights into the extent of innovative progress and the contributions made by the University, Industry, and Government sectors to the aggregated index of innovative development across Russian regions. The numerical outcomes for regional innovation indexes align closely with the rankings provided by NRU HSE ISSEK, validating the effectiveness of this econometric tool for addressing diverse analytical challenges, particularly those incorporating the synergistic dynamics among University, Industry, and Government. The reliability of the research data is ensured by the use of officially sourced statistical datasets. The analytical framework is centered on a robust set of statistical metrics specific to innovation, which can be tailored to meet the specific objectives and aims of the study. It is important to highlight that this preliminary publication aims to showcase the application of quantitative evaluations in addressing various practical issues within the sphere of regional innovative economic development, employing the Triple Helix model. Such numerical investigations into the innovative capacities of individual regions are invaluable, providing a basis for understanding the comparative strengths and weaknesses of each, which in turn informs policy-making and the development of regulatory and software frameworks responsive to the nuances of regional innovation profiles.

Consequently, the suggested software solution facilitates discrete analysis and assessment of the current status in the innovation domain of diverse economic system entities of varying scales. Additionally, it serves as a valuable tool for experts in science, innovation, and the management of economic systems. Regional analytical bodies and research institutions focused on scrutinizing and overseeing regional economic progress also find this software instrumental.

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