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BASIC RESEARCH PROGRAM

WORKING PAPERS

SERIES: ECONOMICS

WP BRP 232/EC/2020

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REGIONAL CONVERGENCE IN RUSSIA: ESTIMATING A NEOCLASSICAL GROWTH MODEL[4]

This paper studies the convergence in per capita gross regional products (GRPs) across Russian regions in the period from 1996 to 2017. We estimate growth equations, which are directly derived from a neoclassical growth model, augmented with human capital and migration. To our knowledge, this is the first paper that explicitly applies a neoclassical model to analyze regional convergence in Russia. We also take into account possible spatial effects and do a series of other robustness checks. Our main estimates establish a convergence rate of around 2% per year. While we fail to find any role of human capital for regional economic growth, we find that interregional migration and the interdependencies of the growth of Russian regions contribute to the economic convergence between them.

Key words: convergence, economic growth, regional economics, migration, Russia.

JEL codes: O47, R11, P2.

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[4] The authors are grateful to Federico Belotti, Furio Rosati, Fabian Slonimczyk, Robert Stehrer, and Ilya Voskoboinikov for their helpful comments. The paper has benefited much from discussions held at the IARIW-HSE Conference in September 2019 in Moscow. Lehmann and Oshchepkov are grateful for the financial support provided by the Russian Academic Excellence Project '5-100' within the framework of the HSE University Basic Research Program.

1. Introduction

Ever since the seminal papers by Solow on growth (Solow, 1956, 1957) researchers have analyzed the convergence of income levels across countries. The Solow model predicts that poor countries, having lower per capita incomes and capital to labor ratios, grow faster than rich countries and thus will eventually catch up with them. A large body of empirical literature motivated by this far-reaching prediction shows, however, that convergence occurs only in samples of countries with similar characteristics (first of all, similar saving and population growth rates). In larger and more heterogeneous samples of countries, incomes converge only after controlling for differences in those characteristics. A remarkable empirical fact is that in many cases the estimated rate of convergence is close to 2% per year, a regularity which is sometimes called "the iron law of convergence" (e.g., see Abreu, Groot & Florax, 2005; Barro, 2015; Gennaioli, La Porta & Schleifer, 2014).

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 to policy, especially in large countries. Raising the standard of living of poor regions in a country is an important policy aim, since large income disparities within a country can be destabilizing and can hamper overall growth (Shankar & Shah, 2003).

Russia is a particularly interesting object of study since it is a very large and economically heterogeneous country with income disparities between regions, which are large by international standards (Benini & Czyzewski, 2007; Badunenko & Tochkov, 2010). For example, in 2015 the top-5 regions in the country had GRP per capita (in purchasing power parity) which reached the levels of rich developed economies while the bottom-5 regions had GRPs per capita that placed them among the poorest countries of the world (see World Bank, 2017). Figure 1 traces the development of the coefficient of variation of GRP per capita for the period between 1996 and 2017, for which reliable and consistent data are available. It clearly shows that throughout the period disparities were large and persistent.

[Figure 1 near here]

Given the importance of regional convergence in Russia, there have been many studies on this topic in recent years. We think, however, that our study contributes to the literature in an important fashion. First, we use the longest possible time span in our growth estimates given the availability of reliable and consistent data across time. Second, our estimations take spatial correlations into account. Third, and most importantly, all the previous studies on regional convergence in Russia used *ad hoc* specifications when estimating growth regressions. It strikes us as worthwhile to develop estimable 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 of migratory flows and arrive at an augmented neoclassical growth model that we then estimate. To the best of our knowledge, no study on regional convergence in Russia has used such an approach.

What are the main results of our empirical analysis? Our main specification, which uses system GMM, 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 role of human capital is ambiguous in our empirical analysis. 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 furthers economic convergence between regions since the amount of human capital of migrants is, on average, higher than that of the native population. Finally, investigating the role of spatial interdependencies, we find that they strongly contribute to the convergence process since their inclusion in the empirical growth equation leads to a substantial fall in the rate of convergence between Russian regions.

The next Section 2 embeds our research in the literature dealing with convergence in general and across Russian regions in particular. Section 3 presents our growth model and Section 4 discusses the methodology with which we estimate this model and presents the data. Section 5 is the core of the paper where we present the results and report on various robustness checks. Section 6 concludes.

2. The literature on convergence

2.1 Core literature

Convergence has been on the economics research agenda for decades. As the neoclassical growth model of the Solow-type predicts that poorer countries will eventually catch up in per capita income with richer countries, early empirical literature tested this prediction. The findings 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 early empirical evidence hence rejected unconditional convergence, but found conditional convergence. The seminal papers by Barro (1991) and Barro & Sala-i-Martin (1992) found a convergence rate of 2% in per capita income across a large set of countries, controlling for saving and fertility rates and the quality of human capital and institutions. These early studies were followed by Barro et al. (1995), Caselli et al. (1996), Aghion et al. (2005) and Barro (2012, 2015) among others.

Conditional convergence also seems to imply that convergence across regions within a country should actually occur more rapidly than across individual countries since regions tend to be more homogenous regarding the above-mentioned variables. Barro and Sala-i-Martin (ibid.) establish a convergence rate of roughly 2% in per capita personal income using a long-term panel of the 48 contiguous US states. Other studies on regional convergence in the US and in other OECD countries include Blanchard & Katz (1992), Cashin (1995), Coulombe & Lee (1995) and Spilimbergo & Che (2012). 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 establish the astonishing result that regional convergence is about 2% per year, again in line with the iron law of convergence. The authors rightly ask why the speed of regional convergence is not faster than the speed of convergence across countries given that there is much more homogeneity within a country than across countries. In the final analysis, they attribute this relatively slow regional convergence to low factor mobility within countries.

As espoused in Islam (2003), the issue of convergence was hotly debated in the literature because when testing for convergence, one could test for the validity of alternative growth theories, with neoclassical growth theory implying convergence, while new endogenous growth theories did not. However, with time it became clear that neoclassical growth models which include human capital and migration as factors of growth are capable of predicting the observed growth and convergence patterns well. Regarding research on regional convergence, it also became apparent that models of regional growth and convergence have to be estimated taking spatial dependence among regions into account. We first turn to a discussion of augmented neoclassical growth models which include human capital and migration as important drivers of growth and convergence, and then conclude our survey with studies that incorporate spatial effects in their empirical models of regional growth and convergence.

2.2 Extensions: human capital and migration

Having received, on the one hand, tremendous popularity, and, on the other hand, a challenge from empirical research, the original Solow model has acquired a number of important extensions. The now classic study by Mankiw, Romer & Weil (1992) shows that augmenting the original Solow model with human capital produces results that are consistent with the cross-country evidence on the variation of per capita income. These authors also recover the parameters of the Solow model which become more reasonable once human capital is included in the production function. A more recent paper by Gennaioli et al. (2013), using a similar regional data set as the one in Gennaioli et al. (2014), looks at the importance of human capital in regional development. The paper points to the importance of the returns to education for entrepreneurs. Having neglected human capital externalities arising from entrepreneurial activities, researchers in the past have underestimated the importance of education in regional development.

Migration within or between countries is considered another important driver of growth and convergence. Many early papers on regional convergence in the context of capitalist economies, for which migration is an important driver, take their inspiration from Barro & Sala-i-Martin (1991). The principal innovation in the studies of Barro & Sala-i-Martin is to identify migration as an important driver of convergence. In a neoclassical framework with homogeneous labor, positive net migration will increase the rate of convergence as long as labor migrates from poorer to richer countries or regions because of higher wage rates. Positive net migration will lower the capital-labor ratio in this scenario, hence the productivity of capital will be diluted and diminishing returns on capital per worker will set in more rapidly, leading *ceteris paribus* to a higher convergence coefficient. When labor is not homogeneous and migrants bring human capital and raise the productivity of capital, positive net migration can contribute to divergence. The authors provide a careful analysis of the empirical patterns of convergence and of net migration across the 48 US continental states, using predominantly 10 year-intervals, with data from 1900 to 1988 and taking into account the endogeneity issues connected with migration. Their main results state that convergence of income per capita proceeds at around 2%, and that migration contributes very marginally to this convergence. Their empirical analysis of convergence across 74 regions within the EU also confirms the results for the US.

How important is internal migration for regional convergence? Ozgen, Nijkamp and Poot (2010) provide a meta-analysis of papers estimating cross-sectional equations essentially identical to the one developed by Barrow and Sala-i-Martin. The authors summarize these results by stating that the overall effect of net migration on growth is positive, but small. They also point out that the evidence of the 12 studies means that in contrast to the results found by Barrow and Sala-i-Martin, internal net migration contributes to divergence rather than convergence, albeit marginally.

Two papers that are close to our approach are Dolado, Goria & Ichino (1994) and by Boubtane, Dumont & Rault (2016). They both develop a structural growth model which introduces migration and human capital as factors for growth. The earlier study by Dolado et al. was the first to highlight the ambiguous effect of net migration on growth. This effect depends on the relative contribution of human capital of foreign- and native-born migrants, on net migration rates of foreign-born and natives and on the parameters of the production function. In the augmented Solow model, there are two countervailing forces brought on by positive net migration: capital dilution as more workers are spread over the existing capital stock, and the contribution of migrants to the accumulation of human capital, which increases the productivity of capital. Only if the latter factor dominates the former will migration positively affect growth. Dolado et al. (ibid.) estimate the augmented growth model using panel data from 23 OECD countries for the period between 1960 and 1985. Their main result states that the dilution effect of migration is strongly reduced by the human capital which migrants bring to the host country.

Boubtane et al. (2016) has empirical evidence which employs system GMM estimation, and thus uses more appropriate techniques to take account of the endogeneity issues connected to migration than in Dolado et al. In addition, the skill composition of migrants in the period analyzed by Boubtane et al. is more in line with the skill composition of internal migrants in Russia. The authors use panel data from 22 OECD countries from 1986 to 2006, when international migratory flows were large and a substantial number of migrants had high skill levels. In contrast, the period investigated by Dolado et al. was characterized by relatively limited international migration and most of the migrants were unskilled and working in the manufacturing sector. Their careful econometric analysis leads Boubtane at al. (2016) to arrive at the following central conclusion: "The results show that in the short run, taking into account the skill composition of foreign-born migrants , a 50% increase in the net migration rate of foreign-born migrants would increase GDP per worker by three-tenths of a percentage point per year [...]. The long-run effect of foreign-born migration on GDP per worker is, on average 2% per year."

These two papers look at the effect of migration on convergence across countries. We conclude this section by briefly discussing Huber & Tondl (2012) who look at the effect of migration on convergence at the regional level in the EU. The authors employ data from 27 EU NUTS 2 regions to estimate the effect of net migration on unemployment, per capita GDP and productivity. They find no effect of migration on unemployment, but a positive effect on GDP per capita growth and productivity. The authors infer from their results that migration contributes to divergence rather than convergence since net migration across EU regions predominantly occurs from poorer to richer regions.

2.3. Growth models with spatial effects

One strand of the literature, which is particularly relevant for our study, deals with spatial effects when analyzing regional convergence. Not taking into account these spatial effects, leads to omitted variable bias and thus to misleading inferences about regional convergence. Before honing in on econometric issues in connection with spatial dependence, let us summarize important papers that take as their point of departure a neoclassical growth model. The studies by Fingleton and Lopez-Bazo (2006), Egger and Pfaffermayr (2006), Lopez-Bato et al. (2004) and Fischer and Pfaffermayr (2018) are particularly in line with our study since the authors base their analysis of spatial dependence on a structural growth model which includes externalities based on productivity spillovers and knowledge diffusion across economies or regions. Since spatial dependence in the theoretical model of Lopez-Bazo et al. (2004) is of substance and not brought about by random shocks across economies or regions, a spatial lag specification rather than a spatial error model is preferred when estimating conditional convergence. The empirical analysis confirms that conditional convergence should be estimated with a spatial lag specification. Using data on NUTS 1 or NUTS 2, all four studies establish the importance of spatial dependence when analyzing conditional regional convergence. According to Fischer & Pfaffermayr (2018), migrants and not initial technology or income levels are the main channels through which regional spillovers materialize.

Focusing more on purely econometric issues, Rey & Montouri (2010) demonstrate the importance of spatial dependence for the convergence process in the US in an exemplary fashion. The authors undertake a very careful analysis of the question of whether per capita income growth is clustered in groups of states, that is, whether there is spatial autocorrelation in the regional income per capita data. They find very convincing evidence that this is the case and conclude that empirical models of regional convergence that ignore these spatial effects are clearly misspecified. Employing data from 1929 to 1994, they estimate an average rate of convergence of roughly 2% when spatial effects are ignored, although this estimate is lower when the convergence rate is estimated with a maximum likelihood spatial error model. Goodness of fit tests in the form of the Akaike Information Criterion show that the spatial error model fits the data best, implying that models à la Barrow & Sala-i-Martin (1991) are underspecified due to omitted spatial dependence. Econometric issues are also at the center of Badinger, Müller & Tondl (2004) who discuss the need to develop models that take account of both spatial dependence and endogeneity issues when estimating regional convergence of per capita income. Using data from 212 NUTS 2 European regions for 1985 to 1999, they proceed in two steps: first they filter out the spatial effects from the data, then they apply standard estimators for dynamic panel data. They show that neglecting spatial dependence leads to an implausible convergence coefficient that implies divergence, while applying a GMM estimator in first differences or a system GMM estimator leads to a convergence coefficient which implies convergence. The authors also provide evidence that the GMM estimator in first differences might be plagued by weak instruments and that the system GMM estimator is preferred when estimating regional convergence.

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.[5] 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 2000s) was growing economic inequality and divergence, regardless of the methodology used (Badunenko & Tochkov, 2010; Benini & Czyzewski, 2007; Berkovitz & 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 & Laeven, 2006; Falcetti, Lysenko & Sanfey, 2006). While initial conditions (e.g., the overall level of economic and technological development, economic structure and industrial specialization) had a visible effect on regional growth, most studies conclude that the scale of the privatization and the liberalization of economics also had an important impact.

Subsequent studies covering the 1990s and 2000s started to find some β-convergence, typically at a rate of about 1% (e.g., Drobyshevsky et al., 2005; Kholodilin, Oshchepkov and Siliverstovs, 2012; Lugovoi et al., 2007), while studies analyzing longer data series and covering the most recent periods typically report much higher rates of β-convergence. Guriev and Vakulenko (2012) report 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 innovation (Kaneva and Untura, 2019), fiscal federal transfers and public spending (e.g., Di Bella et al., 2017;

[5] There are also a few studies that examine the issue of convergence in Russia at the city level. Ivanova (2018) establishes conditional sigma-and beta-convergence of real wages in spatially close cities in the period between 1996 and 2013. According to Skorobogatov (2018), consumption and productive (dis)amenities tend to equalize across Russian cities, which gives rise to income convergence between them.

[6] Lehmann and Silvagni (2013), however, established weak divergence for the years 1995 – 2010. All these estimates are hardly comparable due to big discrepancies in methodologies.

Durand-Lasserve and Blöchliger 2018), FDI (Iwasaki & Suganuma, 2015), and even the rate of regional unemployment and regional economic structures (World Bank, 2017). In the absence of underlying theoretical models, however, the variables included were usually determined *ad hoc* and substantially differ from study to study. This lack of theoretical underpinnings of the estimated empirical growth models also extends to the other papers on Russian regional convergence.

3. Theoretical Model

Our model of regional convergence is based on the classic Solow model (Solow, 1956) augmented with human capital (Mankiw, Romer & Weil, 1992) and migration (Dolado, Goria & Ichino, 1994). The economy has a Cobb-Douglas production function with labor-augmenting technological progress:

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

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

A is assumed to grow exogenously with rate g:

$$A_t = A_0 e^{gt} \ [2],$$

L grows with rate (n + m):

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

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

The dynamics of physical capital are described as:

$$\dot{K} = s_k Y - \delta_k K \ [4pc],$$

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

The dynamics of human capital are characterized by:

$$\dot{HC} = s_h Y - \delta_{hc} HC + m \cdot \varepsilon \cdot HC \quad [4hc],$$

where s_h is the fraction of output invested in human capital; δ_{hc} is the depreciation rate of human capital; ε is the ratio of the human capital of immigrants to natives. Immigration increases the overall amount of human capital in the region if $\varepsilon > 0$.[7]

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:

$$y = hc^{\varphi} \cdot k^{\alpha} \quad [5],$$

[7] Following Dolado, Goria & Ichino (1994), migrants are not assumed to bring significant amounts of physical capital with them.

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

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

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 & 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.

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

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

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

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 capita:

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

$$-\frac{\varphi}{1-\alpha-\varphi}\ln(g+\delta+n+m-\varepsilon\cdot m) \; [10].$$

The last term may be rewritten as:

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

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

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

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

$$-\frac{\varphi}{1-\alpha-\varphi}\cdot\varepsilon\cdot\frac{m}{g+\delta+n+m} \; [12].$$

Finally, as noted by Mankiw, Romer & Weil (1992), equation [12] may be rewritten in terms of the human capital stock:

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

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, Romer & Weil, 1992, p. 418).

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

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

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 toward the steady state becomes:

$$ln(y_t) - ln(y_{t-1}) = -\left(1 - e^{-\lambda\tau}\right)\ln(y_{t-1}) + \left(1 - e^{-\lambda\tau}\right)\frac{\alpha}{1-\alpha}\ln(s_{kt}) +$$
$$+\left(1 - e^{-\lambda\tau}\right)\frac{\varphi}{1-\alpha}\ln(hc_t) - \left(1 - e^{-\lambda\tau}\right)\frac{\alpha}{1-\alpha}\ln(g + \delta + n + m) + \left(1 - e^{-\lambda\tau}\right)\frac{\alpha}{1-\alpha}\varepsilon \cdot migr_t +$$
$$+\left(1 - e^{-\lambda\tau}\right)Ln(A_0) + \nu_t \qquad \text{[15]},$$

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

4. Methodology and Data

4.1 Methodology

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

$$\Delta\ln(y_t) = \beta\ln(y_{t-1}) + \beta_1\ln(s_{kt}) + \beta_2\ln(hc_t) - \beta_3\ln(g + \delta + n + m) +$$
$$+\beta_4 migr_t + regionFE + TimeFE + \nu_t \quad \text{[16]}.$$

Compared to the theoretical model, this equation includes two additional variables, $region\ FE$ and $Time\ FE$, reflecting regional and time fixed effects (FE), respectively. Since Islam (1995), it is common practice to include in empirical growth equations region (or country) FE, which control for the unobserved heterogeneity of regions. More specifically, regional FE control for unobserved interregional 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, as stressed by Islam (2003). 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 FE control for the influence of either positive or negative macroeconomic shocks affecting all regions in the country. This is especially important in the Russian case, since the period that we consider, 1996-2015, straddles both economic crises and recoveries, including the on-going period of sanctions, which started in 2014. Time FE can, in principle, control for possible changes in the statistical methodology of the calculation of variables by Rosstat.[8]

Although the inclusion of regional FE helps to avoid the omitted variable bias in equation [9], it creates a bias of another sort. Regional FE are correlated with lagged GRP per capita, which leads to a downward bias in the OLS estimates, known in the literature as the Hurwicz-Nickell bias (Hurwicz, 1950; Nickell, 1981). To avoid this bias, we estimate equation [16] by system GMM (Arrelano & Bover, 1995; Blundell & Bond, 1998), which has become the most popular approach to estimate dynamic panel data models, as it is more efficient than the Arrelano-Bond method (Arrelano & Bond, 1991).

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 as in the Arrelano-Bond estimator, but also with lagged first differences. Apart from traditional Sargan-Hansen tests, the important diagnostic in this case involves the tests for the autocorrelation of the residuals. While the residuals of the differenced equation should follow an AR(1) serial correlation process, they should not exhibit an AR(2) process, since in this case the second lags may not serve as valid instruments for current values.

There are additional issues related to the estimation of equation [16]. The first issue concerns the parameters g and δ. Following Mankiw, Romer & Weil (1992), many studies on convergence across different countries or regions assume $g + \delta$ = 0.05. Although there are studies that applied this assumption to analyze convergence across Russian regions (e.g, Zemtsov & Smelov, 2018), we are not aware of studies that explicitly 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 as a robustness check we use alternative values to see whether our estimates are affected.

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 & Sala-i-Martin, 1991). A panel data setting allows averaging over periods of different lengths. A straightforward approach is to use yearly data. However, some recent studies including Barro (2015) and Gennaioli, La Porta & Schleifer (2014) average all variables over non-overlapping 5-year periods. Averaging variables makes results less vulnerable to potential data errors, however, as formulated by Islam (1995), “If we think that the character of the process of getting near to the steady state remains essentially unchanged over the period as a

[8] We are aware of, at least, one such change. In 2011, Rosstat changed the definition for internal migration. It started to take into people who moved to another region and stayed there more than 9 months (instead of 12 months before 2011). This led to a visible increase in the amount of internal migration in 2011 compared to 2010 (e.g., see Buranshina & Smirnykh, 2018).

whole, then considering that process in consecutive shorter time spans should reflect the same dynamics." Therefore, from a theoretical point of view, averaging over different periods should give similar results.

In our study, we average over 3-year non-overlapping periods. 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. The period 2008 to 2010 encompasses the global financial crisis, which produced a large negative shock to real GDP per capita in 2009, but we see a recovery in 2010. The next period shows the resumption of consistent growth albeit at a lower level than in the 2000s. Finally, the last period, 2014 to 2017, is the period of sanctions and countersanctions.

The third issue is that our theoretical model has 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 the dynamics of labor productivity because of different behavior of regional employment rates (e.g., see Dunford, 1996; Meliciani, 2006). To reconcile our theoretical model with the empirical analysis, we add the log of the employment rate (taken in differences) to the RHS of equation [16]. However, our results show that this adjustment does not affect the estimates in the Russian case.

The fourth issue potentially relevant in the Russian context relates to large price differentials across regions. However, some previous studies show that possible adjustments of regional GDPs for price differentials barely affect the scale of variation in GDP and the relative order of regions and have almost no effect on convergence results (e.g., see Kholodilin, Oshchepkov & Siliversotvs, 2012; Durand-Lasserve & Blöchliger, 2018). This is in line with the broader international evidence (see Gennaioli, La Porta & Schleifer, 2014). Therefore, for the sake of simplicity, we use regional GDPs without price corrections.

Finally, as suggested by the studies reviewed in Section 2.3, the overall convergence process may be affected by spatial interdependence between regions. Omitting spatial interdependencies between regions may distort the estimation results of the regional growth equation. Many previous studies have also emphasized the presence of spatial effects in the Russian case (e.g., Demidova and Ivanov, 2016; Kholodilin, Oshchepkov and Siliverstovs, 2012; World Bank, 2017). Therefore, although our theoretical model does not involve any spatial interdependencies, we need to take them into account in the econometric analysis. For this, we follow López-Bazo, Vayá & Artís (2004) and introduce two spatial terms to the RHS 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:

$$\Delta \ln(y_t) = \beta \ln(y_{t-1}) + \beta_1 \ln(s_t) + \beta_2 \ln(HC_t) - \beta_3 \ln(n+g+\delta) + \beta_4 migr_t + region\,FE + \\ + Time\,effects + \beta_5 W \cdot \Delta \ln(y_t) + \nu_t \quad [17],$$

where $W \cdot \Delta \ln(y_t)$ is the spatial lag of $\Delta \ln(y_t)$; W is a spatial weighting matrix, normalized by rows $w_{ij} = \frac{1}{d_{ij}{}_{ij}}$, where d is geographical (arc)distance between regions i and j. Following the literature, we expect that the estimate of $\beta_5$will be significant and positive, i.e., that growing regions tend to be located closer to other growing regions, either due to growth spill-overs, or because growing regions have similar economic structures pre-determined by similar geo-climatic conditions.

The spatial lag of the dependent variable complicates the estimation of equation [17] as this lag is endogenous by nature. We are aware of at least two general approaches to estimate such a dynamic panel data model with a spatial lag. The first approach is based on (quasi-)maximum likelihood estimation. Two different realizations of this approach are developed by Elhorst (2005) and Lee, de Jong, & Yu (2008). The second approach is system GMM that instruments the spatial lag variable like any other RHS endogenous variables (Kukenova & Monteiro, 2009).[9]

We choose system GMM as it is best suited to cases when there are other potential endogenous variables in addition to a spatial lag of the dependent variable (see Kukenova and Monteiro, 2009, for more details). In our case, all RHS variables may be potentially endogenous, especially immigration and human capital. By using system GMM as our estimation method, we generate consistent estimates of the coefficients on all potentially endogenous variables.[10,11]

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

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9 Badinger, Mueller & Tondl (2004) combine system GMM with 'spatial filtering'.
10 In the Russian context, system GMM has been also applied by Buranshina and Smirnykh (2018), Vakulenko (2016), World Bank (2017).
11 In practical terms, we estimate Equations 16 and 17 in STATA using –the xtabond2- module 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, for instance, Ahrend (2002) excluded Ingushetia; Guriev & Vakulenko (2012) and Vakulenko (2016) excluded Chukotka and Ingushetia; Kholodilin et al. (2012) excluded Chukotka and Kalmykia. These regions tend to be excluded because of implausible fluctuations in regional output per capita. Figure A1 presents the yearly growth rates of real GRP per capita along with 3-year averages for all Russian regions, using original Rosstat data. Two regions, Chukotka and Ingushetia, exhibit extremely volatile and implausible fluctuations even when averaged over three years. So, following previous research on regional convergence in Russia, we also exclude these two regions from our analysis. We also check how our estimation results change when we exclude Kalmykia.

Most variables we use come from Rosstat regional statistics, i.e., the 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 GRP.

There are two possible ways to measure the stock of human capital across Russian regions. One is to use the share of the regional population or, alternatively, the share of employed with higher education. Since Mankiw, Romer & Weil (1992), this measure has been widely used in cross-national studies. However, it has been heavily criticized since formal education may only poorly reflect learning.[12] The same level of enrollment in two countries or regions does not necessarily reflect similar skill levels (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 lead, in many cases, to a serious devaluation of 'old' human capital, acquired in the Soviet period. Such human capital might be characterized by zero or even negative returns under current market conditions (see, e.g., Gimpelson, Kapelushnikov & Oshchepkov, 2016).

The second option is to use the share of employed in the R&D sector, as was done by 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 enough 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 be not straightforward as it reflects not only human capital per se but is intertwined with regional R&D investment arising, for instance, from policy initiatives. As there are pros and cons for the use of the two measures, we try both of them in our estimations.

[12] See, for example, the discussion in Angrist et al., 2019.

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 1 shows the top-10 and bottom-10 regions of Russia in terms of GRP per capita for the beginning (1996) and the end (2017) of the period under study.

[Table 1 near here]

In 2017, the richest Russia's region, Tyumenskaya oblast', had GRP per capita slightly less than 100,000 rubles (in 1996 prices), while the poorest region, the Republic of Ingushetia, had GRP per capita about 3,000 rubles. Therefore, the level of GRP per capita in the richest region was about 30 times (!) higher than the level of GRP per capita in the poorest one. All regions among the top-10, except 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 the 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 of the country that shows GRP per capita in 2017 (see Figure A2 in Appendix).

Table 1 also suggests that the relative position of Russia's regions was stable over time. Tyumenskaya oblast' and the Republic of Ingushetia were the richest and poorest regions, respectively, in 1996 and 2017. Over the 21-year period, from 1996 to 2017, the composition of the top-10 and bottom-10 regions changed by less than half: only 4 regions left each group. Overall, the correlation between GRP per capita in 1996 and 2017 was 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.

Which of Russia's regions were growing the fastest? Figure 2 presents average real GRP per capita growth rate over 1996-2017 vs. the level GRP per capita in 1996.

[Figure 2 near here]

The data suggest a negative relationship between the average growth rate of GRP per capita and its initial level over the period, implying a rate of convergence of about 0.6% per year. Therefore, a simple *ad hoc* analysis reveals unconditional convergence between Russia's regions. Although unconditional convergence between regions within one country is more plausible than between individual countries, such a result should be treated very skeptically due to the strong and stable heterogeneity of Russia's regions, the interdependencies between them, and positive and negative time shocks, which are not taken into account. The results of the estimation of our theoretical model using sophisticated panel data estimation techniques are presented in the next section. Table A1 (in Appendix) contains the descriptive statistics on all variables used in that analysis.

5.2 Estimating the complete model

The main estimation results are presented in Table 2.

[Table 2 near here]

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.

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 results of many previous studies (e.g., Barro, 2015; Gennaioli, La Porta & Schleifer, 2014) and may reflect the downward Hurwicz-Nickell bias.

Finally, Column 3 of Table 2 presents estimation results obtained by using system GMM, which avoids the Hurwicz-Nickell bias (all technical parameters of the system GMM estimation are discussed below). The estimate of the coefficient on lagged GRP per capita is -0.022 and statistically significant at the 1% level. The obtained system GMM coefficient lies between the OLS and FE estimates, which is a good sign, according to Roodman (2009b). The implied rate of convergence is 2.2% per year, which is remarkably close to the 2% rate of the iron law of convergence.

When applying system GMM, it is crucial to report and discuss several technical parameters, tests, and robustness checks. For instance, as system GMM estimates may be highly sensitive to the number of instruments, "…it is good practice to report the instrument count and test the robustness of results to reducing it." (Roodman, 2009, p.99). To maintain uniformity in the rows of Table 1, we present all the necessary test parameters in connection with the application of system GMM separately in Table A2 in the Appendix. The next paragraph discusses these test parameters in some detail.

We estimated the specification in Column 3 of Table 2 by system GMM several times, applying different restrictions on the number of lags and using different methods of estimating the covariance matrix, namely two-step GLS-like estimation vs. robust estimation. As Table A2 shows, in all cases the AR tests for the autocorrelation of the residuals suggest that residuals 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 results are not sensitive to how the covariance matrix is estimated. However, estimates are quite sensitive to different restrictions on the lags of dependent variables used as instruments. As Column 1 of Table A2 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). This p-value slightly declines 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 reduces to 79 and becomes equal to the number of panels. Therefore, Column 6 reflects our preferred results, which are transferred to Table 1.

In line with the theoretical expectations, the saving term *ln(s)* is significant and positive, while *ln(n+g+δ)* is significant and negative. Moreover, coefficients on *ln(s)* and *ln(n+g+δ)* are not statistically different from each other in absolute terms, which is in line with the theoretical model (equation [15]). According to our estimates, the share of physical capital in output (α) is 0.49. As theoretically grounded growth equations have not been estimated for Russia before, we cannot compare this estimate to previous results for Russia. However, estimated measures in the literature are very close to ours. Durand-Lasserve and Blöchliger (2018) estimated a version of the Cobb-Douglas production function for cross-sections of Russian regions in 2005 and 2015 and establish α to be equal to about 0.5. 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 the average value of 0.32. If the share of tax incomes is equally distributed between the shares of labor and physical capital, this increases the share of physical capital to 0.42. Our estimates are also remarkably close to the estimates by Mankiw, Romer and Weil (1992) who obtained α=0.48 for their total sample of 98 countries.

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

Another remarkable fact is that both human capital proxies are positive and significant in equations estimated using pooled data. As mentioned by Islam (1995, p.1153), "Whenever researchers have attempted to incorporate the temporal dimension of human capital variables into growth regressions, outcomes of either statistical insignificance or negative sign have surfaced" (see also the discussion in Katzikaliadis et al., 2001). In general, human capital measures may become insignificant in FE or first difference (FD) estimations for several reasons.

One possible reason is that FE/FD estimation excludes all unobservable individual time-invariant regional characteristics, which are correlated with regional human capital (for instance, the initial level of regional technological development, $Ln(A_{0i})$). If these regional characteristics are correlated with human capital positively, then their exclusion will reduce the size of the coefficient of variables reflecting human capital.

Another reason is that FE/FD transformation rules out all "between" (cross-sectional) 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 when differences in enrollment rates between countries reflect differences in terms of skills much better than differences in enrollment rates within countries, as rising enrollment was not accompanied by rising educational quality, especially in developing countries. 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" (temporal) variation. If this is the case, one should observe a substantial increase in standard errors. Indeed, as Table 2 shows, the standard error of the coefficient for the variable reflecting employment with higher education tripled after the FE transformation. All in all, 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 human capital coming with migrants from other regions exceeds the amount of human capital of the native population.[13] As $\varepsilon > 1$, interregional migration in Russia, according to our model, should have a positive impact on the output of the receiving and relatively rich region and thus impede economic convergence between regions. Again, there are no previous studies on Russia that provide any benchmark for our estimate of ε, while existing studies dedicated to internal migration do not usually measure the human capital of migrants. Nonetheless, similar to other countries (see, e.g., Lkhagvasuren, 2014), it is plausible to expect that interregional movers in Russia have, on average, a higher amount of human capital than non-movers in receiving regions.

[13] Dolado, Goria & Ichino (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 lower amount of human capital than native population. One may expect that for migration within one country ε should be higher.

5.3 The role of human capital and migration

Next, we examined 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 from that specification with the rate derived from the complete model. Table 3 presents these estimation results. In Column 1, we repeat the GMM estimates and the implied theoretical parameters of the full specification shown in Table 2.

[Table 3 near here]

We find that the exclusion of the human capital proxy from the full specification 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. This suggests that migration contributes to *convergence* in the Russian case. This result differs from that of Vakulenko (2016), who finds that migration had no impact on income convergence between Russian regions in the period 1995-2010, but in line with the findings of Buranshina & Smirnykh (2018) who establish a positive (albeit weak) role of migration in the regional convergence of wages.

5.4 Robustness Checks

To assess the stability of our main finings, 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 method of estimation of standard errors.

Second, we tried an alternative value of $(g+\delta)$. Using officially published data on stocks of physical capital for the beginning and end of each year and data on investments, we estimate the average depreciation rate (δ) for the period under study to be about 4% per year. Following Mankiw, Romer & Weil (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 $(g+\delta)$ of 0.08.[14] Using this value, we re-estimated all our specifications. As Tables A3 and A4 show, all our findings and their substantive interpretations remained almost the same.

Third, 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

[14] Alternatively, following a study by Turganbayev (2016) for Kazakhstan, we used the coefficient of liquidation of fixed assets (which equals in Russia to 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 $(g+\delta)$.

conclusions on the role of human capital, the implied rate of convergence slightly reduces in this case to 1.9% (see Table A5 and A6).

Finally, a particularly important check for the robustness of our findings is introducing spatial effects. Table A7 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, which is in line with previous studies on Russia. While all our findings and interpretations remain qualitatively the same, the estimated convergence rate declines substantially to 1.3% per year. This suggests that spatial connectedness of Russian regions in the form of spatial correlation of regional economic growth is an important factor in their *convergence*, which is in line with some earlier evidence (e.g., see Kholodilin et al., 2012). As Table A8 shows, the introduction of spatial terms, however, does not change our conclusions on the role of human capital and interregional migration in the convergence process.

6. Summary and Conclusions

We studied convergence in per capita GRP across Russian regions in the period from 1996 to 2017, the longest period for which data are available. 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. Therefore, our paper presents, strictly speaking, the first empirical test for the applicability of the standard growth model to Russian regional economic development. 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, as voiced by Durlauf & Quah (1999) and Durlauf, Kourtellos & Tan (2008), among others. Our estimates also allow us to derive a set of plausible parameters of the augmented growth model.

Our main specification provides an estimate for 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. In our view, this finding suggests that the general (long-run) dynamics of the economic development of Russian regions may be analyzed within the framework of a neoclassical growth model, despite the strong structural differences between Russian regional economies.

Concerning the role of human capital for the 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 received using pooled and panel data is completely 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 (richer in monetary terms but poorer in terms of general quality of life, see Oshchepkov, 2015) to relatively poorer western and southern regions – the so-called 'western drift', which was especially strong during 1990s and 2000s (see Heleinaik, 1999 and Kumo, 2017 among others), we can infer that interregional migration contributes to economic convergence between Russian regions.

Additionally, we investigated the role of spatial interdependencies between Russian regions. We find that their inclusion 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 per capita GRPs to regions with the relatively low ones, which helps the latter to catch up. A more detailed investigation of the underlying mechanisms is a task for future research.

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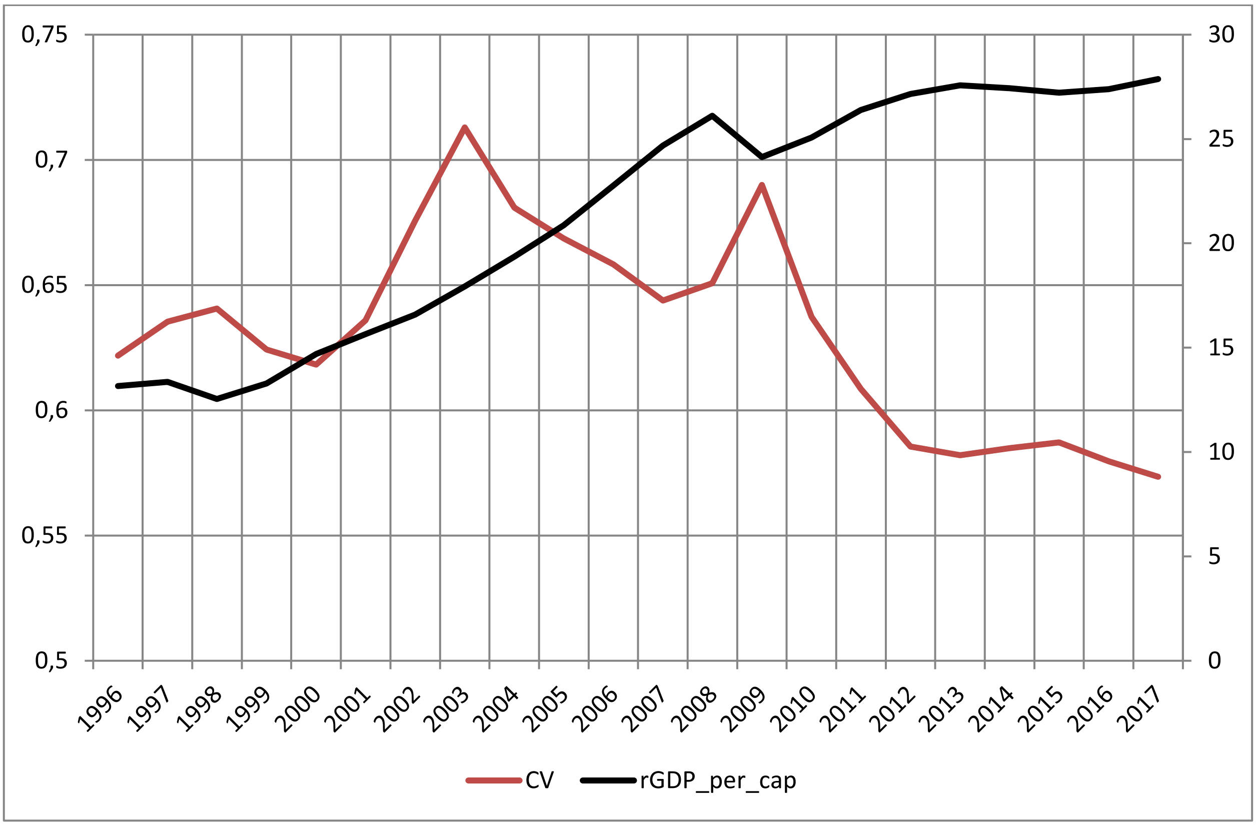
Figure 1. Real GDP per cap over time (right scale) and coefficient of variation (CV) in per capita GRP of Russian regions (left scale) in 1996-2017.



Note: Real GDP per capita in Russian rubles (in 1996 prices).

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

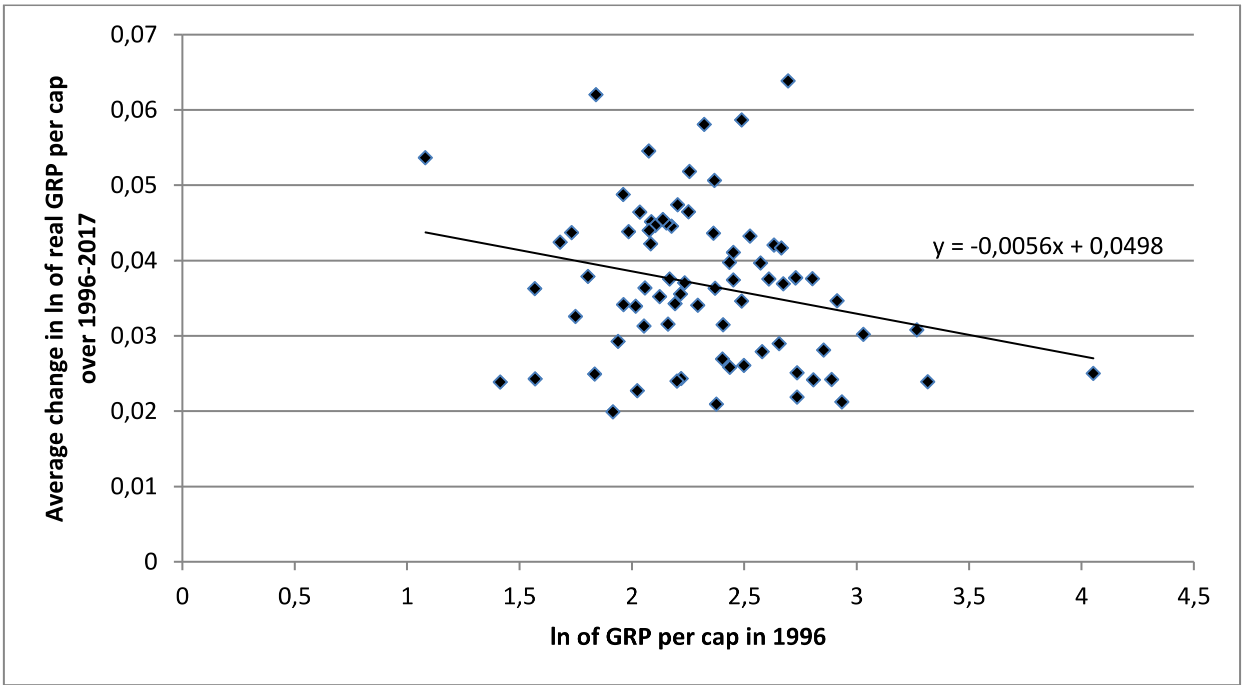


Table 1. Top and bottom 10 Russian regions in terms of GRP (thousand rubles) per capita in 1996 and 2017.

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 2. 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 effects	YES	YES	YES
region effects	NO	YES	YES
N	537	537	537
Derived theoretical parameters			
Implied 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
Implied α	0,72	0,15	0,49
Implied ϕ for human capital	0,11	-0,06	0,05
Implied ε for migration	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. N = 537 which is less than 77*7=539 as 2 observations with negative values of (n+g+δ) are excluded.

Table 3. Estimated growth equation for the panel of Russian regions without human capital and migration (1996-2017).

	Full equation	Equation without HC	Equation 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 effects	YES	YES	YES
region effects	YES	YES	YES
N	537	537	537
Derived theoretical parameters			
Implied 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
Implied α	0,49	0,51	0,46
Implied ϕ for human capital	0,05		0,03
Implied ε for migration	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. N = 537 which is less than 77*7=539 as 2 observations with negative values of (n+g+δ) are excluded.

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

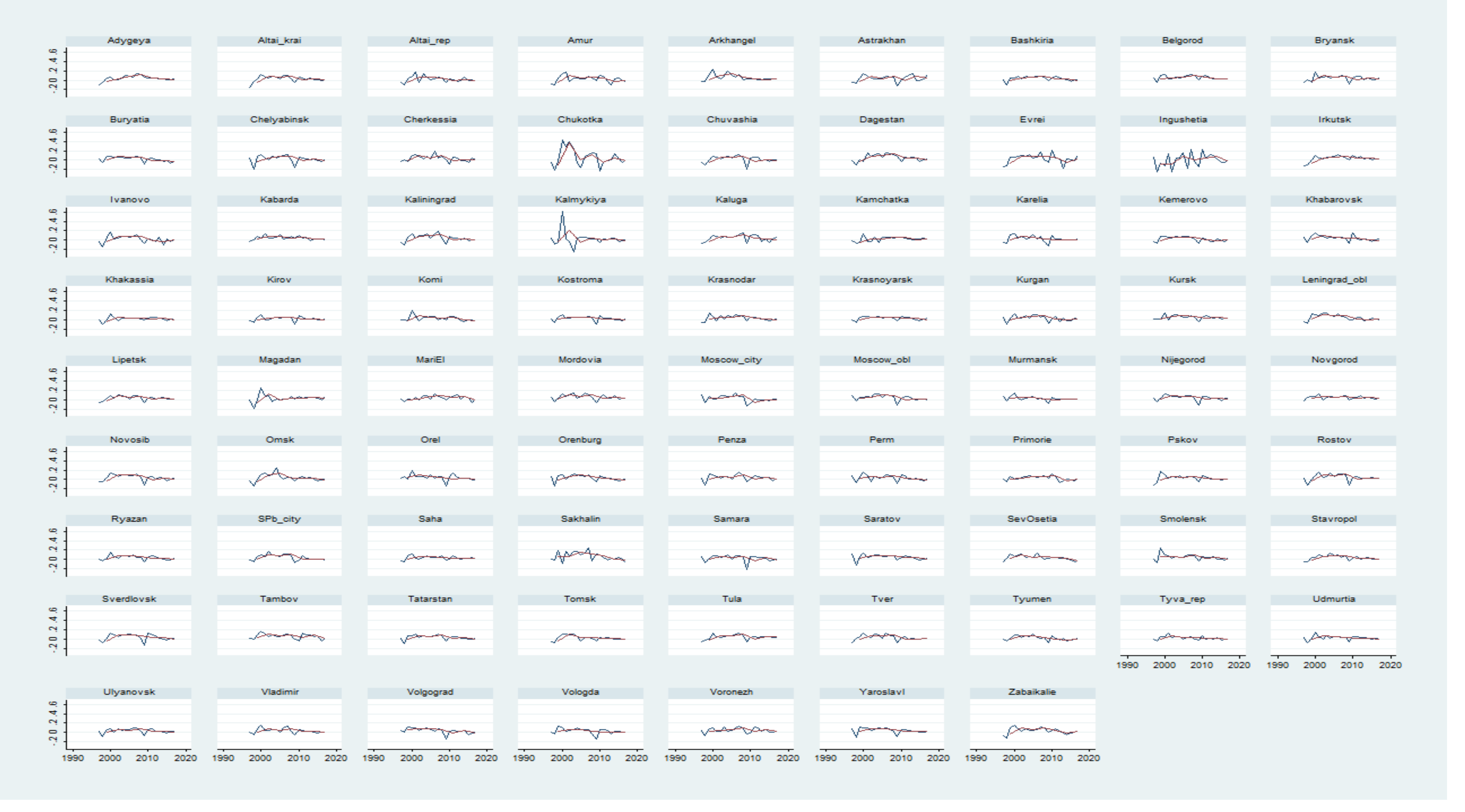


Figure A2. GRP per capita across Russia's regions in 2017.

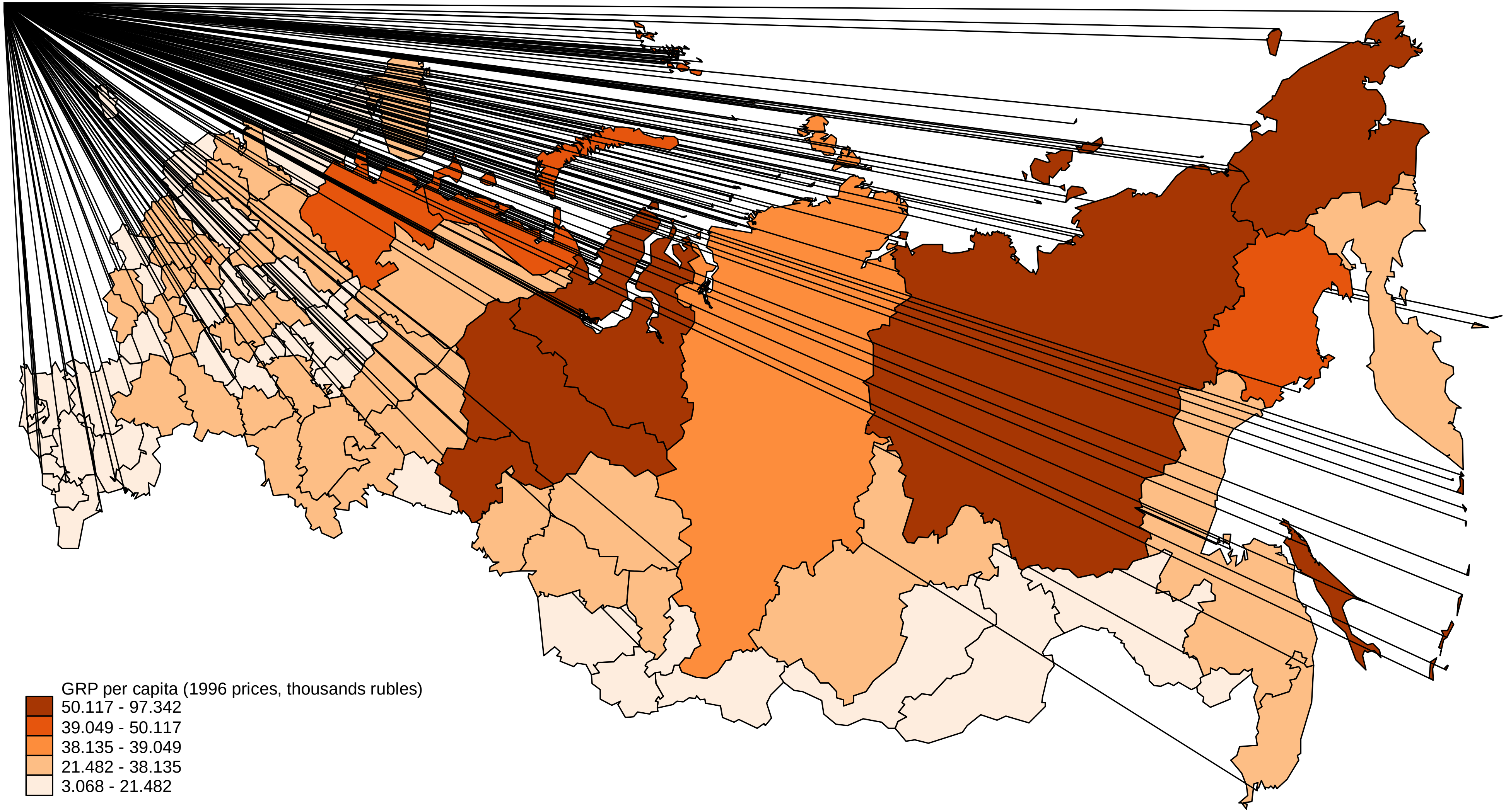


Table A1. Descriptive statistics on the variables used in the main analysis.

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
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-years 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 A2. 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	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 A3. 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	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 A4. 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	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 A5. 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)
spatial lag of ln gdp per cap growth	0,247***	0,169**	0,301***
	(0,070)	(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	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 A6. 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)	
spatial lag of ln gdp per cap growth	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	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 A7. 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(empl with higher educ)	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	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 A8. 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	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.

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