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Spatial Analysis of Regional Productivity Based on Β-Convergence Models

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ABSTRACT

The convergence of productivity in the regions means their sustainable development and the protection of the national economy from external challenges. Accelerating digitalization of society expands the sphere of services and exacerbates the issue of measuring the productivity of the region's economy and the impact on it of internal knowledge factors (including innovations). The spatial heterogeneity of Russian regions, when identifying interrelationships, requires taking into account the spatial aspect. The main aim of the work is to assess the conditional β-convergence of the gross regional product per capita growth rates of the employed population and the impact of technological innovations on productivity in the regional economy on the basis of spatial-econometric models. Research hypotheses suggest that, spatial dependence contributes to the productivity growth rates convergence in the regional economy, technological innovations have a positive impact on productivity growth in the regional economy. The study uses Moran and Geary global spatial correlation indices, Moran local spatial correlation index, econometric model with spatial auto-regression lag, econometric model with spatial interaction in errors, maximum likelihood estimation. We revealed the spatial positive correlation of labor productivity, while the growth rates of real costs for technological innovations have a spatial negative correlation (strong regions "pull" innovations from weak neighbors). Authors didn’t confirm the impact of the patents number for inventions and the use of the Internet in organizations on the growth rate of the gross regional product. Based on spatial-econometric models of panel data analysis, no β-convergence of productivity growth rates in the regions was found.

INTRODUCTION

The digital transformation of the economy creates favorable conditions for the service sector development, changes the methods of its measurement and raises new questions for researchers. The service sector increases its share in the economy and makes the modern economy less tangible and convenient to measure through GDP, which was originally intended to take into account the sphere of material production and production opportunities (Coyle, 2014; Rymarczyk, 2020). The issue of measuring productivity in the regional economy in the context of the economy's digital transformation is becoming the subject of scientific research. In the context of measuring productivity in a regional economy, the mutual influence of regions on each other can become a significant external determinant, increasing the convergence of the growth rates, the mobility of factors and production results (Sobierja and Metelski, 2021). Therefore, the inclusion of a spatial lag in econometric models will allow obtaining unbiased estimates of the explanatory factors.

Convergence of productivity growth rates in the economy means faster growth of regions with low productivity in the future. According to the Solow-Sven theory in the work of P. Barro (1990), the term β-convergence of economic growth is introduced as a negative dependence of growth rates on the initial level of development, that is poor regions have higher economic growth rates than rich ones. In the long term, this should lead to the alignment of regional levels of economic development. According to the theory of endogenous growth, technological progress is the only source of sustainable long-term economic growth. However, the technological inequality of the regions hinders balanced economic development and leads to inequality in the distribution of income and in the welfare of the nation. The interest in forecasting possible inequality in regional development under the assumption of the income fair distribution determined the implementation of the study in the context of β-convergence. The main purpose of the article is to assess the unconditional and conditional β-convergence of the gross regional product growth rates per capita of the working-age population and the impact of technological innovations on productivity in the regional economy on the basis of spatial-econometric models. *Scientific novelty: spatial correlation and lack of convergence of performance in regions based on panel data of Russian regions from 2009 to 2018 were measured for the long term.* The research methodology is largely based on the works of (Barro and Sala-i-Martin, 1992; Rey and Montouri, 1999).

The study assumed that spatial dependence contributes to the productivity growth rates convergence in the regional economy, while technological innovations have a positive impact on productivity growth in the regional economy. As a result of econometric calculations, the need to take into account spatial externalities in econometric models of β-convergence of average productivity growth rates in regions is confirmed, local spatial clustering of regions in Yamalo-Nenets Autonomous district, Khanty-Mansi Autonomous district, Nenets Autonomous district with similar values of variables is revealed: regions with high growth rates of variables are surrounded by neighbors with the same high growth rates. σ-convergence and β-convergence of the average productivity growth rates in the regions in 2009-2018 were not detected. Statistically significant global Moran spatial correlation indices and estimates of the spatial autoregressive coefficient indicated the cooperation of regions in the production of gross regional product per capita of the working population and the competition of regions in the costs of technological innovations. The study revealed the influence of technological innovations costs per capita of the employed population, the volume of investment in fixed assets, the number of university students on the productivity growth rate in the economy. The expected correlation between the gross regional product per capita of the working-age population and the number of issued patents for inventions, the use of the Internet in organizations was not confirmed. *Practical significance: the main conclusions of the article can be used in scientific and practical activities in the policy formulation to stimulate productivity in the regions.*

The article includes the following sections: Literature review, Method and data, Results, and discussion, and Conclusion. The first section presents a review of the literature regarding the results of the β-convergence of the gross regional product growth rates study, taking into account the spatial dependence, it formulates the hypotheses of this study. The second section describes the used econometric models with a spatial component, presents descriptive statistics of variables and justifies the choice of independent variables for the models. The third section contains a discussion of the results of measuring spatial correlation and evaluating models. The conclusion reflects the conclusions of the study.

1. LITERATURE REVIEW

Many researchers have tested the β-convergence hypothesis of economic growth on Russian regional data. In the work of L. Solanko (2003) according to the data for 1992-1998 and from 1999 to 2001, the author confirms a strong σ-divergence of the gross regional product per capita simultaneously with β-convergence. Y.Andrienko, and S. Guriev (2003) concluded that regions with common borders are characterized by a higher degree of convergence in terms of GDP per capita due to increased mobility, knowledge dissemination and trade relations. The conclusion that there is no conditional convergence of the gross regional product per capita according to the data from 1993 to 2000 is made in the work of D. Berkowitz and d. DeJong D. (2005). In the work of T. Buccellato (2007), according to data for the periods from 1992-1998 and 1999-2004, a conditional convergence of the growth rates per capita was found, the author made the conclusion on the role of hydrocarbon production in increasing divergence, about the insignificance of spatial effects from research and development expenditures. In the work of K. Kolomak (2010) according to the data for the period from 1996 to 2008, the author discovers a convergence of the gross regional product growth rates and comes to the conclusion that the effects of interregional cooperation dominate over the effects of interregional competition, and if positive externalities of economic growth prevail in the European part of the country, then negative externalities dominate in its eastern part of it.

In the study of Ivanova V. (2014) according to data from 1996 to 2012 the convergence of the regional average per capita income of the population was confirmed, a significant influence of the spatial features of the regions on the characteristics of convergence was also established. In the work of O. Lugovoy et al. (2007), according to data for the period 1996-2004, it is shown that spatial cooperation of regions prevails over competition and the formation of relatively rich and dynamically developing macroregions and relatively underdeveloped periphery is predicted in the long term, the hypothesis of the presence of conditional convergence is not rejected. Also, in the work of K. Kholodilin et al. (2012) the authors find a positive spatial correlation of regions and a strong regional convergence between high-income regions, conclude that the rate of regional convergence in Russia decreases after taking into account spatial effects. The same conclusion about the positive spatial impact on neighboring regions in economic growth according to data from 1996 to 2013 was obtained in the work of V. Ivanova (2018). The work of O. Demidova and D. Prokopov (2019) is closed to the study in terms of the methodology, which tests the hypothesis of conditional convergence in four types of economic activity (industrial production, construction, agriculture, retail trade), the authors found convergence only in retail trade in 2000-2017 and in industrial production in 2009-2017.

Economic development based on low cost and natural resources cannot last for a long period. Independent innovations play an irreplaceable role in the modern technologically intensive development. Theoretical and empirical studies have revealed a spatial dependence in regional innovation activity: (Fischer and Varga, 2003, Qiu et al., 2020).

Based on the study of R. Barro (2004) and the aims of the work, two main hypotheses can be developed:

- spatial dependence contributes to the productivity growth rates convergence in the regional economy;
- technological innovations have a positive impact on productivity growth in the regional economy.

To test the first hypothesis, it is proposed to use the spatial autoregressive coefficients ρ. To test the second hypothesis, it was proposed to check the statistical significance of the corresponding regression coefficient in the models of conditional β-convergence.

2. METHOD AND DATA

The data sample was obtained from the statistical edition: "Regions of Russia. Socio-economic indicators" for 83 regions of the Russian Federation for the period from 2009 to 2018. The Republic of Crimea and the city of Sevastopol were not included in the sample due to changes in the administrative borders of Russia. Descriptive statistics of variables is presented in Table 1.

Table 1. Descriptive statistics of variables

Variables	*Mean*	*St. D.*	*Min*	*Median*	*Max*
The average growth rate of the real gross regional product per capita of the working-age population in 2009 prices	1,01	0,03	0,91	1,00	1,08
Expenditures on technological innovations per capita of the working-age population, thousand rubles	1,11	0,14	0,71	1,12	1,52
Investments volume in fixed assets per capita of the working-age population	83,41	50,15	26,35	73,86	305,07
Number of issued patents for inventions, pcs.	261,80	314,58	0,00	159,50	1994,00
Number of university students, thousand people	246,32	83,94	44,11	247,99	549,01
The use of the Internet in organizations,%	88,60	6,34	68,40	89,85	98,10

Source: obtained by the authors according to the data of the "Regions of Russia. Socio-economic indicators. 2018" edition.

Spatial-econometric models based on panel data allow taking into account possible variations of the gross regional product per capita of the working-age population to measure the β-convergence of productivity in the regions in the long-term time period. The research is largely based on the works of (Barro and Sala-i-Martin, 1992; Rey and Montouri, 1999). Dependent variables are the logarithm of the average growth rate of the real gross regional product per capita of the working-age population in 2009 prices as measure the conditional β-convergence of productivity in the regional economy (Barro and Sala-i-Martin, 1992; Tsionas, 2010; Cuaresma et al. 2014). The variable of interest are the expenditures on technological innovations per capita of the working-age population (Romer, 1994). To control the heterogeneity of convergence, control explanatory variables of the matrix X are: investments volume in fixed assets per capita of the working-age population, thousand rubles, Number of issued patents for inventions, pcs. Number of university students, thousand people, the use of the Internet in organizations, %. Below the authors explain such a sample.

This article uses models in which productivity is studied from the perspective of knowledge determinants of economic growth, which are a kind of public good, their effects go beyond the administrative boundaries of territories (Krugman, 1991, Romer, 1994; Aghion and Howitt, 1992).

Theories of economic growth have shown the key role of investment and knowledge capital in achieving economic growth (Krugman P. 1991). The spatial effects of investments were measured in the works of H. Huang and Y. Wei (2016), O. Demidova and D. Prokopov (2019). Therefore, the model includes the volume of investments in fixed assets per capita, thousand rubles, as a characteristic of the economic development of the region.

A positive relationship between economic growth and human capital has been found in a number of studies (Lugovoy et al., 2007; Cuaresma et al. 2014; Yunfu and Aiya, 2019). A positive relationship between the namber of corporate patent applications as a direct result of the R&D process has also been noted in studies (Scherngell et al., 2014; Qiu et al., 2020). In this study, the number of issued patents for inventions, pcs, and the number of university students, thousand people, were used to measure the knowledge capital and the human capital stock.

The link between access to websites and telecommunications and economic growth has been identified for many regions of Europe (Scherngell et al. 2014, Cuaresma et al. 2014). Therefore, we include the indicator of Internet usage in organizations, %, in the model. To identify spatial dependence, global Moran's indices are defined (Anselin, 1988):

$$I(X) = \frac{N}{\sum_{i,j} w_{ij}} \cdot \frac{\sum_{i,j} w_{ij}(X_i - \bar{X})(X_j - \bar{X})}{\sum_i (X_i - \bar{X})^2},$$

where N – the number of regions, $\bar{X}$ - average value of an indicator X , w_{ij} - elements of the boundary matrix of weights, W indicates the amount for all w_{ij}.

The Moran index takes values in the range of [-1; 1]. A positive spatial correlation coefficient means that a growing region contributes to the growth of its neighbors; a negative value means that a growing region "pulls" the resources of its neighbors. The insignificance of the coefficient indicates the absence of processes interrelation in different regions.

To identify local spatial dependence, local Moran's indices are defined (Anselin, 1995):

$$I_{Li} = N \cdot \frac{(X_i - \bar{X})\sum_i w_{ij}(X_j - \bar{X})}{\sum_i (X_i - \bar{X})^2}$$

If a given region differs significantly from its neighbors (outlier), then the negative value of the local Moran's index belongs to it. A positive correlation indicates that the region is similar to neighboring territories (cluster). The larger the LISA value in modulus, the stronger the similarity / difference between the region and its neighbors. According to the concept of σ-convergence (reduction of variance), measuring the heterogeneity of economic growth and the costs of technological innovations in regions involves the analysis of spatial variance over time based on the coefficient of variation or standard deviation (Rey and Montouri, 1999; Barro and Sala-Martin, 2004; Ivanova, 2014). β-convergence usually leads to σ-convergence, but this process can be hindered by other processes and external shocks that cause an increase in variance (Barro and Sala-Martin, 2004).

In the case of unconditional β-convergence based on the neoclassical growth theory, all regions are identical in structure and possess the same technologies, have the same steady-state equilibrium (steady-state level) for all regions, but differ only in initial conditions. In this case, poor regions grow faster than rich ones and catch up with them in the long run, and in a stable state, regions have the same growth rate. Conditional β-convergence models test the hypothesis that there is a negative link between the average growth rates and the starting level of productivity in 2009, assuming that the regions have their own stable state. To control the heterogeneity of convergence, the conditional β-convergence model includes characteristics of regional differences in the levels of equilibrium stable states-explaining the variables of the X matrix.

To empirically verify the relationship in the R software environment, the maximum likelihood method is used to evaluate β-convergence models with a spatial component (splm package) of the SAR and SEM type on panel data (Anselin, 1988; Barro and Sala-i-Martin, 1992; Vakulenko, 2016).
SAR-model with spatial autoregressive lag:

$$\frac{1}{T}\ln\frac{y_{it_{0+T}}}{y_{it_0}} = \alpha_i + \delta_{t_{0+T}} + \beta \ln y_{it_0} + \sum_{k=1}^{K}\gamma_k X_{kit} + \rho W_{ij} \ln\frac{y_{it_{0+T}}}{y_{it_0}} + \varepsilon_{i,t_{0+T}} \quad (1)$$

where i=1,...83 – region number, $[t_0+T]$ – convergence period from 2009 to 2018, $y_{i,t0}$ – GRP per capita of the working-age population in region *i* at the initial moment of time (2009), k – explanatory variable number, K – number of explanatory variables, α_i – vector of regional fixed effects, which allow to control for unobserved spatial heterogeneity, δ_{t0+T} – time fixed effects, set by a number of dummy variables for years, is a time effect in order to control for common country factors affecting dynamics of considering factors, β – parameter to be estimated for the GRP per capita of the working-age population at the initial moment of time (2009), γ_k - parameters to be estimated for explanatory variables; W_{ij} - boundary weighting matrix for dimensions (N=83×N=83), ρ – spatial autoregressive coefficient, $\varepsilon_{i,t0+T}$ – random error, which are normally distributed. β represents the convergence. If β<0, then there is conditional beta convergence. This means that poorer regions have higher growth rates than richer regions — which is why they are able to 'catch up'. SEM-model with spatial interaction in errors with fixed effects:

$$\frac{1}{T}\ln\frac{y_{it_0+T}}{y_{it_0}} = \alpha_i + \delta_{t_{0+T}} + \beta\ln(y_{it_0}) + \sum_{k=1}^{K}\gamma_k X_{kit} + \lambda W\varepsilon_{i,t_0+T} + u_{i,t_0+T} \qquad (2)$$

SEM-model with spatial interaction in errors with random effects:

$$\frac{1}{T}\ln\frac{y_{it_0+T}}{y_{it_0}} = \alpha_i + \delta_{t_{0+T}} + \beta\ln(y_{it_0}) + \sum_{k=1}^{K}\gamma_k X_{kit} + \lambda W\varepsilon_{i,t_0+T} + v_{i,t_0+T} \qquad (3)$$

where λ – spatial autocorrelation coefficient for shock, $v_{i,t_0+T} = \mu + u_{i,t_0+T}$ (Kapoor et al. 2007)

The dependent variable autoregression coefficient ρ for the spatial lag allows one to identify the influence of the gross regional product per capita of the working-age population in other regions on the studied region. The statistical insignificance of the spatial autoregression coefficient means that the processes of increasing gross regional product per capita of the working-age population in different regions are not related to each other, a positive value indicates regional cooperation, and a negative value indicates regional competition. The spatial autocorrelation coefficient for shock λ reveals the influence of the spatial structure of errors. The statistical insignificance of λ means that the shocks of neighboring regions that affect the productivity growth rates in a given region are not related to each other.

3. RESULTS AND DISCUSSION

Local Moran indices confirmed the regional local spatial clusters with a higher level of the gross regional product per capita of the working-age population: Yamalo-Nenets Autonomous district, Khanty-Mansi Autonomous district, Nenets Autonomous district. Local spatial clusters of regions similar to neighboring territories were found in the Ural Federal District, the Siberian Federal District, Northwestern Federal District in terms of the expenditures on technological innovations per capita of the working-age population (Figure 1).

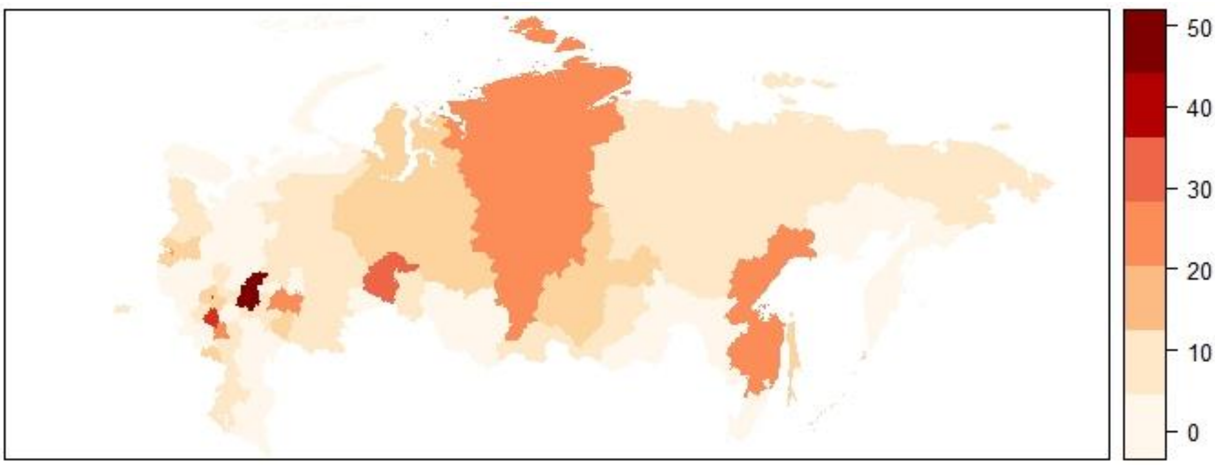

Figure 1. Cartogram of technological innovations costs per capita of the employed population, in 2019, thousand rub.

Source: obtained by the authors according to the data of "Regions of Russia. Socio-economic indicators. 2019" edition.

Most of these clusters are characterized by the orientation of the economy to the raw materials extraction. The predominance of costs for technological innovations is observed in the regional clusters of the Urals and Siberia, which have a raw material orientation of the economy, as well as in Moscow. The Moran diagram (Figure 2) shows that most regions are concentrated in the LL quadrant (weak regions surrounded by weak ones) and in the LH quadrant (weak regions surrounded by strong ones). Most of the industrial regions of central Russia with a high population density belong to clusters with low costs for technological innovations per capita of the working-age population.

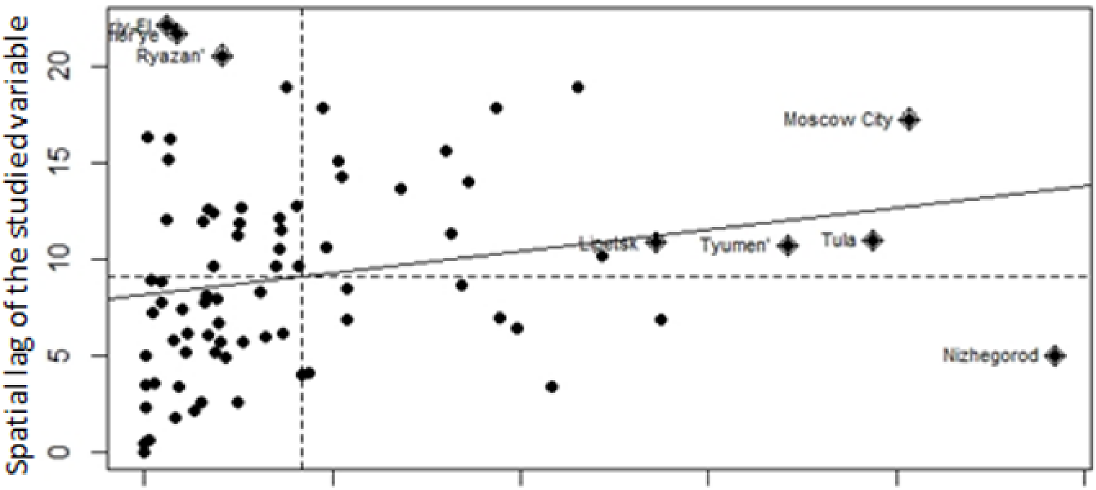

Figure 2. Spatial diagram of the technological innovations costs per capita of the employed population, thousand rubles, in 2019

Source: obtained by the authors according to the data of "Regions of Russia. Socio-economic indicators. 2019" edition.

Global spatial correlation indices demonstrated the presence of a positive spatial correlation of the gross regional product per capita of the working-age population, which means that strong regions contribute to the growth of their neighbors (Table 2).

Table 2. Global Moran spatial Correlation Indices for GRP per capita of the working-age population

Index	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
The gross regional product per capita of the working-age population										
Moran Index	0,345***	0,344 ***	0,332 ***	0,314 ***	0,301 ***	0,356 ***	0,347 ***	0,362 ***	0,367 ***	0,349 ***
Geary Index	0,704***	0,715 ***	0,724 ***	0,759 ***	0,787 **	0,755 ***	0,753 ***	0,733 ***	0,793 **	0,767 **
The expenditures on technological innovations per capita of the working-age population										
Moran Index	0,013	- 0,271 *	- 0,291 *	- 0,264 *	- 0,232 *	- 0,118 *	0,034	0,043	- 0,115 *	0,031
Geary Index	0,999	1,273	1,233	1,226	1,251	1,148	0,950	0,959	1,221	1,024

Notes: *** p<0.01, ** p<0.05, * p<0.1.

Source: obtained by the authors according to the data of "Regions of Russia. Socio-economic indicators. 2019" edition.

As demonstrated on the graphs (Figure 3), there is no tendency to decrease the coefficients of variation, which means that there is no convergence of regions in terms of the average growth rate of the real gross regional product per capita and the average growth rate of the costs of technological innovations per capita.

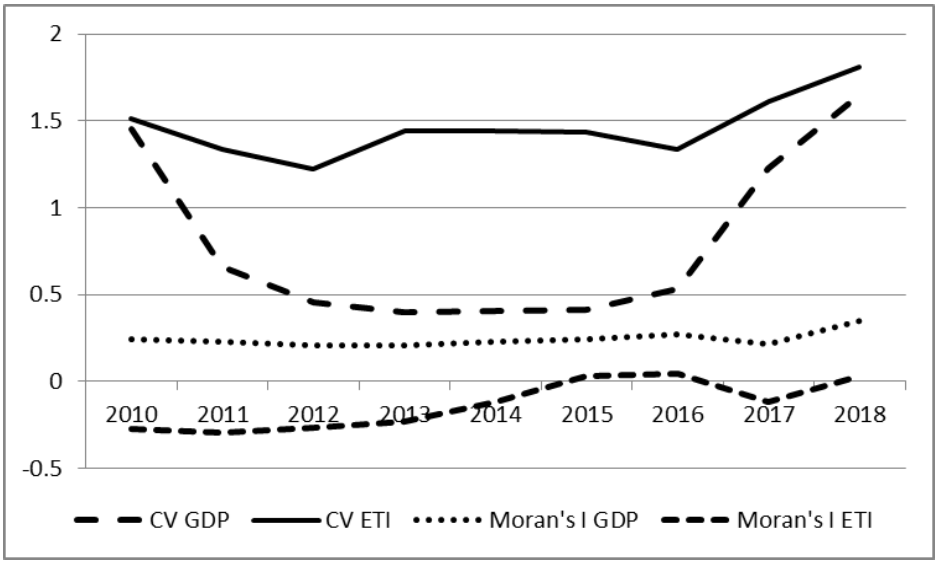

Figure 3. Dynamics of changes in the coefficient of variation and the global Moran index for dependent variables

Source: obtained by the authors according to the data of "Regions of Russia. Socio-economic indicators. 2019" edition.

Both specifications of the β-convergence models of the average real gross regional product per capita growth rate of the working-age population with a spatial component (Table 3) showed the absence of a β-convergence process in 2009-2018. The convergence of the levels of development of regions, taking into account spatial externalities, has not been confirmed. The expected correlation between the gross regional product per capita of the working-age population and the investments volume in fixed assets per capita, the expenditures on technological innovations, the number of university students, was confirmed.

Table 3. Evaluation results of the β-convergence models of the average productivity growth rate in the Russian regions

Regressors	*Without a spatial component*			*With a spatial component*	
	OLS	*FE*	*RE*	*SAR_RE*	*SEM_RE*
The logarithm of the average growth rate of the gross regional product per capita of the working-age population in 2009 prices	-2.345e-02*		-2.658e-02	-2.749e-02	-2.789e-02
Expenditures on technological innovations per capita of the working-age population, thousand rubles	2,679 e-04**	3,674 e-04 **	3,267e-04**	3,689e-04	3,563e-04**
Investments volume in fixed assets per capita of the working-age population	2.453e-04***	4.578e-04 ***	3.342e-04 ***	3.563e-04	3.478e-04***
Number of university students, thousand people	2.673e-04***	3.894e-04 ***	3.567e-04 ***	2.458e-04	2.589e-04***
Number of issued patents for	9.563e-06	-1.237e-05	-2.452e-07	-1.348e-07	3.367e-06

inventions, pcs.					
The use of the Internet in organizations,%	3.783e-04	2.454e-04	1.784e-04	6.457e-05	-3.784e-04
Intercept	5.583e-02		4.569e-02	6.569e-02	1.378e-01
Time lag				3.673e-02***	2.569e-02***
Spatial lag (lambda)					0.267***
Spatial lag (rho)				0.679***	
p-value(F)	< 2.22e-16	2.22e-16			
Adj. R^2	0.167	0.160	0.245		
AIC	-584	-476	-763	-1706	-1895
Hausman test (p-value)			2.22e-16	0.051	< 2.4e-16
n	747	747	747	747	747

Notes: *** p<0.01, ** p<0.05, * p<0.1.

Source: obtained by the authors according to the data of "Regions of Russia. Socio-economic indicators" edition.

The expected correlation between the gross regional product per capita of the working-age population and the number of issued patents for inventions, the use of the Internet in organizations was not confirmed. This can be explained by the high proportion of widespread use of telecommunications technologies, and, at the same time, low results of inventions in the regions. The models showed a statistically significant positive spatial autoregressive p coefficient for the average growth rate of the gross regional product per capita. This confirms the hypothesis about the spatial influence of neighboring regions on this one and indicates the cooperation of regions: if the average growth rate of the gross regional product in one region increases, then similar changes will occur in the neighboring ones, that is, strong regions "pull" the weak ones after them. Also, the models (with the exception of SAC_RE) demonstrated a statistically significant positive spatial autocorrelation coefficient for shock. This once again confirms the cooperation of the regions.

CONCLUSIONS

The authors confirmed the need to take spatial effects into account in econometric studies of the modern digital economy growth rates. Regions clustering according to the growth rates of the real gross regional product per capita is characterized by a spatial positive correlation (strong regions contribute to the growth of their neighbors), while the growth rates of real costs for technological innovations have a spatial negative correlation (strong regions "pull" innovations from weak neighbors). Using spatial econometrics models, the study reveals the absence of β-convergence of average productivity growth rates in the regions. This means that this process is hindered by internal and external economic shocks that cause an increase in variance, which correlate with the explanatory variables and have an impact on groups of regions. A conditional β-divergence in the growth rate of expenditures on technological innovations in the short term is revealed. This predicts higher short-term growth in regions with higher initial levels of technological innovation, assuming that the regions have their own sustainable state. At the same time, spatial cooperation of regions has emerged in recent years. A statistically significant positive spatial autoregression p coefficient for the short term forecasted the cooperation of regions in terms of the technological innovations' growth: clusters of technologically growing regions "pull" their neighbors (Bagautdinova and Kadochnikova, 2020). In the absence of new shocks, the variance will gradually return to the value that characterizes the stability. The models showed a statistically significant impact of technological innovations costs per capita of the employed population, the volume of investment in fixed assets, the number of university students on the productivity growth rate in the economy. The positive spatial impact of productivity in neighboring regions on this region was found. Therefore, in order to manage problematic regions through the mechanism of cooperation, it is advisable to influence the growth of labor productivity in neighboring leading regions.

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