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INEQUALITY AND SPATIAL EFFECTS IN THE DEVELOPMENT OF THE DIGITAL ECONOMY ACROSS RUSSIAN REGIONS

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The relevance of the study stems from the growing digital inequality among Russian regions amid the rapid development of the digital economy. Disparities in digitalization levels perpetuate existing interregional gaps and create risks of concentrating human and technological potential in a limited number of regions. The aim is to identify and quantify the dynamics and spatial structure of digital inequality in Russian regions (2011–2023), differentiating it into primary (infrastructural — internet access) and secondary (human capital and competency-based — ICT employment) levels. The methodology combines cartographic methods of quantile classification, the Gini index, kernel density estimation (KDE), and Moran's index to verify neighborhood effects. The results indicate divergent dynamics: a steady reduction in the infrastructural gap in internet access is accompanied by an increasing concentration of human capital in ICT. Significant spatial autocorrelation is confirmed, manifested in the formation of stable clusters of leading and lagging regions. Conclusions. The key challenge for regional development is shifting towards overcoming the secondary divide, necessitating a transition from universal infrastructure policies to targeted measures that stimulate the diffusion of digital competencies and the development of human capital in peripheral regions.

Keywords:

digital inequality, regional development, mobile internet, fixed internet, neighbourhood effects

Introduction

The relevance of the problem of interregional digital inequality manifests itself in several aspects. First, it acts as a significant barrier to the country's technological development. Studies have identified a relationship between the level of

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digitalisation and socio-demographic characteristics. The share of Internet users varies by type of settlement [1], while the spread of mobile Internet is associated with per capita income [2], and access to networks depends on the age, income, and educational attainment of residents [3]. Digital inequality is not reducible to differences in access to technology; it reproduces and deepens existing socio-economic disparities [4].

Second, the empirical verification of the “neighbourhood effect” in digitalisation processes is a priority task of regional policy. Although theoretically spatial proximity can accelerate the diffusion of technologies [5], these processes, given the high spatial differentiation of Russia [6], have been studied only fragmentarily and require systematic monitoring [7].

Third, empirical evidence indicates a relationship between digital development and household income. Digitalisation has heterogeneous effects on income distribution across regions [2]. For instance, in China, the digital economy has been found to have a non-linear (inverted U-shaped) effect on income inequality [8].

The aim of the study is to identify and quantitatively assess the dynamics and spatial structure of digital inequality across regions of the Russian Federation, distinguishing between primary (infrastructural) inequality, defined as access to mobile and fixed Internet, and secondary (human capital and competence-based) inequality, reflected in employment in the ICT sector.

Research objectives were defined as follows: (1) to assess the dynamics of regional inequality in terms of access to mobile and fixed Internet (2011–2023) using the Gini index and Lorenz curves; (2) to analyze changes in the concentration of ICT employment across regions using the Gini index and kernel density estimation (KDE); (3) to identify spatial clusters of regions for each of the three indicators (mobile Internet, fixed Internet, ICT employment) by calculating global and local Moran’s indices; (4) to test for the presence and direction of neighbourhood effects for each level of the digital divide.

Observed trends reveal a contradiction: technological logic and state policy are oriented toward infrastructure equalisation, whereas studies consistently show a strong link between digitalisation and socio-economic stratification, as well as heterogeneity in spatial effects. This suggests that the dynamics of the infrastructure and human capital divides may be asynchronous, and that the influence of neighbourhood effects may differ across various dimensions of digital development. Hence, the following research hypotheses are proposed.

H1: Infrastructural digital inequality (the primary divide) among Russian regions is decreasing, as evidenced by a declining Gini index for mobile and fixed Internet penetration rates.

H2: Human capital and competence-based digital inequality (the secondary divide) is increasing, which is expressed in a rising Gini index for the share of ICT-employed individuals and the formation of a multimodal distribution according to the KDE method.

H3: For all three digitalisation indicators, there is positive spatial autocorrelation, confirmed by statistically significant Moran's index values.

H4: Neighbourhood effects manifest differently: for infrastructural indicators, they contribute to convergence, whereas for ICT employment, they reinforce polarisation, producing clusters of leading and lagging regions.

The research problem is to identify and explain the mechanisms driving the reproduction of spatial digital inequality despite a formal reduction in the infrastructural divide, as reflected in the emergence of stable hierarchical clusters of leading and lagging regions and the growing concentration of human capital and competence-based potential in a limited number of territories.

Theoretical foundations of the study

Digital inequality refers to the gap in opportunities to access, use, and derive benefits from digital technologies, driven by differences in digital and social context, skills, and patterns of Internet use [9]. It encompasses not only access to infrastructure (broadband and mobile Internet [10]), but also the level of digital competencies, as well as the accessibility of content and services.

Four factors influence the effectiveness of digitalisation [9]: (1) technical means (quality of devices, software, Internet speed [11]); (2) autonomy of use (access at the right time and place, freedom of use); (3) social support networks (assistance from experienced users); (4) experience (level of digital literacy).

The neighbourhood effect (spatial effect) is a phenomenon of mutual influence of digitalisation levels among geographically proximate territories through the spillover of tacit knowledge, innovations, or policy measures, generating externalities for regional competitiveness.

Below, we review selected academic studies on digital inequality and neighbourhood effects (Table 1).

Table 1

Selected studies on digital inequality and the identification of neighbourhood effects

Key findings	Author(s), year
Spatial analysis revealed clustering of digital inequality in the EU; the neighbourhood effect influences competitiveness, necessitating appropriate interregional policy	Tislenko M., 2024 [12]
The digital economy increases income and helps reduce inequality through industrialisation and inclusive initiatives	Shen C. et al., 2025 [13]
The digital economy generates spatial spillovers, which are amplified by Moore's and Metcalfe's laws	Zhao & Zhang, 2020 [14]
The widening gap in wages and income in developed countries is largely driven by technological changes	Card & DiNardo, 2002 [15]

The end of Table 1

Key findings	Author(s), year
Digital inequality is driven by education, income, place of residence, and social status, reinforcing social barriers. Overcoming it requires infrastructural, educational, and inclusive measures	Heeks, 2022 [4]
Digital inequality limits access to institutions; digital inclusion and literacy development are crucial for full economic participation	Sharma et al., 2018 [16]

Three levels of digital inequality are distinguished [1]: (1) access inequality — differences in Internet connectivity [17; 18] and technology diffusion, where industrial innovation is highly correlated with the level of digitalisation [19]; (2) skills inequality — differences in competencies [20] and the quality of human potential, where, given high levels of access, it is precisely the number of specialists and the purposes of technology use that determine inequality; (3) opportunity inequality — the gap in the application of digital technologies in everyday life and firm-level activities [4].

To address regional disparities, it is important to account for the specific characteristics of the primary and secondary digital divides. The primary divide refers to inequality in physical access to ICTs (computers, Internet, mobile communications). It exists both between countries and within them — between urban and rural residents, as well as among groups differing in income, education [21], and age. Traditional studies (e.g., by the International Telecommunication Union) have focused on this level, measuring the penetration of broadband access and mobile communications.¹

As basic access has spread, it has become evident that having a connection does not guarantee equal opportunities. Alongside the primary divide, the concept of the secondary digital divide (DiMaggio, Hargittai) emerged, focusing on the quality of access and skills in technology use. This divide manifests itself in differences in competencies: some use the internet for work, education and civic engagement, whilst others use it in a more limited way, for entertainment and communication. Inequality in skills persists even when physical access is universal [22]. The secondary divide, linked to human and social capital, exacerbates social inequality in the knowledge economy. As the OECD emphasises, digital literacy is becoming a key factor of stratification, and overcoming it requires not so much infrastructural investments as educational programmes and inclusive content.

¹ e.g., Measuring digital development Facts and Figures 2025, 2025, *ITU. Telecommunication Development Sector*, URL: <https://www.itu.int/itu-d/reports/statistics/facts-figures-2025/> (accessed 03.02.2026) ; Global Connectivity Report 2025, 2025, *ITU. Development Sector*, URL: https://www.itu.int/hub/publication/D-IND-ICT_MDD.GCR-2025-4/ (accessed 03.02.2026).

Focusing on the first two levels is methodologically justified, as official statistics allow for the identification of structural preconditions of inequality. The reduction of the primary divide and the widening of the secondary divide indicate a likely future exacerbation of the opportunity divide (the third level), which sets the agenda for subsequent qualitative research.

Neighbourhood effects do not always resolve inequality problems. Contrary to expectations, digital networks tend to transform and reproduce geographical differences, creating isolated communities. Successful projects are not replicated universally, which requires authorities to implement measures that stimulate interterritorial linkages for information justice.

This study introduces a terminological distinction. Digital inequality refers to a multidimensional state, a system of disparities between regions, statistically measured as a distribution (e.g., Gini index). The digital divide refers to a specific manifestation of this inequality between groups (e.g., leaders and outsiders), the 'distance' between poles. Inequality is the general characteristic of distribution, whereas the divide is its structural consequence. An increase in inequality (a rise in the Gini index) deepens the divide. The analysis of 'inequality' (using Gini indices, Moran's indices, KDE) serves as the basis for conclusions regarding the dynamics of the infrastructural and human capital 'divides'.

Research Methodology

The methodological framework comprises several approaches.

1. Cartographic methods with quantile clustering visualize regional differences in access to digital technologies and employment. Partitioning into equal groups reveals the mobility or persistence of inequality classes, enabling comparative analysis of shifts in digital development.

2. The Gini index and Lorenz curve measure inequality in communication accessibility and the share of ICT-employed individuals. This instrument has been used to assess digital infrastructure in federal districts [23] and at the international level, revealing the concentration of technologies in developed regions [4].

3. Kernel density estimation (KDE) [24; 25] analyses the distribution of regions across digitalization indicators. A smooth KDE curve better reflects the shape of the distribution (normal, bimodal, skewed) than a histogram; multiple peaks indicate clustering, while dispersion points to a gap between leaders and outsiders [26].

4. Spatial autocorrelation (Moran's index) identifies neighbourhood effects. The index evaluates the relationship between values in neighboring regions, capturing clustering (positive autocorrelation) or dissimilarity (negative autocorrelation). Values range from -1 (dispersion) to $+1$ (complete clustering); values close to 0 indicate random distribution. Lavrikova and Suvorova, using a sample of regions, demonstrated the influence of geographical location on the concentration of population and industry [27]; other studies confirm the importance of spatial effects for development strategies [28; 29].

Spatial autocorrelation (Moran's index) is a statistical property that captures the clustering of similar values. The neighbourhood effect is the presumed mechanism (diffusion of technologies, knowledge, resources, or policies). Significant autocorrelation is a necessary but not sufficient condition for spillover effects: clustering may be driven by common external factors (policy, economic structure, historical characteristics). This study establishes the fact of persistent spatial clustering, thereby providing a foundation for investigating the specific mechanisms involved.

The objects of the study are the regions of Russia for which the necessary statistical data for the period 2011–2023 are available.¹ The source of data is the Federal State Statistics Service (Rosstat). This ensures representativeness and a unified data collection methodology. To ensure the comparability of the data series for 2011–2023, the following measures were taken: (1) the indicators for the number of mobile and fixed broadband subscribers (per 100 people) were compiled by Rosstat using a consistent methodology throughout the entire period, ensuring full comparability of the series; (2) for the ICT employment indicator, a transition from OKVED-2001 to OKVED2-2014 occurred during the analysed period. Therefore, the official recalculated Rosstat series for the aggregated category of “ICT activities” were used, which made it possible to minimise the discontinuity associated with the change in classification. Consequently, the dynamics of the indicator reflect actual changes in the employment structure.

All calculations and maps were performed by the authors using unified data series. The source data are available in statistical yearbooks and on the Rosstat website.

Research Results

Geography of Digitalisation and Spatial Distribution

Mobile broadband consumption is one of the indicators of digitalisation. An increase in this indicator reflects the accessibility of services, the bridging of the digital divide, improvements in service quality (speed, stability, price), and digital inclusiveness (use of the Internet in healthcare, education, and the public sector). This indicator should not trend toward 100%; rather, the target is access for all who need it and are ready to use it. Today, penetration in Russia has reached a high level, but a significant interregional gap persists (Fig. 1). The development of infrastructure in lagging regions is an important task for ensuring equal access to digital services.

¹ To ensure data comparability, a balanced panel of regions within the 2023 boundaries was constructed. Data for the Republic of Crimea and Sevastopol are available only from 2014 onward; therefore, these entities were excluded from calculations of the Gini index and KDE for the years 2011–2013. The contiguity matrix for Moran's index was constructed for 85 regions, but Crimea and Sevastopol were not included in the calculations prior to 2014 due to missing data.

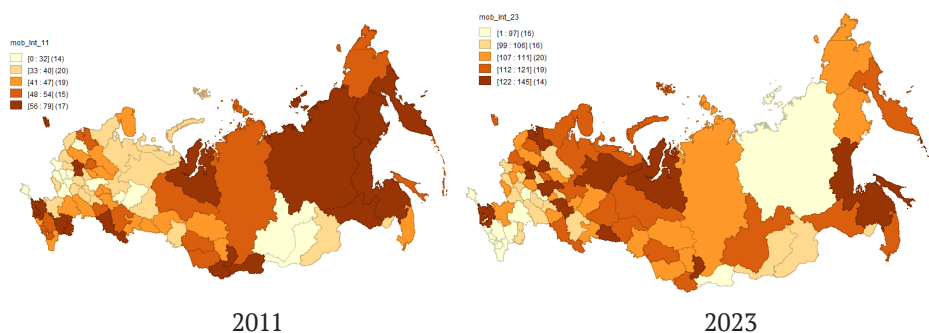


Fig. 1. Cartogram of Russian regions by number of active mobile broadband Internet subscribers, people per 100 inhabitants, in 2011 and 2023, by quantiles¹

Compiled based on Rosstat data using the GeoDA software package. Regional boundaries correspond to 2023. Values in parentheses indicate the number of regions within the range.

Over the period analysed, all regions experienced significant growth in mobile Internet penetration. Whereas in 2011 the values for most regions ranged from 30 to 60 subscribers per 100 people, by 2023 the indicator had exceeded 100 almost everywhere, indicating the widespread diffusion of the technology. The highest values are observed in Saint Petersburg and Leningrad regions (145.4), Yamalo-Nenets Autonomous Okrug (143), and Moscow and Moscow region (142.5).

The high indicator in Yamalo-Nenets Autonomous Okrug can be explained by a combination of factors: a developed oil and gas industry provides high incomes and effective demand; a ‘point-based’ settlement pattern (administrative centers and shift camps) makes network deployment economically feasible; for the population in the Far North, mobile Internet serves as the primary channel of communication with the outside world; and the business segment is represented by large fuel and energy corporations with stable demand for data transmission. Thus, economic prosperity, compact urbanisation, and socially conditioned demand outweigh the infrastructural challenges of remote territories.

High indicators are also characteristic of Tatarstan (126.9), Khabarovsk Krai (139.6), and the Kaliningrad region (117.9). In terms of average annual growth rates, Irkutsk region (16.88%), Nizhny Novgorod region (15.56%), and Perm Krai (13.92%) are the leaders. Since 2017, growth has accelerated due to the expansion of 4G networks and affordable pricing plans; in 2020–2021, the COVID-19 pandemic provided an additional impulse. In 2022–2023, growth rates slowed, which may indicate market saturation.

Another indicator of digitalisation is fixed Internet, measured as the number of active broadband access subscribers (per 100 people) (Fig. 2).

¹ To verify the obtained results regarding the distribution of regions by the indicator, an additional robustness check of the findings was conducted. Constructing cartograms using the equal intervals method instead of quantiles did not alter the overall geographical pattern.

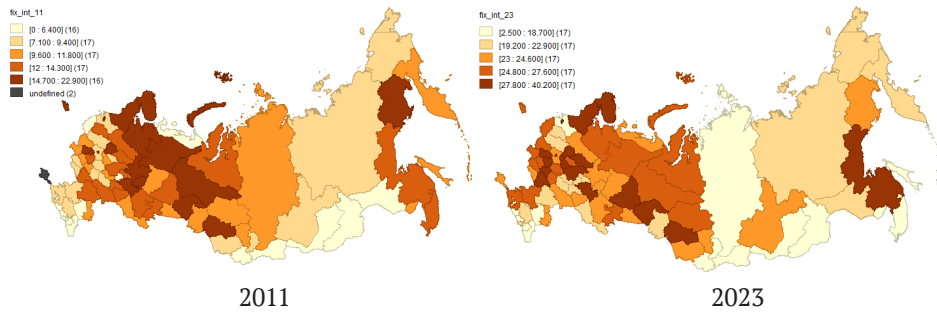


Fig. 2. Cartogram of Russian regions by number of active fixed broadband Internet subscribers, people per 100 inhabitants, in 2011 and 2023, by quantiles

Compiled based on Rosstat data using the GeoDA software package. Regional boundaries correspond to 2023. Values in parentheses indicate the number of regions within the range.

Analysis of fixed broadband access demonstrates steady growth in most regions: average values increased from 10–15 subscribers per 100 people in 2011 to 20–30 by 2023. The highest growth rates are observed in regions with initially low levels of connectivity: the Republic of Crimea (from 0.5 in 2014 to 23.1 in 2023), Nenets Autonomous Okrug (from 2.8 in 2016 to 24.0 in 2023), and the Chechen Republic (from 0.1 in 2011–2013 to 6.6 in 2023).

The highest values are recorded in Karelia (40.2), Murmansk region (36.0), Moscow (35.8), and Novosibirsk region (35.1); the lowest are found in Ingushetia (2.5), Adygea (7.9), and Tyva (9.9). This indicates the persistence of significant digital inequality driven by economic, infrastructural, and geographical factors.

In Moscow and Saint Petersburg, where the indicator was initially above average, growth rates are lower (Moscow: 22.9–35.8; Saint Petersburg: 19.0–28.5), which may be explained by market saturation and a shift of users toward mobile Internet.

In certain regions, a decline in the indicator was observed: Krasnoyarsk Krai (16.9–15.9) and the Komi Republic (30.2–25.7). This is attributable to a demand shift in favour of mobile technologies, population decline, and migration outflows (in the Komi Republic).

In remote regions (the Far East, the North Caucasus), growth rates are below the national average due to infrastructural challenges. However, isolated cases (Chukotka Autonomous Okrug: 7.6–21.5) demonstrate sharp increases resulting from the implementation of targeted programmes.¹

¹ Overcoming infrastructural constraints was declared a key task for the development of Chukotka Autonomous Okrug starting in 2013 within the state programme “Information Society” (Decree of the Government of Chukotka Autonomous Okrug No. 402 of October 21, 2013, available at: <https://docs.cntd.ru/document/460193813> (accessed 06.02.2026)) and the Regional Digital Transformation Strategy (approved August 7, 2021) (available at: <https://digital.gov.ru/uploaded/files/690338-690403.pdf> (accessed 06.02.2026)). The overarching goal is to create a sustainable infrastructure for high-speed data transmission accessible to all organizations and households in the okrug. Specific tasks include ensuring Internet access with the provision of one-time free traffic (1 GB) and reducing the cost of access to the average level for the Far Eastern Federal District.

ICT employment (the share of the employed in the ICT sector, Fig. 3) is a key indicator of a region's technological development and competitiveness. This indicator reflects the population's involvement in high-tech industries, the quality of human capital, the development of digital infrastructure, and the capacity to adapt to the challenges of the digital age. An increase in the share of ICT-employed individuals is associated with higher labour productivity and a reduction in digital inequality by ensuring access to modern communication and data processing tools for both businesses and the population.

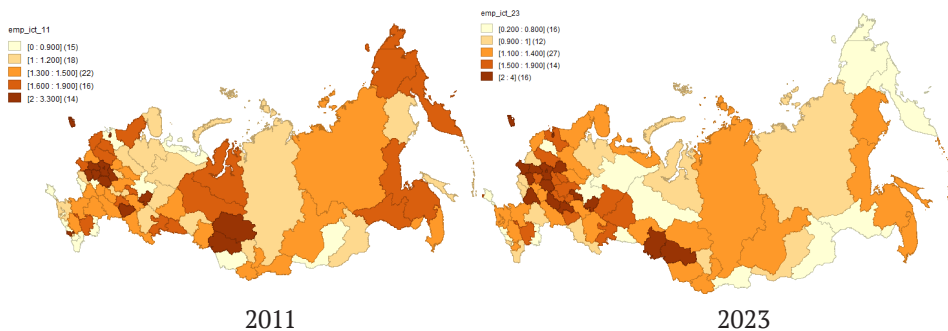


Fig. 3. Cartogram of Russian regions by ICT employment, %, in 2011 and 2023, by quantiles

Compiled based on Rosstat data using the GeoDA software package. Regional boundaries correspond to 2023. Values in parentheses indicate the number of regions within the range.

Analysis of ICT employment reveals persistent trends and regional characteristics. The highest values are observed in major technology hubs: Moscow (4.0 % in 2023), Saint Petersburg (3.2 %), and the Moscow region (2.7 %), confirming the concentration of human capital and infrastructure in cities with a developed scientific and educational environment. A high share of ICT employment is also recorded in the Kaluga region (3.8 %), Novosibirsk region (3.0 %), and the Udmurt Republic (3.3 %).

In resource-oriented regions (Khanty-Mansiysk Autonomous Okrug — 0.4 %, Yamalo-Nenets Autonomous Okrug — 0.9 %), the indicator is low due to weak employment diversification. Low values are characteristic of several regions in the North Caucasus (Chechen Republic — 1.1 %, Republic of Ingushetia — 0.7 %) and the Far East (Amur region — 0.3 %, Chukotka Autonomous Okrug — 0.2 %), where the development of the ICT sector is at an early stage.

The analysis confirms significant interregional differentiation in digitalisation, associated with the level of economic development, the presence of competence centres, and state support.

Regional inequality in digitalisation Levels

Digital inequality among Russian regions can be assessed using the Gini index and visualised with the Lorenz curve. The Lorenz curve (Fig. 4) shows that less inequality is observed in the distribution of mobile Internet, and this inequality decreases over time.

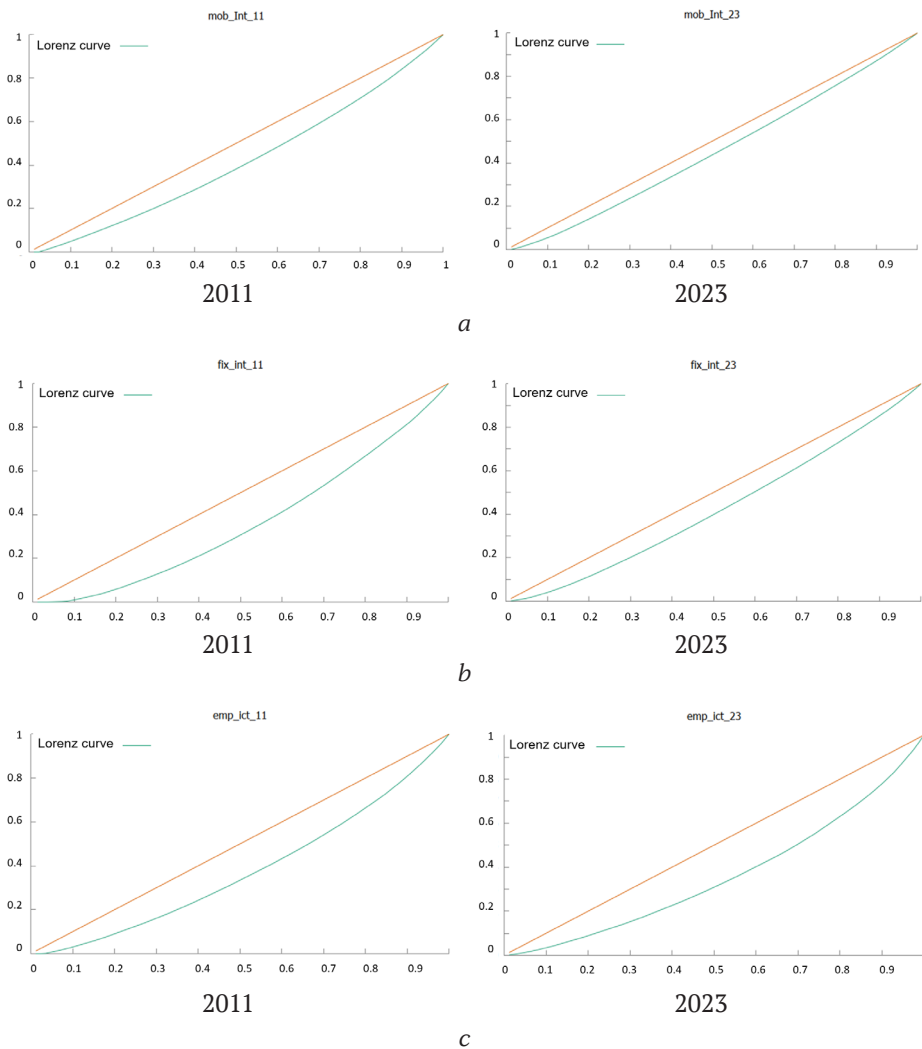


Fig. 4. Lorenz curve for digitalisation indicators across Russian regions in 2011 and 2023: (a) number of active mobile broadband Internet subscribers; (b) number of active fixed broadband Internet subscribers; (c) ICT employment

Compiled based on Rosstat data using the Gretl software package.

The highest and increasing inequality is recorded for the share of ICT employment, which indicates a secondary digital divide: the benefits of digitalisation

are captured by regions that develop human capital. The dynamics of primary (Internet access) and secondary (ICT employment) inequality are reflected in the Gini index (Table 2 and Fig. 5).¹

Table 2

**Dynamics of the Gini index for digitalisation indicators
in Russian regions, 2011 – 2023**

Year	Mobile Internet	Fixed Internet	ICT Employment
2011	0.171	0.277	0.243
2012	0.164	0.260	0.232
2013	0.170	0.257	0.241
2014	0.153	0.243	0.231
2015	0.142	0.228	0.224
2016	0.139	0.217	0.219
2017	0.110	0.203	0.215
2018	0.110	0.182	0.242
2019	0.104	0.175	0.235
2020	0.100	0.170	0.239
2021	0.102	0.164	0.239
2022	0.098	0.161	0.261
2023	0.100	0.153	0.279

Compiled based on Rosstat data using the Gretl software package.

The data in Table 1 record a steady decline in regional inequality in Internet access since 2011. The most significant reduction is observed for the mobile Internet gap (Gini index decreasing from 0.171 to 0.100). For fixed Internet, the decline is more gradual (from 0.277 to 0.153), starting from an initially higher level of inequality.

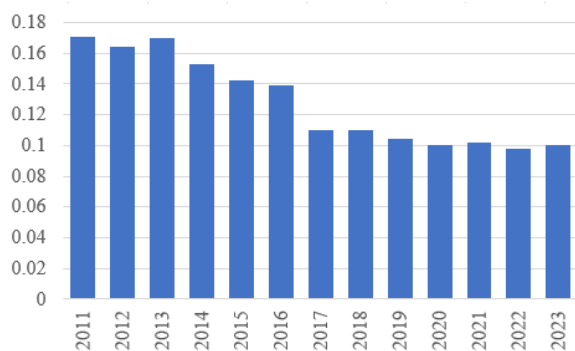
The dynamics of inequality in ICT employment are multidirectional: after a decline until 2017, the index began to rise, reaching its maximum value in 2023 (0.279) and exceeding the 2011 level. This indicates an increasing concentration of human capital potential in a limited number of regions and the emergence of a secondary digital divide.

It is important to distinguish between relative and absolute inequality, as well as to account for access quality. The decline in the Gini index for infrastructural indicators reflects a reduction in relative disparities, but does not automatically imply a decrease in absolute gaps². Critically significant is the gap in access

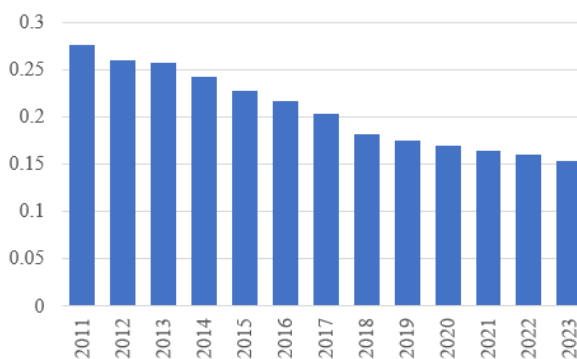
¹ To verify the robustness of the findings, the Theil index was additionally calculated. The dynamics of both indices exhibit qualitatively identical trends: a decline for infrastructural indicators and an increase for ICT employment. This confirms that the conclusion regarding the divergence of the primary and secondary divides does not depend on the choice of index. Calculations were performed in Gretl.

² For example, if the number of subscribers in a leading region increases from 140 to 145, while in a lagging region it increases from 40 to 80, relative inequality (according to the Gini index) will decrease, but the absolute gap will remain substantial (65 people per 100 people).

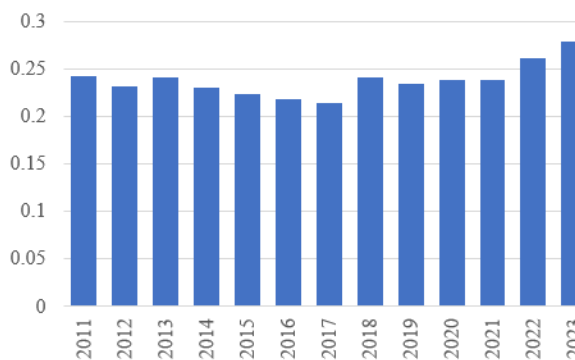
quality (speed, stability, price), which is not directly measured by penetration statistics. The decline in the index may be partially driven by a saturation effect in leading regions, while lagging regions increase connectivity based on lower-quality infrastructure. Assessing the overcoming of the primary divide requires a comprehensive approach that takes into account not only quantitative but also qualitative parameters.



a



b



c

Fig. 5. Dynamics of the Gini index for mobile Internet penetration, fixed Internet penetration, and ICT employment in Russian regions, 2011 – 2023, by indicator: (a) mobile Internet; (b) fixed Internet; (c) ICT employment

Kernel density estimation

The secondary digital divide is most clearly manifested in the territorial distribution of ICT specialists. Kernel density estimation (KDE) analysis of the share of ICT employment reveals a trend of heterogeneous development of the digital sector across Russian regions (Fig. 6).

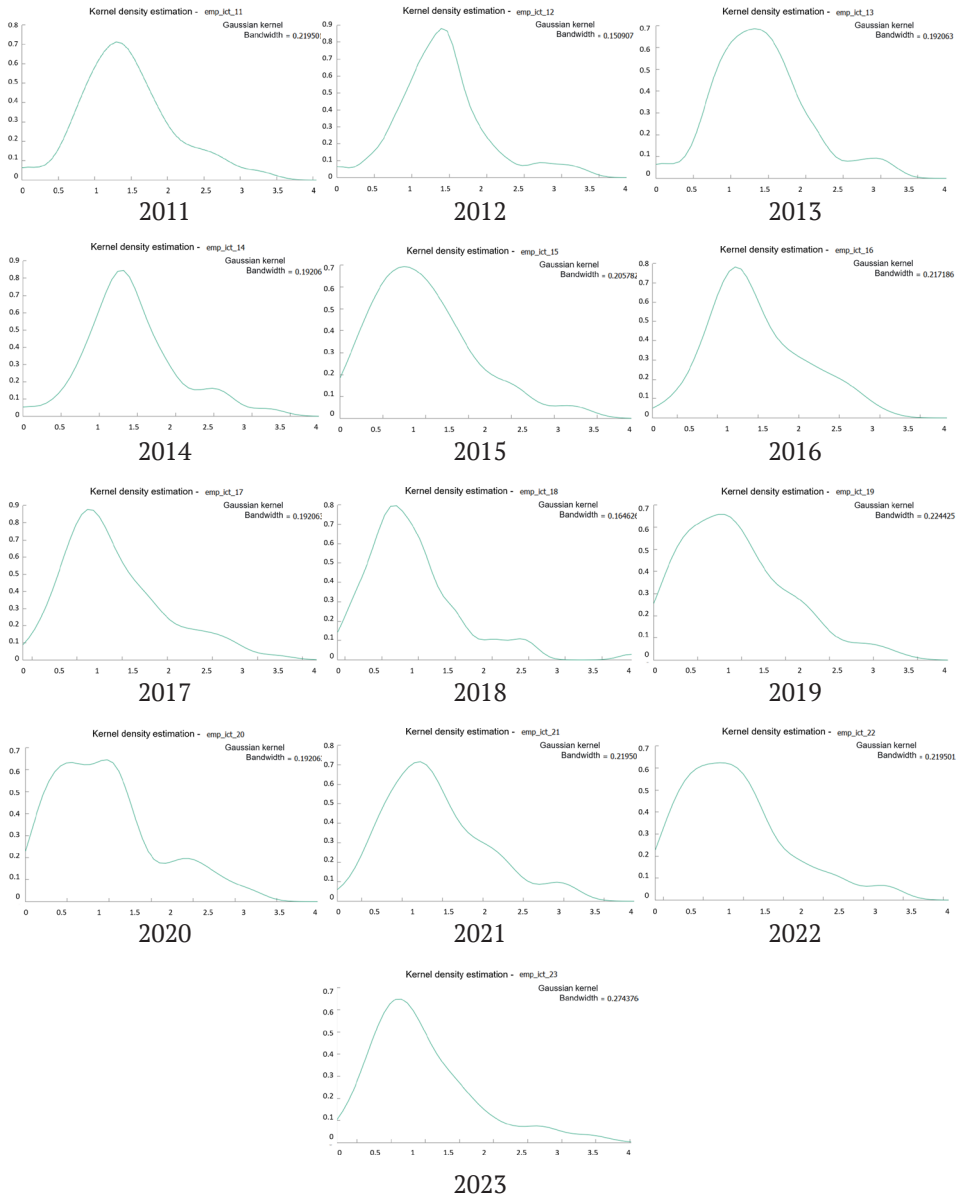


Fig. 6. Kernel density estimation for the share of ICT employment across Russian regions, 2011—2023

Compiled based on Rosstat data using the Gretl software package.

Kernel density estimation revealed heterogeneity in the distribution of ICT employment. In certain years (2011, 2016), the distribution was close to normal. The longest periods (2012–2013, 2015, 2017–2019, 2021–2023) were characterised by two clusters (with high and medium shares). In 2014 and 2020, three peaks were observed. Fluctuations in the number of peaks reflect the dynamics of ICT employment concentration under the influence of economic, political, and technological factors. Overall, digital inequality persists: some regions become centres for the development of high-tech sectors, while others lag behind.

The sharp increase in the Gini index and persistent spatial clustering in the share of ICT employment indicate a strengthening of the secondary digital divide, driven by a combination of factors:

1. Agglomeration effects and demand concentration — large centres form a self-sustaining ecosystem; demand for specialists attracts talent and stimulates their training.

2. Uneven distribution of the scientific and educational complex — leading technical universities and research centers are historically concentrated in a few regions, creating a structural advantage.

3. Migration of skilled personnel — high wages, career prospects, and a high-quality environment in leading regions cause an outflow of graduates and specialists from the periphery, exacerbating the human capital deficit.

4. Location of headquarters — key functions of IT companies and their statistical reporting are concentrated in metropolitan agglomerations, which formally inflate ICT employment indicators in these regions without always reflecting the actual diffusion of competencies.

Spatial effects

Spatial effects were analysed for all three dimensions: mobile and fixed Internet (primary divide) and ICT employment (secondary divide). A binary spatial weights matrix (contiguity based on shared borders, queen contiguity rule) with row standardisation was used. Cartograms of the local Moran's index are presented in Figures 7–9.

Throughout the entire period, persistent clustering of regions by mobile Internet penetration level is observed. Regions with high values (HH) — Moscow, Saint Petersburg, oil and gas producing okrugs, and territories of the Far East — form clusters of digital leaders. Fluctuations in the number of clusters do not negate the persistence of spatial disparities.

Mixed-type clusters (HL, LH) are rare, indicating a weak influence of local breakthroughs. An exception occurred in 2020–2023, when isolated HL cases (Krasnodar Krai) emerged amidst less developed neighbours, likely due to targeted investments.

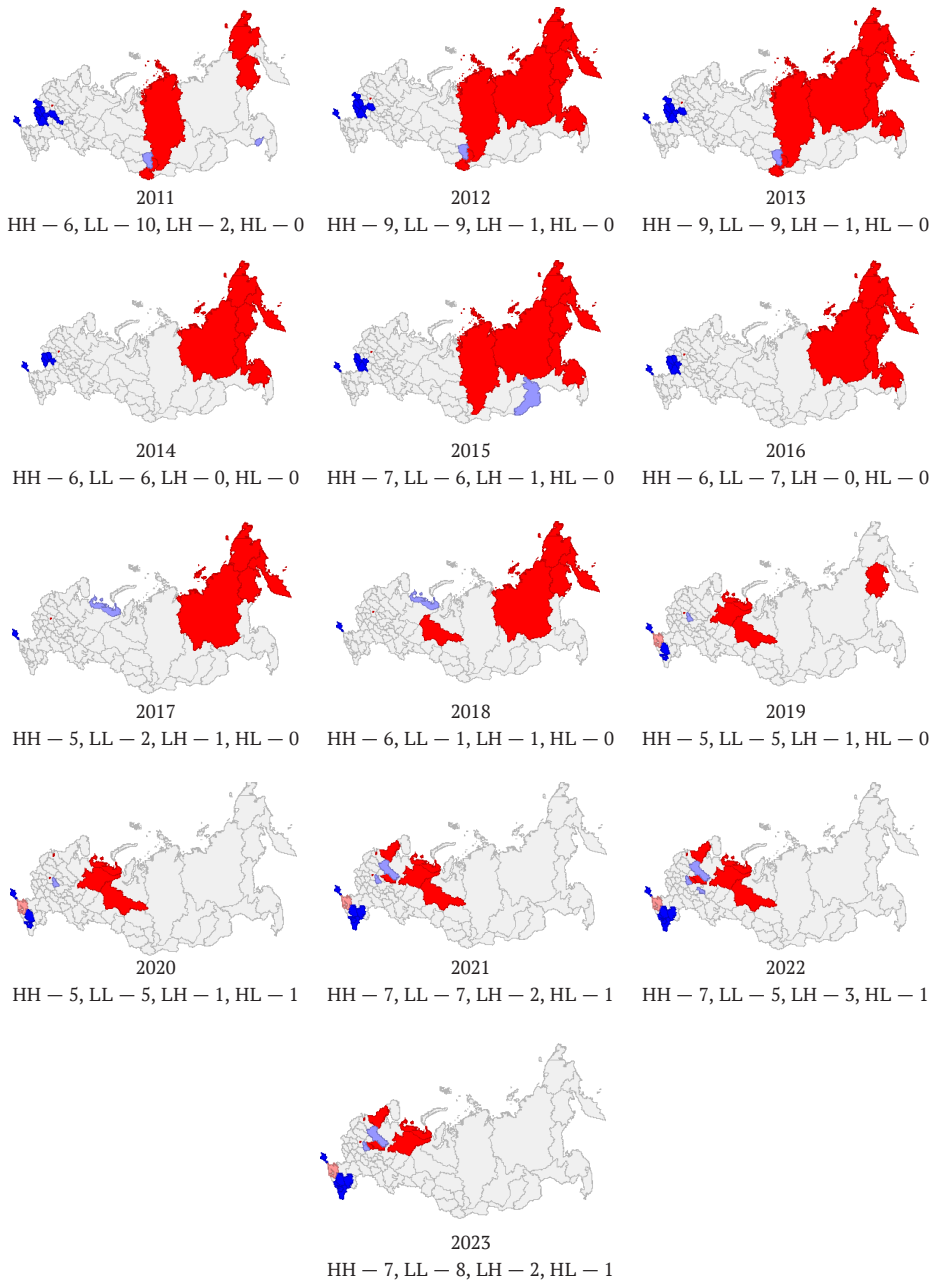


Fig. 7. Cartograms of the univariate local Moran's index for the number of active mobile broadband Internet subscribers, people per 100 inhabitants, across Russian regions, 2011 – 2023.

Note: HH (red) — high values surrounded by high values; LL (blue) — low values surrounded by low values; LH (light blue) — low values surrounded by high values; HL (pink) — high values surrounded by low values. For colored regions, p -value = 0.001 – 0.05; grey regions are statistically insignificant.

Compiled based on Rosstat data using the GeoDA software package.

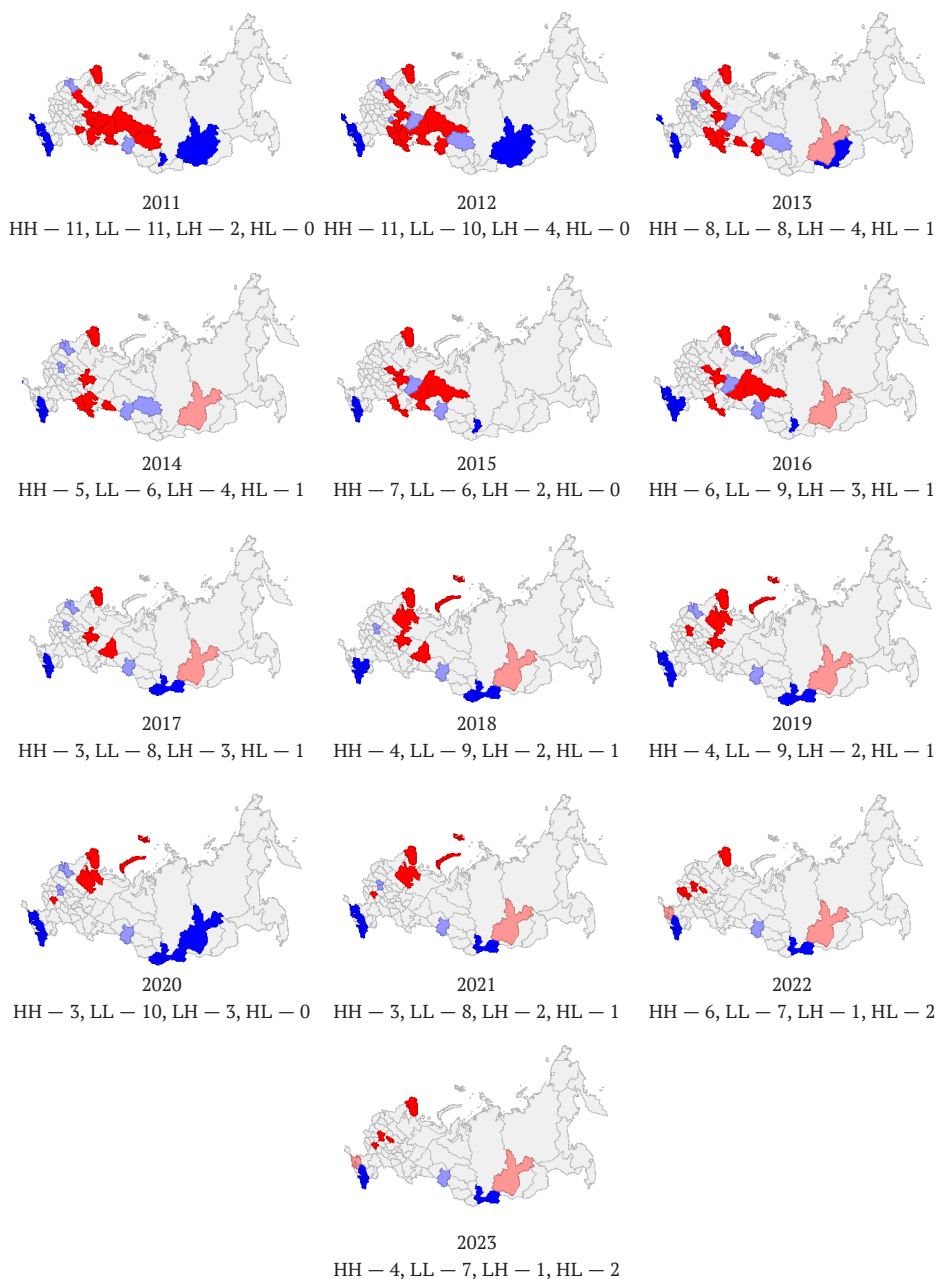


Fig. 8. Cartograms of the univariate local Moran’s index for the number of active fixed broadband Internet subscribers, people per 100 inhabitants, across Russian regions, 2011 – 2023

Note: HH (red) – high values surrounded by high values; LL (blue) – low values surrounded by low values; LH (light blue) – low values surrounded by high values; HL (pink) – high values surrounded by low values. For colored regions, p-value = 0.001 – 0.05; grey regions are statistically insignificant.

Compiled based on Rosstat data using the GeoDA software package.

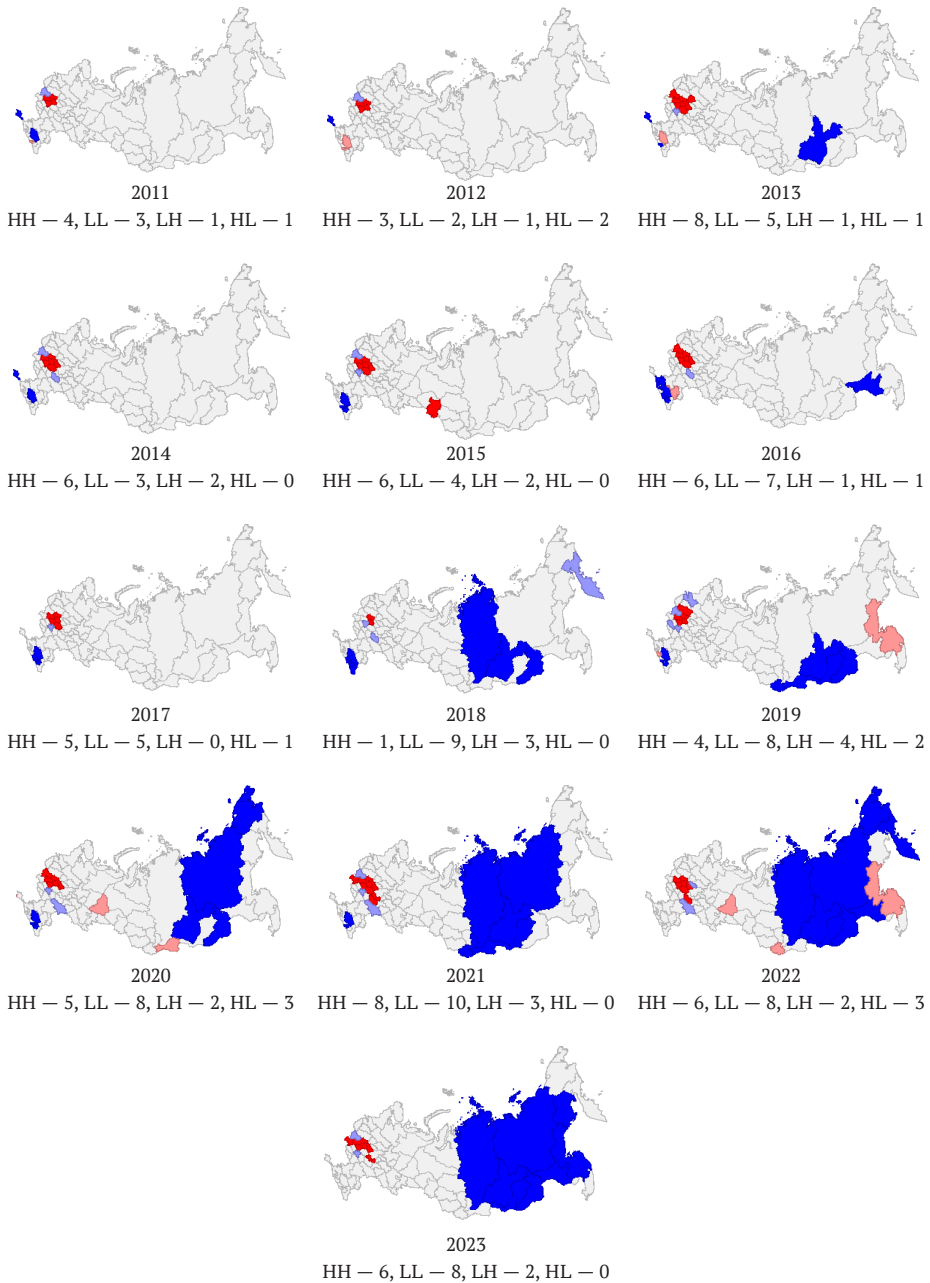


Fig. 9. Cartograms of the univariate local Moran's index for ICT employment, %, across Russian regions, 2011 – 2023

Note: HH (red) — high values surrounded by high values; LL (blue) — low values surrounded by low values; LH (light blue) — low values surrounded by high values; HL (pink) — high values surrounded by low values. For colored regions, p -value = 0.001 – 0.05; grey regions are statistically insignificant.

Compiled based on Rosstat data using the GeoDA software package.

After 2017, the number of LL clusters decreased (from 6–10 to 5–8), which may be associated with the implementation of the “Digital Economy” programme and the expansion of coverage. However, complete equalisation has not occurred.

Moran’s index throughout the entire period is positive and statistically significant (Table 2), confirming spatial dependence. The diffusion of mobile Internet follows a wave-like pattern: technology gradually diffuses from centres to the periphery, but with delays and the formation of ‘blind spots’.

The distribution of clusters for fixed Internet is more diverse. Until 2016, regions formed ‘belts’ of high values, either spreading influence or contrasting with neighbours. The dynamics of Moran’s index (Table 2) confirm persistent spatial autocorrelation.

In 2011–2014, the index declined (from 0.383 to 0.283), indicating a weakening of clustering and selective convergence. In 2015–2018, the increase to a peak of 0.407 reflected greater differentiation and the focal nature of technology diffusion. Since 2019, the index has stabilised, remaining above the initial period level, which points to the structural stability of spatial dependence.

The high level of the secondary digital divide in ICT employment is also captured by Moran’s index (Fig. 9).

Clusters with a high share of ICT employment are few in number and are concentrated primarily around Moscow. At the same time, a zone of low values, reflecting a negative trend, is emerging in Siberia and the Far East. Overall, spatial clustering in ICT employment remains persistent.

The dynamics of Moran’s index (Table 3 and Fig. 10) are wave-like. After an increase in 2011–2014 (peak of 0.332 in 2013), a sharp decline followed to a minimum of 0.139 in 2015–2018, which may indicate a temporary diffusion of ICT personnel to the periphery. However, since 2019, the index has been steadily increasing, reaching 0.316 in 2023 — a level close to the values of 2013–2014. This indicates a return to and intensification of spatial polarisation: ICT employment is once again concentrating in a limited number of leading regions, deepening interregional differentiation.

Table 3

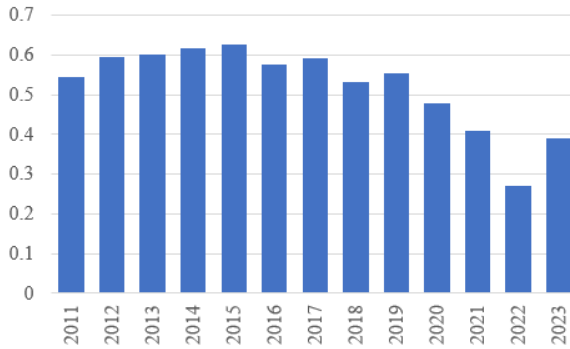
Dynamics of Moran’s index for digitalisation indicators in Russian regions, 2011–2023

Year	Mobile Internet	Fixed Internet	ICT Employment
2011	0.543	0.383	0.255
2012	0.595	0.39	0.248
2013	0.601	0.344	0.332
2014	0.618	0.283	0.313
2015	0.626	0.315	0.139
2016	0.576	0.369	0.191
2017	0.592	0.342	0.195
2018	0.531	0.407	0.139
2019	0.555	0.38	0.2
2020	0.479	0.363	0.272

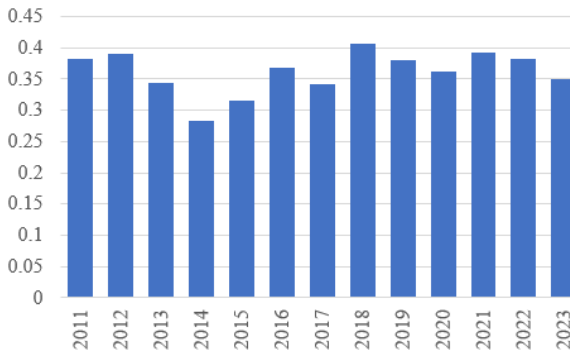
The end of Table 1

Year	Mobile Internet	Fixed Internet	ICT Employment
2021	0.408	0.393	0.285
2022	0.269	0.382	0.293
2023	0.3884	0.349	0.316

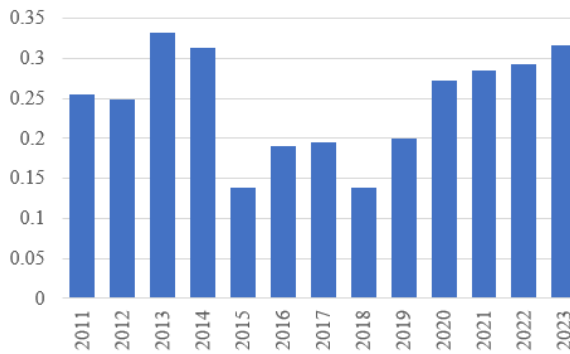
Compiled based on Rosstat data using the Gretl software package.



a



b



c

Fig. 10. Dynamics of Moran's index for mobile Internet penetration, fixed Internet penetration, and ICT employment in Russian regions, 2011 – 2023, by indicator: (a) mobile Internet; (b) fixed Internet; (c) ICT employment

Discussion of results

The study has revealed a significant increase in the accessibility of mobile and fixed Internet in Russia; however, pronounced regional asymmetry persists. The highest growth rates are observed in regions with initially low penetration levels, whereas in more developed regions the dynamics are slowing down, which may indicate market saturation. Further reduction of digital inequality requires targeted support measures, particularly in regions with underdeveloped telecommunications infrastructure.

Significant interregional differences in the development of the ICT sector have been identified, driven by economic potential, the presence of scientific and educational centres, and government support measures. Reducing these gaps requires targeted policies that stimulate demand for ICT services and the development of digital skills among the population.

Moran's index demonstrates persistent spatial autocorrelation but does not allow for unambiguous identification of causal mechanisms: whether clustering is a consequence of government policy, neighbourhood effects, or common historical and economic preconditions remains an open question for further research.

The identified polarisation in the ICT human capital sphere calls into question the effectiveness of existing spatial equalisation measures and requires a revision of approaches to stimulating knowledge diffusion. The key policy implication is a shift from uniform approaches to targeted instruments tailored to the specific characteristics of different types of clusters.

For leading regions (HH type), the priority is not to maintain their lead but to transform into national "generators" of digital competencies. It is advisable to establish federal competence centres on this basis, with obligations to provide internships, retraining, and methodological support to lagging regions. Regional authorities can incentivise ICT companies to create distributed teams and branches in partner regions through tax benefits tied to job creation outside metropolitan agglomerations. A key mechanism is co-financing academic and professional mobility programmes to facilitate the flow of personnel and knowledge.

For lagging clusters (LL type), the central task is integration into the digital space. Financial support for local enterprises is necessary, provided that technologists from leading regions are mandatorily involved. Authorities should develop targeted housing and educational programmes ('digital mortgages', support for IT repatriates) to attract and retain ICT specialists. An important mechanism is the establishment of digital departments at anchor universities in partnership with leading universities from the leading clusters.

For mixed clusters (HL, LH) and territories with medium development levels that are at risk of falling behind, the priority is to leverage spatial interaction for a 'catch-up' effect. Joint interregional projects in priority sectors (logistics, tourism, agriculture) and the creation of interregional ICT clusters with federal support are advisable, whereby 'growth poles' stimulate demand and competencies in neighbouring regions.

At the federal level, a shift from infrastructure grants to a system of ‘smart’ contracts that link funding to the achievement of human capital and cooperation indicators is advisable. Regional digital transformation strategies should include a section on interregional cooperation. Business associations can act as operators of distributed employment and mentoring programmes. Thus, overcoming digital inequality requires differentiated solutions and a shift in focus from infrastructure to managing the diffusion of knowledge and human capital.

The identified trajectories of digitalisation in Russia — a reduction of the infrastructural divide alongside the strengthening of the secondary divide and its spatial clustering — reflect general patterns observed in countries with pronounced territorial differentiation. Studies on the EU and OECD countries show that as basic infrastructure becomes saturated, the key challenge becomes inequality in skills [12; 22]; the phenomenon of the ‘digital ladder’ has been described across different contexts.

Persistent spatial autocorrelation and the clustering of leaders and outsiders have direct analogues in other countries and regions (Silicon Valley, Shenzhen—Guangzhou, metropolitan areas of Europe). The concentration of high-tech personnel in limited agglomerations is a key driver of growth and a source of new territorial inequality in the knowledge era. The specificity of Russia lies not in the fact of clustering per se, but in its extreme degree and its rigid linkage to a hierarchy (a powerful centre, resource enclaves, and an extensive periphery).

Conclusion

This study demonstrates a divergence in the digitalisation trajectories of Russian regions. Against the backdrop of a gradual reduction in relative inequality in access to basic digital infrastructure (the primary divide), significant absolute gaps and challenges related to connection quality persist. The key threat to balanced development is the rapid increase in the secondary digital divide, which has a cumulative nature and is fueled by agglomeration effects, labour migration, and the uneven distribution of scientific and educational potential. Persistent spatial clustering indicates that market mechanisms and geographical proximity do not lead to automatic equalisation; on the contrary, they reproduce the “center—periphery” hierarchy. This necessitates a shift from universal infrastructure programmes to targeted regional policies aimed at developing human capital, stimulating innovative activity, and creating growth poles for the digital economy outside the established metropolitan agglomerations.

Returning to the hypotheses formulated in the introduction, the following can be stated. Hypothesis H1, concerning the reduction of infrastructural digital inequality, is confirmed: the dynamics of the Gini index for mobile (from 0.171 to 0.100) and fixed (from 0.277 to 0.153) Internet demonstrate a steady decline. Hypothesis H2, concerning the strengthening of human capital and competence-based inequality, also found empirical confirmation: the Gini index for ICT employment increased from 0.243 to 0.279, and kernel density estimation (KDE)

revealed a tendency toward the formation of a multimodal distribution. Hypothesis H3, concerning the presence of positive spatial autocorrelation, is confirmed for all three indicators, as evidenced by statistically significant Moran's index values throughout the entire study period. Hypothesis H4, concerning the divergent nature of neighbourhood effects, is partially confirmed. For infrastructural indicators, convergence is observed (a decline in the Gini index), but for ICT employment, the hypothesis of polarisation is confirmed — the increase in Moran's index in recent years (from 0.139 in 2018 to 0.316 in 2023) and the persistent presence of LL and HH clusters indicate the reproduction of the spatial gap between leaders and outsiders.

A sustained positive spatial autocorrelation was identified for all indicators, manifested in a statistically significant global Moran's index and the formation of stable spatial clusters of the 'high—high' (leaders) and 'low—low' (outsiders) types. This clustering indicates that a region's digitalisation level is closely related to the level of its neighbours; however, the nature of this relationship requires further investigation. Thus, the key challenge for balanced regional development is not so much ensuring basic access to infrastructure, but rather overcoming the growing human capital and competence-based inequality, which requires comprehensive measures aimed at developing human potential and stimulating innovative activity in all constituent entities of the Russian Federation.

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