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Regional convergence in Russia: Estimating an augmented Solow model

Aleksey Oshchepkov[1], Hartmut Lehmann[2] and Maria Giulia Silvagni[3]

Abstract

This paper studies convergence in per capita gross regional products across Russian regions in the period from 1996 to 2017. By applying the system GMM technique we estimate growth equations that are directly derived from the classic Solow model, augmented with human capital and migration and considering possible spatial effects. Our main estimates establish a convergence rate of around 2% per year. While interregional migration and interdependencies of the growth of Russian regions contribute to the convergence process, the role of human capital is ambiguous: when we employ system GMM we do not find any significant impact of human capital on regional growth no matter how we measure human capital, while pooled OLS estimates establish a positive contribution.

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1. Introduction

The famous Solow model (Solow, 1956) predicts that poor countries grow faster than rich countries and will thus eventually catch up with them. However, a large body of empirical

[1] National Research University Higher School of Economics (Moscow, Russia), Centre for Labour Market Studies, Senior Research Fellow, E-mail: aoshchepkov@hse.ru Address: 101000, ul. Myasnitksaya, 20, Moscow, Russia. Phone: +74956258714 (**corresponding author**).
[2] Leibniz Institute for East and Southeast European Studies and University of Regensburg, Vice-Director and Professor of Economics; IZA Institute for Labor Economics (Bonn, Germany), Program Coordinator. E-mail: lehmann@ios-regensburg.de
[3] University of Bologna, E-mail: mariagiulia.silvagn2@unibo.it

literature shows that convergence occurs only in homogenous samples of countries, while in larger and more heterogeneous samples incomes converge only after controlling for differences in certain macro-level parameters. It is a remarkable empirical fact that in many cases the estimated rate of convergence is close to 2% per year, a regularity sometimes called 'the iron law of convergence' (Abreu et al., 2005; Gennaioli et al., 2014; Barro, 2015).

An important variant of convergence analysis is the convergence of gross regional products (GRP) per capita within one country. Regional convergence analysis not only fulfills the *ceteris paribus* condition better than cross-country analysis, it is also relevant for policy. Raising the standard of living of poor regions in a country and smoothing cross-regional income disparities is an important policy aim, since large disparities within a country can be destabilizing and hamper overall growth (Shankar and Shah, 2003).

Russia is a particularly interesting object of study as it is a very large and economically heterogeneous country with income disparities between regions that are impressive by international standards (Benini and Czyzewski, 2007; Badunenko and Tochkov, 2010). For example, in 2015, the top 5 regions in the country had GRPs per capita (in purchasing power parity) reaching the levels of rich developed economies, while the GRPs per capita of the bottom 5 regions placed them among the poorest countries of the world (World Bank, 2017). Figure 1 shows that these disparities were not only large but also persistent.

Given the importance of regional convergence in Russia, there have been many studies on this topic in recent years. However, all of them used *ad hoc* specifications when estimating growth regressions. In this paper, we develop growth functions that are well grounded in theory. Taking the classic Solow model as a point of departure, we extend this model by adding measures of human capital and migration and arrive at an augmented growth model that we then estimate using system GMM.[4]

[4] This paper studies β-convergence between Russian regions, i.e., we analyze whether there is a negative correlation between the initial income level and the subsequent growth rate. Another popular concept of convergence is σ-convergence, which is the declining dispersion of the cross-sectional distribution of income over time (see Fedorov,

Our main specification provides an estimate of the convergence rate equal to 2.2% per year, which is remarkably close to the iron law of (conditional) convergence. The role of human capital is ambiguous: when we employ system GMM, we do not find any significant impact of human capital on regional growth, no matter how we measure human capital, while pooled OLS estimates establish a positive contribution. We also find that interregional migration and spatial interdependencies contribute to the convergence process.

The paper is organized as follows. The next section embeds our research in the literature on convergence in general and across Russian regions in particular. Section 3 presents our model and Section 4 discusses the methodology we use to estimate this model and introduces the data. Section 5 is the core of the paper, where we present our results and report on robustness checks. Section 6 concludes.

2. The literature on convergence[5]

2.1 Core literature

The findings of the early empirical literature on convergence were quite clear-cut: countries with similar saving and fertility rates, levels of human capital and institutions (i.e., countries with a similar steady state) converge, while countries with differing values regarding these key variables do not. The empirical evidence hence rejected unconditional convergence, but supported conditional convergence (see Barro and Sala-i-Martin, 1991; Barro et al., 1995; Caselli et al., 1996; Aghion et al., 2005; Barro, 2015, among others).

Conditional convergence also implies that convergence across regions within a country should occur more rapidly than across individual countries, since regions tend to be more homogenous regarding the above-mentioned variables. However, Barro and Sala-i-Martin (1991)

2002; Carluer, 2005; Tochkov, 2021, among studies that applied this distributional approach in the Russian case). Although β-convergence is a necessary but not sufficient condition for the reduction of differences, examining β-convergence is directly related to theoretical growth models and provides estimates of their structural parameters.

[5] The literature survey discusses those papers in the literature that are particularly salient in the context of our study. A more extensive literature survey regarding aspects of convergence can be found in Lehmann et al. (2020), the IZA Discussion Paper version of our study.

find roughly the same 2% convergence rate when studying the long-term dynamics of per capita incomes of the 48 continental US states. Similar estimates were reported in many other studies on regional convergence in the US and other OECD countries. The most comprehensive attempt to look at regional convergence on a global scale is Gennaioli et al. (2014), who use a sample of 1,528 regions from 83 countries. The authors find convergence of about 2% per year, again in line with 'the iron law'.

2.2 Extensions: Human capital and migration

After receiving challenges from empirical research, the Solow model has acquired a number of important extensions. The now classic study by Mankiw et al. (1992) augments the original model with human capital, which produces results that are more consistent with the cross-country evidence on the variation of per capita income and also allows recovering more plausible theoretical parameters. Since then, human capital has been considered an essential factor in neoclassical growth models.

Barro and Sala-i-Martin (1991, 1992) emphasize migration as another possible driver of convergence. In a neoclassical framework with homogeneous labor, migration should increase the rate of convergence as long as labor migrates from poorer to richer countries or regions, since such migration lowers the capital-labor ratio in receiving regions and thus diminishes returns to capital per worker. When labor is not homogeneous and migrants bring human capital and thus raise productivity, migration can contribute to divergence. While in their original studies Barro and Sala-i-Martin found that migration contributes to convergence, many subsequent papers conclude that it contributes to divergence, albeit marginally (Ozgen et al., 2010).

Two papers that are close to our approach are those by Dolado et al. (1994) and Boubtane et al. (2016). Both develop a structural growth model that introduces migration and human capital, and reach similar conclusions: the dilution effect of migration on productivity is strongly reduced by the human capital migrants bring to the host country.

2.3 Spatial effects

Another strand of the literature relevant to our study deals with spatial interdependencies between regions. Failing to take these into account may lead to misleading inferences about convergence. Rey and Montouri (1999) were among the first to emphasize this issue in their analysis of convergence of incomes per capita across US states in 1929-1994. The analysis of spatial effects has been extensively developed in the subsequent literature (see Egger and Pfaffermayr, 2006; Fingleton and Lopez-Bazo, 2006; Fischer and Pfaffermayr, 2018; Lopez-Bazo et al., 2004, among others), becoming a necessary ingredient of regional convergence analysis.

2.4 Literature on regional convergence in Russia

Due to its large size and strong regional heterogeneity, Russia is attractive to scholars studying regional economic convergence. The literature already counts dozens of published journal articles and working papers, and their number is constantly growing. They cover different time periods, emphasize the role of different factors, and apply various methodologies. In this regard, providing a comprehensive and systematic review of the existing literature on Russia is a challenging task deserving a separate study. The aim of this section is more modest: First, to reflect common conclusions regarding the pattern of regional economic growth (either convergence, divergence, or neither), and, second, to highlight the factors which, according to the authors, influenced that pattern.

The common conclusion of studies examining patterns of regional economic growth in Russia in the early transition period (from the 1990s until the beginning of the 2000s) was growing economic inequality and divergence, regardless of the methodology used (Badunenko and Tochkov, 2010; Benini and Czyzewski, 2007; Berkovitz and Dejong, 2002; Carluer, 2005; Fedorov, 2002; Dolinskaya, 2002; Popov, 2001). These patterns were often considered through the lens of the more general "initial conditions vs. reforms" debate (Beck and Laeven, 2006;

Falcetti et al., 2006). While initial conditions (e.g., the overall level of economic and technological development and industrial specialization) had a visible effect on regional growth, most studies conclude that the scale of the privatization and liberalization of economics was no less important.

Studies covering the 2000s started to find some β-convergence, typically at a rate of about 1% (e.g., Drobyshevsky et al., 2005; Kholodilin et al., 2012), while studies analyzing longer data series and covering the most recent periods typically report much higher rates of β-convergence. Guriev and Vakulenko (2012) find 4.6% for 1995-2010, Akhmedjonov et al. (2013) report 10% for 2000-2008, while Durand-Lasserve and Blöchliger (2018) report about 2.5% for 2005-2015.[6] Most of these studies abandoned the "initial conditions vs. reforms" perspective and considered a wide set of variables in their empirical growth equations, including different measures of human capital (Akhmedjonov et al., 2013; Vakulenko, 2016), migration (Vakulenko, 2016), R&D and innovations (Kaneva and Untura, 2019), fiscal federal transfers and public spending (Alexeev and Chernyavskiy, 2018; Di Bella et al., 2017; Durand-Lasserve and Blöchliger 2018; Mikhaylova et al., 2018; Zubarevich, 2014), FDI (Iwasaki and Suganuma, 2015), and even the rate of regional unemployment (World Bank, 2017) and regional cultural heterogeneity (Bufetova et al., 2020). In the absence of underlying theoretical models, however, the variables included were usually determined *ad hoc* and substantially differed from study to study. The lack of theoretical underpinnings also extends to the other papers on Russian regional convergence not mentioned in this section.

3. Theoretical model

[6] Carvelli (2020) also reports β-convergence for 1995-2015 but points out that the relationship between growth rates and initial income levels may be non-linear. Lehmann and Silvagni (2013), however, established weak divergence for the years 1995–2010, while the analysis of dynamics of GRP per capita distributions over 1995-2015 conducted by Tochkov (2021) suggests growing regional polarization. However, all these studies and estimates are hardly comparable due to big discrepancies in their methodologies.

Our model of regional convergence is based on the classic Solow model augmented with human capital (Mankiw et al., 1992) and migration (Dolado et al., 1994). The economy has a Cobb-Douglas production function with labor-augmenting technological progress:

$$Y = HC^{\varphi} \cdot K^{\alpha} \cdot (A \cdot L)^{1-\alpha-\varphi}\ , \qquad (1)$$

where *Y* is output; *K* is physical capital; *HC* is human capital; *L* is labor (natives plus net immigrants); and *A* is the level of technology.

A is assumed to grow exogenously at rate *g*:

$$A_t = A_0 e^{gt}\ , \qquad (2)$$

L grows at rate (*n* + *m*):

$$L_t = L_0 e^{(n+m)t}\ , \qquad (3)$$

where *n* is the growth rate of the native population; m is the net immigration rate, and $m = \frac{M}{L}$; *M* is the net number of new immigrants.

The dynamics of physical capital are described as:

$$\dot{K} = s_k Y - \delta_k K, \qquad (4pc)$$

where s_k is the fraction of output invested, while δ_k is the depreciation rate.

The dynamics of human capital are characterized by:

$$\dot{HC} = s_{hc} Y - \delta_{hc} HC + m \cdot \varepsilon \cdot HC\ , \ (4hc)$$

where s_{hc} is the fraction of output invested in human capital; δ_{hc} is the depreciation rate of human capital; and ε is the ratio of the human capital of immigrants to natives. Immigration increases the overall amount of human capital in the region if $\varepsilon > 0$.

In terms of per effective units of labor (AL), the production function and the dynamic equations of physical and human capital can be written as:

$$\mathrm{y} = hc^{\varphi} \cdot k^{\alpha}, \quad (5)$$

$$\dot{k} = s_k y - (g + \delta_k + n + m)k\ , \qquad (6)$$

$$\dot{hc} = s_{hc} y - \big(g + \delta_{hc} + n + m \cdot (1 - \varepsilon)\big) \cdot hc\ . \quad (7)$$

Equations (6) and (7) suggest that immigration has a negative impact on economic growth in the region as migration contributes to the overall population growth $(n+m)$, which impedes the accumulation of physical and human capital (per effective labor). As a result, migration from poor to rich regions should contribute to regional convergence, which is the standard prediction of neoclassical growth theory (see Barro and Sala-i-Martin, 2004).

However, Equation (7) indicates that when $\varepsilon > 1$, migration starts to decrease the negative impact of the overall population growth on human capital in the region. Moreover, when $\varepsilon > 2$ and $|m| > |n|$, i.e., when the immigration rate is larger than the native population growth rate, the positive impact of immigration on human capital counterbalances the negative impact of the total population growth. As a result, immigration will have a positive influence on economic growth (per effective labor), which means that interregional migration may impede regional convergence.[7]

Equations (6) and (7) imply steady-state levels of physical and human capital (when $\dot{k} = 0$ and $\dot{hc} = 0$) as follows:

$$k^* = \left(\frac{s_k}{g+\delta_k+n+m}\right)^{\frac{1-\varphi}{1-\alpha-\varphi}} \left(\frac{s_{hc}}{g+\delta_k+n+m(1-\varepsilon)}\right)^{\frac{\varphi}{1-\alpha-\varphi}}, \qquad (8)$$

$$hc^* = \left(\frac{s_k}{g+\delta_k+n+m}\right)^{\frac{\alpha}{1-\alpha-\varphi}} \left(\frac{s_{hc}}{g+\delta_k+n+m(1-\varepsilon)}\right)^{\frac{1-\alpha}{1-\alpha-\varphi}}. \qquad (9)$$

Substituting equations (8) and (9) into the production function (5) and taking logs, and assuming that $\delta_{hc} = \delta_k$, gives steady-state output per effective worker (AL):

$$\ln(y^*) = \frac{\alpha}{1-\alpha-\varphi}\ln(s_k) + \frac{\varphi}{1-\alpha-\varphi}\ln(s_{hc}) - \frac{\alpha}{1-\alpha-\varphi}\ln(g+\delta+n+m) -$$
$$-\frac{\varphi}{1-\alpha-\varphi}\ln(g+\delta+n+m-\varepsilon\cdot m). \qquad (10)$$

The last term may be rewritten as:

[7] Migration may be endogenous to economic growth as faster growing regions or countries usually attract more migrants. Following the tradition of existing studies (since Dolado et al., 1994), we do not model this endogeneity explicitly within the structural model, but take it into account in our econometric analysis. Therefore, we use "reduced form" estimated coefficients to reconstruct theoretical parameters (see Section 4.1).

$$\frac{\varphi}{1-\alpha-\varphi}\ln(g+\delta+n+m-\varepsilon\cdot m)=\frac{\varphi}{1-\alpha-\varphi}\ln((g+\delta+n+m)\cdot\left(1-\frac{\varepsilon\cdot m}{g+\delta+n+m}\right))=$$

$$\frac{\varphi}{1-\alpha-\varphi}\ln(g+\delta+n+m)+\frac{\varphi}{1-\alpha-\varphi}ln\left(1-\frac{\varepsilon\cdot m}{g+\delta+n+m}\right). \quad (11)$$

Assuming that ln(1-x) ≈ -x, the steady-state output per effective worker is:

$$\ln(y^*)=\frac{\alpha}{1-\alpha-\varphi}\ln(s_k)+\frac{\varphi}{1-\alpha-\varphi}\ln(s_{hc})-\frac{\alpha+\varphi}{1-\alpha-\varphi}\ln(g+\delta+n+m)-$$

$$-\frac{\varphi}{1-\alpha-\varphi}\cdot\varepsilon\cdot\frac{m}{g+\delta+n+m}. \quad (12)$$

Finally, as noted by Mankiw et al., (1992), equation (12) may be rewritten in terms of the human capital stock:

$$\ln(y^*)=\frac{\alpha}{1-\alpha}\ln(s_k)+\frac{\varphi}{1-\alpha}\ln(hc^*)-\frac{\alpha}{1-\alpha}\ln(g+\delta+n+m)-\frac{\alpha}{1-\alpha}\cdot\varepsilon\cdot\frac{m}{g+\delta+n+m}. \quad (13)$$

In practice, the choice between equations (12) and (13) should depend on "whether the available data on human capital correspond more closely to the rate of accumulation or to the level of human capital" (Mankiw et al., 1992, p. 418).

The pace of the convergence of output to its steady-state level is given by:

$$ln(y_t)-ln(y_{t-1})=\left(1-e^{-\lambda\tau}\right)(\ln(y^*)-ln(y_{t-1})), \quad (14)$$

where τ is the period between moments t and t-1, and λ is the rate of convergence.

Finally, the theoretical growth equation capturing the dynamics of output per capita (L) toward the steady state becomes:

$$ln(y_t)-ln(y_{t-1})=-\left(1-e^{-\lambda\tau}\right)\ln(y_{t-1})+\left(1-e^{-\lambda\tau}\right)\frac{\alpha}{1-\alpha}\ln(s_{kt})+$$

$$+\left(1-e^{-\lambda\tau}\right)\frac{\varphi}{1-\alpha}\ln(hc_t)-\left(1-e^{-\lambda\tau}\right)\frac{\alpha}{1-\alpha}\ln(g+\delta+n+m)+\left(1-e^{-\lambda\tau}\right)\frac{\alpha}{1-\alpha}\varepsilon\cdot migr_t+$$

$$+\left(1-e^{-\lambda\tau}\right)Ln(A_0)+g(t-e^{\lambda t}(t-1))+\nu_t, \quad (15)$$

where $migr=\frac{m}{g+\delta+n+m}$.

4. Empirical methodology and data

4.1 Methodology

Our theoretical model from equation (15) may be rewritten as a regression as follows:

$$\Delta \ln(y_t) = \beta \ln(y_{t-1}) + \beta_1 \ln(s_{kt}) + \beta_2 \ln(hc_t) - \beta_3 \ln(g + \delta + n + m) +$$

$$+\beta_4 migr_t + regionFE + timeFE + \nu_t \, . \quad (16)$$

Compared to equation (15), this equation includes two additional variables, $regionFE$ and $timeFE$, reflecting regional and time fixed effects (FE), respectively. Since Islam (1995), it is common practice to include region (or country) FE, which control for unobserved heterogeneity of regions, in empirical growth equations. More specifically, regional FE control for unobserved differences in the initial levels of technological development ($Ln(A_0)$ in equation (15)) and for other differences such as resource endowments and geo-climatic conditions. Not taking into account unobserved heterogeneity results in an upward bias in the OLS estimate of β, which means an underestimated rate of convergence.

Time fixed effects control for the countrywide dynamics of technology (reflected in $g(t - e^{\lambda t}(t-1))$ in equation (15)) as well as for the influence of macroeconomic shocks affecting all regions in the country. This is important in the Russian case, since the period that we consider, 1996-2017, straddles both economic crises and recoveries, including the period of sanctions since 2014. [8]

Although the inclusion of regional fixed effects helps avoid omitted variable bias, it creates a bias of another sort. Regional fixed effects are correlated with lagged GRP per capita, which leads to a downward bias in the OLS estimates, known as the Hurwicz-Nickell bias (Hurwicz, 1950; Nickell, 1981). To avoid this, we estimate equation (16) using system GMM (Arrelano and Bover, 1995; Blundell and Bond, 1998), which has become the most popular approach to estimate dynamic panel data models.

[8] Additionally, time FE control for possible changes in the statistical methodology of the calculation of variables. We are aware of at least one such change. In 2011, Rosstat changed the definition for internal migration and started to take into account people who moved to another region and stayed there for more than 9 months, instead of 12 months before 2011 (Buranshina and Smirnykh, 2018).

The estimation procedure involves two steps. First, equation (16) is first-differenced. Second, the first differences of $\ln(y_{t-1})$ are instrumented not only with lagged levels of y, but also with lagged first differences. The residuals of the differenced equation should follow an AR(1) correlation process but should not exhibit an AR(2) process, since in this case the second lags may not serve as valid instruments for current values.[9]

There are additional issues related to the estimation of equation (16). The first concerns the parameters g and δ. Following Mankiw et al. (1992), many authors assume $g + \delta = 0.05$. Although there are studies that applied this assumption to analyze convergence across Russian regions (e.g., Komarova and Kritsyna, 2012; Zemtsov and Smelov, 2018), we are not aware of any that justify the use of such an assumption in the Russian case. In our study, we assume $g + \delta = 0.05$ in our main regressions but try alternative values as a robustness check.

The second issue concerns the frequency of the data used. In a cross-sectional setting, the rate of economic growth on the LHS is usually averaged over a long time span (20-25 years or even more; see, for example, Barro and Sala-i-Martin, 1991). A panel data setting allows averaging over periods of different lengths. Some recent studies including Barro (2015) and Gennaioli et al. (2014) average all variables over non-overlapping 5-year periods as averaging makes results less vulnerable to potential data errors. Since from a theoretical point of view averaging over shorter periods should give similar results (Islam, 1995), we average over 3-year non-overlapping periods in our study. As Figure 1 shows, the first period, 1996 to 1998, includes a substantial fall of GDP per capita in connection with the Russian financial crisis. This is followed by three consecutive 3-year periods of strong growth between 1999 and 2007, when real GDP per capita roughly doubled.

[9] The validity of the system GMM estimator is based on the assumption that the lagged first differences used as instruments are not correlated with regional FE. As discussed in Bond et al. (2001), this assumption is quite plausible in the context of empirical Solow-type growth models. In contrast, the first-differenced GMM (the Arrelano-Bond estimator) is problematic as output is a highly persistent series and thus its lagged levels are weak instruments for its subsequent first differences. Therefore, system GMM seems to be the best available estimator in the context of empirical growth models.

The period 2008 to 2010 encompasses the global financial crisis, which produced a large negative shock to real GDP per capita in 2009 with a recovery in 2010. The next period shows the resumption of consistent growth albeit at a lower rate than in the 2000s. Finally, the last period, 2014 to 2017, is the period of sanctions and countersanctions.

<insert Figure 1 around here>

The third issue is that our theoretical model includes GDP per employed, i.e., labor productivity, but in the empirical equations we use GDP per capita. Some studies indicate that the dynamics of GDP per capita may differ from those of labor productivity because of the different behavior of regional employment rates (Meliciani, 2006). To reconcile our theoretical model with the empirical analysis, we add the log of the employment rate (taken in differences) to the right-hand side of equation (16). Our results show that this adjustment does not affect the estimates in the Russian case.

The fourth issue that is potentially relevant in the Russian context relates to price differentials across regions. However, some previous studies on Russia show that possible adjustments of GRPs for price differentials barely affect the scale of variation in GRPs and the relative order of regions and have almost no effect on convergence results (Kholodilin et al., 2012; Durand-Lasserve and Blöchliger, 2018). This is in line with the broader international evidence (Gennaioli et al., 2014). We therefore use GRPs without price corrections.

Finally, the overall convergence process may be affected by spatial interdependencies between regions. A few previous studies have emphasized spatial correlations in the Russian case (Kholodilin et al., 2012; Demidova and Ivanov, 2016; World Bank, 2017). In order to take these into account in the econometric analysis, we follow López-Bazo et al. (2004) and introduce two spatial terms to the right-hand side of equation (16): the spatial lag of the dependent variable and the spatial lag of the initial level of GRP per capita. Therefore, the extended growth equation takes the form:

$$\Delta \ln(y_t) = \beta \ln(y_{t-1}) + \beta_1 \ln(s_t) + \beta_2 \ln(hc_t) - \beta_3 \ln(n + g + \delta) + \beta_4 migr_t + region\ FE + $$
$$+ time\ FE + \beta_5 W \cdot \Delta \ln(y_t) + \beta_6 W \cdot \ln(y_{t-1}) + \nu_t, \qquad (17)$$

where W is a spatial weighting matrix, normalized by rows $w_{ij} = \frac{1}{d_{ij}{}_{\text{ij}}}$, where d is geographical (arc)distance between the capitals of regions *i* and *j*; $W \cdot \Delta \ln(y_t)$ is the spatial lag of $\Delta \ln(y_t)$; $W \cdot \ln(y_{t-1})$ is the spatial lag of $\ln(y_{t-1})$.

The spatial lag of the dependent variable is endogenous by nature, but this should not complicate the estimation of equation (17) as the system GMM we use is able to generate consistent estimates of the coefficients on all potentially endogenous variables (Kukenova and Monteiro, 2011).[10] Following the literature, we expect that β_5 will be significant and positive, i.e., that growing regions tend to be located closer to other growing regions (either due to growth spillovers, or because growing regions have similar economic structures pre-determined by similar geo-climatic conditions).

The estimated coefficients from equations (16) and (17) allow us to derive a set of crucial theoretical parameters. First of all, we are interested in the convergence rate $\lambda = \frac{-\ln(1+\beta)}{t}$. We can also derive the physical capital share $\alpha = \frac{\beta_1}{\beta+\beta_1}$, the human capital share $\varphi = \frac{\beta_2}{\beta}(\alpha - 1)$, and the ratio of human capital of immigrants versus that of natives $\varepsilon = \frac{\beta_4}{\beta_1}$.

4.2 Data and measurement issues

We analyze convergence among Russian regions using data for the longest period available, from 1996 to 2017. As in virtually all papers on Russia, we treat the Nenetskiy autonomous district as an integral part of the Arkchangelsk oblast' and Khanti-Mansiyskiy and Yamalo-Nenetskiy

[10] We estimate Equations (16) and (17) in STATA using xtabond2 proposed by Roodman (2009b).

autonomous districts as integral parts of the Tumen oblast'. Furthermore, we exclude Chechnya from our analysis.

Most previous studies also excluded other regions. Ahrend (2002) excluded Ingushetia, Guriev and Vakulenko (2012) and Vakulenko (2016) excluded Chukotka and Ingushetia, Kholodilin et al. (2012) excluded Chukotka and Kalmykia. These regions tend to exhibit implausible fluctuations in GRP per capita even when averaged over three years (see Figure A1 in the Appendix). Thus, following previous research, we additionally exclude Chukotka and Ingushetia and check how our estimates change without Kalmykia.[11] Therefore, we have 77 regions in our main sample.

Most variables we use come from Rosstat's statistical yearbooks "*Regioni Rossii*". To measure real GRP per capita, we take nominal GRPs, divide them by regional population size, and then adjust them to 1996 prices using physical volume indices.

To measure saving rates, we take data on investments (*investicii v osnovnoi capital)* and divide it by GRPs.

There are two ways to measure the stock of human capital across Russian regions. One is to use information about the educational structure of the regional population and calculate the average number of years of education (e.g., see Stertser, 2006), or, alternatively, to only use the share of employed with higher education. Since Mankiw et al. (1992), such measures have been widely used in cross-national studies. However, they have received strong criticism, since formal education may be a poor reflection of learning (Angrist et al., 2019; Hanushek, 2013). Such concerns are relevant in the Russian context, given the unprecedented growth of enrollment in higher education institutions during the 1990s and 2000s and the accompanying decline in educational quality. Moreover, the transition to a market economy led to a serious devaluation of 'old' human capital acquired in the Soviet period (Gimpelson et al., 2016).

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[11] Another region traditionally deserving attention in regression analysis in the Russian context is Moscow City. Although the fluctuations of GRP per capita in this region look plausible, Moscow City is an obvious outlier in many important characteristics, such as population size and density, concentration of both physical and human capital, or immigration rates. In this regard, we also check whether our estimates are sensitive to the exclusion of Moscow City.

The second option is to use the share of employed in R&D, as was done, for instance, by Komarova and Kritsyna (2012) and Akhmedjonov et al. (2013) for Russia. An advantage of this measure is that it reflects the actively used part of human capital of presumably high quality. Its disadvantage is that this measure is too narrow to reflect the whole stock of human capital in a region. Moreover, its interpretation may not be straightforward, as it not only reflects human capital *per se* but is also intertwined with regional R&D investments. As there are pros and cons for each of the two approaches to measuring human capital, we try both of them.

Finally, as a measure of net immigration into a region, we use the coefficient of net migration, which is calculated as net migration divided by the regional population at the beginning of the period.

5. Results

5.1. Descriptive analysis

Table A1 (in the Appendix) shows the top 10 and bottom 10 Russian regions in terms of GRP per capita for the beginning (1996) and the end (2017) of the period under study. In 2017, the richest Russian region, Tyumenskaya oblast', had GRP per capita of slightly less than 100,000 rubles (in 1996 prices), while the poorest region, the Republic of Ingushetia, had GRP per capita of about 3,000 rubles, with the gap between the richest and poorest region being about 30 times as much (!). All regions among the top 10 except for two (Moscow City and Belgorodskaya oblast') are located in the northern and eastern part of Russia. Among the bottom 10 regions, 5 are located in the south of Russia, 2 in Southern Siberia, and the remaining 3 in the central part. The uneven distribution of relatively poor and rich regions is clearly visible in the map (see Figure A2 in the Appendix).

The data also suggest that the relative positions of Russia's regions were stable over time. Tyumenskaya oblast' and the Republic of Ingushetia were the richest and poorest regions, respectively, in 1996 and 2017. Over this 21-year period, the composition of the top 10 and bottom

10 regions changed by less than half: only 4 regions left each group. The correlation between GRP per capita in 1996 and 2017 is about 0.9, which implies that even if some convergence between Russia's regions took place, it had almost no effect on their relative positions.

Figure 2 presents the average real GRP per capita growth rate over 1996-2017 vs. the level of GRP per capita in 1996. The data suggest a negative relationship between them, implying a rate of convergence of about 0.6% per year. Therefore, a simple *ad hoc* analysis reveals *unconditional* convergence between Russia's regions over the period 1996-2017. Such a result, however, should be treated very skeptically due to the strong and stable heterogeneity of Russia's regions and spatial interdependencies between them, which are not considered. The results of the estimation of our theoretical model using sophisticated panel data techniques are presented in the next section. Table A2 in the Appendix contains the descriptive statistics of all variables used in the analysis.

<insert Figure 2 around here>

5.2 Estimating the complete model

The main results are presented in Table 1. We start with the specification of equation (16), which does not include regional FE (Column 1). In this case, the OLS estimate of the coefficient on lagged GRP per capita is about -0.007 and highly significant. As mentioned, this estimate may suffer from an upward bias.

<insert Table 1 around here>

Column 2 presents the results with regional FE. The estimated coefficient on lagged GRP per capita remains highly significant but becomes large in absolute terms (-0.1), which implies an implausible convergence rate among Russian regions of about 10.5% per year. Such a sharp decrease in this coefficient after the inclusion of regional FE is in line with the results of previous studies (Gennaioli et al., 2014; Barro, 2015) and reflects the downward Hurwicz-Nickell bias.

Finally, Column 3 of Table 1 presents estimation results obtained by using system GMM. The estimate of the coefficient on lagged GRP per capita is -0.022 and statistically significant at the 1% level. This estimate lies between the OLS and FE estimates, which is a 'good sign', according to Bond et al. (2001) and Roodman (2009b). The implied rate of convergence is 2.2% per year, which is close to the 2% rate of the 'iron law'.

We estimated the specification in Column 3 of Table 1 by system GMM several times, applying different restrictions on the number of lags and using different methods of estimating the covariance matrix (two-step GLS-like estimation vs. robust estimation). As Table A3 in the Appendix shows, in all cases the AR tests for autocorrelation of the residuals suggest that they follow an AR(1) process but do not exhibit an AR(2) process, which indicates that lagged first differences may be used as valid instruments. It also shows that the results are not sensitive to how the covariance matrix is estimated. However, the estimates are quite sensitive to different restrictions on the lags of dependent variables used as instruments. As Column 1 of Table A3 shows, without any restrictions there are 169 instruments. As a result, the Hansen test of the joint validity of instruments has an 'implausibly good' p-value of 1, which reflects the problem of 'too many instruments' (Roodman, 2009a,b). The p-value declines slightly when only first and second lags are used as instruments (see Column 2 or Column 5) and drops to 0.456 when only the second lags are used (Columns 3 or 6). Such a p-value means that the Hansen test fails to reject the null hypothesis of the joint validity of all instruments at high levels of significance, while the number of instruments decreases to 79 and becomes equal to the number of panels. Therefore, Column 6 reflects our preferred results, which are reported in Table 1.

In line with the theoretical expectations, the saving term $ln(s)$ is significant and positive, while $ln(n+g+\delta)$ is significant and negative. Moreover, the coefficients on $ln(s)$ and $ln(n+g+\delta)$ are not statistically different from each other in absolute terms. According to our estimates, the share of physical capital in output (α) is 0.49, which is very close to the estimates reported in the literature (e.g., Durand-Lasserve and Blöchliger, 2018). According to statistics of the national accounts of Rosstat, in the period 2006-2013, the physical capital share in Russia was in the range from 0.29 to 0.35 with an average value of 0.32. If the share of tax incomes is equally distributed between the shares of labor and physical capital, the share of physical capital increases to 0.42. Our estimates are also remarkably close to those of Mankiw et al. (1992), who obtained α=0.48 for their total sample of 98 countries.

The share of employed in R&D, which reflects the stock of human capital in the region, is insignificant. As our robustness checks show (see below), the result is the same when the share of employment with higher education or average years of education is used instead. Taking these results at face value suggests that human capital does not play any significant role in regional economic growth in Russia. However, this conclusion would be too hasty, because those measures may be poor proxies for human capital at the regional level.

It is also noteworthy that both human capital measures are positive and significant in equations estimated using pooled data, which is in line with previous studies that estimated parameters of the Cobb-Douglas production function in Russia using cross-section or pooled data (e.g., Komarova and Kritsyna, 2012; Stertser, 2006). They may become insignificant in FE or first difference (FD) estimations for several reasons. One possible reason is that FE/FD estimation excludes all time-invariant regional characteristics that are correlated with regional human capital. If these regional characteristics are positively correlated with human capital, then their exclusion will reduce the size of the coefficient of human capital variables.

Another reason is that FE/FD transformation rules out all “between” (cross-regional) variation in human capital variables and leaves only the “within” (temporal) variation, which may have two important consequences. First, this may change the extent to which the human capital variable reflects the true level of human capital. For instance, Hanoushek (2013) analyses the case where differences in enrollment rates between countries reflect differences in terms of skills much better than differences in enrollment rates within countries, as rising enrollment may not be accompanied by rising educational quality. As mentioned, a similar logic may be applied to the Russian case. Second, human capital variables may become insignificant after FE/FD transformation just because they exhibit low "within" variation. This seems to be the case as the standard error of the coefficient for employment with higher education tripled after the FE transformation (see Table 1). Overall, these caveats prevent us from concluding that human capital is not important for regional economic growth in Russia.

Finally, the migration term is significant and positive. Our estimates imply that the ratio of human capital of immigrants to that of natives (ε) is about 1.5. This suggests that the amount of migrant human capital exceeds the amount of human capital of the native population.[12] As $\varepsilon > 1$, interregional migration should have a positive impact on the stock of human capital (per effective labor) of the receiving region and thus support regional economic growth. Unfortunately, there are no previous studies on Russia that provide any benchmark for our estimate of ε, while existing studies dedicated to internal migration usually do not measure the human capital of migrants. Nonetheless, similar to other countries (Lkhagvasuren, 2014), it is plausible to expect that interregional movers in Russia on average have a higher amount of human capital compared to stayers.

5.3 The role of human capital and migration

Next, we examine the role of human capital and migration in the convergence process. To do this, we exclude one factor from the complete model, estimate the resulting specification, and compare the convergence rate derived from that specification with the rate from the complete

[12] Dolado et al. (1994) provide estimates for ε ranging from 0.57 to 0.85 for immigration in OECD countries, which suggests that those who move to OECD countries on average have a lower amount of human capital than the native population. One may expect that for migration within one country ε should be higher.

model.[13] Table 2 presents these estimation results. In Column 1, we repeat the GMM estimates and the implied theoretical parameters of the full specification shown in Table 1.

<insert Table 2 around here>

We find that the exclusion of the human capital proxy leaves the coefficient on the lagged value of GRP per capita almost unchanged, which is in line with the fact that this proxy is insignificant. The exclusion of the migration variable, however, leads to an economically and statistically significant *increase* in the parameter of convergence. In other words, controlling for migration makes convergence less intense. This suggests that migration contributes to convergence in the Russian case (even though $\varepsilon > 1$). This result differs from that of Vakulenko (2016), who found that migration had no impact on income convergence between Russian regions in 1995-2010. At the same time, it is in line with the theoretical discussion provided by Guriev and Vakulenko (2015), who argued that the weakening of geographical poverty traps in Russia in the 2000s facilitated interregional migration, contributing to the regional convergence in incomes and wages. It is also consistent with the findings of Buranshina and Smirnykh (2018), who established a positive (albeit weak) role of migration in the regional convergence of wages.

5.4 Robustness checks

To assess the stability of our main findings, we performed several robustness checks. None of them altered our results qualitatively. First, as discussed above, we checked the robustness of our system GMM estimates to different lag restrictions and methods of estimation of standard errors.

[13] We do not interpret the results of the incomplete model as it may suffer from omitted variable bias. We use this empirical exercise just to understand the role of migration and human capital in the convergence process (see the discussion in Ozgen et al., 2010).

Second, we tried an alternative value of *(g+δ)*. Using officially published data on stocks of physical capital for the beginning and end of each year and data on investments, we estimated the average depreciation rate (*δ*) for the period under study to be about 4% per year. Following Mankiw et al., (1992), we also assumed that the rate of technological progress (*g*) in Russia may be equal to the average long-run growth rate, which is about 4%. This results in an estimate for *(g+δ)* of 0.08.[14] Using this value, we re-estimated all our equations. As Tables A4 and A5 in the Appendix show, all our findings and their interpretations remained almost the same.

Third, as mentioned, we excluded Kalmykia from the sample (as it exhibited implausible fluctuations in GRP per capita), and this barely changed any coefficients. The exclusion of Moscow City did not change our main findings either.[15]

Fourth, as mentioned, we used the share of employment with higher education as a proxy for human capital instead of R&D employment. While this does not change our results or the conclusions on the role of human capital, the implied rate of convergence slightly decreases to 1.9% (see Tables A6 and A7 in the Appendix). Using the average number of years of formal education as a human capital proxy leads to very similar results, which are available upon request.

Fifth, Table A8 in the Appendix shows the re-estimated main results when spatial lags of GRP growth and initial GRP are included. While the spatial lag of initial GRP is insignificant, the spatial lag of GRP growth is highly significant and positive, in line with previous studies on Russia. Although all our findings and interpretations remain qualitatively the same, the estimated convergence rate declines substantially to 1.3% per year. This suggests that the spatial correlation of economic growth of Russian regions is an important factor in their *convergence*, which is in line with some earlier evidence (Kholodilin et al., 2012). As Table A9 in the Appendix shows,

[14] Alternatively, following a study by Turganbayev (2016) for Kazakhstan, we used the coefficient of liquidation of fixed assets (which in Russia equals about 1% for the period under study) as a crude proxy for the depreciation rate. When we add it to our estimate for g, we receive the classic 0.05 value for (g+δ).

[15] Not all results are shown here, but they are available upon request.

however, the introduction of spatial terms does not change our conclusions on the role of human capital and interregional migration.

6. Summary and conclusions

We studied convergence in per capita GRP across Russian regions in the period from 1996 to 2017. The key feature distinguishing our study from many previous ones is that we estimate growth equations that are directly derived from the classic Solow model, augmented with human capital and migration. Estimating theoretically grounded equations allows us to justify the choice of explanatory variables, and thus avoid the criticism raised about *ad hoc* approaches to specifying empirical growth equations (Durlauf et al., 2008). Our estimates also allow us to derive a set of plausible theoretical parameters.

Our main specification provides an estimate of the convergence rate equal to 2.2% per year, which is remarkably close to the 2% 'iron law' of (conditional) convergence. The estimated share of physical capital in output (α) equals 0.49, which is also very close to classic estimates. These findings, which are shown to be robust to a battery of robustness checks, suggest that the general long-run dynamics of the economic development of Russian regions is subject to certain universal mechanisms (first of all, the law of diminishing returns to physical capital) and may be analyzed within the framework of a neoclassical growth model.

Concerning the role of human capital for regional economic growth and convergence, our results provide ambiguous evidence. On the one hand, we do not find any significant impact of the human capital variables on economic growth in our main specifications estimated using system GMM. On the other hand, OLS estimations using pooled data suggest a positive influence. Such ambiguity and the discrepancy between results from using pooled and panel data is in line with the existing international literature and calls for further analysis of the role of human capital in the Russian case.

According to our findings, the amount of human capital of migrants is on average higher than that of natives, which implies that immigration from other regions tends to accelerate economic growth in receiving regions. Consequently, as most interregional migration flows in Russia are oriented from richer northern and eastern regions to relatively poorer western and southern regions – the so-called 'western drift' (e.g., Kumo, 2017) – we can infer that interregional migration contributes to economic convergence between Russian regions.

We also find that the inclusion of spatial interdependencies in the empirical growth equation leads to a substantial decrease in the rate of convergence, which implies their strong positive contribution to the convergence process. It seems that economic growth spills over from regions with relatively high to regions with relatively low per capita GRP, which helps the latter to catch up. A more detailed investigation of the highlighted underlying mechanisms of convergence should be a task for future research once serious research on economic development and well-being again becomes possible in Russia.

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Figure 1. Real GDP per capita over time (in thousands Russian rubles 1996, right scale) and coefficient of variation (CV) in per capita GRP of Russian regions (left scale) in 1996-2017

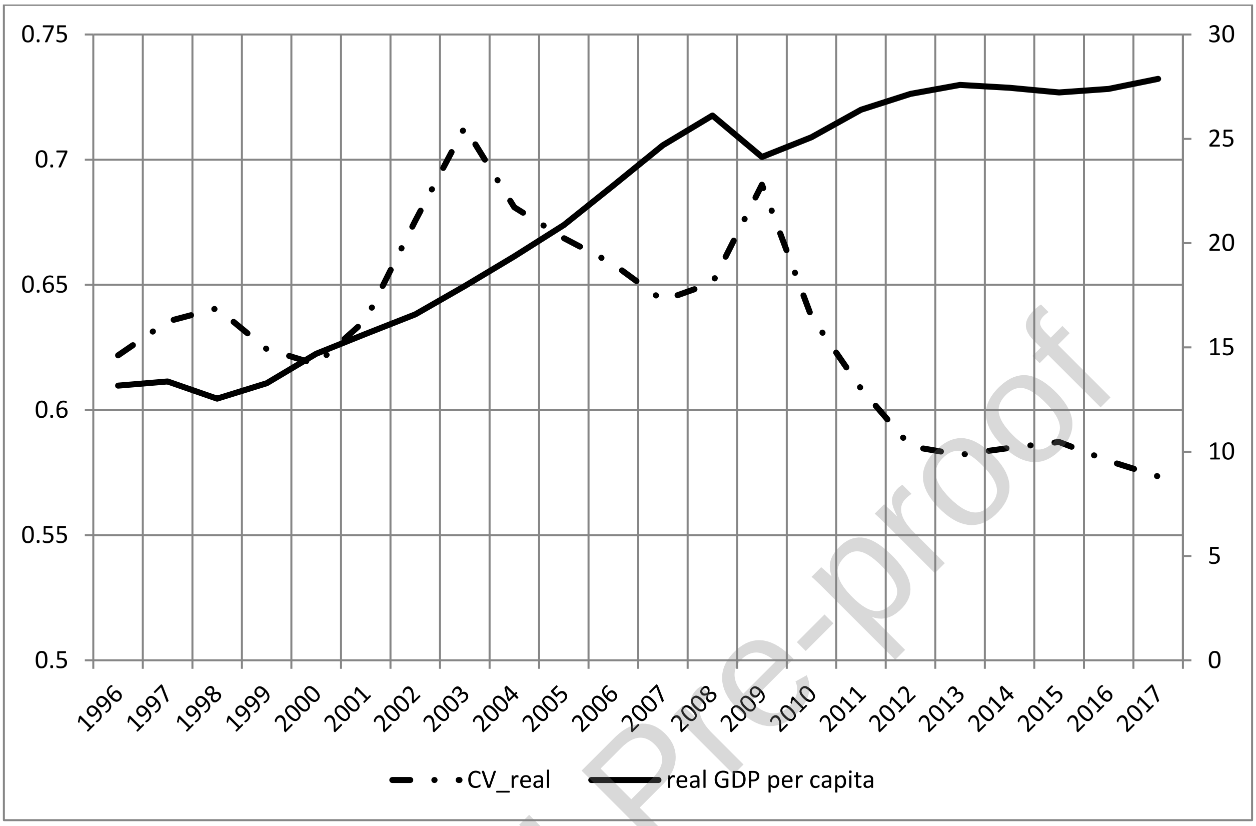
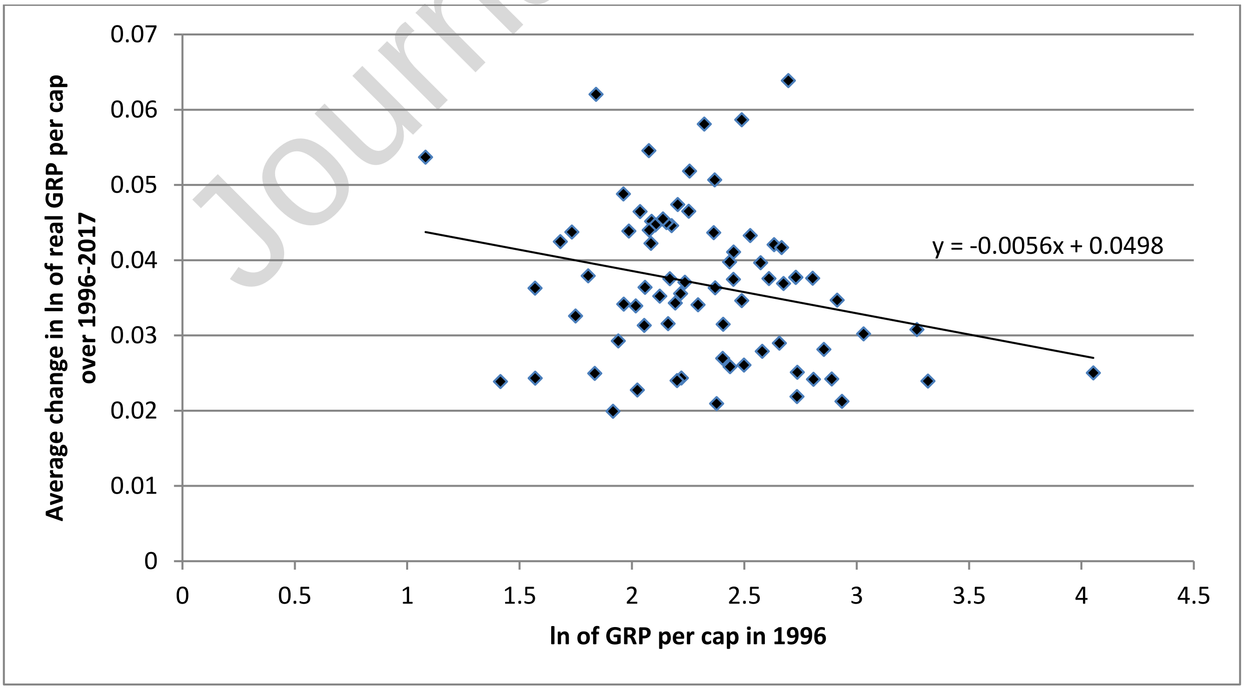


Figure 2. Average real GRP per capita growth rate over 1996-2017 vs. the level of GRP per capita in 1996



TABLES

Table 1. Estimated growth equation for the panel of Russian regions (1996-2017)

	Pool	FE	sGMM
initial grp per cap (ln)	-0,007***	-0,100***	-0,022***
	(0,002)	(0,013)	(0,008)
ln(s)	0,018***	0,018**	0,021**
	(0,005)	(0,008)	(0,009)
ln(n+g+δ)	-0,027***	-0,030***	-0,029***
	(0,006)	(0,009)	(0,006)
ln(R&D pers)	0,003***	-0,007	0,002
	(0,001)	(0,006)	(0,003)
Migr	0,036***	0,022	0,043***
	(0,011)	(0,024)	(0,015)
change in (log) E/P ratio	0,268***	0,178**	0,353***
	(0,069)	(0,081)	(0,106)
time FE	YES	YES	YES
region FE	NO	YES	YES
N	537	537	537
Derived theoretical parameters			
convergence rate (%)	0,73	10,56	2,24
p-value of F-TEST on ln(s) + ln(n+g+δ) = 0	0.2926	0.3913	0.0646
α	0,72	0,15	0,49
ϕ	0,11	-0,06	0,05
ε	1,30	0,73	1,48

Notes: *** significant at 1% level; ** significant at 5% level; * significant at 10% level. Standard errors robust to heteroscedasticity and clusterization within regions are in parentheses. All variables are averaged over 3-year periods. Excluded regions: Chechnya, Chukotka, and Ingushetia. 2 observations with negative values of (n+g+δ) are excluded.

Table 2. Estimated growth equation for the panel of Russian regions without human capital and migration (1996-2017)

	Full equation	Without HC	Without migration
initial grp per cap (ln)	-0,022***	-0,024***	-0,031***
	(0,008)	(0,009)	(0,010)
ln(s)	0,021**	0,025**	0,027**
	(0,009)	(0,010)	(0,014)
ln(n+g+δ)	-0,029***	-0,029***	-0,010
	(0,006)	(0,008)	(0,006)
ln(R&D pers)	0,002		0,002
	(0,003)		(0,005)
migr	0,043***	0,044***	
	(0,015)	(0,014)	
change in (log) E/P ratio	0,353***	0,314***	0,381***
	(0,106)	(0,098)	(0,107)

time FE	YES	YES	YES
region FE	YES	YES	YES
N	537	537	537
Derived theoretical parameters			
Convergence rate (%)	2,24	2,44	3,12
p-value of F-TEST on ln(s) + ln(n+g+δ) = 0	0.0646	0.7554	0.3092
α	0,49	0,51	0,46
ϕ	0,05		0,03
ε	1,48	1,53	
Technical parameters			
N of instruments	79	67	67
AB test for AR(1): p-value	0.002	0.001	0.000
AB test for AR(2): p-value	0.432	0.367	0.237
Hansen's J test of joint validity of all instruments			
Chi-sq (df)	66.62(66)	57.37(55)	62.15 (55)
p-value	0.456	0.387	0.237

Notes: *** significant at 1% level; ** significant at 5% level; * significant at 10% level. Standard errors robust to heteroscedasticity and clusterization within regions are in parentheses. All variables are averaged over 3-year periods. Estimation method for all specifications: system GMM. Excluded regions: Chechnya, Chukotka, and Ingushetia. 2 observations with negative values of (n+g+δ) are excluded.

Appendix

Figure A1. The yearly growth rates of real GRP per capita along with their 3-year averages across all Russian regions, 1996-2017

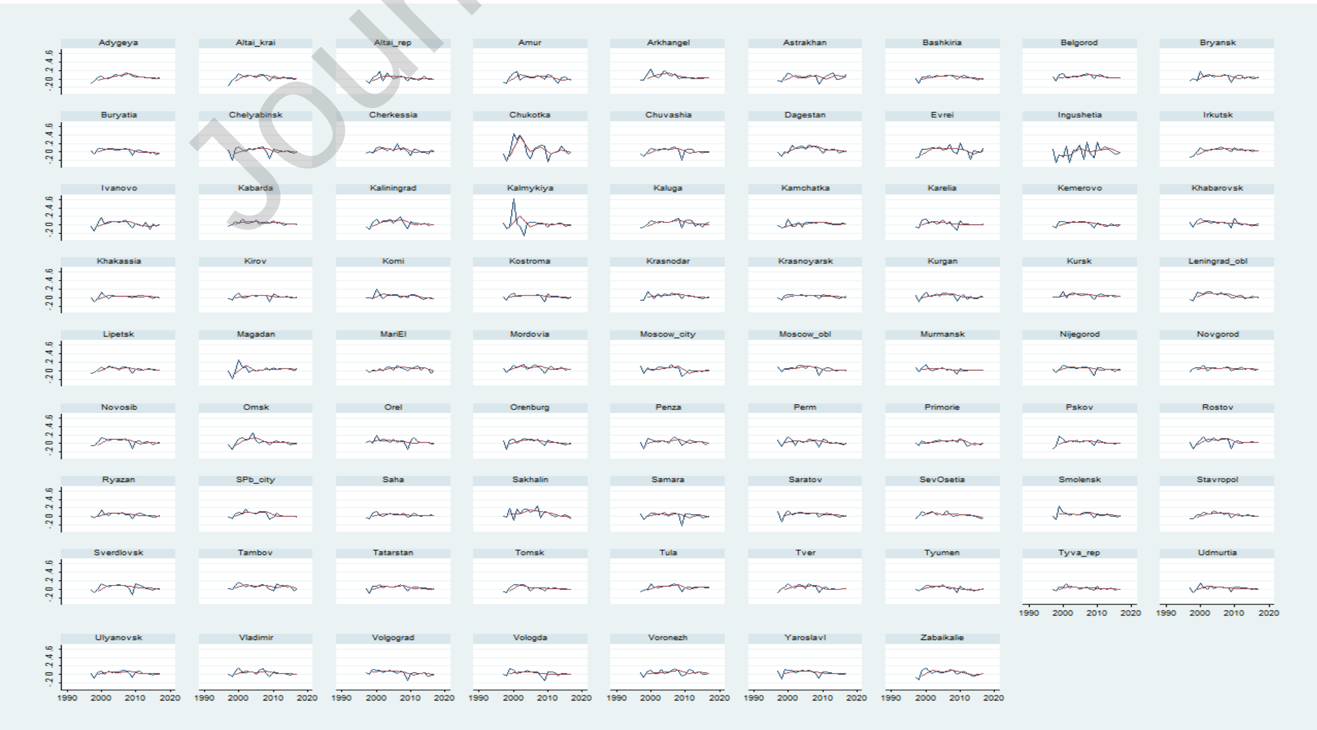


Figure A2. GRP per capita across Russia's regions in 2017

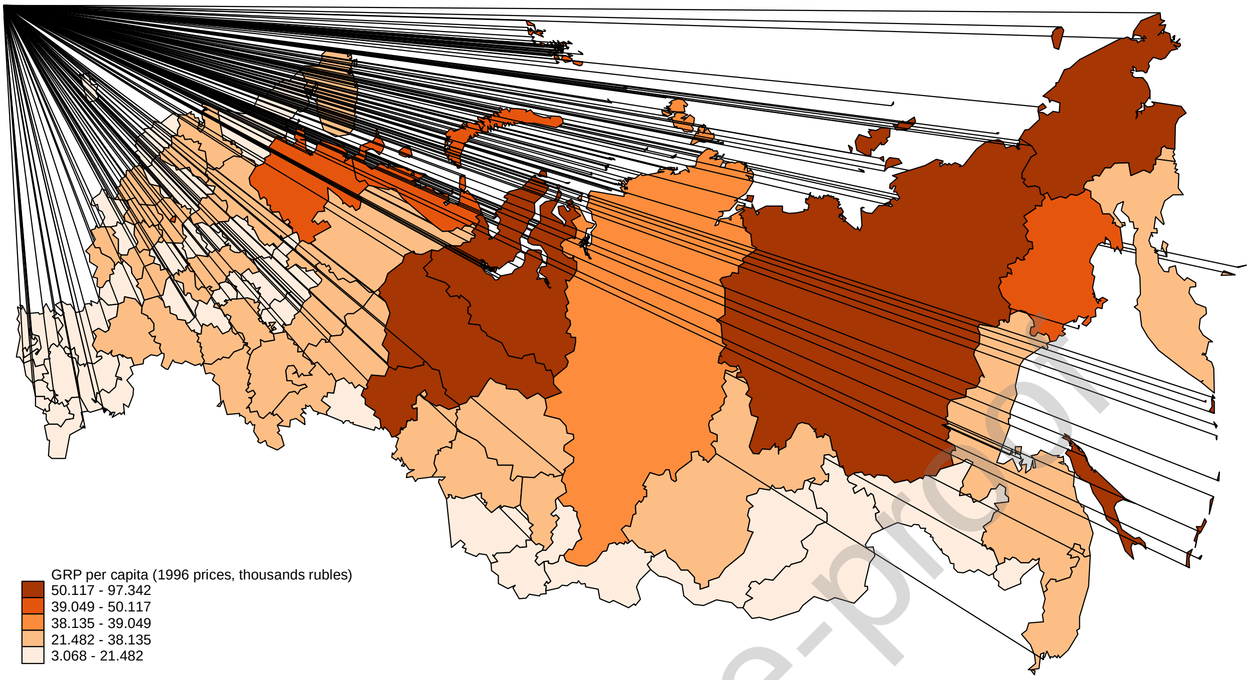


Table A1. Top and bottom 10 Russian regions in terms of GRP per capita (thousand rubles) in 1996 and 2017

Region	GRP per cap in 1996	RANK	Region	GRP per cap in 2017 (1996 prices)
Tyumen	57.562	1	Tyumen	97.342
Moscow_city	27.569	2	Chukotka	81.184
Saha	26.253	3	Sakhalin	56.651
Chukotka	24.065	4	Saha	50.117
Magadan	20.705	5	Moscow_city	45.571
Kamchatka	18.803	6	Arkhangel	41.288
Krasnoyarsk	18.406	7	Magadan	39.049
Samara	17.974	8	Krasnoyarsk	38.135
Komi	17.353	9	Irkutsk	36.351
Tomsk	16.573	10	Belgorod	34.529
RUSSIA	13.164	23(24)	RUSSIA	27.873
Altai_rep	6.263	71	Pskov	12.855
MariEl	6.083	72	Chuvashia	12.201
Cherkessia	5.748	73	Cherkessia	11.395
Kabarda	5.656	74	Altai_rep	10.576
Adygeya	5.372	75	Ivanovo	10.320

Tyva_rep	4.803	76	SevOsetia	10.289
SevOsetia	4.802	77	Dagestan	9.106
Kalmykiya	4.117	78	Tyva_rep	8.004
Dagestan	2.949	79	Kalmykiya	6.797
Ingushetia	2.829	80	Ingushetia	3.068

Table A2. Descriptive statistics on the variables used in the main analysis

Variable	Obs	Mean	Std. Dev.	Min	Max
change in real GRP per capita (difference in logs)	539	0.037	0.040	-0.068	0.199
initial level of real GRP per capita (for the beginning of a 3-year period, thousands rubles)	539	17.466	11.535	2.680	100.408
ln of initial level of real GRP per capita	539	2.704	0.546	0.986	4.609
investment-to-GRP ratio	539	0.237	0.094	0.032	1.103
ln of investment-to-GRP ratio	539	-1.506	0.362	-3.449	0.098
n+g+δ	539	0.045	0.011	-0.037	0.122
ln(n+g+δ)	538	-3.115	0.245	-4.817	-2.100
share of R&D personnel in regional employment	538	0.666	0.791	0.038	5.196
ln of the share of R&D in regional employment	538	-0.888	0.964	-3.280	1.648
share of employed with higher education in total regional employment	539	0.244	0.062	0.113	0.492
ln of share of employed with higher education in total regional employment	539	-1.442	0.249	-2.176	-0.710
average years of education	539	12.795	0.464	11.634	14.310
ln of average years of education	539	2.548	0.036	2.454	2.661
quasi-migration variable	539	-0.027	0.156	-1.827	0.807
change in employment rate (difference in logs)	539	0.004	0.016	-0.055	0.076

Notes: all variables are averaged over seven non-overlapping 3-year periods, according to our methodology. Data restrictions: 1) the maximum level of the investment-to-GRP ratio is greater than 1 due to the large spike in investments that occurred in Evrei AO in 1999; 2) the minimum value of (n+g+δ) is negative due to large outmigration from Magadan oblast' in the second 3-year period (1999-2002); 3) data on R&D personnel are not available for the Evrei AO for the last 3-year period (2014-2017).

Table A3. Robustness of results to different restrictions on lags used as IVs and to methods of estimating covariance matrix

Method to estimate covariance matrix:	Robust			2-step		
Restrictions on lags used as IVs:	None	1st&2nd	1st	None	1st&2nd	1st
	1	2	3	4	5	6
initial grp per cap (ln)	-0.008**	-0.012**	-0.021***	-0.007	-0.014**	-0.022***
	(0.003)	(0.006)	(0.007)	(0.006)	(0.007)	(0.008)
ln(s)	0.021***	0.019**	0.022**	0.022***	0.022***	0.021**
	(0.006)	(0.008)	(0.009)	(0.007)	(0.009)	(0.009)
ln(n+g+δ)	-0.027***	-0.030***	-0.030***	-0.030***	-0.033***	-0.029***
	(0.006)	(0.006)	(0.007)	(0.008)	(0.006)	(0.006)
ln(R&D pers)	0.002	0.003	0.003	0.002	0.003	0.002
	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)

migr	0.040***	0.045***	0.042***	0.044***	0.047***	0.043***
	(0.010)	(0.011)	(0.013)	(0.014)	(0.010)	(0.015)
change in (log) E/P ratio	0.291***	0.302***	0.314***	0.266***	0.250**	0.353***
	(0.078)	(0.084)	(0.094)	(0.084)	(0.100)	(0.106)
time effects	YES	YES	YES	YES	YES	YES
region effects	YES	YES	YES	YES	YES	YES
N	537	537	537	537	537	537
Derived theoretical parameters						
Implied convergence rate (%)	0.80	1.23	2.17	0.73	1.42	2.24
p-value of F-TEST on ln(s) + ln(n+g+δ) = 0	0.5741	0.3134	0.5254	0.5054	0.3150	0.
Implied α for physical capital	0.73	0.61	0.51	0.75	0.61	0.49
Implied φ for human capital	0.07	0.08	0.08	0.07	0.07	0.05
Implied ε for migration	1.52	1.50	1.37	1.48	1.44	1.48
Technical parameters						
N of instruments	169	109	79	169	109	79
AB test for AR(1): p-value	0.002	0.002	0.001	0.002	0.002	0.002
AB test for AR(2): p-value	0.418	0.435	0.253	0.464	0.484	0.432
Hansen's J test of joint validity of instruments						
Chi-sq (df)	64.12 (156)	68.19 (96)	66.62 (66)	64.12 (156)	68.19 (96)	66.62 (66)
p-value	1.000	0.986	0.456	1.000	0.986	0.456

Notes: *** significant at 1% level; ** significant at 5% level; * significant at 10% level. Standard errors robust to heteroscedasticity and clusterization within regions are in parentheses. All variables are averaged over 3-year periods. Excluded regions: the Republic of Chechnya, Chukotskiy AO, and the Republic of Ingushetia. N = 537, which is less than 77*7=539 as 2 observations are excluded due to data restrictions.

Table A4. Estimated growth equation for the panel of Russian regions (1996-2017), assuming (g+δ) = 0.08

	Pool	FE	sGMM
initial grp per cap (ln)	-0.007***	-0.101***	-0.024***
	(0.002)	(0.012)	(0.007)
ln(s)	0.018***	0.018**	0.020**
	(0.005)	(0.008)	(0.009)
ln(n+g+δ)	-0.046***	-0.055***	-0.061***
	(0.011)	(0.017)	(0.012)
ln(R&D pers)	0.003**	-0.007	0.001
	(0.001)	(0.006)	(0.004)
migr	0.069***	0.048	0.126***
	(0.024)	(0.079)	(0.040)
change in (log) E/P ratio	0.254***	0.160*	0.272***
	(0.068)	(0.088)	(0.100)
time effects	YES	YES	YES
region effects	NO	YES	YES
N	537	537	537
Derived theoretical parameters			
Implied convergence rate (%)	0.75	10.61	2.40
p-value of F-TEST on ln(s) + ln(n+g+δ) = 0	0.0331	0.1027	0.0178
Implied α for physical capital	0.71	0.15	0.46
Implied ϕ for human capital	0.11	-0.06	0.02
Implied ε for migration	1.50	0.87	2.08

Notes: *** significant at 1% level; ** significant at 5% level; * significant at 10% level. Standard errors robust to heteroscedasticity and clusterization within regions are in parentheses. All variables are averaged over 3-year periods. Excluded regions: the Republic of Chechnya, Chukotskiy AO, and the Republic of Ingushetia. N = 537, which is less than 77*7=539 as 2 observations are excluded due to data restrictions.

Table A5. Estimated growth equation for the panel of Russian regions without human capital and migration (1996-2017), assuming (g+δ)=0.08

	Full model	Model without HC	Model without migration
initial grp per cap (ln)	-0.024***	-0.028***	-0.030***
	(0.007)	(0.008)	(0.009)
ln(s)	0.020**	0.021**	0.025*
	(0.009)	(0.010)	(0.013)
ln(n+g+δ)	-0.061***	-0.061***	-0.021**
	(0.012)	(0.013)	(0.010)
ln(R&D pers)	0.001		0.002
	(0.004)		(0.005)
migr	0.126***	0.126***	
	(0.040)	(0.036)	
change in (log) E/P ratio	0.272***	0.266***	0.377***
	(0.100)	(0.097)	(0.108)
time effects	YES	YES	YES
region effects	YES	YES	YES
N	537	537	537
Derived theoretical parameters			
Implied convergence rate (%)	2.40	2.83	3.01
p-value of F-TEST on ln(s) + ln(n+g+δ) = 0	0.0178	0.0271	0.8161
Implied α for physical capital	0.46	0.43	0.46
Implied ϕ for human capital	0.02		0.04
Implied ε for migration	2.08	2.06	
Technical parameters			
N of instruments	79	67	67
AB test for AR(1): p-value	0.003	0.002	0.000
AB test for AR(2): p-value	0.500	0.407	0.278
Hansen's J test of joint validity of all instruments			
Chi-sq (df)	66.09(66)	59.07(55)	62.06(55)
p-value	0.474	0.326	0.239

Notes: *** significant at 1% level; ** significant at 5% level; * significant at 10% level. Standard errors robust to heteroscedasticity and clusterization within regions are in parentheses. All variables are averaged over 3-year periods. Excluded regions: the Republic of Chechnya, Chukotskiy AO, and the Republic of Ingushetia. N = 537, which is less than 77*7=539 as 2 observations are excluded due to data restrictions.

Table A6. Estimated growth equation for the panel of Russian regions (1996-2017), with share of employed having higher education as a measure of human capital

	Pool	FE	System GMM
initial grp per cap (ln)	-0.006**	-0.101***	-0.019***
	(0.002)	(0.013)	(0.007)
ln(s)	0.018***	0.017*	0.026***
	(0.005)	(0.009)	(0.009)
ln(n+g+δ)	-0.031***	-0.030***	-0.033***
	(0.007)	(0.009)	(0.009)
ln(empl with higher educ)	0.011*	-0.014	0.009
	(0.006)	(0.020)	(0.022)
migr	0.041***	0.019	0.047***
	(0.011)	(0.023)	(0.015)
change in (log) E/P ratio	0,247***	0,169**	0,301***
	(-0,007)	(-0,079)	(-0,096)
time effects	YES	YES	YES
region effects	NO	YES	YES
N	537	537	537
Derived theoretical parameters			
Implied convergence rate (%)	0.57	10.62	1.89
p-value of F-TEST on ln(s) + ln(n+g+δ) = 0	0.1752	0.3634	0.6277
Implied α for physical capital	0.76	0.14	0.58
Implied ϕ for human capital	0.48	-0.12	0.21
Implied ε for migration	1.30	0.64	1.83

Notes: *** significant at 1% level; ** significant at 5% level; * significant at 10% level. Standard errors robust to heteroscedasticity and clusterization within regions are in parentheses. All variables are averaged over 3-year periods. Excluded regions: the Republic of Chechnya, Chukotskiy AO, and the Republic of Ingushetia. N = 537, which is less than 77*7=539 as 2 observations are excluded due to data restrictions.

Table A7. Estimated growth equation for the panel of Russian regions without human capital and migration (1996-2017), with share of employed having higher education as a measure of human capital

	Full model	Model without HC	Model without migration
initial grp per cap (ln)	-0.019***	-0.024***	-0.026***
	(0.007)	(0.009)	(0.008)
ln(s)	0.026***	0.025**	0.032**
	(0.009)	(0.010)	(0.013)
ln(n+g+δ)	-0.033***	-0.029***	-0.009
	(0.009)	(0.008)	(0.007)
ln(empl with higher educ)	0.009		-0.002
	(0.022)		(0.030)
migr	0.047***	0.044***	
	(0.015)	(0.014)	
change in (log) E/P ratio	0.301***	0,314***	0.347***
	(0.096)	(0.098)	(0.093)
time effects	YES	YES	YES
region effects	YES	YES	YES
N	537	537	537
Derived theoretical parameters			
Implied convergence rate (%)	1.89	2.44	2.62
p-value of F-TEST on ln(s) + ln(n+g+δ) = 0	0.6277	0.7554	0.1879
Implied α for physical capital	0.58	0.51	0.55
Implied ϕ for human capital	0.21		-0.03
Implied ε for migration	1.83	1.53	
Technical parameters			
N of instruments	79	67	67
AB test for AR(1): p-value	0.001	0.001	0.000
AB test for AR(2): p-value	0.393	0.367	0.226
Hansen's J test			
Chi-sq (df)	62.40(66)	57.37(55)	56.62(55)
p-value	0.603	0.387	0.414

Notes: *** significant at 1% level; ** significant at 5% level; * significant at 10% level. Standard errors robust to heteroscedasticity and clusterization within regions are in parentheses. All variables are averaged over 3-year periods. Excluded regions: the Republic of Chechnya, Chukotskiy AO, and the Republic of Ingushetia. N = 537, which is less than 77*7=539 as 2 observations are excluded due to data restrictions.

Table A8. Estimated growth equation for the panel of Russian regions (1996-2017), controlling for spatial effects

	Pool	FE	System GMM
initial grp per cap (ln)	-0.006***	-0.098***	-0.013**
	(0.002)	(0.012)	(0.006)
ln(s)	0.017***	0.016*	0.017*
	(0.005)	(0.009)	(0.010)
ln(n+g+δ)	-0.024***	-0.024***	-0.020***
	(0.006)	(0.008)	(0.007)
ln(R&D pers)	0.003***	-0.008	0.002
	(0.001)	(0.006)	(0.003)
migr	0.031***	0.017	0.030**
	(0.010)	(0.023)	(0.012)
spatial lag of ln gdp per cap growth	0.541***	0.508***	0.518***
	(0.122)	(0.147)	(0.148)
spatial lag of initial grp per cap (ln)	-0.005	0.006	0.003
	(0.006)	(0.039)	(0.011)
change in (log) E/P ratio	0.239***	0.165**	0.296***
	(0.071)	(0.081)	(0.093)
time effects	YES	YES	YES
region effects	NO	YES	YES
N	537	537	537
Derived theoretical parameters			
Implied convergence rate (%)	0.63	10.27	1.30
p-value of F-TEST on ln(s) + ln(n+g+δ) = 0	0.3958	0.5590	0.8498
Implied α for physical capital	0.73	0.14	0.58
Implied ϕ for human capital	0.12	-0.07	0.07
Implied ε for migration	1.30	0.69	1.50

Notes: *** significant at 1% level; ** significant at 5% level; * significant at 10% level. Standard errors robust to heteroscedasticity and clusterization within regions are in parentheses. All variables are averaged over 3-year periods. Excluded regions: the Republic of Chechnya, Chukotskiy AO, and the Republic of Ingushetia. N = 537, which is less than 77*7=539 as 2 observations are excluded due to data restrictions.

Table A9. Estimated growth equation for the panel of Russian regions without human capital and migration (1996-2017), controlling for spatial effects

	Full model	Model without HC	Model without migration
initial grp per cap (ln)	-0.013**	-0.013**	-0.017***
	(0.006)	(0.007)	(0.006)
ln(s)	0.017*	0.020**	0.018*
	(0.010)	(0.010)	(0.011)
ln(n+g+δ)	-0.020***	-0.020***	-0.009
	(0.007)	(0.007)	(0.007)
ln(R&D pers)	0.002		0.003
	(0.003)		(0.003)
migr	0.030**	0.032**	
	(0.012)	(0.013)	
spatial lag of ln gdp per cap growth	0.518***	0.611***	0.583***
	(0.148)	(0.160)	(0.180)
spatial lag of initial grp per cap (ln)	0.003	0.016	0.009
	(0.011)	(0.012)	(0.015)
change in (log) E/P ratio	0.296***	0.264***	0.334***
	(0.093)	(0.092)	(0.102)
time effects	YES	YES	YES
region effects	YES	YES	YES
N	537	537	537
Derived theoretical parameters			
Implied convergence rate (%)	1.30	1.34	1.70
p-value of F-TEST on ln(s) + ln(n+g+δ) = 0	0.8498	0.9344	0.4534
Implied α for physical capital	0.58	0.60	0.51
Implied ϕ for human capital	0.07		0.07
Implied ε for migration	1.70	1.55	
Technical parameters			
N of instruments	100	88	88
AB test for AR(1): p-value	0.003	0.002	0.001
AB test for AR(2): p-value	0.351	0.324	0.236
Hansen's J test			
Chi-sq (df)	67.74(85)	64.11 (74)	70.77(74)
p-value	0.915	0.762	0.585

Notes: *** significant at 1% level; ** significant at 5% level; * significant at 10% level. Standard errors robust to heteroscedasticity and clusterization within regions are in parentheses. All variables are averaged over 3-year periods. Excluded regions: the Republic of Chechnya, Chukotskiy AO, and the Republic of Ingushetia. N = 537, which is less than 77*7=539 as 2 observations are excluded due to data restrictions.

Highlights:

- We study convergence in per capita gross regional products across Russian regions in the period from 1996 to 2017.
- Our empirical growth equations are directly derived from the classic Solow model, augmented with human capital and migration and considering possible spatial effects.
- We find that Russian regions converge with a rate equal to 2.2% per year, which is remarkably close to the 'iron law' of convergence.
- This suggests that the long-run dynamics of the economic development of Russian regions is subject to certain universal mechanisms and may be analyzed within the framework of a neoclassical growth model.
- While interregional migration and the interdependencies of the economic growth of Russian regions contribute to the convergence process, we failed to find any significant impact of human capital on regional growth and convergence.