ANALYSIS OF THE CONVERGENCE OF DIGITAL INEQUALITY ACROSS RUSSIAN REGIONS

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In contemporary information societies, digital inequality among populations has become a significant challenge, impeding both social and economic progress. This study aims to investigate the convergence of digital inequality across 79 regions of Russia from 2014 to 2021, with a particular focus on the population's access to information and communication technologies. Through the analysis of dispersion and Theil indices, the study reveals a trend of convergence and a growing uniformity in digital inequality indicators among the population of Russian regions over the observed period. Notably, there has been a relatively homogeneous distribution of digital inequality indicators across regions throughout this timeframe. The general trend of reduced dispersion signals a more stable and consistent dynamic of indicators across regions, suggesting enhanced stability and similar development trajectories. Moran dispersion diagrams for both 2014 and 2021 have enabled the identification of regional shifts between quadrants, highlighting progress in the trend towards reducing digital inequality among Russian regions. Regions initially characterised by lower levels of internet development have gradually advanced to higher quadrants in the Moran chart in subsequent years. This indicates a convergence process, wherein these regions are narrowing the gap with, or even surpassing, regions with more advanced internet development. This upward trend reflects the effectiveness of governmental policies and measures aimed at enhancing internet infrastructure and technological integration across the regions.

Keywords:
digital inequality, internet, convergence, digital technologies, digital economy, Russian regions, digital divide, econometric modeling

Introduction

The economic development of Russian regions exhibits considerable disparities, shaped by vast geographical distances, climatic conditions, historical trajectories and other factors. Moreover, there are considerable differences among Russian regions in households' access to digital technologies. In a digital society, access to information and communication technologies is increasingly essential for education, employment, healthcare and participation in public life. However,

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financial, geographical and socio-cultural barriers may limit this access. As a potential impediment to economic development, digital inequality restricts certain groups from accessing vital information, resources and opportunities, thereby reducing their chances of self-actualisation and civic engagement.

The development of a modern digital economy is a crucial phase in Russia's economic advancement at both national and regional levels. The digitalisation of socio-economic processes significantly broadens opportunities for businesses, individuals and the state as a whole [1]. Leadership in digital accessibility can inspire transformational change by enabling cities to embrace digital inclusivity and equity, thereby fostering a barrier-free digital urban logic [2]. In contemporary societies, the digital divide has direct implications for efforts to digitalise the welfare state [3], while also posing significant challenges for local governments striving to provide equitable and inclusive access to essential public services for all community members [4].

Despite the growing role and significance of digitalisation in the current phase of global economic development, digital inequality remains an increasingly pressing issue [5].

The digital divide is commonly understood as the gap between individuals with and without access to information and communication technologies such as computers and the Internet. In some cases, it also includes mobile phones — particularly smartphones — as well as other digital hardware and software.

The digital divide emerged as a prominent issue in the early 1990s with the expanding access to the Internet and personal computers [6]. The initial approach to the problem was simplistic, focusing on the binary distinction between those with Internet access and those without [7], with the latter perceived as being at a greater disadvantage [8]. This definition refers to first-level inequality, which will be examined in the present study.

Exploring different ways of using the Internet [9] and the challenges of fully embracing technology [10] have become key issues in discussions on the digital divide. Eszter Hargittai [11] introduced the term second-level gap, while Jan van Dijk and Kenneth Hacker [12] stressed that digital inequality does not end with physical access but begins with the everyday use of digital media.

As a result, the discourse has shifted from the binary distinction of access versus no access to a focus on skills and usage, with an emphasis on meaningful outcomes — a concept introduced in 2011 as third-level digital inequality [13]. This gap arises when possessing digital skills and using the Internet do not translate into tangible benefits [14; 15].

The digital divide is now understood as a multidimensional phenomenon shaped by various factors [16]. Furthermore, it is widely assumed to reinforce existing social inequalities [17—19].

Studies on first-level digital inequality have shown that Internet access is unevenly distributed among people with varying demographic characteristics, such as age, gender, socioeconomic status, ethnicity and geographic location [20].

This study aims to examine the trend towards reducing digital inequality across 79 regions of Russia from 2014 to 2021, focusing on the population's access to information and communication technologies. It analyses trends and patterns in digital inequality indicators to assess whether regions are moving towards greater uniformity in access to these technologies. Additionally, the research seeks to identify trends indicating a decrease in dispersion and increased digital uniformity across regions. Russia's vast and diverse geographical landscape and socio-economic conditions lends particular relevance to the study of this phenomenon.

Literature review

A literature review on the narrowing of the digital divide must begin with the recognition that it is not static but evolves in response to political, economic and social processes. Studies on the bridging of the digital divide examine how regions with varying levels of access to digital resources either converge or diverge in their development. This approach helps to identify the trends and mechanisms that contribute to the narrowing or widening of the digital divide. The mitigation of the digital divide is often linked to the concept of economic convergence.

Numerous academic studies have meticulously examined various types of convergence, with two widely recognised models being β-convergence and σ-convergence. The seminal work of William J. Baumol [21] stimulated extensive research into convergence hypotheses, following the examples set by Robert J. Barro, Xavier Sala-I-Martin et al. [22; 23]. These studies employ the β-convergence approach, which is based on the principle that if a significant convergence coefficient is observed in the equation, growth rates in poorer countries will exceed those in wealthier ones, indicating a process of convergence. According to Sala-i-Martin [24], absolute β-convergence occurs when poorer economies tend to grow faster than richer ones. Conversely, a group of countries is considered σ-convergent when the variation in their real GDP levels declines over time. The so-called σ-convergence, proposed by Danny Quah, is typically measured using either the standard deviation or the coefficient of variation over different periods [25].

Various forms of economic convergence are frequently the subject of rigorous discussion and extensive debate in academic circles. In several articles, Sergio J. Rey in collaboration with Brett D. Montouri [26] and Mark V. Janikas [27] have incorporated spatial effects into the assessment of convergence trends, with a particular focus on the spatial distribution of variables. They contend that both the magnitude and spatial distribution of the variable play a crucial role. Cinzia Alcidi has examined the β-convergence hypothesis at the regional level within the EU [28]. Nina Schönfelder and Helmut Wagner have applied the concepts of σ-convergence and unconditional β-convergence to institutional development across several country groups, using World Bank indicators and identifying β-convergence within the EU [29].

In recent decades, convergence has emerged as a central issue in economic growth. However, both σ-convergence and β-convergence frequently depend on methodologies that overlook the geographic characteristics of data [30].

Regarding studies on the convergence of digital inequality, the following works merit particular attention.

Keun-Yeob Oh and Vinish Kathuria tested the narrowing of the digital divide in 40 Asian countries over 10 years from 2000 to 2009. The GINI coefficient and HH index indicate that countries are becoming more equitable in relative terms regarding information and communication technology (ICT) usage. Relative convergence suggests a convergence rate of approximately 9 %. In contrast, advanced methodologies that test for panel nonstationarity, both with and without cross-sectional dependence, provide little evidence of convergence across countries. Although ICT use is increasing more rapidly in less developed countries, the absolute gap between nations is not narrowing [31]. Badri N. Rath examined ICT convergence across 47 developed and developing countries, using annual data from 2000 to 2012 and constructing the ICT Development Index through principal component analysis. Findings from a dynamic panel data model suggest a widening gap in ICT development, with greater disparity observed in emerging economies compared to developed ones [32].

By examining the digital divide across 108 countries, Seung Rok Park et al. aim to better understand the factors contributing to a more creative global economy. The study finds that the level of convergence in digitalisation among these countries can be categorised into three groups. Group 1, characterised by the highest level of convergence, also exhibits the highest level of digitalisation, whereas Group 3, conversely, displays the lowest level of convergence and digitalisation among the countries studied [33].

Yu Sang Chang et al. have examined the dynamics of the digital divide between middle- and low-income groups in 44 African countries in the context of three technologies: mobile cellular, Internet and fixed broadband, from 2000 to 2015. At the macro level, the relative digital divide decreased by 0.72 % to 11.3 % per year, while the absolute digital divide increased by 31.33 % to 17.11 % per year. The faster the absolute digital divide increases, the higher the catch-up rate of low-income countries [34].

Herdina Dwi Ramadhanti and Erni Tri Astuti have provided evidence of both absolute and conditional convergence in ICT development in Indonesia [35], while Vagia Kyriakidou et al. have assessed the convergence of the digital divide using a dataset on broadband service penetration across all European countries over an extended period [36].

The findings of Tanushree Agarwal and Prasant Kumar Panda indicate uneven access to ICT facilities across Indian states. Over the past decade, low-income states have experienced faster growth than high-income states in access to facilities such as telephones and mobile phones [37]. Spatial econometric methods applied to panel data from Russian regions confirm short-term technological cooperation between regions. Furthermore, they demonstrate convergence in the growth rates of innovation expenditures and patents granted over the long term [38].

Stepan Zemtsov et al. have found that as markets become saturated with digital services, digital inequality between Russian regions decreases due to the accelerated adoption of new technologies in lagging regions, i. e. convergence. Overall, patterns of Internet use align with the spatial diffusion of innovations. Leading regions include those with major agglomerations and the northern territories of Russia, whereas regions with a high proportion of rural populations lag behind. Coastal and border regions (e. g., St. Petersburg, Kaliningrad, Karelia and Primorsky *krai*) benefit from better Internet access due to their proximity to centres of technological innovation and the high intensity of external connections. Leading regions influence their neighbours through spatial diffusion [39].

Material and methods

This article seeks to analyse digital inequality among the population of Russian regions in terms of access to information and communication technologies between 2014 and 2021. Digital equality or inequality within Russia's regions reflects their level of development and plays a crucial role in achieving sustainable development goals, both nationally and regionally, by illustrating the distribution and use of information resources across the country.

The study is based on objective indicators of digital inequality among regional populations, sourced from the website Russia's statistical service Rosstat, as of 20 November 2023.[1]

The final dataset on digital inequality in access to ICT across Russian regions comprises eight key indicators. It covers 79 Russian regions over an eight-year period from 2014 to 2021.

However, due to the absence of official statistics for the Republic of Crimea, the city of Sevastopol and the Republic of Chechnya during this period, these regions were excluded from the study. Additionally, the data for the Yamalo-Nenets and Khanty-Mansiysk autonomous *okrugs* were combined as a single entry under the Tyumen region. Consequently, the analysis was conducted on a dataset of 79 regions, including the cities of St Petersburg and Moscow, without affecting the overall results of the study.

The first indicator used in the sigma-convergence analysis is the coefficient of variation. Dispersion values reflect changes in the growth rate of indicators over different years [40]. Higher variance values may indicate greater fluctuations, while lower variance values suggest more stable and uniform growth rates [41; 42].

[1] Appendix to the *Regions of Russia. Socio-economic indicators* statistics yearbook, 2023, *Rosstat*, URL: https://rosstat.gov.ru/folder/210/document/47652 (accessed 23.08.2023).

$$\sigma_t = \frac{\sqrt{\frac{\sum_{i=1}^{n}(y_i - y)^2}{n}}}{y}, \tag{1}$$

where y_i represents the value of the variable in region i;

y is the average of the variable

n is the number of regions.

The Theil indices in the study were calculated using the following formulas [43]:

$$\text{The Theil index} = \frac{1}{N}\sum_{i=1}^{N} ln(\frac{\mu}{x_i}), \tag{2}$$

$$\text{The Theil index} = \frac{1}{N}\sum_{i=1}^{N} \frac{x_1}{\mu} ln(\frac{\mu}{x_i}), \tag{3}$$

where x_i is the indicator of the i^{th} regional economy, μ is the average indicator, and n is the number of regions.

The Theil indices were calculated for indicators of digital inequality across the regions to assess the degree of disparity in their distribution throughout Russia. The Theil index, derived from absolute values, can be considered an indicator of beta-convergence, while variance and the Theil index based on growth rates correspond to sigma-convergence.

A value closer to zero indicates a more even distribution, whereas a value approaching one signifies greater inequality. The second Theil index is used to analyse inequality in the year-on-year growth rate of the indicator.

Analysing Theil indices provides valuable insights into the extent of regional disparities and forms the basis for further investigation into the underlying drivers of these inequalities, as well as potential strategies for fostering more equitable digital access across Russian regions.

The Theil indices in this study were computed using the following formula [44]:

$$I_i = \frac{x_i - \bar{x}}{m_2}\sum_{j=1}^{N} \omega_{ij}\left(x_j - \bar{x}\right), \tag{4}$$

where

$$m_2 = \frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N}, \tag{5}$$

and

$$I = \sum_{i=1}^{N} \frac{I_i}{N}; \tag{6}$$

I is the Global Moran's I measuring global autocorrelation; I_i is its local counterpart. N stand for the number of spatial units indexed by i and j; x_i is the variable of interest; $\bar{x}$ is the mean of x_i; ω_{ij} are the elements of a spatial weight matrix with zeros on the diagonal.

When regions fall into the first quadrant of the Moran scatter diagram, this may indicate a spatial concentration of higher values of indicators, where regions with such a high concentration are typically surrounded by others with similarly high values. Regions in the second quadrant score low on the standardised indicator while being surrounded by regions with higher values. Territories in the third quadrant exhibit both a low score on the standardised indicator and are adjacent to other regions with similarly low values. Finally, regions in the fourth quadrant score highly on the standardised indicator but are surrounded by neighbouring regions with low values.

To test the hypothesis regarding the impact of digital inequality indicators on convergence, significant and relevant factors were analysed using dispersion indices, the Gini coefficient and two Theil indices, including that based on the growth rate of the indicator. The Lorenz curve is employed to visualise inequality in data distribution, with its approximation aiding in identifying patterns. The data are tested for normality using the Kolmogorov — Smirnov and Shapiro-Wilk tests. Spatial inequality is assessed using the Moran index, calculated based on the distance along highways from Moscow to the capital of each region. The results are visualised through graphs and charts, offering a comprehensive depiction of changes in household access to information and communication technologies across Russian regions.

Table 1 outlines the analysed factors contributing to digital inequality in the population of Russian regions.

Table 1

Indicators of digital inequality in public access to information and communication resources

<table>
<tr><th>Indicator number</th><th>Indicator</th><th>Units of measure; calculation of indicator; data source</th></tr>
<tr><td>X_1</td><td>Percentage of the population accessing the internet daily or almost daily</td><td rowspan="2">Based on a sample survey of ict usage, expressed as a percentage of the total population of the respective Russian region (Rosstat)</td></tr>
<tr><td>X_2</td><td>Percentage of the population using the internet</td></tr>
<tr><td>X_3</td><td>Percentage of households with a personal computer</td><td rowspan="3">Based on data from a sample survey on ict use, expressed as a percentage of the total number of households in the respective Russian region (Rosstat)</td></tr>
<tr><td>X_4</td><td>Percentage of households with access to the internet</td></tr>
<tr><td>X_5</td><td>Percentage of households with broadband access to the internet</td></tr>
<tr><td>X_6</td><td>Number of active fixed broadband internet subscribers per 100 population</td><td rowspan="3">At the end of the year; units; Rosstat</td></tr>
<tr><td>X_7</td><td>Number of active mobile broadband internet subscribers per 100 population</td></tr>
<tr><td>X_8</td><td>Number of mobile subscribers with active connections per 1,000 population</td></tr>
</table>

Source: prepared by the authors based on Rosstat data.

Results

As a result of the correlation and regression analysis, a correlation matrix was obtained, from which only four indicators (X_5—X_8) were selected due to their low correlation with one another. This allows for the assessment of their independent impact on digital inequality.

Table 2

Correlation matrix of digital inequality indicators

Indicator number	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
X_1	1.00	0.83	0.67	0.64	0.51	0.46	0.34	0.39
X_2	0.83	1.00	0.76	0.78	0.50	0.42	0.45	0.50
X_3	0.67	0.76	1.00	0.85	0.61	0.50	0.39	0.62
X_4	0.64	0.78	0.85	1.00	0.45	0.32	0.48	0.47
X_5	0.51	0.50	0.61	0.45	1.00	0.45	0.08	0.48
X_6	0.46	0.42	0.50	0.32	0.45	1.00	0.06	0.57
X_7	0.34	0.45	0.39	0.48	0.08	0.06	1.00	0.41
X_8	0.39	0.50	0.62	0.47	0.48	0.57	0.41	1.00

Source: prepared by the authors based on Rosstat data.

Let us now analyse the selected indicators of digital inequality as regards the population's access to information and communication resources across Russian regions.

In 2014, St Petersburg, Moscow, the Murmansk region and the Tyumen region recorded the highest percentages of households with broadband Internet access. However, by 2021, broadband Internet access had expanded across regions. Notable percentages were observed not only in Moscow (94.4 %) but also in the Orenburg region (93.2 %), the Magadan region, Kalmykia and the Chukotka autonomous *okrug*. The spread of broadband Internet access has been rapid, exemplified by the Chukotka autonomous *okrug*, where the share of households with broadband access rose from 26 % to 92 %, and the Republic of Ingushetia, where it increased from 30.5 % to 76.7 %. In 2021, the lowest percentage among the regions analysed was observed in the Novgorod region at 69.5 %.

The Theil index consistently records low values, both in absolute terms and growth rates, indicating uniform growth in broadband access across households (Fig. 1). The minimal disparity in growth rates further supports this trend of convergence.

Our analysis reveals a notable decline in dispersion rates, from an initial 0.2619 to 0.0933, followed by a slight rebound to 0.1251 by 2021, as illustrated by the black line in Figure 1. This shift in dispersion suggests a convergence trend. The estimated convergence rate, derived from the growth rate of the Theil index, is 0.0088 or 0.88 %.

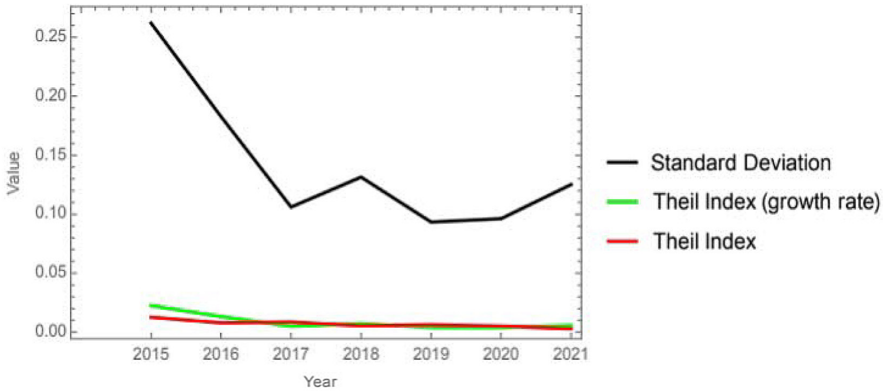


Fig. 1. Visualisation of dispersion and key indicators for 'Percentage of households with broadband access to the Internet'

Source: calculated by the author based on Rosstat data.

Additionally, the Gini coefficient for this indicator has declined over the period under review, reflecting a more equitable distribution of broadband access among households and indicating progress towards greater social equity in resource distribution.

Figure 2 presents the Lorenz curve with approximations using linear and quadratic dependence functions. The strong fit of the approximations to the actual data may suggest underlying patterns in the distribution of the indicator across the study regions.

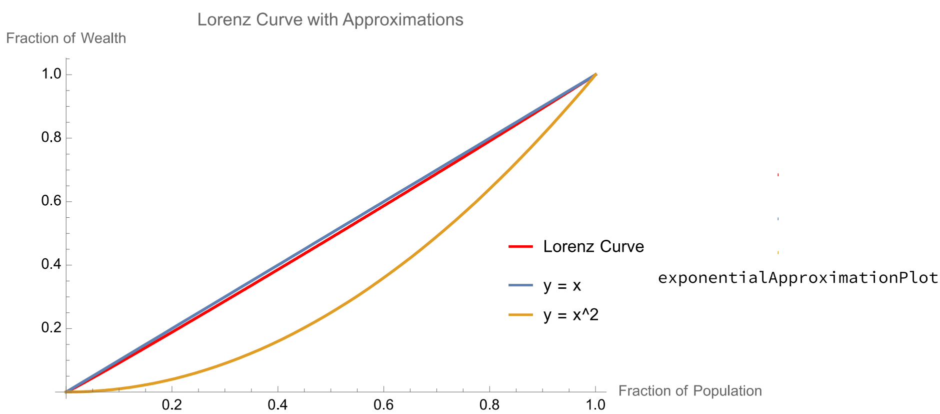


Fig. 2. Lorenz curve with approximations using linear and quadratic functions for the indicator 'Percentage of households with broadband Internet access'

Source: calculated by the author based on Rosstat data.

The Kolmogorov — Smirnov test, which yielded a p-value of 0.86, indicates that the distribution of broadband percentage data does not significantly deviate from a log-normal distribution (Fig. 2). This result is further supported by the quantile-quantile (Q—Q) plot (Fig. 3), which shows a strong alignment between the dataset's quantiles and those of a theoretical log-normal distribution, indicating a strong correspondence.

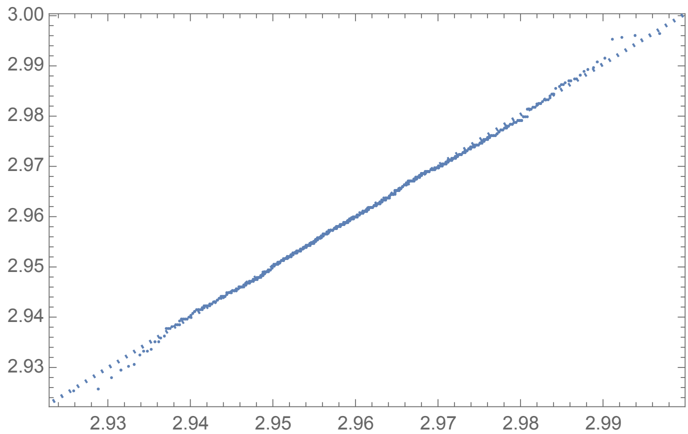


Fig. 3. Quantile-quantile (Q—Q) plot for the indicator 'Percentage of households with broadband Internet access'

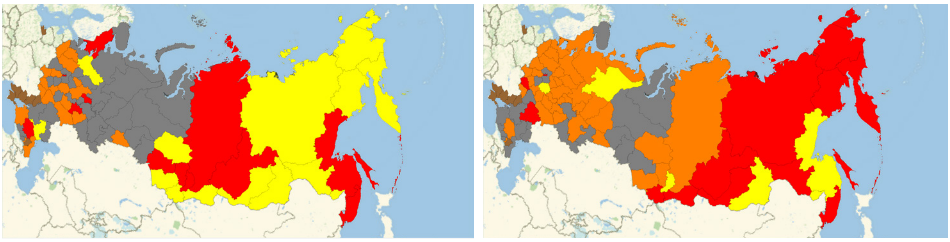
Source: calculated by the author based on Rosstat data.

Additionally, the Shapiro-Wilk test, with a p-value of 0.684, provides no strong evidence to reject the hypothesis that the data follows a normal distribution. This reinforces the conclusion that the distribution of percentages of households with broadband access among can be effectively modelled using normal or log-normal statistical distributions.

A Moran index value near zero suggests a lack of significant spatial autocorrelation, indicating that neighbouring regions show only a limited resemblance in the percentage of households with broadband access.

Figure 4 presents a visualisation of Russian regions based on the Moran scatter diagram for the indicator 'Percentage of households with broadband access to the Internet' for 2014 (*a*) and 2021 (*b*).

One of the objectives of Russia's sustainable development is to increase the proportion of households with broadband access. In 2021, broadband Internet access was available to 82.6 % of households in the country, compared to 64.1 % in 2014. The changes in the distribution of regions across quadrants from 2014 to 2021 are as follows: Moscow remains in the first quadrant, maintaining its stable digital dominance. The Republic of Khakassia, Primorsky *krai*, Khabarovsk *krai* and Kamchatka *krai*, initially in the first quadrant, shifted to the second quadrant due to a decrease in the growth rate of the specific weight indicator by 2021. This shift illustrates the convergence of highly digitised Russian regions, based on the reduction of dispersion rates, and confirms the theory of diffusion in the later stages.



a *b*

Fig. 4. Visualisation of regional clusters based on Moran's dot plot for the indicator 'Percentage of households with broadband access to the Internet' for 2014 (*a*) and 2021 (*b*) years

Source: calculated by the author based on Rosstat data.

Certain regions, such as Irkutsk, Novosibirsk, Sakhalin, Amur, Magadan and the Chukotka autonomous *okrug*, moved from the second quadrant to the first, reflecting their digital growth and development.

One of the main reasons for these changes is the high per capita incomes of northern residents, as well as the policy aimed at the digitalisation of remote and northern regions of the country.

Regions distinguished by high education levels and excellence in innovation, such as Voronezh, Ivanovo and Kaluga, have significantly improved their positions, moving from the third quadrant to the fourth.

It is worth noting that, amid the COVID-19 pandemic, these regions saw a sharp rise in demand for communication services due to isolation measures and the need to interact with the country's financial and economic centre, Moscow. Another contributing factor was the presence of numerous subsidiaries of the oil and gas sector in these territories.

Moreover, regions initially in lower connectivity quadrants have moved towards higher connectivity categories over time, suggesting a potential reduction in regional connectivity disparities.

The number of active fixed broadband subscribers per 100 population increased between 2014 and 2021, rising from 32.90 to 38.4 in Moscow and from 29.30 to 31.70 in the Novosibirsk region.

In 2014, Ingushetia had the lowest number of subscribers among the regions, at 0.30, which increased to 2.10 by 2021.

Figure 5 presents the Theil index values for the indicator 'Number of active subscribers of fixed broadband Internet access per 100 population', demonstrating near-zero values. This indicates a relatively uniform growth pattern, with negligible disparity in growth rates.

Additionally, the dispersion indices remain close to zero. However, dispersion increased noticeably to 0.334 by 2016 before declining to 0.074. This trend suggests a convergence in broadband access distribution over time. The revealed convergence rate for the indicator 'Number of active subscribers of fixed broadband Internet access per 100 population' is 0.0095 or 0.95 %, indicating a steady trend towards convergence in broadband subscription rates across the population.

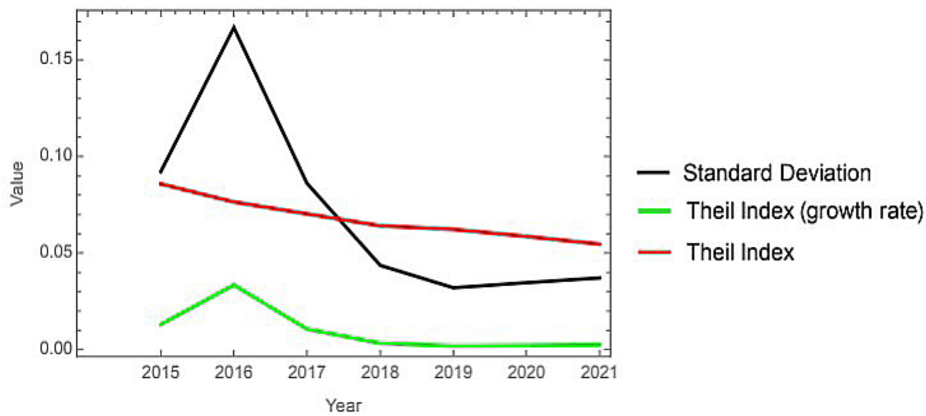


Fig. 5. Visualisation of dispersion and key indicators for the indicator 'Number of active subscribers of fixed broadband Internet access per 100 people'

Source: calculated by the author based on Rosstat data.

Figure 6 presents the Lorenz curve with an approximation. The approximation curve, however, does not accurately correspond to the actual indicator of broadband subscribers' distribution.

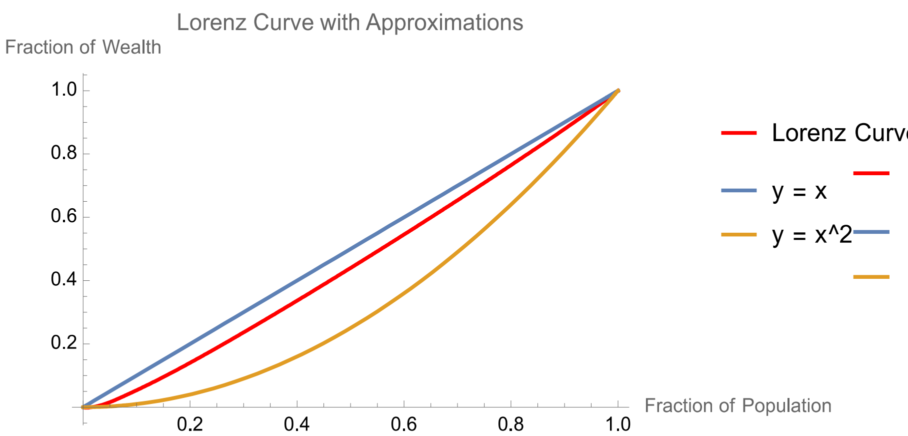


Fig. 6. Lorenz curve with approximations using linear and quadratic functions of dependence for the indicator 'Number of active subscribers of fixed broadband access to the Internet per 100 population'

Source: calculated by the author based on Rosstat data.

The statistical analysis using the Kolmogorov — Smirnov test yielded a p-value of 0.57, which exceeds the significance level of 0.05. Consequently, this result provides insufficient evidence to reject the hypothesis that the data on the 'Number of active subscribers of fixed broadband Internet access per 100 population' follows a log-normal distribution.

The points on the Q—Q graph (Fig. 7) are aligning with a straight line, indicating a strong correspondence between the data and the log-normal distribution. The Shapiro-Wilk test yielded a p-value of 0.291, providing insufficient evidence to reject the hypothesis that the data follows a normal distribution. This result reinforces the conclusion that the broadband subscriber indicator dataset aligns well with a log-normal distribution.

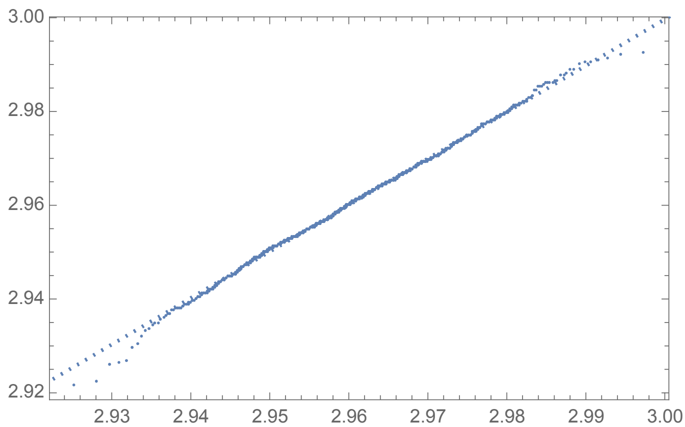


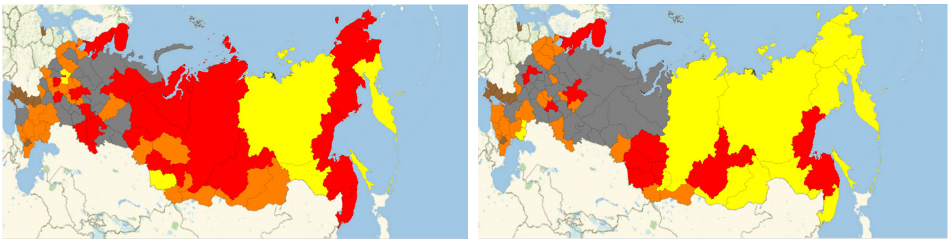
Fig. 7. Quantile-quantile (Q—Q) plot of the indicator 'Number of active subscribers of fixed broadband access to the Internet per 100 people of the population"'

Source: calculated by the author based on Rosstat data.

Over the course of eight years, the Moran index remained consistently close to zero, with a gradual decline from −0.10 to −0.03. This indicates a steady reduction in spatial disparity or clustering in the distribution of broadband access across regions during this period.

Figure 8 presents a visualisation of Russian regions based on Moran's scatter diagram for the indicator 'Number of active subscribers of fixed broadband Internet access per 100 population' for 2014 (*a*) and 2021 (*b*).

Analysing the data from 2014 and 2021, several changes in the distribution of regions across quadrants can be noted. For instance, the Tyumen region, the Republic of Komi and the Khabarovsk *krai* moved from the first quadrant to the second due to a decline in other regions' performance indicators. At the same time, the transition of territories such as the Kaluga, Oryol and Kirov regions to the first quadrant is associated with an increase in the number of subscribers with broadband Internet access in 2021, in the presence of neighbours with similarly high indicators, which may confirm the 'neighbourhood diffusion' effect. These regions are involved in innovative activities and have a population with a relatively high level of education, as well as a significant proportion of working-age youth.



a *b*

Fig. 8. Visualisation of regional clusters based on Moran's dot diagram for the indicator 'Number of active subscribers of fixed broadband Internet access per 100 population' for 2014 (*a*) and 2021 (*b*)

Source: calculated by the author based on Rosstat data.

It is also important to highlight the growth in the number of subscribers with broadband Internet access in Povolzheye, particularly the Voronezh region, Tatarstan and the Samara region. The status of these territories as industrial and innovative centres has contributed to their transition from the third quadrant to the fourth.

Initiatives aimed at promoting digitalisation and fostering information technology awareness and digital skills may have contributed to the increased number of Internet users in these regions.

For the indicator 'Number of active subscribers of mobile broadband Internet access per 100 population,' the highest values were observed in the Orenburg region at 100.8 active subscribers per 100 population, followed by the Moscow region and Moscow at 99.2. In 2014, the lowest values were recorded in Buryatia and the Irkutsk and Nizhny Novgorod regions, at 39.3, 37.9 and 39.9, respectively. By 2021, the situation had changed, with St Petersburg and the Leningrad region scoring the highest at 141.4, followed by Moscow and the Moscow region (138.7). Notably, 38 of the regions considered have an index value above 100, while the lowest indicators are found in regions such as Dagestan, Adygea and Ingushetia (51.1).

The Theil index values, both in absolute terms and growth rates, are close to zero, indicating a relatively uniform growth pattern in Internet usage across the population. This suggests minimal disparity in growth rates among different segments.

The dispersion value, shown by the black line in Figure 9, drops sharply from 0.22 to 0.03 over time, reflecting a convergence in mobile broadband distribution and reduced variability.

The convergence rate, calculated at 0.0050, indicates steady progress towards uniformity in subscriber rates. Additionally, the declining trend in the Gini coefficient suggests decreasing inequality in mobile broadband distribution.

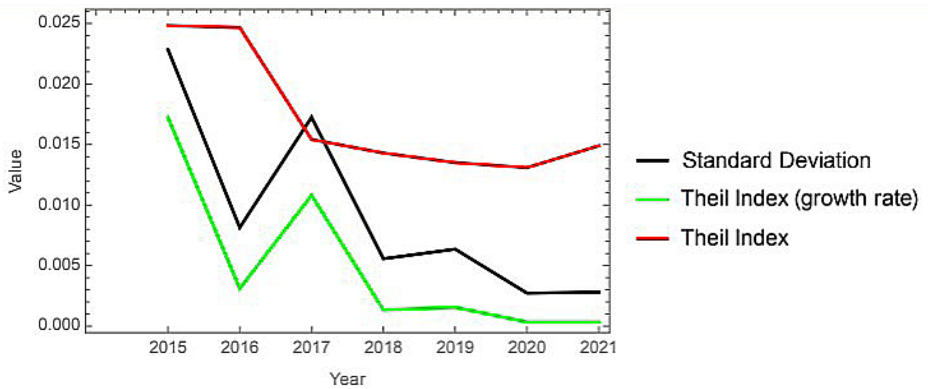


Fig. 9. Visualisation of the dispersion and main indicators of the ‘Number of active subscribers of mobile broadband Internet access per 100 population’

Source: calculated by the author based on Rosstat data.

The probability curve of cumulative distribution and the Lorenz curve, represented as a diagonal line from the origin in Figure 10, further support the observation of a relatively even data distribution.

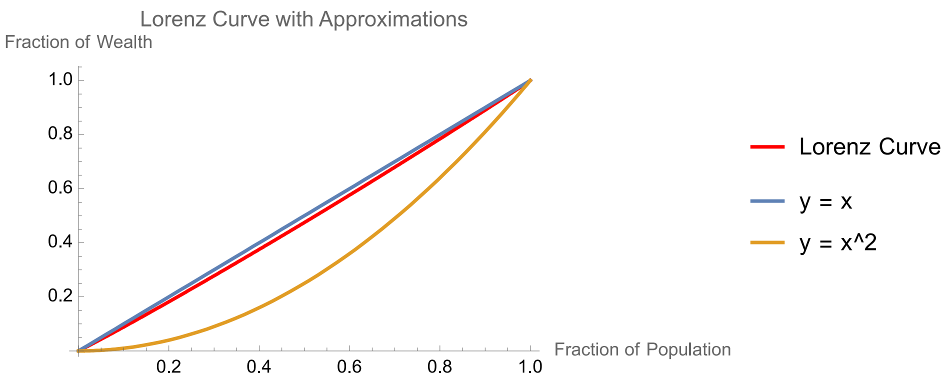


Fig. 10. Lorenz curve with approximations using linear and quadratic functions for the indicator ‘Number of active subscribers of mobile broadband Internet access per 100 population’

Source: calculated by the author based on Rosstat data[1].

Statistical tests, including the Kolmogorov — Smirnov test (p-value = 0.6789) and the quantile-quantile (Q—Q) distribution graph in Figure 11, indicate a strong alignment of the data with a log-normal distribution. The positioning of points along a straight line in the Q—Q graph suggests consistency with this distribution model. The Shapiro-Wilk test yielded a p-value of 0.668, providing insufficient evidence to reject the hypothesis of normality for the distribution of mobile broadband subscribers.

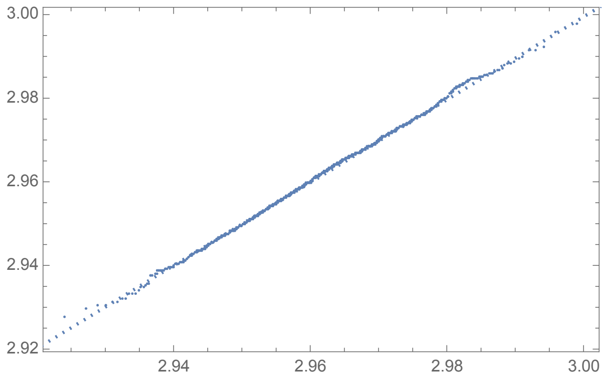
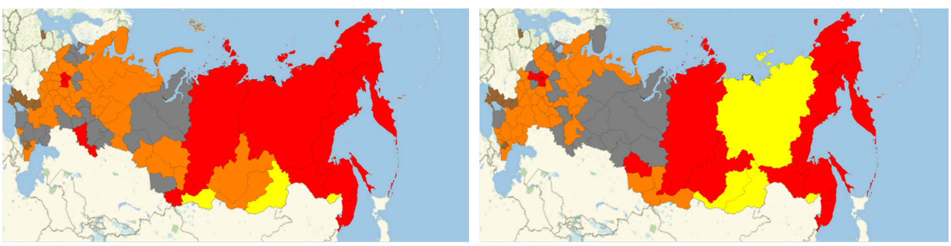


Fig. 11. Quantile-quantile (Q—Q) plot of the indicator 'Number of active subscribers of mobile broadband Internet access per 100 population'

Source: calculated by the author based on Rosstat data.

Over eight years, the Moran index for the indicator 'Number of active subscribers of mobile broadband Internet access per 100 population' consistently approaches zero, showing a decreasing trend from −0.12 to −0.01. This suggests a gradual reduction in spatial inequality among regions over the period.

Figure 12 presents the visualisation of Russian regions based on Moran's scatter diagram for the indicator 'Number of active subscribers of mobile broadband Internet access per 100 population' for 2014 (*a*) and 2021 (*b*).



a *b*

Fig. 12. Visualisation of regional clusters based on Moran's dot diagram for the indicator 'Number of active subscribers of mobile broadband Internet access per 100 population' for 2014 (*a*) and 2021 (*b*)

Source: calculated by the author based on Rosstat data.

By 2021, a relative slowdown in the growth rate of active mobile subscribers was observed in northern regions, such as Khakassia, the Republic of Komi and the Khabarovsk *krai*. This led to these regions transitioning from the first cluster to the second, further supporting the hypothesis of diffusion in later stages.

The development of state programmes for the digitalisation and communication of hard-to-reach regions contributed to increased growth rates of active mobile subscribers in areas such as the Altai Republic, Primorsky *krai*, Tuva, the Kursk, Irkutsk and Volgograd regions, Buryatia, the Republic of Sakha (Yakutia) and Kamchatka *krai*. This facilitated their transition from the second cluster to the first.

Additionally, the growth in some regions may be linked to the rapid development of neighbouring areas — the Belgorod, Saratov and Sverdlovsk regions among others. The expansion of communication networks and information technologies in these regions could have positively influenced mobile communications accessibility and quality, boosting their rankings. Overall, the data suggests a discernible trend towards convergence in mobile broadband access levels across regions, yet not towards uniformity.

The near-zero values of the Theil index, both in absolute terms and growth rates, point to a relatively uniform growth pattern in the 'Number of mobile subscribers with active connections per 1,000 population'. This suggests minimal inequality among regions regarding mobile subscriber rates. The dispersion indices (Fig. 13) also approach zero, further indicating convergence in the distribution of mobile subscribers across the population.

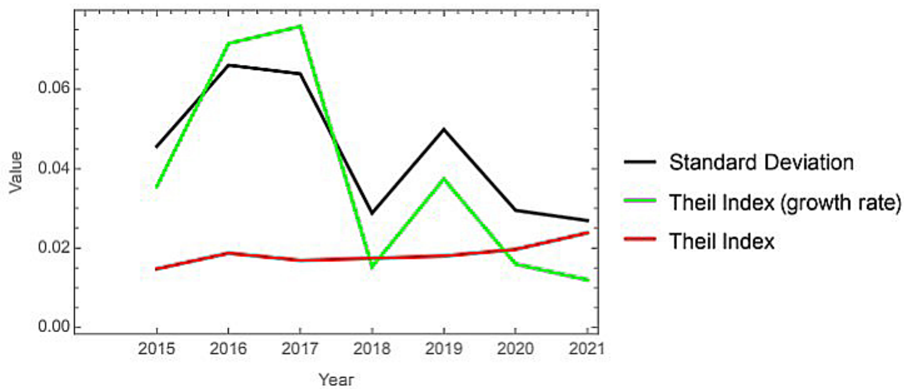


Fig. 13. Visualisation of dispersion and key indicators for the 'Number of mobile subscribers with active connections per 1,000 population'

Source: calculated by the author based on Rosstat data.

The convergence rate of the 'Number of connected mobile subscribers per 1,000 population' is 0.0011, indicating a reduction in the disparity of mobile connectivity levels across regions or demographic groups over time. The observed decrease in the Gini coefficient may indicate a shift towards a more equitable distribution of mobile subscriber rates across the population.

Additionally, this trend is supported by the probability curve of cumulative distribution and the Lorenz curve (Fig. 14), reflecting potential improvements in the accessibility and availability of mobile services across diverse demographic groups or regions. Figure 14 presents the Lorenz curve with an approximation.

The results of the Kolmogorov — Smirnov test, with a p-value of 0.328, indicate that the distribution of mobile subscriber devices does not significantly deviate from a log-normal distribution, as suggested by the statistical test outcomes.

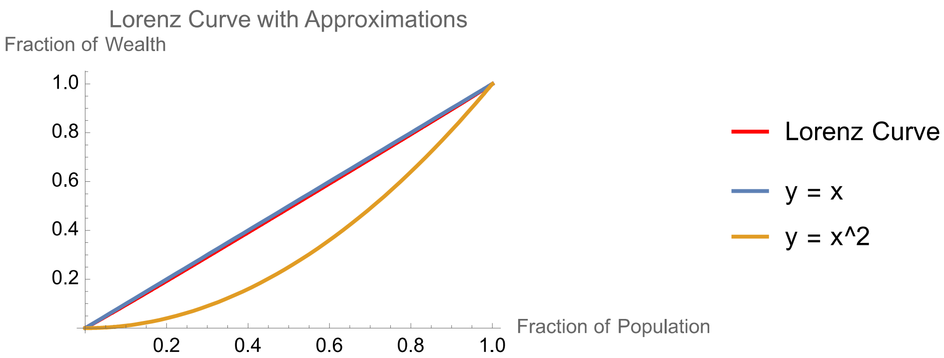


Fig. 14. Lorenz curve with approximations using linear and quadratic functions for the indicator 'Number of mobile subscribers with active connections per 1,000 population'

Source: calculated by the author based on Rosstat data.

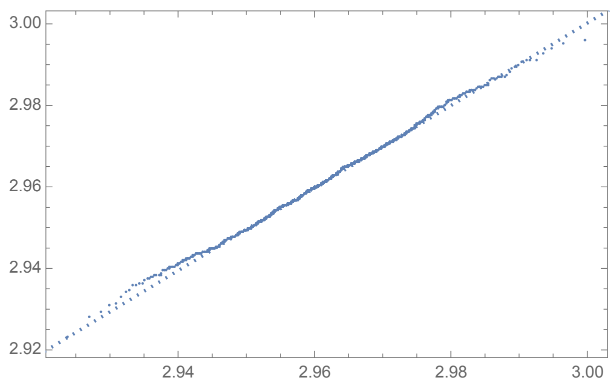
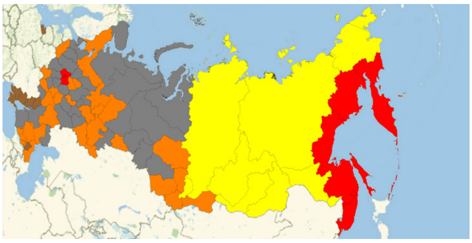


Fig. 15. Quantile-quantile (Q—Q) plot of the indicator 'Number of mobile subscribers with active connections per 1,000 population'

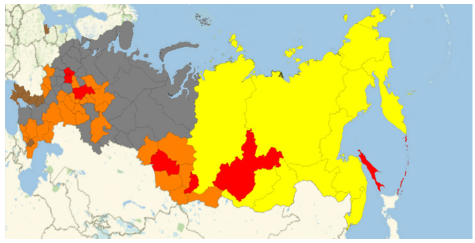
Source: calculated by the author based on Rosstat data.

Both the Q—Q plot (Fig. 15) and the Shapiro-Wilk test support the assumption that the data for the indicator 'Number of mobile subscribers with active connections per 1,000 population' conforms well to a log-normal distribution, whereas statistical analysis did not reveal strong evidence of deviation from normality.

The Moran index shows the spatial inequality of Russian regions according to this indicator. Over the eight years, the Moran index remained consistently near zero. Figure 16 presents the visualisation of Russian regions based on Moran's scatter diagram for the 'Number of mobile subscribers with active connections per 1,000 population' for 2014 (*a*) and 2021 (*b*).



a



b

Fig. 16. Visualisation of regional clusters based on Moran's dot diagram for the indicator 'Number of mobile subscribers with active connections per 1,000 population' for 2014 (*a*), 2021 (*b*)

Source: calculated by the author based on Rosstat data.

In 2014, the first quadrant was dominated by major agglomerations such as Moscow and the Moscow region, owing to their high economic development and appeal to youth, driven by the presence of numerous educational institutions. Moscow, as the financial and economic hub of Russia, stood out with the highest GDP per capita. At the same time, regions with a significant share of rural population (Khakassia), as well as northern and border areas, such as Kamchatka and Primorsky *krai*, were also included in the first quadrant.

By 2021, there was a notable change in the composition of several quadrants, as regions such as Nizhny Novgorod, the Republic of Khakassia, Irkutsk, Novosibirsk and Sakhalin moved from the second quadrant (which had the lowest indicator values despite neighbouring regions scoring highly on the number of mobile subscribers) to the first quadrant.

The Republic of Khakassia, for instance, moved from ninth place in 2014 to 41st in 2021 in terms of mobile subscribers, indicating that the growth rates of the second quadrant regions began to exceed those of the first quadrant.

Special attention should be given to the study of the transition from the first quadrant to the second quadrant due to the relative decline in the performance of regions such as Kamchatka, Primorsky, Khabarovsk, Amur, Magadan, the Jewish autonomous region and the Chukotka autonomous *okrug*.

In 2021, several Russian regions with innovative potential and a sufficiently high level of education moved from the third quadrant to the fourth quadrant, significantly improving their positions regarding the number of mobile subscribers. These regions include Voronezh, Ivanovo, Kaluga, Lipetsk, Oryol, Ryazan, Smolensk, Tver, Tula, Leningrad, St. Petersburg, Tatarstan and others.

It is important to note that due to the pandemic and the relocation of a portion of the working population back to their native regions, as well as the rise of remote work, there was increased demand for relevant technologies and heightened competition among providers, leading to reduced Internet service charges.

In addition, it is important to highlight the impact of government policies in northern regions such as the Republic of Karelia and the Republic of Komi, where communication infrastructure has been improved, in contrast to neighbouring regions where the number of mobile subscribers has remained low.

Discussion

The econometric assessment of first-level digital inequality indicators among Russia's regional populations, combined with spatial analysis using Moran's I index, reveals a significant trend towards convergence across all examined indicators. The strong spatial correlation among Russia's regions, akin to patterns observed in Indonesian regions [35], indicates the growing development of ICT in neighbouring areas, which contributes to convergence. This process was evident from 2014 to 2021, with digital inequality between Russian regions diminishing by 2021, largely due to the accelerated adoption of new technologies in remote and northern regions.

Although previous research in other countries [32] identified divergence, our findings indicate convergence in ICT development across Russia's regions. This study is in line with previous literature [38; 39], reaffirming established patterns. Regions with large agglomerations and northern territories in Russia have emerged as leaders, while those with substantial rural populations continue to lag behind. Coastal and border regions (e. g., St Petersburg, Kaliningrad, Karelia and Primorsky Krai) benefit from better Internet access, owing to their proximity to technological innovation hubs and strong external connectivity. Leading regions exert influence on their neighbours through spatial diffusion [39].

This analysis highlights a significant trend in which regions initially positioned in different quadrants transition over time, reflecting changes in their economic, social and political trajectories.

The transition of regions between quadrants also reflects strategic governmental initiatives aimed at advancing digital infrastructure across Russia's regions. These changes mirror broader trends in regional economic development and societal digitalisation. Measures implemented at both the national and regional levels to enhance digital accessibility have contributed to reducing digital inequality and accelerating convergence.

The reductio in first-level digital inequality reflects a narrowing gap in regional access to digital technologies — including the Internet, computers and mobile devices. Moreover, the increasing adoption of digital technologies across all regions, including remote and sparsely populated areas, supports a more equitable distribution of digital resources and opportunities.

To sustain this convergence and facilitate the progression of regions to higher quadrants, increased investment in communication networks and the expansion of Internet accessibility in remote areas are crucial. Furthermore, digital modernisation initiatives and government-led regional digitalisation programmes can enhance the growth of active Internet subscribers.

Overall, these findings underscore the importance of investing in broadband infrastructure and considering regional characteristics when developing and implementing information technology policies. A key factor in the convergence process is the development of digital infrastructure and services, which foster equitable access to and use of digital technologies.

Conclusions

The steady reduction in the Theil index and the variance of digital inequality indicators across Russian regions from 2014 to 2021 provides evidence of both sigma and beta convergence, affirming the effectiveness of regional and national policies in addressing digital inequality.

The cumulative distribution probability curves and Lorenz curves obtained in this study further support the observation of a log-normal distribution across all examined indicators of digital inequality. Statistical tests, including the Kolmogorov — Smirnov test and the quantile-quantile plot, also confirm a strong alignment of the data with the log-normal distribution.

Moran dispersion diagrams for 2014 and 2021 helped identify regional transitions between quadrants, shedding light on shifts in the trend towards narrowing digital inequality. Regions that initially exhibited lower levels of Internet development progressively moved to higher quadrants in the Moran chart, reflecting a convergence process in which they close the gap with, or even surpass, regions with higher levels of Internet development. These shifts indicate regions that require heightened focus and increased investment in Internet infrastructure. Regions that remain in lower-performing quadrants may need further support and targeted interventions to ameliorate their circumstances.

This change underscores the effectiveness of governmental measures and policies in fostering Internet infrastructure development and technological integration across regions.

Government digitalisation policy plays a crucial role in Internet infrastructure development across regions. Effective support mechanisms and incentive frameworks can thus foster a more equitable distribution of Internet access nationwide.

The information on regional developments presented in the Moran diagram can assist governments, organisations and analysts in understanding Internet infrastructure dynamics, identifying successful development strategies and addressing inequalities to ensure sustainable growth.

To gain a deeper understanding of regional economic development in Russia, future research could investigate additional factors contributing to convergence, such as human capital, infrastructure and institutional elements.

This study utilised official data from Rosstat — Russia' state statistics service, which, while generally reliable, may have limitations in accuracy and completeness. Moreover, the analysis focused on a limited set of indicators, excluding other socio-economic factors that influence digital inequality. Future studies could incorporate a broader range of indicators to provide a more comprehensive understanding of economic convergence.

The findings of this study can inform the design and refinement of public policies on digitalisation and Internet infrastructure development. They help pinpoint problem areas, prioritise investments and enhance support mechanisms. Identifying regions on the path to convergence enables the optimisation of resource allocation to maximise efficiency and outcomes. Insights into the evolution of Internet infrastructure across Russian households can also contribute to academic research by offering a deeper understanding of the factors driving convergence and divergence in the economic and society.

Thus, these findings hold practical significance for policymakers, managers, investors and researchers, aiding in the formulation of informed decisions and strategies concerning Internet infrastructure and the digital economy. Despite observed convergence trends, continuous monitoring of regional development and the factors influencing sustainable economic growth remains essential.

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