Bank of Russia

Regional convergence in Russia: geographically weighted regression approach

WORKING PAPER SERIES

No. 98/ June 2022

D. Mamontov, E. Ostrovskaya

CONTENTS

Denis Mamontov
Bank of Russia, Saratov Regional Division of the Volga-Vyatka Main Branch
E-mail: mamontovds@cbr.ru

Elena Ostrovskaya
Bank of Russia, Saratov Regional Division of the Volga-Vyatka Main Branch
E-mail: ostrovskayaea@cbr.ru

The Bank of Russia's Working Paper Series is subject to blind review by Bank of Russia Advisory Board members and external reviewers.

The authors are grateful for the discussion of results at a Bank of Russia research workshop in February 2022.

Cover photo: Shutterstock / FOTODOM

12 Neglinnaya Street, Moscow, 107016
+7 499 300-30-00, +7 495 621-64-65 (fax)
Bank of Russia website: www.cbr.ru

ABSTRACT

The objective of this study is to test the hypothesis suggesting a correlation between the growth rate of gross regional product (GRP) and its initial level (β-convergence). Geographically weighted regression (GWR) was chosen as an analysis tool due to the significant spatial heterogeneity of parameters. Matrices of distance, trade and migration flows between regions were used as weights. The Akaike criterion (AIC) and the cross-validation criterion (CV) were used to calculate the best number of nearest neighbours (bandwidth).

It appears reasonable to group Russian regions in western and eastern clusters. The study shows the existence of unconditional β-convergence and σ-convergence in the western regions. The evaluation of conditional β-convergence model evidences that the convergence is slower in the regions with a larger share of the public sector. The use of trade and migration flows matrix instead of the distance matrix allowed to have more certain results, however, the convergence rate of regions is moderate.

Key words: convergence, regions, economic growth, spatial analysis, geographically weighted regression.

JEL classification: C21, D63, O11.

INTRODUCTION

In the mid-20th century and later on, the relevance of issues related to differences in economic growth rates around individual regions of the world has significantly increased alongside the development of globalisation processes and mutual integration at state level. The scope of research of the economic growth factors is broad enough given the various sources of influence on this indicator. Along with the development of new economic geography, studies connecting the economic growth with the location of regions have become more frequent recently.

The assessment of regional convergence processes of the economic and social development rates seems especially relevant for the countries with a large number of heterogeneous geographic areas, including the Russian Federation. At the same time, analysis of the influence of interregional ties on their convergence in terms of economic growth rates is of particular interest. Such ties include not only geographical distance but also other indicators, e.g. the intensity of trade and migration flows.

The significant differentiation of Russian regions by standard of living draws attention of numerous economists who study the dynamics of interregional inequality. Analysis of the processes of convergence of regional economic growth rates in the federal state context, and identification of factors contributing to the convergence of regional growth paths are of great importance for determining the priorities of the regional economic policy of the state and clarifying the parameters of the necessary alignment of regional differences with fiscal policy tools.

This study examines the data of constituent territories of the Russian Federation to measure absolute and conditional convergence as applied to the economic growth rate. The models are built on a set of regions' proximity measures: a distance matrix, a migration and trade flows matrix. The objective of this study is to test the hypothesis suggesting a considerable regional variability of the convergence in Russia. It is assumed that the change in the method for accounting for the spatial factor (the application of various matrices) will make it possible to lower the heterogeneity of results. Besides, the study revealed factors which impacted the rates of convergence of the economic growth of regions to their sustainable paths.

The paper has the following structure: in Chapter 1, we review the studies covering the convergence process including that in the Russian regions. In Chapter 2, we substantiate our choice of a basic model and the methodology for describing the data used. In Chapter 3, we make a primary analysis of the differentiation among regions and of the process of their unconditional convergence. In Chapter 4, we describe a conditional β-convergence and σ-convergence and check the robustness of the received estimates. In summary, we analyse the results of the study.

1. REVIEW OF EXISTING STUDIES

The problems associated with economic growth were first described in the study by Solow (1956), which considered the development of economies in different countries of the world, examined the factors determining economic growth and defined the convergence concept as the commitment of countries to the common sustainable growth path.

According to the Solow model, there are three reasons for the convergence effect:

1. The countries' economies move along balanced growth paths, i.e. the difference in output per employee exists only because of the difference in the position of countries relative to the balanced growth path. Accordingly, more 'productive' poor countries catch up with less 'productive' rich countries.
2. In the countries with a higher capital per worker, the marginal return on capital is lower, and consequently, the capital flow from rich countries to poor ones would lead to the narrowing of income gap between countries.
3. Due to the distribution of technologies over time, the resulting income differences between countries begin to shrink after poor countries have gained access to them.

However, the Solow fundamental model does not consider the territorial factor. The role of geography in the non-uniformity of the economic development of individual territories was considered by a new economic geography concept (Krugman, 1991). According to this concept, the spatial non-uniformity of the development of countries and individual regions is caused by unequal distribution of the main economic resources, such as capital and labour resources, which, in a broader concept, includes the labour force qualification and technologies used in production. In addition, according to this theory, the level of development of a region is influenced by its geographical position and the neighbouring regions. The economic dynamics of a region are closely associated with its location and external environment. For example, if a relatively poor region is surrounded by poor regions, it is more likely to remain on the same economic growth path, but the vicinity to richer regions will bolster its development. In addition to physical and human capital, the new economic geography takes into account the influence on the economic growth rates caused by the agglomeration effect, institutional environment and external effects. The latter include relationship between organisations, a flow of intellectual and physical resources, and market effects.

Nowadays, there are many studies on convergence both at the global and interregional levels. The basic study (Barro, Sala-i-Martin, 1991) defines two concepts of convergence.

Absolute or β-convergence means that poor regions tend to grow at a faster rate than rich ones which means that the regional gaps in the considered indicators would narrow soon. The study of β-convergence is based on quantification and comes to checking the nature of dependence (direct or inverse) between the growth rate and initial level of per capita income.

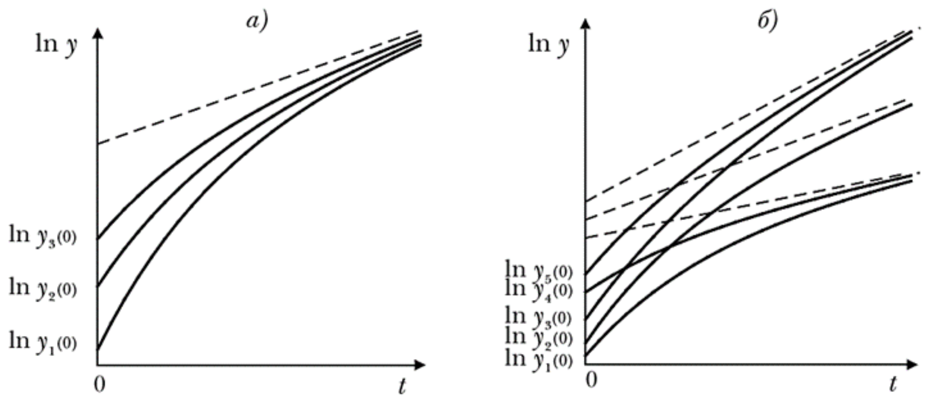
In the case of **σ-convergence (relative)**, it is assumed that the interregional variance (the Gini coefficient or other values describing the variation) of the considered indicators decreases over time. Based on the neoclassical theory, Barro and Sala-i-Martin proposed the following econometric model:

$$\frac{1}{T}\log\frac{y_{it}}{y_{i,t-T}} = \alpha + \left[\log y_{i,t-T}\right]\left[\frac{1-e^{-\beta T}}{T}\right] + u_{it},$$

where *T* is the length of reviewed interval;
y_{it} is GRP or the mean value of per capita income for the region *i* at time *t*.

The above equation is a model of an unconditional (absolute) convergence, where β is a parameter of alignment or convergence. If the parameter becomes negative, it means that the regions with initially lower incomes grow faster than rich ones, i.e. there is a convergence. If $\beta > 0$, there is a divergence in paths. The model of conditional convergence is built by including other explanatory variables in the above formula. It implies that the balanced-growth paths are different for each of the regions (Figure 1), which means that each economy converges to its own equilibrium growth path. That is why the conditional convergence does not lead to a reduction in interregional differentiation.

Figure 1. Unconditional (a) and conditional (b) convergence.



Note. The dotted lines are equilibrium growth paths.

Source: Glushchenko, 2012.

In the study (Glushchenko, 2012), the author explains the difference between the terms ‘alignment’ and ‘convergence’. The author notes that σ-convergence prompts β-alignment, however, the reverse is wrong. The alignment means a process when poor regions grow faster than rich ones. The convergence means a reduction in interregional differentiation. Thus, the alignment does not mean convergence as some regions may grow faster than their theoretical paths and, as a result, may be ahead of other regions while others may stay behind.

According to the study (Glushchenko, 2010a), there is no universal set of additional variables to include in the conditional convergence model. It varies in different studies and remains at the discretion of the author. As a rule, the most common indicators are those that characterise the economy structure and the economic potential of the region (investment in fixed assets, foreign investment, budget expenditure), the level of technology (number of students, postgraduates or patents issued), certain aspects of the GRP structure, e.g. the share of public sector.

In the studies dedicated to the analysis of regional convergence (both inside and outside Russia), the authors check its presence not only by income level, but also by gross regional product (Ledyaeva, Linden, 2008), wages or unemployment (Vakulenko, 2013) and by other indicators (Tolmachyev, 2012).

In the study (Glushchenko, 2010a), the author provides an extensive review of domestic and foreign studies dedicated to the empirical analysis of interregional income inequality in Russia.

As noted in the study (Glushchenko, 2010b), when analysing convergence, econometric models should explicitly take into account regional interaction, which is primarily due to the openness of regional economies. At the same time, such interaction can be considered in different ways. For example, in the studies (Ostbye, Westerlund, 2007; Vakulenko, 2013), the model includes migration indicators. Another approach is to take into account the geographical position of the region. Thus, in the studies (Carluer, Sharipova, 2004; Solanko, 2003), the location of the region was taken into account by including the distance from Moscow in the model.

Another way to consider the interaction between the regions are spatial econometrics models (LeSage, Pace, 2010). In the studies (Balash, 2012; Kolomak, 2009; Buccellato, 2007; Ivanova, 2014), the authors demonstrated that the inclusion of a spatial component in the model is reasonable. Traditionally, with this approach, the proximity of regions is described using the neighbourhood matrix, distance matrix or their various modifications. However, there are some other approaches to determining weights. Thus, in the study (Balash et al., 2020), the authors, in addition to the distance matrix, use a weight matrix that describes the proximity of subjects, based on the region’s industrial specialisation.

Despite the elaboration of this issue, there is no consensus on the presence or absence of convergence in Russia. Moreover, completely opposite results can be observed even within one study. In the study (Kholodilin et al., 2009), the authors divided the regions into several groups and found out that there is no convergence in some of them, while in those where it exists, the convergence rate is different. The study (Gichiev, 2018), in which the regions are divided into several groups, also confirms the variability of the rates of catch-up growth in different groups. Thus, in addition to the spatial positions of the regions, it is worth taking into account the fact that regions can seek to reach their stable states at different velocities. It is confirmed by the study (Eckey et al., 2005), where the authors demonstrate that the convergence rate varies across different regions of Germany.

2. METHODOLOGY AND DATA

There are various approaches to covering spatial effects in econometric models. When using the time-series model, the convergence between two subjects is supposed to be observed if the difference between the observed series is stationary, i.e. the series are co-integrated. The inequality between two regions will not fully disappear with time but settle at some point. Some studies substantiate the sufficiency of stationary initial time series for the existence of convergence. For example, Quah D. (Quah D., 1996) defined the concept of stochastic convergence. According to the said theory, if the change in differences between per capita incomes of two subjects is a stationary process with zero mean, the hypothesis for the existence of stochastic convergence is confirmed. However, the weakness of this approach is that convergence may be identified between no more than two subjects, which means that it will be necessary to assess C_n^2 of co-integrated equations for some sample of regions n. The panel-based approach allows to improve the quality of results thanks to a significantly larger number of observations or introduction of a time factor into the model. The great advantage of the panel-based approach is a focus on the individual features of regions, which considerably improves the quality of the convergence rate estimates. The weakness of this approach is a tendency to overestimate the convergence rate. The reason is the impact of short-term fluctuations while the convergence itself is a long-term process. The existing rectifications of this weakness are inapplicable to the data of the Russian Federation as they require long time series.

The spatial autoregression models (SAR) are widely used in econometric research practices. For instance, a sample may be grouped by the object’s location within the target geography with the model extended with dummy variables. The adaptive analysis of time series supports the continuous transformation of coefficients over time. As for the constant coefficient model, it is assumed that the same global model is right for all objects of the target population. The said models are applicable provided there is a territorial homogeneity of the target population, i.e. the coefficients are constant in all reviewed subfields.

The alternative approach is a geographically weighted regression (GWR) (Brunsdon et al., 1996). This includes building of a separate model for each object based on a subsample of near-by observations. The key difference between GWR and SAR is that the former permits the heterogeneity of coefficients for regressors.

On one hand, conclusions tend to be less general in this way. On the other hand, in the case of considerable heterogeneity of observed object sample, such approach works better and demonstrates a better quality of data fitting. Yet another advantage is a simple calculation procedure and easily interpreted results. Given the significant differences in the economic characteristics of the Russian regions (pleasesee Chapter 3 Analysis of unconditional convergence in Russia) and the above arguments, geographically weighted regression seems to be most preferable modelling method.

The approach is to build a separate model for each object based on a subsample of nearby observations:

$$y_i = X_i\beta_i + \varepsilon_i$$

where index i reflects the dependence of each component of the model on the pair (u_i, v_i), representing the coordinates of the point (location);

i; y_i is the dependent variable;

X_i is the vector of regressors;

β_i is the vector of coefficients to be evaluated;

ε_i is a random error.

Estimate of the vector of unknown coefficients can be calculated using the weighted least squares method by the formula:

$$\hat{\beta}_i = (X'W_iX)^{-1}X'W_iy,$$

where y is the vector of values of the independent variable;

X is the matrix of regressors;

W_i is the diagonal matrix of weight coefficients.

In fact, the heterogeneity of the coefficients from region to region is achieved by using different weighing matrices W_i for each subject, which, in turn, functionally depend on the location of the regions. The location of regions, as understood traditionally, is characterised by distance:

$$W_i = \varphi(D), D = (d_{ij})_{1.1}^{n,n},$$

where d_{ij} is the distance between the objects.

This study uses three different measures of the proximity of regions: distance, trade and migration flows. In the first case, the distance between two subjects is understood to be the shortest path between two points on the ellipsoid (between the geographical coordinates of regional centres)[1]. The same approach is used when building the matrix for trade and migration flows. At the first stage, the values for each pair of regions are summed up for all years to create more stable links between the subjects. Then, we calculate the relative migration flow as the average of proportions of the migration flow to the population in the departure region and that in the destination region:

$$M_{ij}^{i} = \sum_{t=2011}^{2017} \frac{M_{ijt}}{P_{it}}, \qquad M_{ij}^{j} = \sum_{t=2011}^{2017} \frac{M_{ijt}}{P_{jt}},$$

where M_{ijt} is the migration flow from the region i to the region j in year t;

$\mathrm{P_{it}}$ and $\mathrm{P_{jt}}$ is the population in the region i and the region j in year t.

At the second stage, each obtained value was reversed in such a way that if a significant trade or migration flow was observed from one region to another, the distance from the first region to the second one decreased:

$$M'_{ij} = \frac{M_{ij}^{i} + M_{ij}^{j}}{2}.$$

The relative migration flow was calculated to set off the scale of the donor and recipient regions. The same calculation method was applied to the trade flow.

It is worth noting that despite the aggregation of the values of flows (migration for seven years, and trade for eight years) there were pairs of regions with zero values. In the migration matrix, there were 17 such pairs of regions (about 0.3% of all observations), and in the trade matrix they totalled 732 (11.7%). To avoid uncertainty, zeros were replaced with 0.1 (see e.g. Flowerden, Aitkin, 1982).

The consideration of several measures of the proximity of regions in the study was necessitated by the following consideration. When using the distance matrix, closer regions have a stronger influence on each other than distant ones. At the same time, due to the symmetry of the distance matrix, the impact is the same in both directions. The application of the trade or migration flows matrix makes it possible to relax this condition, since the corresponding matrices are no longer symmetric. In this case, net-exporting regions have a stronger influence on their ‘trading neighbours’ than net-importing regions.

Note that when using the matrices described above, the geographical distance is still important. When modelling migration or trade flows, the so-called gravity models are often used (Lee, 1966). Many studies have demonstrated that interregional trade (Mishura, 2012) and migra-

[1] If we used a railway distance matrix, we would have to exclude five constituent entities of the Russian Federation which centres have no railway communication. This would result in a significant bias of the estimates, especially for the East cluster. Besides, the comparability with the results of calculations by means of trade and migration flow matrices covering these regions would be violated.

tion (Andrienko, Guriev, 2004) have a statistically significant negative dependence on the distance between subjects.

When building a geographically weighted regression, it is often assumed that the coefficients for regressors for neighbouring objects differ less than for more distant ones. To implement this prerequisite as a functional dependency $\varphi(\cdot)$, a certain kernel is used. The Gaussian kernel was widely used in this case:

$$w_{ij} = \exp\left[-\frac{\alpha}{2}\left(\frac{d_{ij}}{b}\right)^2\right],$$

where b is a parameter specifying the bandwidth;

α is the scale coefficient;

d_{ij} is the distance between objects.

If set like that, the weight is equal to one at the location i and decreases rapidly when moving away from the object.

If the simulated objects are located evenly in space, then the use of kernels with a constant bandwidth gives acceptable results. However, practically, objects are often located unevenly, which requires the use of adaptive kernels and setting appropriate hyperparameters. For example, the bandwidth can be defined as the distance to the *k*-th neighbour. Let k_i be numerous *k* nearest neighbours for the *i*-th object, then

$$w_{ij} = \begin{cases} \left(1 - \left(\frac{d_{ij}}{\max\limits_{j \in k_i} d_{ij}}\right)^2\right)^2, \text{if } j \in k_i, \\ 0, \text{otherwise.} \end{cases}$$

In this case, the optimum number of nearest neighbours for k can be determined with the use of an iterative procedure, by comparing the quality of models for different values of the parameter.

For Russian environment, the GWR-model with such procedure appears to be more promising than the SAR-model with a distance threshold matrix (covering neighbours only within 500 km, for instance).

Determination of the weight function parameters plays an important role, since the estimates of the regression coefficients vary depending on the values of the parameters. With a quite wide bandwidth, the estimates of the coefficients will be close to the estimates of the classical regression model, i.e. all local features will not be taken into account. In general, the optimum parameters of the weight function can be obtained using leave-one-out cross-validation method

$$\mathrm{C}V(k) = \sum_{i=1}^{n}(y_i - \hat{y}_{-i}(k))^2 \to \min_k,$$

where $\hat{y}_{\neq i}(k)$ is the forecast value at the point i, which is excluded from consideration when such forecast value is calculated.

The optimal value k is selected based on minimising the value of the functional $\mathrm{CV(k)}$.

It was noted earlier that the regions of the Russian Federation are quite heterogeneous in terms of their economic indicators. The global spatial nonstationarity test (Brunsdon et al., 1999) shows that the GWR model is more preferable than the traditional linear regression model (LR) estimated by the least squares method. In this test based on the remnants of the traditional LR and GWR models, the hypothesis for the constancy of regression coefficients is tested with the help of F-statistics.

After all the necessary parameters are selected, as in the case of traditional LR, it is possible to test a hypothesis for the statistical significance of regression coefficients. This can be done using the classic *t*-test

$$t = \frac{\hat{\beta}_k(i)}{\sqrt{Var(\hat{\beta}_k(i))}},$$

where $\hat{\beta}_k(i)$ is the estimate of the k-th regression coefficient at the location i,

$\mathrm{Var}(\hat{\beta}_k(i))$ is the estimate of the variance of this coefficient, which is the k-th diagonal element of the matrix $\hat{\sigma}^2 CC'$.

For this purpose:

$$C = (X'W_iX)^{-1}X'W_i,$$

$$\hat{\sigma}^2 = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n - 2tr(S) + tr(S'S)}, \qquad S = \begin{bmatrix} X_1(X'W_1X)^{-1}X'W_1 \\ \vdots \\ X_n(X'W_nX)^{-1}X'W_n \end{bmatrix},$$

where X_i is the i-th row of the matrix X,

$\mathrm{tr}(S)$ is the matrix trace S.

The theoretical basis for the model are the models of unconditional (1) and conditional (2) β-convergence used in the study (Barro, Sala-i-Martin, 1991). The main econometric model is a geographically weighted regression model with a Gaussian kernel and an adaptive bandwidth that corresponds to the distance to the *k*-th nearest neighbour.

$$g_i = \alpha_i + \beta_i y_i + \varepsilon_i \quad (1)$$

In the model above: g_i is the average GRP growth rate for *T* years, calculated using the formula

$$g_i = \frac{\ln Y_{i,T} - \ln Y_{i,0}}{T},$$

where $Y_{i.0}$ is the real GDP per capita in the base year *t*;

$\mathrm{Y_{i,T}}$ is the real GDP per capita in year *T*;

y_i is the logarithm of real GDP per capita in the base year *t*;

α_i and β_i are parameters to be estimated;

ε_i is a random error.

After the model (1) is evaluated, several values can be calculated that characterise the convergence in each region:

$$\lambda_i = -\frac{\ln(1+\beta_i T)}{T},$$

$$t_i = \frac{\ln 2}{\lambda_i},$$

where λ_i is the convergence rate;

t_i is the time required to overcome half the way to a stable state.

The conditional convergence model (2) differs from the model (1) by the presence of a number of variables that cause the heterogeneity of regional economies:

$$g_i = \alpha_i + \beta_i y_i + \gamma_i X_i + \varepsilon_i \quad (2)$$

where X_i is the matrix of variables for the region *i* in the base year;

γ_i is the vector of the estimated variables.

The analysis covered the data from 80 out of 85 subjects of the Russian Federation. The Republic of Crimea and the federal city of Sevastopol were excluded from consideration due to the short observation period; the Nenets Autonomous District was included in the Arkhangelsk Region; the Khanty-Mansi Autonomous District – Yugra and the Yamalo-Nenets Autonomous District were included in the Tyumen Region.

The study was based on the data from the Federal State Statistics Service. The main parameter is the annual indicator of the gross regional product per capita for the period from 2005 to 2018. The gross regional product was adjusted to the 2005 prices with the application of the deflator index of the gross regional product.

The conditional convergence model additionally includes the following variables for 2005: the value of fixed assets at the residual book value per capita, the level of employment, internal current R&D costs per capita, the share of the public sector in GRP (the sum of the shares of such sectors as Education, Healthcare and Public Administration in the GRP). We took a logarithm of the values of all indicators.

The conditional convergence model also includes the weighted average interest rate on loans to legal entities for a period of more than a year. The data are sourced from reporting forms 0409128 and 0409129 submitted by credit institutions to the Bank of Russia. The interest rate was weighted by the monthly volumes of these loans issued from December 2005 to December 2018 (no earlier data were found), and a logarithm was taken for the indicator as well. It is worth noting that only regional banks are included in reporting forms 0409128 and 0409129. Thus, in some periods there was no data for some regions due to the absence of regional banks there. As there is no figures for the Moscow Region either, Moscow rates were used for it.

Trade and migration flow figures are presented in the form of adjacency matrices for the periods from 2009 to 2016 and from 2011 to 2017, respectively. As the study uses the data for different time periods, the explanatory variables included into the model equation have no endogeneity (see the role of lagged regressors in tackling endogeneity in e.g. (Andrienko, Guriev, 2006)).

In the matrix of migration flows, at the intersection of a row and a column, there is a number of migrants who moved from one region to another, and in the matrix of trade flows there is a number of goods and services (in value terms) exported from one region to another. We examined the data on interregional migration only starting from 2011 due to the drastic change in the statistical accounting of internal migrants in Russia. Earlier, the statistical accounting covered citizens registered at the place of their stay for longer than 12 months. However, since 2011 the sufficient period of a migrant's stay in the destination territory has been nine months.[2]

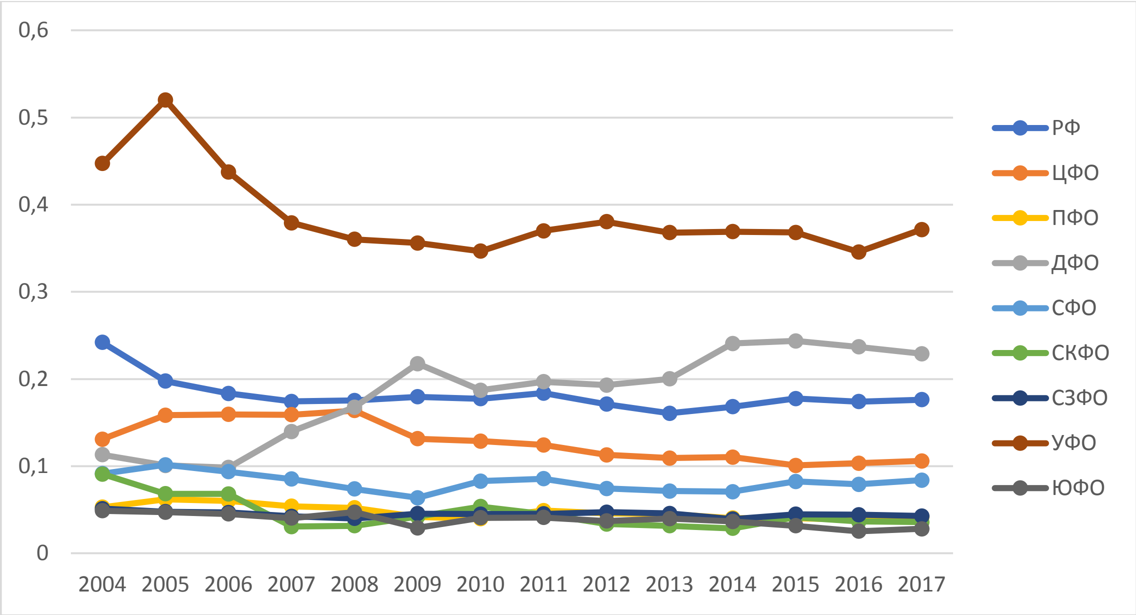
Data on trade flows were obtained from the Federal State Statistics Service on the basis of Form No. 1-export. Such form is provided by all organisations, with the exception of microenterprises, on a quarterly (shorter nomenclature, which includes only food and agricultural products) and on an annual basis.

3. ANALYSIS OF UNCONDITIONAL CONVERGENCE IN RUSSIA

The primary analysis of differentiation was made with the use of the Theil index (Theil's L). This index was selected as it might be decomposed, for example, to identify the inequality component conditioned on the target division (in this case, regional division by federal districts).

Figure 2. The Theil index dynamics (GRP per capita) across Russia and federal districts (2004 – 2017)

[2] The Demographic Yearbook of Russia, the Federal State Statistics Service, 2012

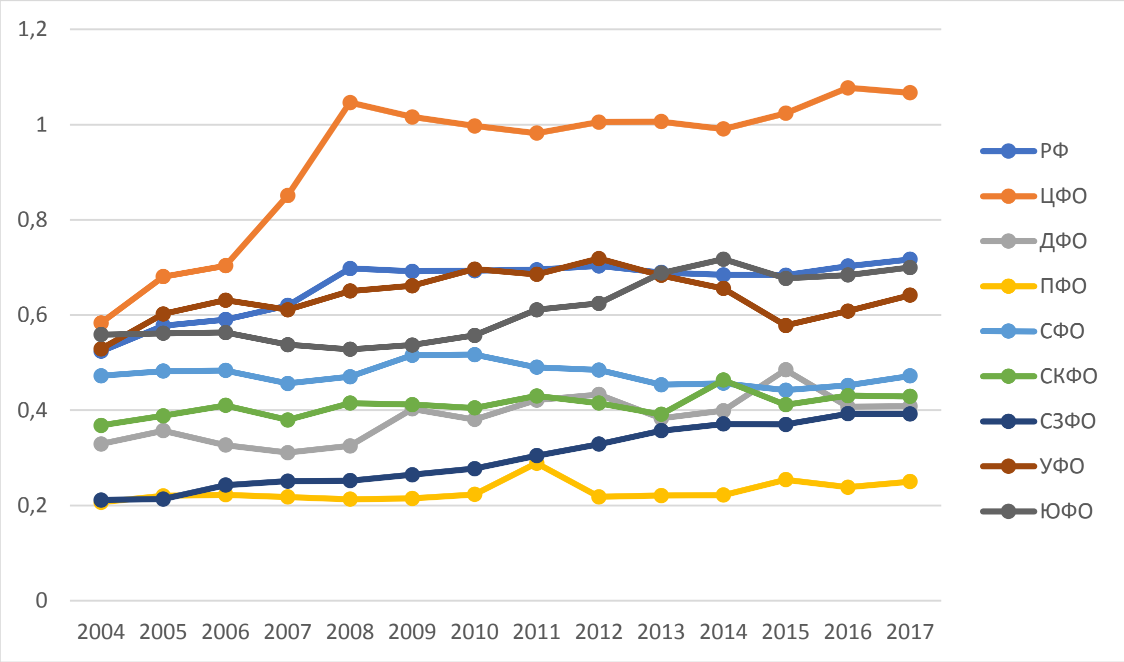


Over the period under review, the national level of regional differentiation by GRP per capital remained quite stable. The share of the component conditioned on the regional division by districts[3] was changing very slightly (ranging from 22% to 30%), notably, there was no trend.

The maximum level of inequality was recorded in the Urals Federal District as there are regions with the opposing GRP levels: the Kurgan Region, on one hand, and the Tyumen Region (including districts), on the other hand. Interestingly, the Far Eastern Federal District demonstrated a notably increasing inequality. There are clear leaders (the Sakhalin Region and Chukotka) and outsiders (Buryatia and the Trans-Baikal Territory). The minimum level of differentiation was recorded in the regions of the North Western FD, the North Caucasian FD, the Volga FD, and the Southern FD with the two latter ones showing a noticeable trend of its further decrease.

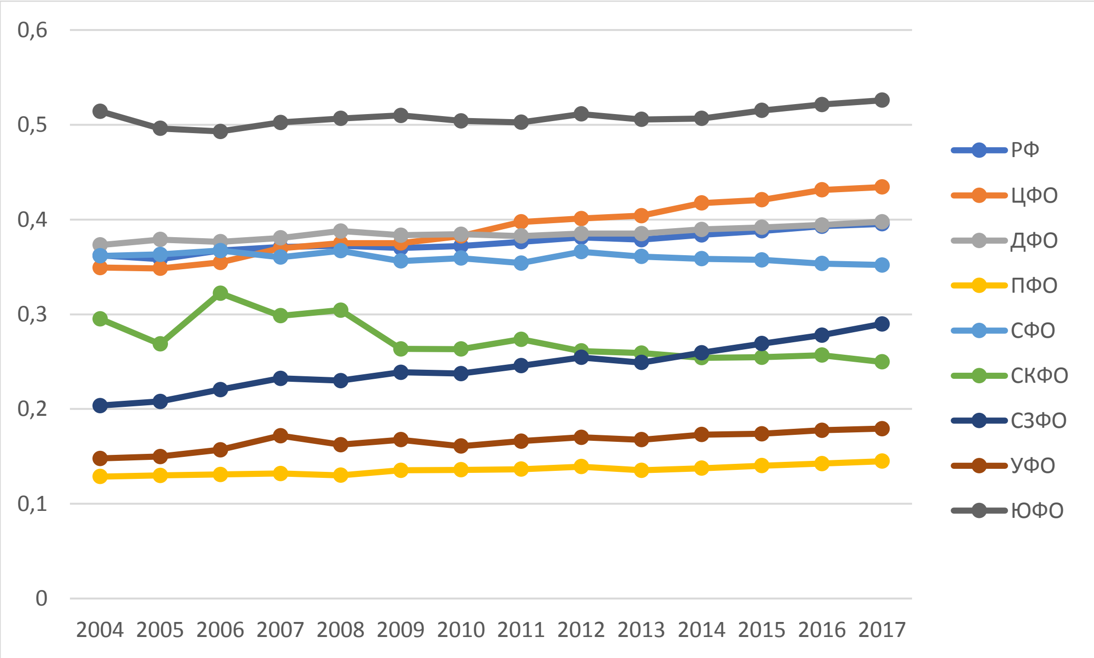
Figure 3. Theil index dynamics (fixed assets value)
across Russia and federal districts (2004 – 2017)

[3] We use the latest (2022) division of regions by federal districts to ensure comparability in time.



The level of regional differentiation by fixed assets value is considerably (2.5 to 3 times) higher than by GRP per capita (Figure 3) with a noticeable tendency to grow. The share of the component conditioned on the regional division declined from 18% to 5% over the period under review. There is a very high inequality in the Central Federal District (the Theil index exceeds 1, however, the maximum possible value is $ln80 \approx 4.38$), which obviously reflects the impact of Moscow and the Moscow Region. The significant level of differentiation is recorded in the Urals and Southern FDs, the minimum level – in the Volga FD.

Figure 4. Theil index dynamics (workforce)
across Russia and federal districts (2004 – 2017)



The Theil workforce index (Figure 4) was growing in the Russian regions slowly but surely (from 0.36 to 0.39). The share of the component conditioned on the regional division declined from 21% to 18%. The highest level of inequality is recorded in the Southern FD. The differentiation tended to grow in the Central and North Western FDs. The lowest level of differentiation is seen in the Urals and Volga FDs.

From 2004 to 2017, the regional inequality in the Russian Federation was decreasing by GRP per capita and increasing by fixed assets and workforce. Thus, the key factors of the classical model (capital and labour) in Russian regions demonstrate a reverse trend in relation to GRP. Besides, their inequality share conditioned on the regional division by districts is much lower than that of GRP per capita and was continuously declining over the reviewed period. The Theil index developments across federal districts do not show any tendency for inequality levels to align.

Thus, the results of primary analysis of interregional indicators allow to note that the reviewed stage of the Russian economic development is characterised by sizable regional disproportions. Dynamics of GRP per capital and other indicators suggest that the distribution of investment and innovation potential is not even and there are great differences in the growth paths and development rates of regions.

The study of the convergence of Russian regions by the level of GRP began with building a β-convergence model (1). Then, the regions were divided into eastern (the Urals, Siberian and Far Eastern Federal Districts) and western (all others). The model (1) was evaluated for them as well. The results of the evaluation of all models are shown in Table 1.

Table 1. Estimates of the least squares method of the global model of unconditional convergence

	All regions	East	West	West without the North Caucasian Federal District (NCFD)
α	0.078***	-0.0002	0.105***	0.152***
β	-0.004**	0.002	-0.007**	-0.011***
R^2	0.05	0.02	0.09	0.16

*Note. ** – 5% significance level, *** – 1% significance level*

The results of evaluating the models are ambiguous. Overall (considering all regions), it can be argued that there is a β-convergence. The negative relation between the growth rate of per capita income and the initial level of income (β<0) means that the per capita income grows faster in poor regions than in rich ones. However, the convergence rate is only 0.41%, while the time required to overcome half the way to a stable state is more than 168 years. When the country is divided in two parts, the situation changes somewhat. Convergence processes are observed only in the western territory. When excluding the subjects of the NCFD from consideration, the convergence becomes more obvious.

It can be assumed that as the territories are disaggregated, i.e., when building different models for different federal districts or regions, the situation would become more and more ambiguous. In some regions, stable convergence processes may take place, while in others they may be less distinct or absent at all. Thus, the convergence coefficients have a high spatial variability, which requires a special approach. The geographically weighted regression model is chosen as such an approach.

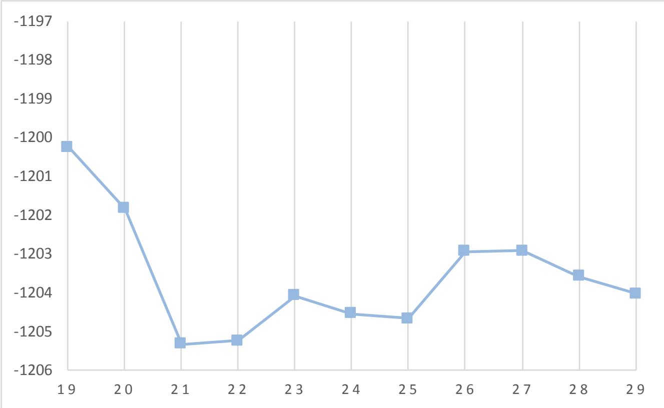
Before analysing the model, the optimum value of *k* (the number of nearest neighbours) is selected for each weight scheme using the Akaike criterion. Then the hypothesis for the constancy of the regression coefficients is tested. In all cases, it is rejected at the 1% significance level, which formally confirms the viability of the transition from the global model to the GWR. The results of evaluation of GWR unconditional convergence model are presented in Table 2.

Table 2. Distribution of GWR coefficients of unconditional convergence (minimum, maximum, median, 1–3 quartiles)

		Min.	1st Q	Med.	3rd Q	Max.
α	Distance, *k*=21	-0.080	0.012	0.111	0.140	0.210
	Migration, *k*=39	0.060	0.090	0.104	0.119	0.143
	Trade, *k*=68	0.082	0.114	0.125	0.133	0.144
β	Distance	-0.015	-0.010	-0.008	0.002	0.009
	Migration	-0.010	-0.008	-0.007	-0.006	-0.003
	Trade	-0.010	-0.009	-0.009	-0.008	-0.005

Distance matrix. The optimum number of nearest neighbours for this pattern was established using the Akaike criterion. The dependence of the criterion on the number of nearest neighbours may be presented in a chart (Figure 5). The minimum is recorded when $k = 21$.

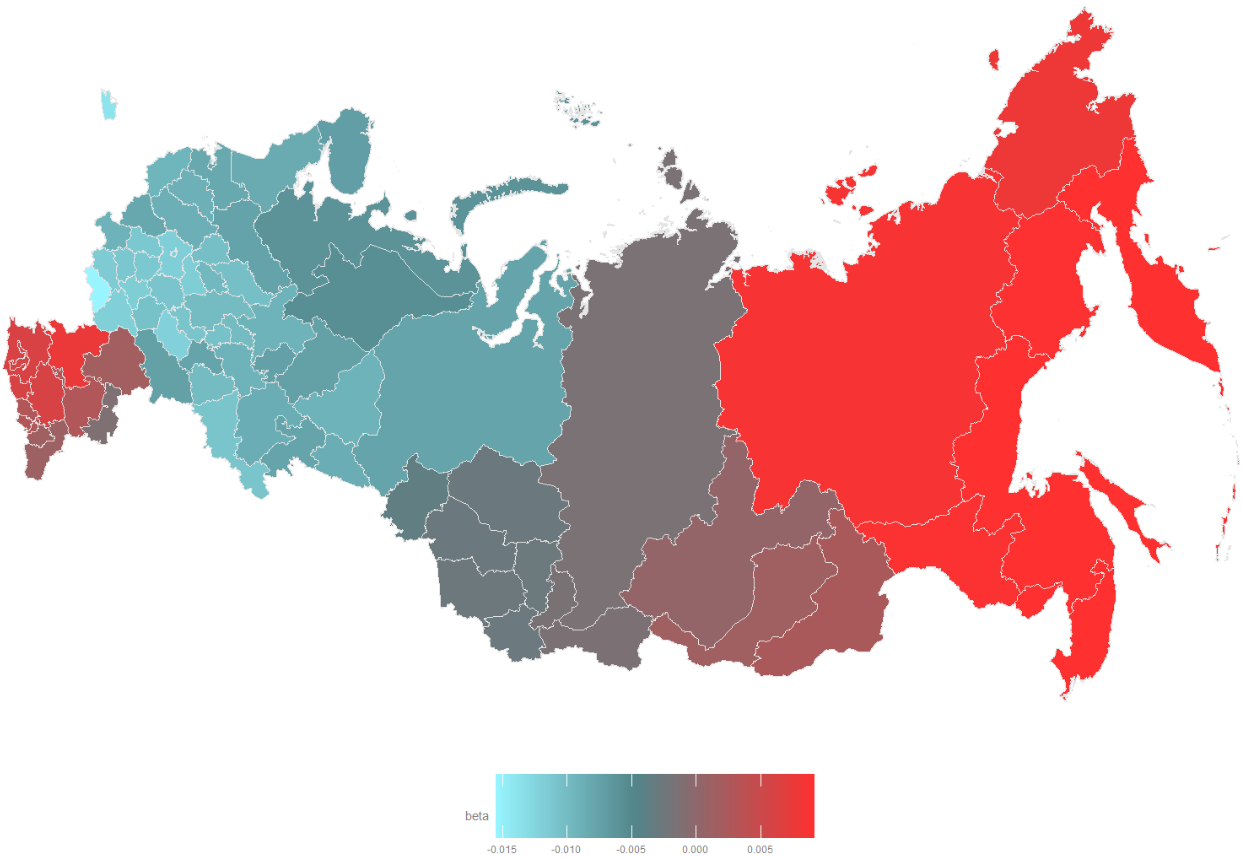
Figure 5. The AIC value dependence on the number of nearest neighbours (distance matrix).



Let us call the model with such a matrix the basic one. Distribution of the values of the estimated β-coefficients across regions of Russia is presented in Figure 6.

The highest rates of convergence are observed in the regions of the Central and Volga Federal Districts. There is no convergence in any regions of the Far Eastern, North Caucasian and Southern Federal Districts, with the exception of the Astrakhan Region. At the same time, the Astrakhan Region itself has the lowest rate among all regions, equal to 0.1%. The highest convergence rate is observed in the Belgorod Region (1.8%). In 41 regions, the estimates are statistically significant at the 1% level of significance, in eight – at 5% and in four – at 10%.

Figure 6. Distribution of convergence coefficients across Russia (distance matrix).

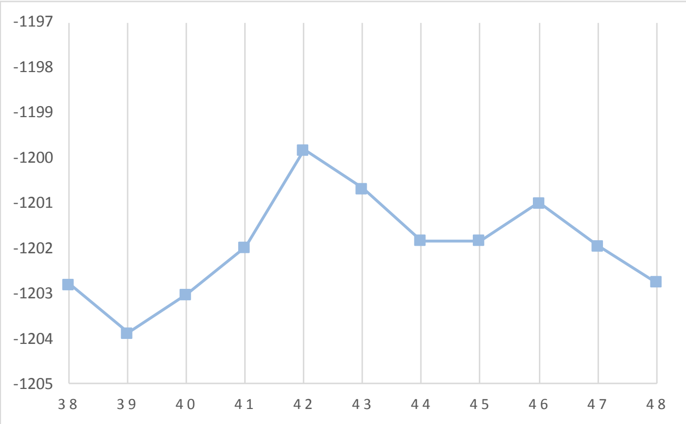


In general, the values of the convergence rate decrease as you move through the country from west to east. The convergence rate in the Siberian Federal District is noticeably lagging behind the western part of the Russian Federation.

In the regions where the convergence process takes place, its average rate, weighted by GRP, is equal to 1%. The standard deviation, also weighted by GRP is 3.4×10^{-3}.

Migration flows matrix. The optimum number of nearest neighbours for this pattern was selected in a similar way. The minimum Akaike criterion is reached when $k = 39$ (Figure 7).

Figure 7. The AIC value dependence on the number of nearest neighbours (migration flow matrix).



Distribution of the values of the estimated β-coefficients across Russian regions when using migration flows matrix is presented in Figure 8.

Figure 8. Distribution of convergence coefficients across Russia (migration flows matrix).

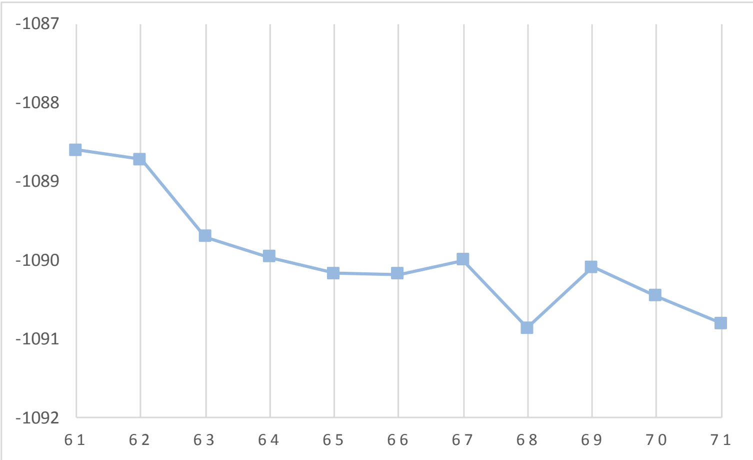
It can be argued that with such a matrix, a convergence process is observed in all Russian regions. The highest rates of convergence are observed in the Central, Volga and North-Western Federal Districts. The maximum value is in the Penza Region – 1.1%. Also, a high rate of convergence is observed in certain regions of the North Caucasian and Far Eastern Federal Districts – the Republic of Daghestan and the Republic of Sakha (Yakutia). The lowest convergence rates are pronounced along the southern and eastern borders of the Asian part of Russia. The minimum value is observed in the Republic of Buryatia (0.3%). The obtained estimates significantly differ from zero at a 5% level of significance in four regions and in 36 regions – at a 10% level.

Compared to the basic model, the convergence process is observed in all regions, while the weighted average value of the convergence rate is lower – 0.8%. The standard deviation is also slightly lower than the corresponding characteristic of the base model and is equal to 1.3×10^{-3}.

The difference in the results between different matrices is primarily due to the fact that in the case of migration flows, the largest and most developed cities of Moscow and St. Petersburg with their regions are ‘neighbours’ for almost all regions, since there is a significant migration flow from these regions (Moscow and St. Petersburg) to almost all subjects in absolute terms. The same fact also explains the greater uniformity of the distribution of coefficients.

Trade flows matrix. For the matrix in question the optimum number of nearest neighbours is $k = 68$. The dependence of the number of nearest neighbours on the Akaike criterion value is presented in Figure 9.

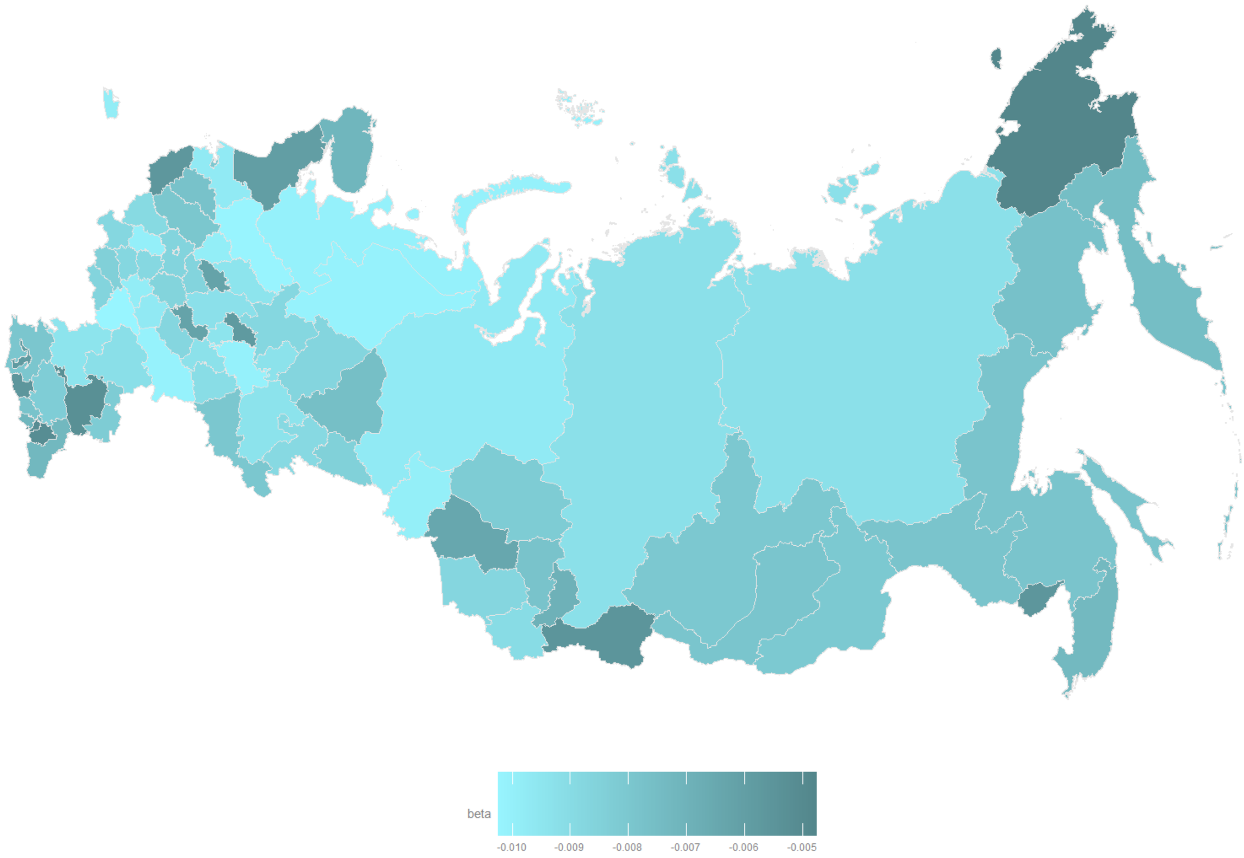
Chart 9. The AIC value dependence on the number of nearest neighbours (trade flow matrix).



Estimates of β-coefficients across Russian regions when using trade flows matrix is presented in Figure 10.

The convergence processes are not uniformly distributed. Comparatively higher rates of convergence are observed mainly in the regions of the Central, North-Western and Volga Federal Districts, as well as in the Omsk, Tyumen and Rostov Regions. The convergence rates generally tend to decrease as we move from west to east, but this trend is less pronounced than in the basic model. In all regions, the estimates differ statistically significantly from zero, 75 of them are at a 1% level of significance, and the rest are at 5%.

Figure 10. Distribution of convergence coefficients across Russia (trade flows matrix).



Comparing to the basic model, it can be noted that the convergence process, as in the case of the migration flows matrix, is observed in all regions. The GDP-weighted average rate is slightly lower than that in the basic model, and is equal to 0.9%. The standard deviation is lower as well, and equals to 1×10^{-3}.

As in the case of the migration flows matrix, the presence of a convergence process in all regions is driven by the fact that Moscow and St. Petersburg are neighbours for the vast majority of regions.

4. ANALYSIS OF CONDITIONAL CONVERGENCE IN RUSSIA

Since in the case of unconditional convergence, the model does not take into account any additional factors other than the level of per capita GRP in the base year, it is assumed that the studied objects-regions are homogeneous in their economic characteristics and the dynamics of their development converges to a single path of balanced growth. However, in practice, each region has its own economic, infrastructural and other features, so it is worth assuming that the paths of balanced growth also vary depending on a particular region. This assumption can be verified by evaluating the conditional β-convergence, that is, by including additional factors in the model.

To study the conditional β-convergence, the model (2) was evaluated. As noted above, with conditional convergence, each region converges to its own path of equilibrium growth, determined by the initial characteristics of the region. As such characteristics, the model (2) included: the value of fixed assets per capita at the residual book value, the level of employment, internal current R&D costs per capita, as well as the share of the public sector in GRP. In addition, the weighted average interest rate on loans to legal entities for a period of more than a year was also included in the model (2).

These variables were included in the model (2) for the following reasons. The value of fixed assets, level of employment and R&D costs are proxy variables for the indicators of capital, labour and the level of technology in terms of the traditional production function. Many authors also include certain characteristics of the GRP structure in the model; in the framework of this study, the share of the public sector was chosen to be such a factor. This indicator is related to the overall level of the region development: it is higher in the regions where there are no competitive industries of specialisation, since in these regions the share in GRP of public services, which are approximately equally presented in all regions, is higher against the background of lower output volumes in other industries. The weighted average rate is included in the model as a proxy variable for assessing the sensitivity of regional economic growth rates to monetary policy. In the modelling process, other variables were also used for indicators of capital (investment in fixed assets), labour (number of students) and the level of technology (number of postgraduates, share of knowledge-intensive industries in GRP). Due to the low quality of the obtained models, these results are not provided.

As in the case of unconditional convergence, the global model was evaluated (Table 3). According to the results obtained, there is a statistically significant (at a 10% level) β-convergence with a rate of 1.19% and the time required to overcome half the way to a stable state (equal to 58 years). The control variables have the correct signs from the point of view of economic logic, but they turned out to be statistically insignificant. All other things being equal, the average growth rate of per capita GRP will be higher in those regions where the initial reserves of labour and capital are higher, as well as where the R&D costs are higher in the initial period of time. More sizeable public sector leads to a slower rate of convergence. It is also worth noting that the economic growth rate is influenced by monetary conditions. The regions, where interest rates were lower on average during the entire observation period, have higher rates of economic growth.

Table 3. Estimates of the global conditional convergence model by the least squares method

α	β	Capital	Labour	R&D	Public	Rate	R^2

				costs	sector share		
0.188**	-0.011*	0.001	0.006	0.002	-0.003	-0.009	0.11

*Note. * – 10% significance level, ** – 5% significance level.*

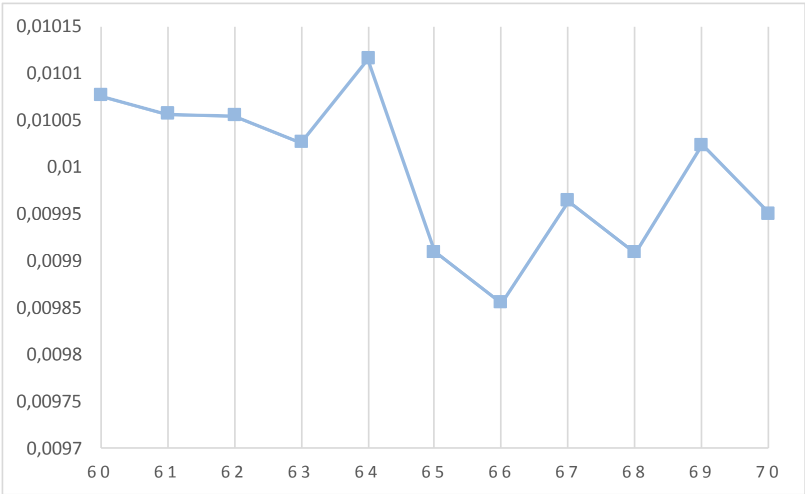
By analogy with unconditional convergence, the optimum number of nearest neighbours is selected for all weight schemes. In this case, we used a cross-checking method due to a growing number of observations. Then the hypothesis for the constancy of the regression coefficients is tested. In the case of the distance and trade flows matrix, it is rejected at the 1% significance level, and in the case of the migration flows matrix, it is not rejected at any significance level. In addition, for a model with migration flows, the estimates of almost all coefficients for all variables do not statistically differ from zero. Therefore, this study does not provide the results of evaluating this model. The figures of evaluation of the GWR conditional convergence model are presented in Table 4.

Table 4. Distribution of GWR coefficients of conditional convergence (minimum, maximum, 1–3 quartiles)

		Min.	1st Q	Med.	3rd Q	Max.
α	Distance, *k=66*	0.176	0.444	0.450	0.457	0.495
	Trade, *k=57*	0.038	0.262	0.319	0.394	0.514
β	Distance	-0.028	-0.026	-0.026	-0.025	-0.010
	Trade	-0.026	-0.020	-0.015	-0.012	-0.004
Capital	Distance	0.003	0.004	0.004	0.005	0.008
	Trade	-0.002	0.005	0.006	0.007	0.010
Labour	Distance	0.002	0.004	0.005	0.005	0.038
	Trade	-0.100	-0.060	-0.045	-0.017	0.019
R&D costs	Distance	0.001	0.001	0.001	0.001	0.002
	Trade	0.000	0.001	0.001	0.002	0.003
Public sector share	Distance	-0.020	-0.020	-0.019	-0.018	0.001
	Trade	-0.015	-0.006	-0.002	0.002	0.009
Rate	Distance	-0.042	-0.029	-0.028	-0.027	0.004
	Trade	-0.082	-0.058	-0.054	-0.042	0.010

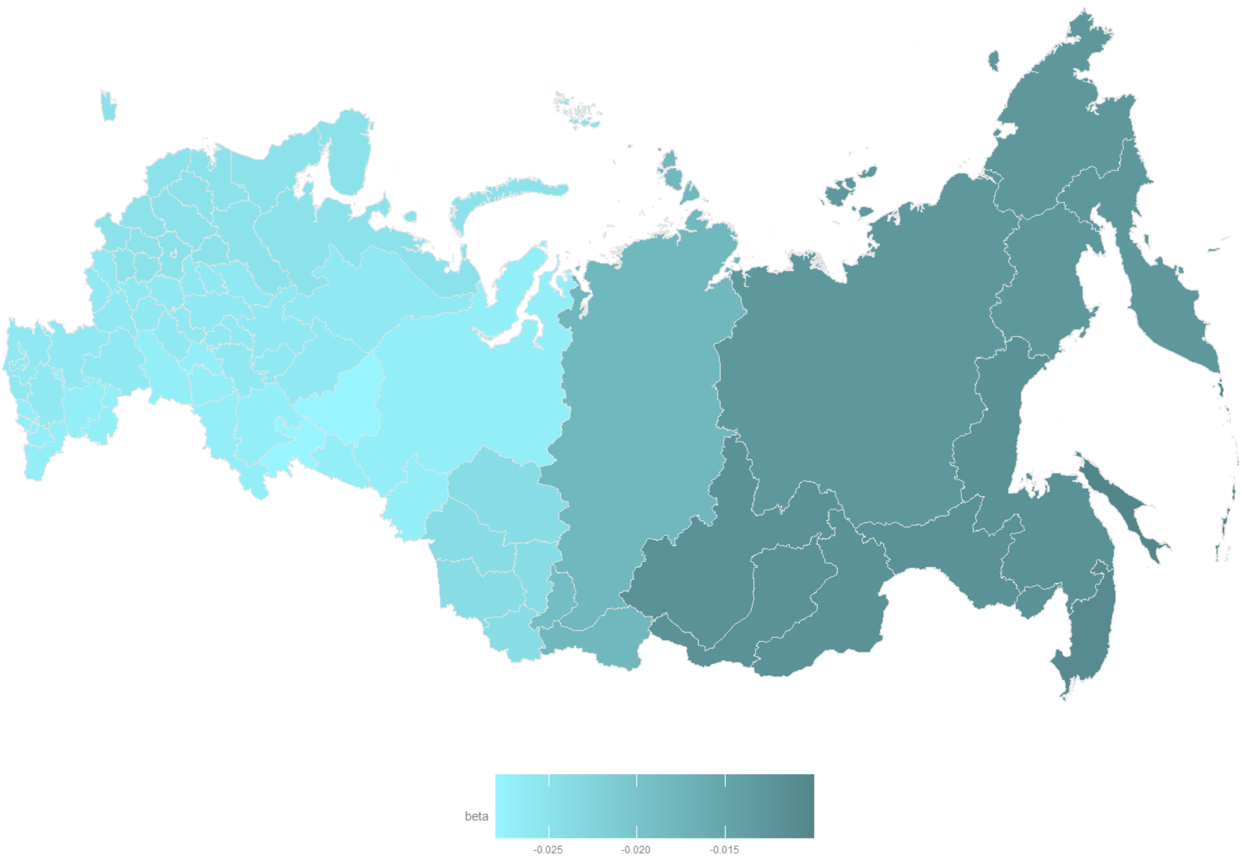
Distance matrix. The optimum number of nearest neighbours was selected by calculating the cross-validation criterion (*CV*). The criterion value dependence on the number of nearest neighbours is presented in Figure 11. The minimum value is reached when $k = 66$.

Figure 11. The CV value dependence on the number of nearest neighbours (distance matrix).



Distribution of the estimated β-coefficients across Russian regions when using the distance matrix for the conditional convergence model is presented in Figure 12.

Figure 12. Distribution of convergence coefficients across Russia (conditional model, distance matrix).



With respect to this matrix, convergence is observed in all regions. The highest rate is observed in the Chelyabinsk Region and the lowest – in the Sakhalin Region. In general, we can note the clustering of the obtained estimates by federal districts, as well as a decrease in the convergence rate when moving from west to east. In all regions, the estimates differ significantly from zero, 79 of them are at the 1% level of significance, and the rest are at 5%.

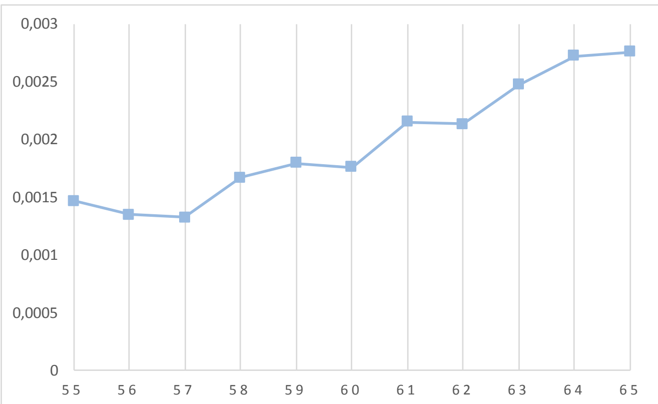
The signs of the coefficients for physical capital, level of employment and R&D costs are in line with economic logic. Their values are generally distributed fairly uniformly and are close to zero. However, the highest values of these indicators are observed in the eastern part of Russia: the Urals FD is characterised by high values of coefficients for capital; the Siberian FD – for capital and R&D costs; the Far Eastern FD – for the level of employment and R&D costs. The coefficients for these variables are statistically insignificant in almost all regions.

The coefficients of the share of the public sector in GRP have negative signs in the vast majority of regions. Their values are distributed fairly evenly across the western part of Russia and in the Urals, and then, when moving east, they decrease, reaching minimum values in the Far Eastern FD. In 64 regions, these coefficients are statistically significant by 1% and in one more region – by 5%.

The interest rate has the opposite effect on the average economic growth rate. The strongest influence is observed among the regions of the Siberian and Urals Federal Districts, while the weakest is in the Far East Federal District. The coefficient for this indicator statistically differs from zero at the 1% level in five regions, in 31 regions – at 5%, and in 31 – at 10%.

Trade flows matrix. The optimum number of nearest neighbours for this matrix was also determined using the cross-validation criterion (*CV*). The dependence is presented in Figure 13. The minimum value is reached when $k = 57$.

Figure 13. The CV value dependence on the number of nearest neighbours (trade flows matrix).



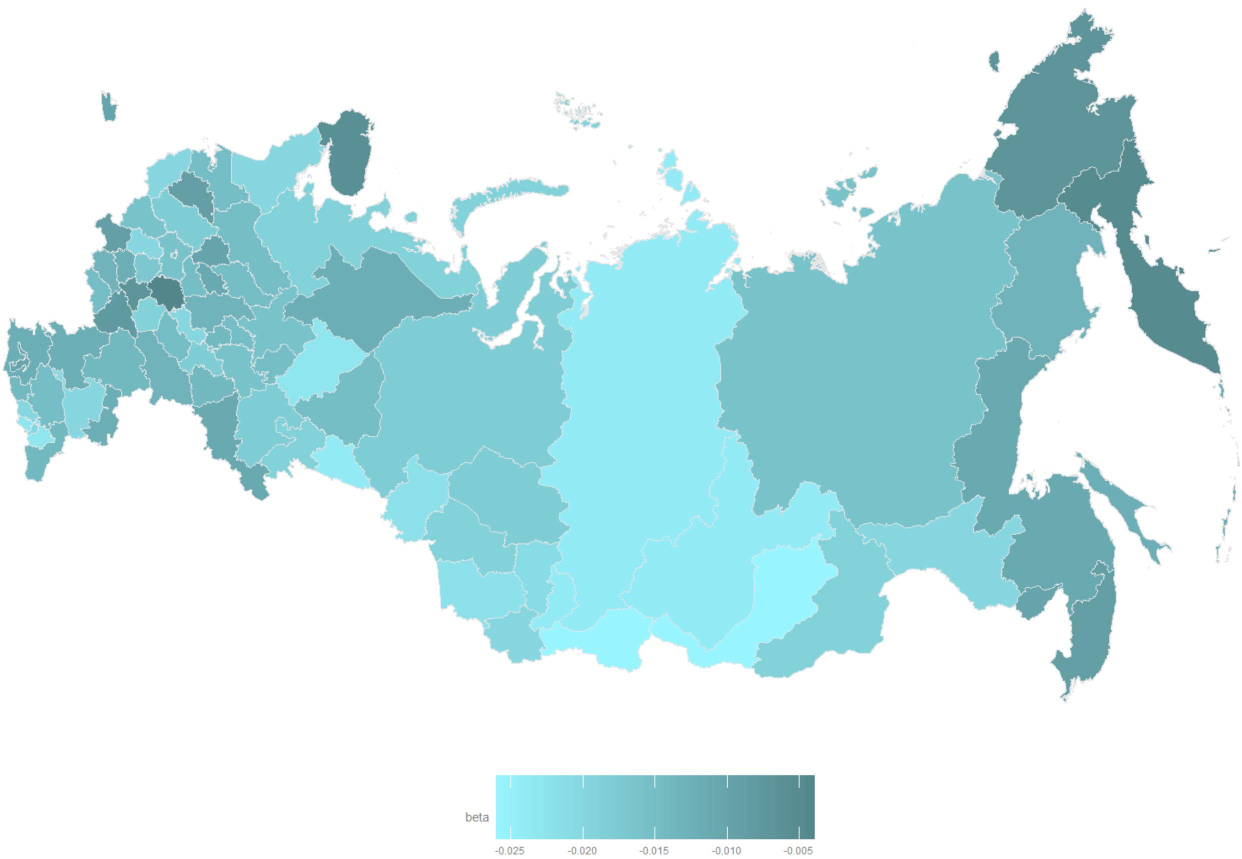
The obtained estimates of β-coefficients for the Russian regions for the conditional convergence model with the trade flows matrix are shown in Figure 14.

As in the previous case, convergence processes are observed all over Russia, while their rates are lower. It is difficult to clearly single out any federal district with the fastest convergence rates. The subjects located in five out of eight federal districts are in the top ten regions by the convergence rate.

Estimates of coefficients for physical capital and research costs, as in the model with a distance matrix, are close to zero and are statistically insignificant in almost all regions. However, their values are slightly higher than in the case of the distance matrix. The coefficient for the level of employment in most regions has a negative sign and is statistically significant in about half of this country's subjects. At the same time, 15 of them have a 1% significance level, 19 – 5%, and eight – 10%.

The coefficient for the share of the public sector in GRP in more than half of the regions has a negative sign, but it turns out to be statistically insignificant almost everywhere.

Figure 14. Distribution of convergence coefficients across Russia (conditional model, trade flows matrix).



It is worth noting that with this matrix, the influence of the interest rate on the average economic growth rate is stronger, the coefficient for this variable is lower than in the distance matrix model. The distribution of indicator across the country is uneven. At the same time, as in the previous case, values close to zero are observed in the Far Eastern FD. The obtained estimates differ statistically significantly from zero in most regions of Russia, in 48 of them at a 1% significance level, in 12 – at 5%, and in three – at 10%.

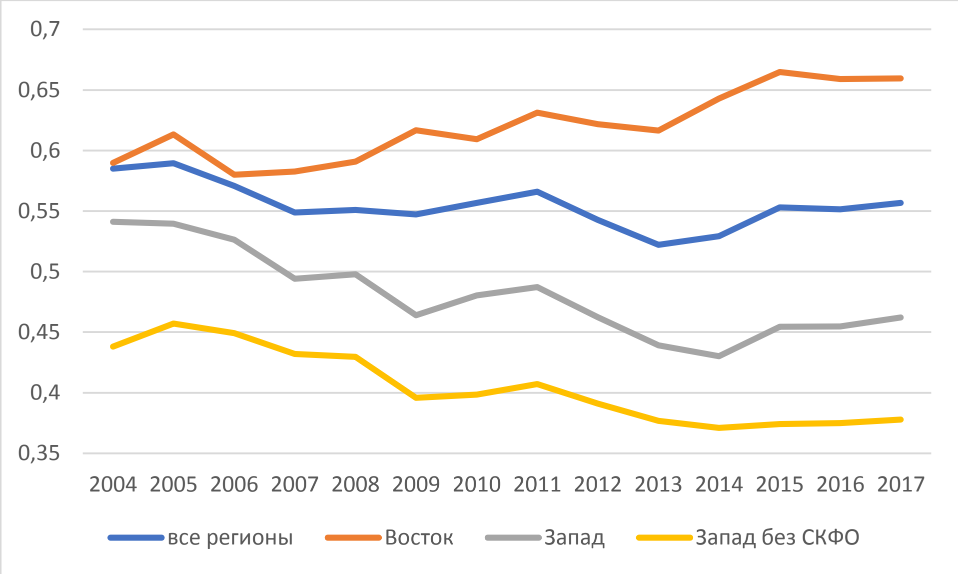
To check the robustness of the results, all regressions were re-evaluated for another indicator that characterises the output. Instead of real GRP per capita, we used GRP adjusted for the cost of a fixed set of goods and services. The change in the indicator did not impact the results considerably. With unconditional convergence, all regions converge, as before, only in the case of migration and trade matrices; as for the distance matrix, convergence is not observed in all regions. The distribution of the convergence rate across regions is generally similar to the distribution in the original regression for all weight schemes.

In the case of conditional convergence, the simulation results are also similar to the model where the real GRP per capita is used as the dependent variable. The difference is noted only in the coefficients for some additional variables (labour, capital). However, due to the statistical insignificance of these estimates in most regions (both in the original regression and in the new one) we consider such a difference in the modelling results insignificant.

Apart from measuring the performance indicator, we checked the robustness in another area: we tested a working hypothesis whereby Moscow and the Moscow Region caused a great distortion in the trade and migration flows matrices. To this end, we analysed the unconditional and conditional β-convergence for 78 regions (excluding Moscow and the Moscow Region). As we expected, the spatial distribution based on the distance matrix remained virtually unchanged while the distributions based on the trade and migration flows matrices changed significantly both spatially and numerically. The main difference is a two-fold reduction in the median levels of β-convergence coefficients with practically unchanged extreme values.

The existence of β-convergence does not imply the existence of σ-convergence at all times, that is, narrowing of the range of regional GRPs over time (please see Chapter 1 Review of Existing Studies). The standard deviation of per capita GRP logarithms was used as an indicator of differentiation. (Figure 15).

Figure 15. σ-convergence of per capital GRP



The obtained calculations generally show that over the interval from 2005 to 2017 there was a σ-convergence. However, the variation did not decline monotonously: there was some growth in the periods from 2009 to 2011 and from 2013 to 2015. The rates of inequality reduction are not the same either. The differentiation remained nearly at the same level in the periods from 2007 to 2009 and from 2015 to 2016.

It appears interesting to compare the dynamics of σ-convergence in the macroregions highlighted above. There is a σ-divergence in the eastern regions (the Urals, Siberian and Far Eastern FDs). However, the σ-convergence trend in the West is more pronounced than across Russia. The Far Eastern FD regions are the main contributor to the divergence in the East. The western regions (excluding the North Caucasian FD) did not record any standard deviation in 2013–2015, which was typical for the East and entire Russia.

5. SUMMARY

In the course of our study, we examined a problem of regional inequality by measuring the conditional and unconditional convergence of the regions of the Russian Federation in terms of economic growth rates using a global model and a geographically weighted regression model. For the GWR model, we analysed several different options of the spatial proximity of regions: by distance, by migration and trade flows.

Based on the results of our analysis we made the following conclusions:

1) The estimates of unconditional convergence calculated using the global model do not allow us to explicitly answer the question about the convergence of economic growth

rates. However, when we divided Russia into 'West' and 'East', we identified the convergence processes in the regions of western group. Based on the results of the GWR model application, we can state a decrease in the rate of regional convergence in terms of economic growth rates when moving from west to east. In addition, the North Caucasian FD is also somewhat distinguished by its low convergence rates. In the context of spatial analysis, this situation can be explained by the weaker ties of the eastern regions, both with their neighbours (due to the large distances between the regions) and with the more dynamically developing regions of the western part (due to the low values of trade and migration flows between the Siberian, Far Eastern regions, and the western regions).

2) The assessment identified a statistically significant relation between the development rates of territories and their initial condition. However, broken down by regions, the results of unconditional convergence modelling appear uneven: the unconditional convergence seems to be typical primarily for the western regions. The convergence was very slow. The coefficient of unconditional convergence is statistically significant but small – 0.4%. However, the analysis of conditional convergence showed that all regions converged to sustainable growth paths with a slightly higher coefficient of conditional convergence of 1.1% and the period of semi-convergence of 58 years.

3) The use of trade and migration flows matrices instead of the distance matrix reduces the ambiguity of the obtained results. Thus, when using the migration matrix, all regions tend to converge in terms of economic growth rates. In the case of conditional convergence, the hypothesis for significance of coefficients is rejected for the distance matrix and trade flows matrix. The signs of obtained β-coefficients are in line with economic logic. According to the built model, all regions converge to their paths of sustainable growth. The difference in these paths is related to the initial reserves of labour, capital and the level of technological progress, which was evaluated indirectly using the indicator of R&D costs.

4) The insignificance of most coefficients of conditional β-convergence equations (other than those for the share of public sector in GRP and interest rate) suggests the need to select factorial features individually for each region based on the specific structure of its economy. To some extent, the share of public sector is an indirect measure of the regional economic development level. On average, higher rates of convergence will be observed in the regions with a lower share of the public sector, that is, with more mature industries of the regional economy unrelated to public services. The number of meaningful coefficients for interest rate increases appreciably (from 5 to 64) when we switch from

the distance matrix to the trade flows matrix. Probably, consideration of trade relations makes it possible to identify the effect of this factor on the per capita GRP growth pace more clearly. All other things being equal, regions with softer monetary conditions are to show higher economic growth.

5) The convergence process of Russian regions is likely to be noticeably impacted by Moscow and the Moscow Region. First, the exclusion of these areas results in lower (on average) rates of β-convergence and a much smaller number of meaningful coefficients for such variable. Second, by rates of σ-convergence, the regions are divided in two clusters: West (σ-convergence) and East (σ-divergence). It appears that the proximity to the metropolis (spatial, trade, and migration) directly translates into the intensity of convergence process in a region.

Given the above, the best solution for Russian environment is to impose additional spatial restrictions on the GWR model, e.g. to use dummy variables to exclude the nearest eastern neighbours from the western regions' bandwidth, and vice versa. The relevant bandwidth reduction should be compensated with the nearest regions from the 'domestic' cluster. When the bandwidth is wider than the number of regions in the cluster, the regression should cover the nearest regions from the 'foreign' cluster.

The results of the study enabled us to define the main factors influencing the rates of convergence of regions to the paths of sustainable growth, taking into account their spatial interaction, which can be used to analyse the regional heterogeneity of the monetary policy effects and to define public policy measures to narrow regional gaps.

REFERENCE

1. Andrienko Y., Guriev S. (2004) Determinants of interregional mobility in Russia. Evidence from panel data. Economics of Transition. Vol. 12, № 1, pp. 1–27.
2. Andrienko Yu., Guriev S. Development of an applied model of internal and external migration flows of the population for the regions of the Russia Federation. Report on the project within the framework of the Program for Support of Independent Economic Analytical Centers of the MNF. – M.: TSEHFIR, 2006. (In Russian)
3. Balash O.S. Convergence Spatial Analysis of Russia's Regions //Izvestiya of Saratov University. New Series. Series: Economics. Management. Law. – 2012. V. 12, N. 4 – pp. 45 – 52. (In Russian)
4. Balash V., Balash O., Faizliev A., Chistopolskaya E. (2020) Economic Growth Patterns: Spatial Econometric Analysis for Russian Regions. Information. № 11, 289.

5. Barro R.J., Sala-i-Martin X. (1991) Convergence across States and Regions. Brookings Papers on Economic Activity. № 1, pp. 107–182.
6. Bernard A.B., Durlauf S.N. (1995) Convergence in International Output. Journal of Applied Econometrics. Vol. 10, pp. 97–108.
7. Brunsdon C., Fotheringham A.S., Charlton M.E. (1996) Geographically weighted regression: A method for exploring spatial nonstationarity. Geographical Analysis. Vol. 28, № 4, X-298.
8. Brunsdon C., Fotheringham A.S., Charlton M. (1999) Some notes on parametric significance tests for geographically weighted regression. Journal of Regional Science. Vol. 39, № 3, pp. 497–524.
9. Buccellato T. (2007) Convergence across Russian regions: a spatial econometrics approach. CSESCE Working Papers. № 72, p. 26.
10. Carluer F., Sharipova E. (2004) The unbalanced dynamics of Russian regions: towards a real divergence process. East-West Journal of Economics and Business. Vol. 7. № 1, pp. 11–37.
11. Eckey H., Kosfeld R., Türck M. (2005) Regional Convergence in Germany: A Geographically Weighted Regression Approach, Spatial Economic Analysis. № 2, pp. 45–64.
12. Flowerden R., Aitkin M. (1982) A method of fitting the gravity model based on the Poisson distribution. Journal of Regional Science. Vol. 22, № 2, pp. 191–202.
13. Gichiev N. S. Regional convergence of economic growth: spatial econometrics. // Regional Economics: Theory and Practice. – 2018. – V. 16. N. 1. – pp. 58-67. (In Russian)
14. Gluschenko K. P. Methodologies of analyzing inter-regional income inequalities. Region: Economics and Sociology, 2010, - N.1(1), pp. 88-119. (In Russian)
15. Gluschenko K. P. Studies of Income Inequality among Russian Regions. Region: Economics and Sociology, 2010, - N.4, pp. 54-87 (In Russian)
16. Gluschenko K. P. Myths about beta-convergence // The Journal of New Economic Association, 2012, N.4(16), pp. 27 – 44. (In Russian)
17. Ivanova V.I. Regional Convergence of Income: Spatial Analysis: Spatial Economics // Spatial Economics, 2014, N. 4. (In Russian)
18. Kolomak E.A. Models of the regional policy: convergence or divergence. Reg. Econ. Theory Pract. 2009, 9, 113 – 120. (In Russian)
19. Kholodilin K., Oshchepkov A., Siliverstovs B. (2009) The Russian Regional Convergence Process: Where Does It Go? DIW Berlin, German Institute for Economic Research. Discussion Papers of DIW Berlin.

20. Krugman P. (1991) Increasing Returns and Economic Geography. Journal of Political Economy. Vol. 99. № 3.
21. Ledyaeva S., Linden M. (2008) Determinants of economic growth: empirical evidence from Russian regions. European Journal of Comparative Economics. Vol. 5. № 1, pp. 87–105.
22. Lee E.S. (1966) A Theory of Migration. Demography. Vol. 3(1), pp. 47–57.
23. LeSage J.P., Pace R.K. (2010) Spatial Econometric Models. In: Fischer M., Getis A. (eds) Handbook of Applied Spatial Analysis. Springer, Berlin, Heidelberg.
24. Mishura A. V. The estimation of gravity models of Russian interregional trade in monopolistically competitive goods // Vestnik NGU. Series: Social-economics science. N. 4. - pp. 52- 58. (In Russian)
25. Ostbye S., Westerlund O. (2007) Is Migration Important for Regional Convergence? Comparative Evidence for Norwegian and Swedish Counties, 1980–2000. Regional Studies. Vol. 41. № 7, pp. 901–915.
26. Quah D. (1993) Empirical Cross Section Dynamics in Economic Growth. European Economic Review. Vol. 37, pp. 426–434.
27. Quah D. (1996) Empirics for Economic Growth and Convergence. European Economic Review. № 40, pp. 1353–1376.
28. Solanko L. (2003) An Empirical Note on Growth and Convergence Across Russian Regions. BOFIT. Discussion Papers. № 9.
29. Solow R. (1956) A Contribution to the Theory of Economic Growth. Quarterly Journal of Economics. Vol. 70, pp. 65–94.
30. Tolmachev M.N. Theoretical and empirical approaches to the agricultural production convergence. // Bulletin of the Volgograd State University. V. 1. N.20. 2012. (In Russian)
31. Vakulenko E.S. Does migration lead to regional convergence in Russia? // Vestnik NGUEU. – 2013. – N. 4. – p. 239-264. (In Russian)