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ARTICLE

Efficiency of regional higher education systems and regional economic short-run growth: empirical evidence from Russia

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ABSTRACT
This paper analyses the link between the efficiency of regional higher education systems and the rates of regional economic development between 2012 and 2015 in Russia. The efficiency scores are calculated at the institutional level using Two-stage Semi-parametric data envelopment analysis. Then, the scores are aggregated at the regional level. We formulate an economic growth model that considers the efficiency of regional higher education systems as one of the explanatory variables. As an econometric method, we employ a robust GMM estimator. The findings highlight a positive, and statistically significant effect of higher education institutions efficiency on the regional economic growth. We also found negative spillover effects.

KEYWORDS
Regional economic development; higher education institutions; efficiency; knowledge spillovers; russia; two-stage Semi-Parametric DEA

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I25; I21; E02

1. Introduction

Higher education institutions (HEIs) are often considered to be economic agents and are analysed in terms of their economic activity. Universities may be engaged in the social and economic development of the territories where they operate and, consequently, they might contribute to economic growth (Pinheiro, Benneworth, and Jones 2012; Varga 1997). There are empirical studies that show a positive and causal relationship between the development of HEIs and rates of economic development (Valero and Van Reenen 2019). This effect is usually conditioned upon the generation and development of human capital by universities, which is one of the most important determinants of economic development (Hanushek 2016), as well as upon knowledge transfer (Drucker and Goldstein 2007).

HEIs are usually positioned in the literature as educational organisations that provide the most substantial contribution to economic growth compared, for instance, to schools. Universities are especially important in the context of economic development since this level of education provides the specific sets of skills needed for generating new ideas and innovations (Hanushek 2016). More detailed discussion of the economic contributions of universities and possible channels through which universities can transmit these contributions is presented in (Drucker and Goldstein 2007). In such a setting, universities are considered not as a burden for state budgets, but as an investment which can bring

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Supplemental data for this article can be accessed here

positive returns in the future. Such a perception of higher education has policy implications. The development of regional or national higher education systems is often seen as a policy instrument that can lead to positive economic outcomes, both in the short run and the long run.

Empirical studies that analyse the relationship between the elaboration of the higher education system and economic development in Russia give evidence that the scale and capacity of the higher education system matters for economic development (see, for example, Egorov, Leshukov, and Gromov 2017). However, the discussion regarding the role of university efficiency is limited. This paper is aimed at filling this gap in the literature and exploring empirically the link between the efficiency of regional higher education systems in Russia and the rates of economic growth of regions where these systems operate.

Russia provides a good case study investigating these issues. Russian economy experienced a significant slowdown during recent years. Average growth rate declined from 6.9% between 2000 and 2008 to 0.9% between 2009 and 2017. A significant part of this decline was associated with the drop in oil prices. However, Russian economy experienced a sharper decline compared even with other oil-producing countries. Economic stagnation observed during last years raises the question about new sources of growth for national economy (Kudrin and Gurvich 2015). The importance of human capital development through greater investment in the education sector, as well as through increasing efficiency of this sector, is highlighted both by academics (Becker and Oxenstierna 2018) and government officials (Medvedev 2016).

The current federal policy tries to take into account both the engagement of universities in social and economic development and the efficiency of their activities. In 2012 the 'Annual Monitoring of Performance of Higher Education Institutions' was launched by the Ministry of Education and Science. Using this policy tool, the Ministry aimed to identify the universities that were inefficient and made managerial decisions in such cases, including reorganisation. In response to the challenge of the limited links between HEIs and regional administrations and enterprises, a federal Flagship Universities Program was launched in 2015 to increase university efficiency in terms of having a positive impact on regional economic development. Another motivation for the choice of Russia for this kind of analysis is that Russia is a federal country with very high level of regional differentiation. Particularly, in the year 2017 the economic growth rates in Russian regions varied from −5.8% to 12.3%; gross regional product per capita – from 0.11 to 1.86 million rubles; share of employed population with higher education – from 8.7% to 46.2%; the share of students in the age cohort 17-25 – from 13.3% to 44.3%.[1] These heterogeneous contexts may be useful for highlighting the universities' contribution to economic development. Despite this regional diversity, the Russian higher education system is highly centralised (Carnoy et al. 2018), and most universities are governed by federal authorities. Therefore, Russian universities have rather specific set of incentives for engaging in processes of regional development (Egorov, Leshukov, and Froumin 2019). The main limitation of the particular choice of Russia is that findings and derived policy recommendations may be relevant only for similar countries with both federal structure and centralised higher education systems.

[1]According to the data provided by Federal State Statistics Service (Rosstat): https://eng.gks.ru.

Our analysis is based on economic growth theory and consists of three methodological steps. First, we estimate the efficiency scores of particular universities using Two-stage Semi-parametric data envelopment analysis (DEA) following Simar and Wilson (2007). Second, we aggregate these results at the regional level, thus obtaining and efficiency scores for regional higher education systems. Third, we propose a model for regional economic growth, treating the efficiency of regional higher education systems as one of the explanatory variables. The specifications of the models take into account the structure of regional economies and spatial effects both in gross regional product (GRP) growth rates and the efficiency of regional higher education systems. The model is estimated by means of a robust GMM system that handles the endogeneity problem between university efficiency and economic performance.

The paper is organised as follows. Section 2 discusses the background of the higher education system and regional development in Russia. Section 3 reviews the literature on the economic impact of universities and highlights the hypotheses of the study. Section 4 describes the data, along with the key descriptive statistics on the HEIs in the sample and focuses on methodology. Section 5 discusses the main results, and Section 6 contains some policy implications and concluding remarks.

2. The background of higher education and regional development in Russia

The Russian system of higher education has undergone unprecedented reform over the past 30 years and the landscape of the university system is still being transformed. This process was primarily the result of the collapse of the USSR and the transition to a market economy (Froumin, Kouzminov, and Semyonov 2014). In Soviet times, universities were part of a unified system of national economy and they were obligated to integrate into national supply chains. The higher education system was centralised and subject to rigid control, in adherence to the state's political agenda (Johnson 2008).

With the emergence of a new nation, new market mechanisms and new branches of the economy after 1991, the higher education system was forced to adapt to new social and economic realities. Most of these changes were not accompanied by any coordination at the national level.

The last decade of 20th century is often considered in the literature as period when the Government left higher education sector (Egorov, Leshukov, and Froumin 2019). This non-intervention was primarily related to significant cuts in public spending on higher education. In these conditions, Russian universities were prompted to seek out fast and effective ways to adapt to new operational conditions (Egorov, Leshukov, and Froumin 2019). The 1992 Law on Education is another factor that determined the decrease in the intensity of state interventions in higher education sector (Froumin, Kouzminov, and Semyonov 2014). This Law made possible the fee-paying slots in the universities, broke the narrow specialisation of the majority of higher education institutions and so on. Egorov, Leshukov, and Froumin (2019) also demonstrated that after 1991 under the pressure of funding cuts collaborations with industrial and regional partners and implementation of the third mission became the central ways to support universities sustainability.

Froumin and Leshukov (2015) highlight the following changes in the higher education system after the collapse of Soviet Union:

- emergence of market mechanisms and a private higher education sector;
- initially declining enrolment demand;
- greater diversification of educational programmes;
- liberalisation of education programmes and increase of university autonomy;
- efforts to become more internationally engaged;
- a recognition of international academic competition and benchmarking, including rankings.

Since the mid-2000 s, a series of public reforms to improve efficiency in the sphere of higher education have been undertaken. This has determined the basic condition of the current system.

The issue of the governance of higher education institutions in a large and heterogeneous country such as Russia remains particularly urgent. The Soviet legacy is responsible for the current centralisation of university governance – 90% of universities are regulated by the federal government. The financial and regulatory possibilities for the participation of regional authorities in university development are substantially restricted (Froumin and Leshukov 2015). Therefore, assessing the contribution of universities to the economic development of Russian regions in such centralised conditions is especially topical from an academic and institutional viewpoint.

Current regional development policy pays special attention to higher education as a source of regional growth. Universities are considered to be organisations which can attract resources to a region and support its competitiveness. This paradigm was reflected, particularly, in a special government programme to form 'flagship universities' to facilitate regional development by their teaching, research activities, knowledge transfer and their active role in society. However, the contribution of higher education to regional economic development is not limited to the flagship universities. All Russian universities contributes to economic development of territories where they are located in the following ways (Egorov, Leshukov, and Gromov 2017):

- universities generate the direct contribution to GRP by paying taxes, salaries, purchasing goods and services from local suppliers and so on;
- universities increase the quality of human capital in the regions by attracting and retaining young talented people, by producing labour force of higher quality;
- universities are centres of urban development, local population usually use universities' infrastructure, residential areas near the university campus are generally more attractive for living.

Regional development in Russia and important role of higher education institutions in this development raise the questions of how the economic contributions of universities can be increased. In this paper, we address this question and consider the efficiency of regional higher education system as an important determinant of universities' contribution to regional economic development.

3. Literature review and hypotheses

3.1. Literature on contributions of universities to economic development

There are different approaches to describing how universities may be engaged in social and economic development, ranging from the triple helix (Etzkowitz 1993) to different econometric approaches based on the theoretical macroeconomic (Romer 1986) and regional development (Capello 2011) models. This paper considers universities as economic agents and analyzes them in terms of macroeconomic models of endogenous economic growth.

The theory of economic growth has been developed and extended over a long period of time. Robert Solow (1956, 1957) provided the basic modern framework for economic growth modelling. He elaborated the long-run economic growth model, which included technological progress in addition to the standard determinants of economic growth, i.e. physical capital accumulation and an increase of the labour force. The technological progress variable was determined exogenously and contained those parts of the economic growth rate which could not be explained by the increase of the labour force or physical capital. This neoclassical growth model (Romer 1986; Lucas 1988; Mankiw, Romer, and Weil 1992) suggested that physical capital accumulation and labour force increases constitute the foundation of economic growth, but the growth of workforce productivity and capital increased as a result of technological progress. Neoclassical growth theories formed the basis for the development of new theories that, on the contrary, consider technological progress as a parameter that is endogenously determined in the economy. We use endogenous growth theory as a theoretical basis for this study since these models assume that development of the educational sector (development of human capital through universities, investment in innovation and knowledge creation) may lead to positive economic outcomes. Another important property of this model is that it allows for spillover effects. Moreover, the most recent models indicate greater importance of tertiary education, particularly for countries near the technological frontier (i.e. the most economically developed countries), where growth requires new innovations (Aghion et al. 2009).

Despite the fact that there is a consensus in the literature regarding positive contributions of universities to economic development, there are a lot of discussions regarding particular channels through which universities' activities may affect economic growth. It is not the aim of this paper to analyse deeper theoretical aspects of particular mechanisms through which universities can contribute to economic growth. However, in this section we provide the review of literature that articulates the links between universities' outputs and regional economic performance (see, for example, Drucker and Goldstein 2007 for more detailed review).

All effects of universities on regional economic performance can be splitted into two groups. The first group includes direct demand-side effects (Elliott, Levin, and Meisel 1988). These effects suggest that universities make different economic transactions within regional economies – pay salaries, taxes, purchase goods and services from local suppliers, provide jobs on the local labour market. These transactions increase the aggregate demand in regional economies and, consequently, transform this demand into GRP with multiplier effects.

The second group of effects includes different channels related to the universities' outputs that are primarily graduates (teaching activity), publications (research activity) and R&D (innovation activity).

According to Florida, Mellander, and Stolarick (2008), production of graduates is one of the main channels of how universities contribute to economic development. Human capital theory (Becker 1964) suggests that more educated workers tend to be more productive and have higher incomes, which is widely emphasised in different endogenous growth models (Romer 1986). University graduates employed in regional economy make direct contribution to GRP growth, firstly, by generating greater GRP due to higher productivity and, secondly, by paying more taxes, having higher expenditures contributing to aggregate demand in regional economy and so on. However, it is not the only mechanism of how universities contribute to economic development through graduates. Riddel and Schwer (2003) highlight that universities' graduates may contribute significantly to innovations by starting up new firms, as well as by increasing the innovativeness, creativity and productivity of local firms (Agasisti, Barra, and Zotti 2019). Wozniak (1987) argues that the skill composition of the local labour force that is significantly determined by the activity of universities in this region affects the technology used by the local firms. In addition, Algieri, Aquino, and Succurro (2013) demonstrated that more educated labour force in the region determines the higher level of innovativeness of this region. The important role of universities' graduates in regional innovation and in transferring knowledge from universities to local industries was also admitted by Varga (1997). Certainly, the economic contributions of higher education institutions through graduates limited to those graduates who do not migrate after graduation. However, more than 70%[2] of Russian universities' graduates find jobs in the region of graduation, that indicates sufficient intensity of the economic contributions of universities through their graduates in Russian case.

The second mechanism from the group of mechanisms related to universities' outputs corresponds to the R&D works implemented in the universities. Russian higher education institutions account for almost 15% of the total R&D volume in the national economy. There are a lot of both empirical (Griliches 1991; Jones and Williams 1998)) and theoretical (Romer 1986; Aghion and Howitt 1992) studies that highlight the strong positive link between R&D volume and rates of economic growth. It is important to note that we use variable reflecting the total volume of R&D as a proxy for a broader list of collaboration types between academics and non-academics. We assume that R&D volume is a good proxy for 'academic engagement' defined by Perkmann et al. (2013) as a 'formal activities such as collaborative research, contract research and consulting, as well as informal activities like providing ad hoc advice and networking with practitioners'. Academic engagement in general and R&D in particular may lead to innovation. According to Bilbao-Osorio and Rodríguez-Pose (2004) 'R&D investment increase the possibility of achieving a higher standard technology in firms and regions, which would allow them to introduce new and superior products and/or process, resulting in a higher level of income and growth'. Examples of particular channels through which academic engagement may contribute to innovation are the founding of the new firms in order to commercially exploit new inventions or offering academics' expertise for solving problems of industrial partner (see detailed review in Perkmann et al. 2013). However, there is evidence that university-industry cooperation may be detrimental to regional innovation (Hou et al. 2019; Teirlinck and Spithoven 2012). In this paper, we analyse the

[2]Regional average for people graduated in 2014. According to the data from Graduates Employment Survey conducted by Russian Ministry of Science and Higher Education.

universities' contribution to economic development within the paradigm of endogenous economics growth model that assumes that R&D are positively related to economic growth rates. In addition, there is an empirical evidence obtained based on the data for Russian regions that R&D is positively related to economic growth (Kaneva and Untura 2018).

Academic research activity is a less obvious source of positive economic contributions of universities. However, there is an evidence that high quality and intensity of academic research are positively associated with higher intensity of industrial innovations (Mansfield 1995). Autant-Bernard (2001) argues that new knowledge created by academic research can facilitate innovation activities of enterprises. According to Barrio-Castro and García-Quevedo (2005), the regional distribution of innovations is positively affected by universities' academic research. Moreover, despite publications in academic journals represent easily transferrable knowledge, the presence of university with strong academic performance may be considered as a channel through which local stakeholders can enter research networks (Audretsch and Lehmann 2005).

In order to estimate the economic impact of universities econometrically, authors usually include in economic growth regression different explanatory variables related to the scale and capacity of higher education systems. Particularly, Valero and Van Reenen (2019) used the number of universities in the regions for these purposes. Egorov, Leshukov, and Gromov (2017) considered the variable reflecting the share of students in the age cohort 17–25 in the region. In this paper, we argue that not only the capacity but also the efficiency of higher education systems may significantly contribute to economic development. The next subsection describes possible channels through which the efficiency level of a higher education system may be related to economic growth rates.

3.2. Literature on efficiency measurements in higher education

There is much literature devoted to efficiency in the higher education sector (see, for example, Abbott and Doucouliagos 2003; Johnes 2006; Agasisti and Johnes 2009; De Witte and López-Torres 2017). These studies usually consider universities as economic agents that transform a set of inputs into a set of outputs according to the specified production function. The production technology may be defined in different ways depending on the context of a given higher education system. In order to obtain efficiency estimates based on the specified production function, data envelopment analysis (DEA) (Farrell 1957; Charnes, Cooper, and Rhodes 1978) and stochastic frontier analysis (SFA) (Aigner, Lovell, and Schmidt 1977) are usually used.

The first attempts to estimate the efficiency of higher education institutions quantitatively were based on data from universities' departments in one country (Johnes and Johnes 1993, 1995). Subsequent studies concentrated on the efficiency of the universities at the institutional level (Flegg et al. 2004) and on the efficiency of higher education systems (Agasisti and Dal Bianco 2006). Another direction of research on efficiency in higher education is comparative studies where higher education systems in different countries are compared with each other in terms of efficiency level (Agasisti 2011; Parteka and Wolszczak-Derlacz 2013).

The efficiency level is considered as an important indicator of university activity, and one of the main goals of modern public policy in higher education. If higher education institutions operate efficiently, it justifies public money invested in this sector. Higher education institutions today are likely to face fiscal constraints, and efficiency gains are the only way to preserve their productivity levels under conditions of resource contraction (Johnes 2014). Moreover, recent studies emphasise that universities' efficiency level is positively related to economic development (Agasisti, Barra, and Zotti 2019). Therefore, efficiency improvement is considered one of the objectives of public policy in higher education.

3.3. Research hypotheses

In this section, we move from characterising the development of regional higher education systems to exploring their relationship with regional economic development. In so doing, we consider two perspectives, a quantitative and a qualitative one. In our approach, both the size of the higher education system and its efficiency are factors in influencing the economic performance of the territories in which it operates. For this purpose, we propose two indicators which are complementary in describing the features of the higher education system.

The first variable is the total number of university graduates in the region; this measure approximates the overall capacity of a regional higher education system. This variable is highly correlated with other characteristics of higher education system performance such as the total number of publications and total volume of Research and Development (R&D). Thus, we assume that this variable captures not only the amount of human capital produced by universities, but the whole scale of a regional higher education system. As described in the literature review section, numerous previous studies argued that this type of variable demonstrates a positive relationship with economic growth rates.

The second variable that is important for measuring universities' economic impact is the efficiency level of a regional higher education system. We consider this variable as a qualitative measure of a regional higher education system development. In other words, we argue that a more efficient higher education system is characterised by higher quality (i.e. better able to use resources for productive ends) and, therefore, can generate greater economic impact. In this perspective, we consider efficiency as a measure of the ability of universities to use their resources productively, meaning that they maximise the outputs produced from a given level of inputs or resources. The outputs produced by the HE system, such as graduates, publications, etc., in turn affect the economic development of the region. To the extent that the process of producing outputs is efficient, we can consider it as the 'quality' of the production process. So for every dollar invested in an efficient HE system, the expected output and its impact on the economy are higher than in its inefficient counterparts. Efficiency level has already been used in previous economic growth studies as a qualitative measure of the development of particular economic sectors. Particularly, Destefanis et al. (2014) used the efficiency of banks in order to approximate the quality of financial institutions. Barra and Zotti (2017) used technical efficiency as a similar proxy measure of quality in the higher education arena.

In the specific context of this paper, we follow Agasisti, Barra, and Zotti (2019) and define the following three channels through which efficiency of regional higher education system may affect economic growth rate:

(1) *The output effect*. If we consider two regional higher education systems with the same available resources, the more efficient one will demonstrate greater performance (by definition of the efficiency concept) – produce more graduates, publications, and R&D, all of which are all positively related to economic growth. It is important to note that the design of this study does not allow for decomposing the total effect into the three channels that we describe. The aim of the research is just to check the existence of this relationship, but outlining the potential channels can clarify the theoretical arguments for understanding the relationship itself.
(2) *The resource effect*. A relatively efficient higher education system may produce the same output with fewer resources. Excess resources can be used more efficiently in the regional economy. Particularly, an efficient higher education system may employ fewer people, and this excess labour force may find employment in other sectors of the regional economy. In Russian context, the individual which lost the job in the University is likely to find a new employment in the same region because of relatively low unemployment rates and low rates of the migration between regions (except the younger age cohorts where intensive education migration is observed).
(3) *The reputation effect*. If a higher education system and its individual universities are efficient, their reputation may be stronger as perceived by stakeholders. For these universities, it may be easier to develop collaborations with industrial partners and perform knowledge transfer.

To sum up, we assume two particular mechanisms through which regional higher education system efficiency may contribute to the overall regional economic performance through the channels mentioned above. The first mechanism suggests the direct contribution of more efficient use of resources by universities (the *output effect* and the *resource effect*). Surely, higher education is just one of the sectors of regional economy and it may be difficult to capture quantitatively the effect of one sector's efficiency on overall regional economic growth. However, in some cases, universities can be considered as one of the main actors in regional economies. Particularly, in some cities, the share of people employed in higher education sector constitutes up to 10% of total employed population.[3] The second mechanism that can substantially strengthen the first one assumes that efficiency of universities can inspire other sectors of regional economy and push them to act in a more efficient way (reputation effect). Possible examples of how this can happen are as follows. Firstly, universities' efficiency can be positively associated with the overall quality and effectiveness of the university's management. High quality management team may be more capable to build collaborations with industrial partners, establish different networks and so on. Consequently, it can lead to greater intensity of the knowledge transfer. Secondly, universities are usually deeply embedded in regional economy and interact with a large number of different stakeholders representing different sectors of regional economy. The high universities' efficiency is usually associated with some best practices of how processes can be organised inside the organisation; therefore, through active interactions with different regional stakeholders, universities can translate these best practices in such a way that pushes the

[3]According to the data provided by Federal State Statistics Services.

partners to act in a more efficient manner. These best practices can also be translated to regional economy through graduates that find employment in regional enterprises. Thirdly, the assumption that it may be easier for external partners to develop collaborations with relatively efficient university suggests that, for example, some technology entrepreneurs that need an access to the universities' resources may decide to start up their business near efficient university instead of stating up these businesses in other regions. Finally, efficient universities can bring external resources to regional economy by participating in different programmes implemented by Federal Government, which involve federal budget funding and cover not only higher education sector (for example, Federal programme aimed at establishing world-class research centres that involve universities and regional industrial partners with significant investment from their side).

The first research hypothesis of this study is aimed at exploring whether these channels work and whether higher education system efficiency is positively related to economic growth rate:

(H1) The efficiency of a regional higher education system positively affects the rate of regional economic growth

Universities located in one region can build collaborations with enterprises located in other regions. However, a regional higher education system may contribute to the development not only of the region where it is located, but also to the development of neighbouring regions. That is why the second hypothesis of the study is related to the existence of spillover effects:

(H2) Positive spillovers exists: the rates of regional economic growth are determined by the efficiency of higher education systems in neighbouring regions.

4. Methodology and data selection

4.1. Efficiency estimation on the institutional level

We employ a two-stage DEA and the bootstrap procedures suggested by Simar and Wilson (2007) called two-stage semi-parametric DEA model. Simar and Wilson (1999) demonstrated that DEA scores obtained in the first stage are biased, and the environmental variables from the second stage are correlated to the output and input variables; therefore, a bootstrap procedure is recommended. The two-stage DEA assumes that environmental variables might affect university outputs and proposes a re-estimation of the DEA model with adjusted outputs for environmental variables through the bootstrap procedure.

DEA involves the selection of the orientation (input or output) and the type of returns to scale. We consider an output-oriented model with the assumption of variable returns to scale (VRS).[4] An output-oriented model evaluates how much outputs can be increased while holding inputs fixed (Agasisti and Perez-Esparrells 2010). This seems to be

[4]The procedure of Färe and Grosskopf (1985) was used to calculate scale efficiency. The indicator thus computed for each year under review was strictly more than one. This result satisfies variable returns to scale condition. We also compared VRS and CRS efficiency scores and found high correlation between them (around 0.89).

a reasonable assumption in the context of efficiency in higher education because of existing regulations that fix education production costs.

The linear programming model, assuming an output-oriented framework and VRS, must be solved for the $k-th$ decision-making unit (DMU). In our case, DMUs are universities, which transform an input vector $X_k = (x_{1k} \ldots x_{Jk})\epsilon R_{+}^{J}$ into an output vector $Y_k = (y_{1k} \ldots y_{Sk})\epsilon R_{+}^{S}$:

$$\max_{\substack{\theta_k, \lambda_i \\ k, i = 1, \ldots, N}} \theta_k \tag{1}$$

$$\theta_k y_{sk} \leq \sum_{i=1}^{N} \lambda_i y_{si}, \; s = 1, \; \ldots \; , S; \; S = \#\{outputs\}$$

$$x_{jk} \geq \sum_{i=1}^{N} \lambda_i x_{ji}, \; j = 1, \; \ldots \; , J; \; J = \#\{inputs\}$$

$$\sum_{i=1}^{N} \lambda_i = 1$$

here θ_k is the value of the efficiency of the $k-th$ DMU and satisfies $\theta_k \geq 1$. θ_k measures the efficiency of the $k-th$ unit as the distance to the frontier, which is the linear combination of the best practice units. $\theta_k \geq 1$ means that the DMU is below the best practice frontier (inefficient), while $\theta_k = 1$ means that the DMU lies on the estimated frontier (efficient). The restriction $\sum_{i=1}^{N} \lambda_i = 1$ imposes variable returns to scale assumption on the reference technology.

Following Simar and Wilson's (2007) approach, the second stage model is constructed as a censored regression:

$$\hat{\theta}_k = \alpha + Z_k \beta + \varepsilon_k, \qquad k = 1, \ldots, N \tag{2}$$

where $\hat{\theta}_k$ is the efficiency score obtained by solving equation (1); $Z_k = (1, z_{1k}, z_{2k}, \ldots, z_{rk})$ is the vector of environmental variables that can influence efficiency through the vector of parameters $\beta = \left(\beta_0, \beta_1, \ldots, \beta_r\right)'$; and ε_k indicates statistical noise. Equation (2) is estimated only for $\hat{\theta}_k > 1$.

The standard DEA model (1) leads to biased estimate $\hat{\theta}_k$[5] In order to get unbiased efficiency estimate in the Simar and Wilson's approach, $\hat{\theta}_k$ from equation (2) needs to be adjusted using the bootstrap procedure. Using the adjusted efficiency estimator, equation (2) can be written as follows:

$$\hat{\hat{\theta}}_k \approx \alpha + Z_k \beta + \hat{\varepsilon}_k, \qquad k = 1, \ldots, N \tag{3}$$

where $\hat{\hat{\theta}}_k = \hat{\theta}_k - BIAS\left(\hat{\theta}_k\right)$. $BIAS\left(\hat{\theta}_k\right)$ denotes a bias correction and can be estimated using the boost procedure in accordance with the algorithm from Annexe 2. $\hat{\varepsilon}_k$ is taken to

[5]The proof of consistent estimators of the standard DEA model is presented in (Kneip, Park, and Simar 1998).

be error from the truncated normal distribution $TN\left(0, \sigma_\varepsilon^2\right)$ with left-truncation at $\hat{\varepsilon}_k \leq 1 - Z_k\beta,\ k = 1, \ldots, N$. A more detailed description of Two-stage Semi-parametric DEA model used as well as the results are presented in Annexe 2.

In order to formulate the efficiency model, it is necessary to make some assumptions regarding production processes in universities and about the input and output sets. At this step, we have to consider universities as multi-product organisations (Baumol, Panzar, and Willig 1982) which utilise different inputs in order to produce different outputs. Following the literature, we assume university production technology to have four inputs. The first input is the financial resources of the university measured by income from all sources at constant prices. This variable is common in research concerning university production functions (Agasisti and Johnes 2009; Agasisti and Perez-Esparrells 2010). The second input is the total number of academic staff. This variable measures the human resources available for HEIs in order to carry out teaching, research and third mission activities. This variable is also widespread in HEIs efficiency studies (Agasisti and Johnes 2009; Agasisti and Perez-Esparrells 2010; Agasisti and Pohl 2012; Wolszczak-Derlacz and Parteka 2011). The third input, which is also related to human resources, measures not the quantity but the quality of available academic staff. This variable is the percentage of academic staff with advanced degrees (Candidate of Sciences, i.e. the Russian analogue to a PhD, or Doctor of Sciences) out of the total number of academic staff (excluding part-time staff and independent contractors). Finally, the fourth input is the average unified state exam (the entrance exam for Russian universities) score (USE), which reflects the quality of entrants. This variable is important for universities; however, often it is not clear if this indicates an output or an input in the production process. If we treat this variable as an input, we assume that more prepared students are an important resource for the university. If we consider it as an output, the underlying assumption is that this variable reflects the ability of the university to attract the most talented students, indicating the reputation of the university. We consider the average entrance exam score as an input variable, following (Johnes 2006; Barra and Zotti 2017).

The set of outputs consists of three variables reflecting three different activities of higher education institutions – research, collaborations with industrial partners as a proxy for knowledge transfer, and teaching. The first output is the total number of publications indexed in Web of Science, Scopus and the Russian Science Citation Index (RSCI). This variable reflects the scientific productivity of university academic staff (Parteka and Wolszczak-Derlacz 2013). It is important to note here that it is difficult to associate the number of publications with the short-run economic growth. We include the number of publications as a control (in order to measure the overall efficiency of the university) and the effect should be interpreted very cautiously. The second output is the total income from grants obtained for applied research carried out by the university. This variable reflects the engagement of the university in collaborations with industrial partners and partially measures the money spent by companies on applied research conducted by the university. We consider this variable as an output and not as a pre-factor for science commercialisation since universities usually receive this money after the research has been conducted. In the Russian context, this factor is a good proxy for knowledge transfer, reflecting cooperation between universities and industry. This variable is usually considered in the literature as a market price that gives information on the quality as well as on the quantity of applied research (Johnes 1997). This variable has been used as an output in university efficiency evaluation, for example, in Kempkes and Pohl (2008). Finally, the third output is the total number of graduates,[6] which is used in most studies as a proxy for a university's teaching activity (Agasisti and Johnes 2009; Bonaccorsi et al. 2007; Agasisti and Pohl 2012).

In order to take into account the different internal characteristics of HEIs which may potentially affect the production process inside the university, we used a set of exogenous variables to determine the efficiency scores correctly. Given the inputs and outputs of the efficiency model, we employ five exogenous variables. The first two variables reflect the structure of the student body: the share of master's students in the total number of students, and the share of full-time students. Such indicators influence the university's strategy and the structure of the production process. For instance, if most students at the university are part-time, the university utilises a fundamentally different educational model with a different structure of costs and resources. The third exogenous variable is a dummy variable for the university being located in the capital city of the region. The underlying assumption here is that a university located in the capital city is usually oriented towards students from the whole region. Capital cities are usually more attractive for living, so compared to universities in other cities, these institutions may be more attractive for students from other cities and regions, and this heterogeneous level of attractiveness might affect efficiency. The level of competition in the regional higher education market is also an important factor which may determine the level of efficiency (Leshukov, Platonova, and Semyonov 2015). Universities that operate in a highly competitive environment tend to consolidate their resources and perform better (see also the conceptual discussion in Agasisti 2009). The general measure of competition, used as an exogenous variable in the efficiency model, is the share of students in the total number of students in the region. Finally, we use a dummy variable which indicates the presence of a medical faculty within the university. A field of study such as medicine may have a strong influence on the technology used by the university.

Table 1 presents the inputs, outputs and environmental variables used for the efficiency model.

4.2. Efficiency estimation on the institutional level

In addition to considering environmental variables for assessing the efficiency scores of HEIs, we must also measure efficiency at the level of the whole regional higher education system. Due to the particularities of regional structures in Russia and data availability constraints, we cannot associate one university with a particular sub-regional territory (c. f. Agasisti, Barra, and Zotti 2019), so we aggregate the efficiency scores obtained at the institutional level to the regional level. Efficiencies calculated at the second step report weighted averages of university performances by the total number of students of local universities in certain regions according to formula (4):

$$eff_j = \frac{\sum_{r=1}^{n} eff_r \times students_r}{\sum_{r=1}^{n} students_r} \quad (4)$$

[6]Due to data availability constraints, the data on the number of graduates for each university were derived based on the total number of graduates in the region. We have calculated the shares of each university in the total number of students in the region, and then we used these shares in order to allocate the total number of graduates in the region to each university.

Table 1. Characteristics of universities.

Variable name	Description	Unit of measurement
Inputs		
Income	The income of educational organisation from all sources	Millions rubles
Number of faculty	Total number of full-time faculty	Persons
Faculty with degrees	The relative weight of academic staff with advanced degrees	%
Exam	The average entrance exam score of entering students	Score (out of 100)
Outputs		
Publications	Total number of publications in science journals indexed in RSCI, Web of Science and Scopus	Units
R&D	The total quantity of R&D	Millions rubles
Number of graduates	Total number of university graduates	Persons
Environmental variables		
Masters' students	Share of masters' students in total number of students	%
Full-time students	Share of full-time students in total number of students	%
Capital city	Location of university in the capital city of the region (dummy)	%
Market share	Market share of university – share of students in the university in total number of students in the region	%
Medical faculty	Presence of medical faculty (dummy)	%

Source: Authors' elaborations from «Annual Monitoring of Efficiency of Higher Education Institutions» data.

where j is a certain region; n is quantity of universities in region r; *eff* is the efficiency score of university r; *students* is the total number of students in university r.

At the end of this aggregation, we obtain one synthetic indicator that measures the average level of university efficiency for any given region.

4.3. Modelling regional economic growth

The third and final step of our methodology is to estimate an economic growth model with the regional higher education system efficiency score among the explanatory variables. Within the theoretical model, we expect education, in general, and the efficiency of higher education systems, in particular, to cause economic growth, as discussed in Section 3.

The regional economic growth model is represented by the formula (5):

$$\begin{aligned}\Delta GRP_{j,t} = {} & \alpha_0 + \alpha_1 \Delta GRP_{j,t-1} + \alpha_2 log\left(GRP_{j,t-1}\right) + \alpha_3 \Delta INV_{j,t} + \alpha_4 \Delta POP_{j,t} + \\ & + \alpha_5 PSEC_{j,t} + \alpha_6 CME_{j,t} + \alpha_7 IND_{j,t} + \alpha_8 EMPHE_{j,t} + GRAD_{j,t} + \\ & + \alpha_9 EFF_{j,t} + \alpha_{10}(EFF \times W)_{j,t} + \alpha_{11}(\Delta GRP \times W)_{j,t} + \mu_{j,t} + \tau_t + \varepsilon_{j,t}\end{aligned} \quad (5)$$

where $\Delta GRP_{j,t}$ is GRP growth rate; $log\left(GRP_{j,t-1}\right)$ is the log of GRP in the previous period; $\Delta INV_{j,t}$ is the investment growth rate; $\Delta POP_{j,t}$ is the population growth rate; $PSEC_{j,t}$ is the share of the public sector in GRP; $CME_{j,t}$ is the share of commercial mineral extraction in GRP; $IND_{j,t}$ is the share of industries in GRP; $EMPHE_{j,t}$ is the share of the population employed in higher education; $GRAD_{j,t}$ is the total number of university graduates (bachelors + masters); $EFF_{j,t}$ is the efficiency level of the regional higher education system; $EFF \times W_{j,t}$ is the efficiency spatial lag; $\Delta GRP \times W_{j,t}$ is the spatial lag of GRP growth rates; $\mu_{j,t}$ are individual region-specific effects; τ_t are time effects; $\varepsilon_{j,t}$ are errors.

The regional economic growth model contains standard variables which are used in most research devoted to economic growth modelling (Kufenko 2014; Sala-i-martin 1994). These variables are the investment growth rate as a proxy for the physical capital stock growth rate; employed population growth rates; the share of employed population with higher education as a measure of average time spent by individual on human capital accumulation; the log of GRP in the previous period, which captures the convergence effect (Sala-i-martin 1994). The economic growth model also contains the efficiency measure of regional higher education systems, reflecting the efficiency of human capital accumulation. We also include the total number of university graduates in order to capture the scale and capacity of regional higher education systems.

As the university may contribute to the development of neighbouring regions (for example, due to educational mobility (Kashnitsky, Mkrtchyan, and Leshukov 2016)), we include the spatial lag of regional higher education system efficiency levels. We also include the spatial interaction of growth rates, which accounts for the positive spatial correlation in regional growth rates in Russia (Demidova 2015). In order to construct spatial interactions, we used a simple inverse distance matrix. This choice is based on evidence that the estimates and inferences in spatial regression models are not sensitive to the choice of the spatial weight matrix (LeSage and Pace 2014).

Finally, we employ a set of variables to capture the structure of regional economies. These variables are the share of the public sector (education, public administration, healthcare) in GRP, the share of commercial mineral extraction in GRP, and the share of industries in GRP.

4.4. Data and descriptive analysis

The source of the data for the efficiency evaluation is the 'Annual Monitoring of Performance of Higher Education Institutions' conducted by the Russian Ministry of Education and Science for the period from 2012 to 2016. Given the limited number of years for which data are available, we must interpret the results as only the effect for short-run region economic growth.

Only public universities of Russia were included in the analysis. Such a limitation is imposed on the sample to reduce the level of university heterogeneity in terms of their production functions. The limitation does not reduce its representativeness since non-public universities account for just 18% of the 5-year average of the total student population. Given all the constraints, the sample contains 449 universities located in 77 regions and has data for each year within the period from 2012 to 2015.

Since the outlier problem and missing values should be taken into account in the efficiency analysis, preliminary data processing was implemented. In order to deal with missing values, we use an imputation procedure with mean and median values. In order to eliminate outliers, we used capping correction – upper outliers were replaced by the values that correspond to the quantile 0.975; the lower outliers were replaced by the values that correspond to the quantile 0.025.

Our starting point is a descriptive analysis of the institutional characteristics needed to assess university efficiency levels. Table 2 presents the key descriptive statistics on the institutions in our sample. The first variable represents the total income from all sources. The value of this variable decreased during the period 2012–14. Overall, the average income from all sources in 2015 (in constant prices) was 16.6% lower than in 2012. This reduction was largely due to the financial crisis in Russia 2014–15 and the related budget cuts in the educational sector. The average number of academic staff decreased

Table 2. Descriptive statistics of the variables used for efficiency evaluation of the institutions.

	2012 (N = 449)			2013 (N = 449)			2014 (N = 449)			2015 (N = 449)		
Variable name	Mean	Std dev	Min/max	Mean	Std dev	Min/max	Mean	Std dev	Min/max	Mean	Std dev	Min/max
Inputs												
Income	1638	1753	73/5960	1578	1664	49/5739	1648	1778	69/6039	1365	1537	38/5166
Academic staff	529	363	34/1355	489	345	4/1296	471	337	4/1262	454	326	4/1199
Academic staff with degrees	63.1	17.7	22.7/85.1	66.5	15.3	27.8/86.2	68.0	15.7	29.4/89.2	69.3	15.3	30.1/90.5
Exam scores	65	9	48.5/82.4	68	10	48.6/88.0	65	9	47.3/84.1	63	8	48.8/78.9
Outputs												
Publications	78	50	0/198	85	54	0/204	129	78	0/298	184	119	0/458
R&D	184	314	0/908	172	294	0/852	162	276	0/800	129	220	0/636
Graduates	2398	1729	53/6361	2260	1623	51/5911	2108	1808	12/6214	2433	1909	45/6675
Environmental variables												
Masters' students	3.7	3.8	0/13.5	4.3	4.0	0/14.1	4.7	4.1	0/14.3	7.0	5.5	0/18.6
Full-time students	62.2	17.5	29.9/97.8	62.8	18.2	23/100	63.9	18.2	27.5/100	63.0	19.3	23.4/100
Capital city	91	-	-	91	-	-	91	-	-	91	-	-
Market share	10.2	11.0	0.01/37.0	10.7	11.8	0.01/39.8	11.5	11.9	0.01/40.7	11.3	12.6	0.01/43.5
Medical faculty	11	-	-	11	-	-	11	-	-	11	-	-

Notes: Information on incomes is adjusted to the level of December 2015 by using the annual national CPI.
Source: Authors' calculations from «Annual Monitoring of Efficiency of Higher Education Institutions» data.

proportionally to income variable by 15.7%. The relative weight of academic staff with advanced degrees is characterised by stable growth – it increased from 63% in 2012 to 69% in 2015. The fourth input variable is the average entrance exam score,[7] which has stable values.

The first output indicator is the total number of publications in journals indexed in the Russian Science Citation Index, Web of Science and Scopus. This indicator increased significantly during the period under review: the indicator was 2.4 times higher in 2015 in comparison with 2012. This dramatic rise can be attributed to the Performance-Based Funding scheme introduced in 2015. The general principle of this scheme is that the number of publicly funded student slots available for the university is determined according to a formula, and scientific productivity is one of the components in this formula. Another explanation for this increase is that during this period several large government projects were launched to increase the scientific productivity of Russian universities. The next output variable is the total quantity of R&D. The value of this indicator decreased for the period 2012–15. The largest reduction of this variable value (20.4%) was between 2014 and 2015. This reduction was determined by the negative macroeconomic shock in Russian economy and consequently by a decrease in private funding for R&D implementation. The last output indicator is the total number of graduates. This indicator was stable during the considered period.

The share of master's students, which is the first environmental variable, rose by 3.3% and reached 7% of the total number of students in 2015. This growth was primarily due to the increase in state-funded spots in master's programmes. The share of full-time students in the total number of students was virtually unchanged for the period. The absence of a clear dynamic was related to the stable proportion of state-funded slots for full-time students. The average market share of universities increased during the period from 10.2% in 2012 to 11.3% in 2015, which was related to the policy of consolidation in the national higher education system (Egorov, Leshukov, and Froumin 2019). This included university mergers and the closing of low-performing universities. The share of universities located in regional capital cities was stable at 91%, as was the share of universities with medical faculties (11%). Overall, we can observe multidirectional dynamics in the institutional characteristics, so we can expect ambiguous dynamics in university efficiency during the period.

The source of the data for the regional economic growth model estimation is the Russian Federal State Statistics Service. The sample includes the 77 regions that have efficiency scores for their regional higher education systems. We used the data for most of the variables for the period from 2012 to 2015, but the variable for GRP growth rate covers the period from 2011 to 2015. The extension of the period for this variable is needed to allow for more lags for the dependent variable in the model identification using the sys-GMM approach. In order to deal with the missing values and the outlier problem we used the same CART algorithm and capping procedure outlined above.

The descriptive statistics for the variables used for the regional economic growth model estimation are presented in Table 3. The average GRP growth rate declined in 2012–15. Due

[7]In Russia University admissions are based on the results of unified national examination (USE exam) which is taken by all school graduates. Therefore, this exam score is comparable among different universities. For more details about this examination see, for example, Francesconi, Slonimczyk, and Yurko (2019).

Table 3. Descriptive statistics of the variables used for economic growth model.

Variable name	2012 (N = 77) Mean	2012 (N = 77) Std dev	2013 (N = 77) Mean	2013 (N = 77) Std dev	2014 (N = 77) Mean	2014 (N = 77) Std dev	2015 (N = 77) Mean	2015 (N = 77) Std dev
GRP growth rates (year to year), %	3.41	5.77	2.07	5.68	1.95	4.74	−0.20	2.52
Efficiency measured by DEA	0.65	0.14	0.63	0.14	0.60	0.15	0.58	0.15
Population growth rates, %	− 0.09	0.01	− 0.08	0.01	− 0.01	0.01	− 0.07	0.01
Investment growth rates, %	2.59	13.32	− 3.01	14.27	− 1.88	17.73	− 9.89	13.72
Gross regional product in previous period, bln rub.	910.8	190.1	927.3	196.3	949.7	198.9	827.9	169.4
Total number of universities' graduates thousand people	17.69	29.90	16.345	26.89	15.13	24.32	16.05	26.75
Share of employed with higher education,%	27.85	4.89	29.14	5.01	29.71	4.78	30.65	4.61
Share of public sector in GRP,%	17.87	7.46	18.99	7.68	18.53	7.39	17.12	7.19
Share of commercial minerals extraction in GRP, %	8.13	12.91	7.95	12.82	7.75	13.03	8.36	13.43
Share of industries in GRP, %	17.89	9.94	17.43	9.34	17.48	9.92	18.02	10.21

Notes: Information on incomes is adjusted to the level of December 2015 by using the annual national CPI.
Source: Authors' calculations from Russian Federation Federal State Statistics Service.

to the economic crisis, in 2015 Russian regions on average experienced economic contraction (−0.2% in 2015 compared to the previous year). This decrease in GRP growth rate was followed by a decline in the investment growth rate. The investment growth rate decreased by 12.5 percentage points – from 2.6% in 2012 to −9.89% in 2015. The most rapid decline (4.3%) was between 2014 and 2015. The average number of graduates in the regions steadily declined by 9.1% – from 18.0 in 2012 to 16.1 in 2015. This reduction is primarily due to demographic factors. The peak in student numbers (7.5 million) was observed in 2008. For demographic reasons, the student body began to decrease at that point, and in 2014 it was 5.2 million. The dynamics of the share of the population employed in higher education correspond to the non-standard mechanism according to which the Russian labour market adapts to macroeconomic shocks. The distinctiveness of this mechanism lies in the dominance of cost adaptation over quantitative adaptation. Wage flexibility mitigates negative shocks by protecting employment and stemming unemployment growth (Gimpelson and Kapeliushnikov 2015). The average efficiency of regional higher education system in 2015 slightly decreased compared to 2012. The other variables used in the economic growth model estimation had stable values.

4.5. Dealing with endogeneity and other econometric issues

In the economic growth model represented by equation (5) we acknowledge the problem of endogeneity, i.e., the correlation between some regressors and the error term. Ignoring this problem, we would obtain biased and inconsistent parameter estimates that would lead to an incorrect interpretation of modelling results (Ebbes, Papies, and van Heerde 2017). Particularly, we may assume here that the efficiency level of a regional higher education system does not influence GRP growth rate, but relatively efficient regional higher education systems tend to be formed in the regions with high rates of economic development. The most widespread way of overcoming this problem is using instrumental variables (Angrist, Imbens, and Rubin 1996). In order to deal with this problem, we employ a GMM dynamic panel data estimator (sys-GMM) (Arellano and Bover 1995). Using this technique gives us evidence that we are exploring the causal relationship between the efficiency of regional higher education system and GRP growth rates. The basic argument here is that efficiency in year t affects the efficiency of year $t + n$ but not the economic growth in the same year $t + n$ directly. In order to check the reliability of the model, we use the Hansen–Sargan test for the over-identifying restriction, as well as a second-order autocorrelation test (Baum, Schaffer, and Stillman 2003).

Results of econometric analysis

4.6. Estimation of HEI efficiency

Simar and Wilson's approach that we employed to estimate efficiency uses Farrell's efficiency concept (Farrell 1957) to analyse the efficiency level of HEIs. According to this concept, it fulfils the condition of $\theta_k \geq 1$, with a value of one indicating that a university belongs to the production frontier, while values between one and infinity correspond to inefficient universities located below the best practice frontier. Within the economic growth model estimation, we prefer to work with Shephard measures (Shephard 1953) which are simply the inverse of the Farrell ones (Bogetoft and Otto 2010). The Shephard concept satisfies the condition $\theta_k \leq 1$. The distributions of the DEA efficiency scores obtained at the institutional level are presented in Figure 1.

The key descriptive statistics of efficiency estimates at institutional and regional levels are presented in Table 4. Figure 1 and Table 4 show that efficiency values for each considered year are above 0.12 and fluctuate around 0.57. The standard deviations of the efficiency scores are rather high; therefore, we note that DEA efficiency scores discriminate the universities in the sample well. The mean value of efficiency scores around 0.57 suggests that, on average, universities produce half of the potentially possible output. This low average level of efficiency may have a twofold explanation. Firstly, it may be caused by the fact that our sample includes all Russian public universities, which form a very heterogeneous group of organisations (as demonstrated by Table 2). This group includes universities of different sizes and different

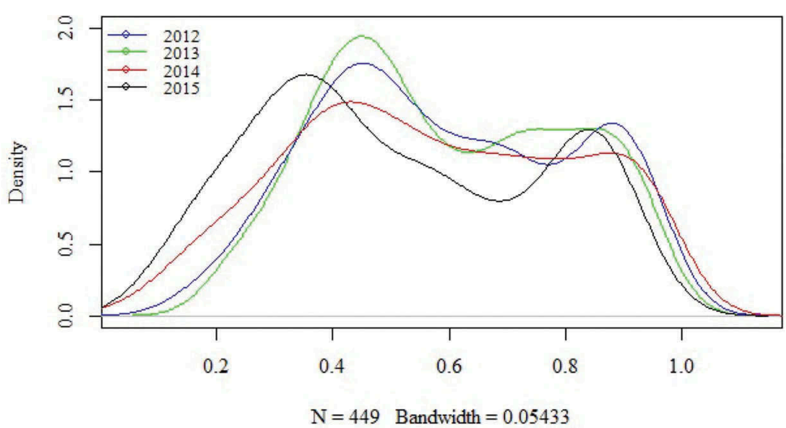

Figure 1. DEA efficiency distribution on institutional level.

Notes: Efficiency scores are distributed between 0 and 1. A value of 1 indicates that a university is efficient and lies on the best practice frontier.

Source: Authors' calculations from «Annual Monitoring of Efficiency of Higher Education Institutions».

Table 4. Descriptive statistics of DEA efficiency scores over 2012–2015.

Statistics	2012 (N = 449)	2013 (N = 449)	2014 (N = 449)	2015 (N = 449)
Institutional level				
Mean	0.593	0.593	0.571	0.515
Median	0.569	0.558	0.551	0.471
Std deviation	0.240	0.205	0.239	0.241
Minimum	0.129	0.209	0.052	0.083
Maximum	0.976	0.966	0.982	0.953
Statistics	2012 (N = 77)	2013 (N = 77)	2014 (N = 77)	2015 (N = 77)
Regional level				
Mean	0.653	0.630	0.601	0.584
Median	0.677	0.653	0.614	0.593
Std deviation	0.139	0.136	0.148	0.154
Minimum	0.263	0.246	0.255	0.190
Maximum	0.938	0.889	0.884	0.889

Notes: Regional efficiency scores conform to estimates of regional HE systems. Regional HE system is a set of universities located within the administrative borders of the region.
Source: Authors' calculations from «Annual Monitoring of Efficiency of Higher Education Institutions» data.

specialisations. However, since the aim of this paper is to measure the efficiency of regional higher education systems and estimate the relationship between this parameter and rates of economic development, we cannot make the sample more homogenous and covering the higher education system just partially. The second possible explanation for low mean efficiencies is that public universities are not-for-profit organisations. Hence, some HEIs may not identify efficiency level as a priority of their activities (Johnes 2006). The analysis of possible determinants of inefficiency is presented in Annexe 1. Table 6 of this annexe presents the results of the second-stage truncated regression in Two-stage Semi-parametric DEA. The results presented in the table show that the share of master's students negatively affects inefficiency, while high share of full-time students on average makes universities less efficient since part-time programmes are usually associated with lower costs. The market share of universities, as predicted by the theory, positively affects their efficiency – universities without competition tend to be less efficient.

The standard deviations presented in Table 4 show that after aggregation at the regional level, the standard deviations of our efficiency scores become lower. DEA efficiency scores, however, still discriminate universities well in terms of their efficiency. At both the regional and institutional levels, the efficiency of HEIs in Russia decreased insignificantly in the period from 2012 to 2015.

4.7. Regional economic growth model estimation

The economic growth model was estimated using Stata 13 software and the package xtabond2 (Roodman 2009). Three different specifications were considered, and the results are reported in Table 5. Figure 2 presents the scatterplot of efficiency and average regional growth rates.

The baseline model (Model 1) includes the standard variables used in economic growth modelling as pointed out in Section 4.3. The parameters of this model are statistically significant and the signs of the estimated parameters correspond to the

Table 5. Results of regional growth model estimation (standard errors are presented in the brackets).

Variable name	Model1	Model2	Model3
Growth rate in previous period	0.860***	0.757***	0.874***
	(0.017)	(0.021)	(0.025)
Investment growth rate	3.873***	3.131***	3.888***
	(0.513)	(0.687)	(0.478)
Employed population growth rate	0.329***	0.309***	0.332***
	(0.026)	(0.044)	(0.043)
Gross regional product in previous period (log)	−5.203***	−4.994***	−4.614***
	(0.470)	(0.322)	(0.518)
Share of employed with HE	0.171**	0.120**	0.155***
	(0.051)	(0.041)	(0.026)
Total number of universities' graduates	0.069***	0.056***	0.069***
	(0.011)	(0.008)	(0.010)
Share of commercial minerals extraction in GRP	−0.069**	−0.083***	−0.073**
	(0.023)	(0.023)	(0.0221
Share of industries in GRP	0.065**	0.062**	0.048*
	(0.021)	(0.024)	(0.026)
Share of public sector in GRP	−0.732***	−0.699***	−0.698***
	(0.047)	(0.067)	(0.071)
Efficiency DEA		2.115*	2.114**
		(1.099)	(1.056)
Efficiency spatial interaction			−1.465*
			(0.512)
Growth spatial interaction			7.981**
			(2.364)
Hansen-Sargan	0.208	0.365	0.453
AR(2)	0.893	0. 737	0.723
# of observations	308	308	308

Significance levels: *** p-value <0.001; ** p-value <0.01; * p-value <0.05;. p-value <0.1

Notes: All equations are estimated through a two-step system generalised method moment estimator with Windmeijer (2005) corrected standard error (in brackets). Presented standard errors are robust.

Source: Authors' calculations from «Annual Monitoring of Efficiency of Higher Education Institutions» and Russian Federation Federal State Statistics.

underlying theoretical assumptions: GRP growth rate is positively related to the employed population growth rate, the growth rate in the previous period, the share of the employed population with higher education, and the total number of university graduates. As expected, GRP growth rate negatively relates to the total GRP in the previous period, confirming the existence of convergence in growth rates: poor regions tend to grow faster than rich ones.

Model 2 contains an additional explanatory variable: the DEA average efficiency score of regional higher education systems. This model confirms the main hypothesis of this study and demonstrates that the efficiency of regional higher education systems is a statistically significant determinant of regional economic development growth rates, even if we control for the number of graduates. The positive and statistically significant relationship between GRP growth and regional higher education system efficiency is stable and can be observed in all specifications of the model. We also implemented a special robustness check in order to obtain additional evidence that this positive relationship exists. We used the stochastic frontier analysis efficiency score instead of the DEA efficiency score in the economic growth model. A detailed description of SFA efficiency estimation and the results of the regional economic growth model with SFA efficiency scores are presented in Annexe 3.

Finally, Model 3 tests the hypothesis about spillover effects, showing that the parameter of efficiency's spatial interaction is statistically significant and negative. This means that we have

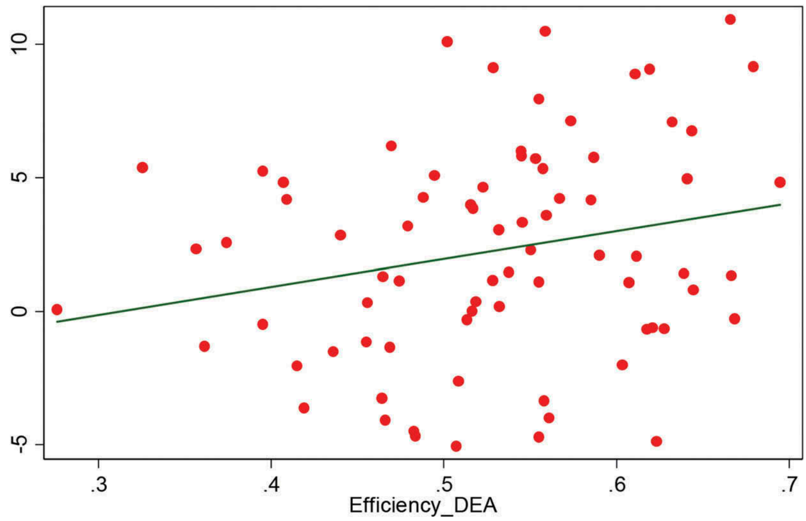

Figure 2. Scatter plot of DEA efficiency scores and GRP growth rates (average values for the period 2012–2015).

Notes: Plot presents the averaged values of efficiency scores of regional HE systems and GRP growth rates over 2012–2015. Regional HE system is a set of universities located within the administrative borders of the region.

Source: Authors' calculations from «Annual Monitoring of Efficiency of Higher Education Institutions» and Russian Federation Federal State Statistics.

negative spillover effects. Such a finding may be explained by the fact that regional higher education systems in Russia tend to compete with each other. Efficient regional higher education systems activate educational migration flows to the territory of its location. This process tends to change the economy of donor and recipient regions first of all from the human capital formation and accumulation perspectives (see, for example, Goldstein and Drucker 2006; Drucker and Goldstein 2007; Huffman and Quigley 2002; Faggian and McCann 2009). So efficient regional higher education system may be a key component of attracting and retaining youth in the region since in-migrants often stay in the city after completing their education (Findlay 2011; Winters 2011; Mironos, Bednyi, and Ostapenko 2015). Therefore, universities help to channel human capital to local labour market and stimulate regional industry, which in turn strengthens the regional economy (Huffman and Quigley 2002). However, this negative spillover effect from efficient educational system can be mitigated the spatial interaction of economic growth, which, as expected, is positive and statistically significant.

5. Discussion and concluding remarks

Universities are multi-product organisations (Baumol, Panzar, and Willig 1982) with multiple impact channels. Usually, three different types of university contributions to economic development are highlighted: a general economic approach, suggesting that universities as economic agents generate additional aggregate demand in regional economy (Elliott, Levin, and Meisel 1988); a skill-based approach, which analyses the contribution of higher education in terms of human capital reproduction (Bluestone 1993);

and an innovation approach, which considers universities as integrators of regional innovation ecosystems.

There is evidence that the economic impact of universities in Russia in terms of these approaches is positively related to the scale of higher education systems (Egorov, Leshukov, and Gromov 2017). In other words, the capacity and scale of higher education systems matter for regional economic development. This study is a first attempt to shed light on the question of whether the efficiency level of regional higher education systems is positively related to regional economic growth rates in Russia. Using a framework which considers efficiency level as a good instrument to capture the impact of universities on the community (Agasisti, Barra, and Zotti 2019), we estimate higher education efficiency at the institutional level, then aggregate these estimates in order to obtain an aggregate measure of regional higher education system efficiency. Finally, we construct a regional economic growth model which treats regional higher education system efficiency as one of the explanatory variables. In order to evaluate efficiency, we assume that there are different exogenous factors that are out of university management control and employ a 2-stage DEA procedure (Simar and Wilson 2007). For causal inference, we employ the sys-GMM approach for the identification of economic growth models. We also employ spatial econometrics techniques in order to analyse spillover effects (the positive economic impact of universities on neighbouring regions).

The estimated economic growth models show that DEA efficiency scores, corrected for exogenous factors, are statistically significantly related to GRP growth rates. Moreover, we find statistically significant and negative spillover effects. The explanation behind this finding is that strong and efficient regional higher education systems may extract resources, predominantly human resources, from neighbouring regions. Particularly, these regional higher education systems are more attractive for students and scholars from other regions. Such findings suggest that universities can ensure the competitiveness of the regions where they are located in relation to other regions. In a highly centralised higher education system such as the Russian one (approximately 90% of all state-owned universities are governed by federal authorities), this fact can be considered a significant incentive for regional authorities to collaborate with the higher education sector more actively.

The results of our analysis allow us to highlight the following policy implications. Firstly, public policy in higher education has to focus not only on the quantity of higher education and its availability, but on its efficiency level as well, since the efficiency of higher education systems may be considered as a significant factor of universities' economic impact. Secondly, despite the fact that Russian higher education system is very centralised, development of higher education can be considered an important regional policy agenda. Our analysis suggests that universities can give a competitive advantage to regions in relation to neighbouring regions. Therefore, additional investment in higher education made by regional authorities can be considered a policy instrument that can contribute to general socio-economic development of the region. Today, the practice of regional governments supporting higher education can be observed in just a few regions. However, according to our analysis, the scaling of these practices promises considerable benefits. Finally, the third policy implication is related to the geographical distribution of higher education institutions. The finding regarding the negative spillover effects in efficiency levels suggests that efficient higher education systems may extract resources from the regions in their neighbourhood. Particularly, a lot of strong and efficient universities are located in Moscow. Accordingly, these universities attract most talented school graduates from regions located in the central part of Russia (Kashnitsky, Mkrtchyan, and Leshukov 2016). Therefore, the recommendation for public policy is to develop a network of strong higher education institutions in different regions in order to avoid skewed migration flows and, consequently, imbalances in regional socio-economic development. The first steps towards a more even distribution of high-quality universities were made within the framework of the 'Flagship Universities Program' developed by the Russian Government in 2016; this should be continued with more intensity. All these findings may also be relevant for other countries with federal structure and centralised higher education systems.

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