=== **COVID-19 PANDEMIC CRISIS** ===

Mutual Influence of Innovation and Human Capital on Regional Growth in Neighboring Countries: The Case of Russia and Kazakhstan

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Abstract—The aim is to assess the impact on regional growth of spending on R&D, technological innovation, healthcare, education, and socioeconomic conditions, their spillovers between the country regions, and, primarily, from the neighboring country regions. In existing studies, the authors examined other regions' impact on regional growth. However, this approach does not reveal the effect the neighboring country's regions had on the regions' economic growth. Our approach novelty is that we assessed the impact of regional growth factors from the country and the neighboring country separately. The panel data analysis method applied to the endogenous growth model made it possible to assess these effects on regional economic growth and identify regional convergence. Our results are consistent with other studies regarding regional drivers and their spillovers to other regions within each country. Moreover, our results confirmed the technological innovation cost stream hypothesis in the Russian regions from Kazakhstan regions. And they confirmed the hypothesis that R&D costs flow to the Kazakhstan regions from the Russian regions. Thus, the study revealed a synergistic effect from the regional growth in spending on R&D and technological innovation between Russia and Kazakhstan, which is asymmetric. The proposed approach to analyzing interregional mutual influence is also applicable to three or more countries.

INTRODUCTION

Recently, there has been significant interest in studying the impact on the regional economic growth of spending on innovation and human capital, which means the R&D, technological innovation, healthcare, education costs, the socioeconomic conditions in the regions, and the knowledge and expenses spillovers between them. These studies examine the relationship between spending on innovation and human capital and regional growth, for example in Europe (Moreno et al., 2005; Rodríguez-Pose and Crescenzi, 2008), the USA (Monchuk et al., 2007), China (Kangjuan et al., 2017; Qiu et al., 2020), Mexico (Rodríguez-Pose and Peralta, 2015), and Russia (Kaneva and Untura, 2018; Kolomak, 2020; Untura, 2013).

Along with the costs spillovers for innovations and human capital between regions within countries, their spillovers between regions in neighboring countries, especially countries with close economic and cultural ties, are quite possible. There are many studies on interregional mutual influence on economic growth in different countries. However, suppose the authors consider several countries. In that case, they consider them as a united large country and study the impact on each region of all other regions, for example, in (Rodríguez-Pose and Crescenzi, 2008) for 15 European countries. Which country regions and by what indicators the influence is significant for regional growth remains unknown.

There are different approaches to the study of regional growth drivers. We follow a methodology similar to that presented in (Rodriguez-Poze and Crescenzi, 2008) for the several European Union countries, in (Kaneva and Untura, 2018) for the Russian regions and some other studies. They examine the impact of knowledge spillovers and costs to each region from all other regions as a *whole*. However, a distinctive feature of our study is that it assesses the impact on a given region of such spillovers from other regions of a given country and from regions of a neighboring country *separately*.

Russia and Kazakhstan are the two largest countries of the Eurasian Economic Union (EAEU) with a recent common historical past, a common border, a language of communication, and free goods and labor resources movement. Therefore, there is a potential
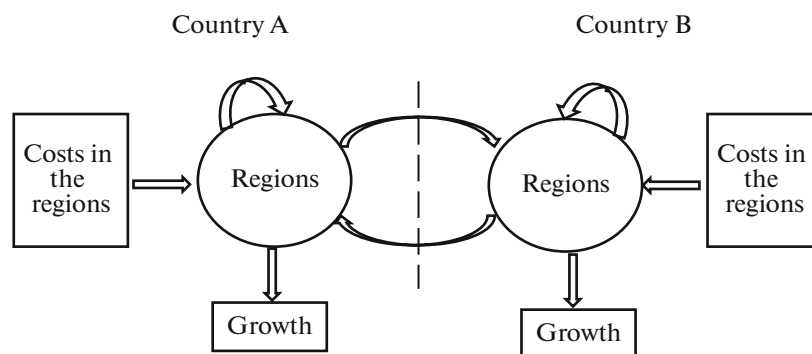
Country A   Country B

Fig. 1. Scheme of cost flows to regions and their overflows between the two countries' regions.

for a mutual influence of these countries' regions. However, differences in their regional development could have accumulated over three decades of separate existence. Considering the purpose of the research, we did not include economic growth factors, such as investment and trade.

The purpose of the research includes analyzing the impact of costs on technological innovation, R&D, healthcare, education, and socioeconomic conditions comparatively on the economic growth in Russia and Kazakhstan and their spillovers between regions within each country. It also includes assessing the impact of their spillovers on the growth of the country's regions from another country's regions (Fig. 1). In country A, spending on innovation and human capital development goes to the regions (arrow on the left), spillovers to other regions of this country (arc arrow above "Regions"), and spillovers across the border to the neighboring country's regions (arrow to the right through the dashed vertical straight line). Similarly, there are spillovers to and from the regions of country B. Ultimately, all these costs and their spillovers affect the economic growth of the regions.

The study tests the following three hypotheses: Hypothesis *H1*. The costs of technological innovation, R&D, healthcare, education, and socioeconomic conditions significantly impact the region's growth.

Hypothesis *H2*. The spillovers of costs for technological innovation, R&D, healthcare, education, and socioeconomic conditions from other country regions have a significant positive impact on the region's economic growth.

Hypothesis *H3*. The spillovers of costs for technological innovation, R&D, health care and education, and socioeconomic conditions from the regions of the neighboring country have a significant positive impact on the region's economic growth.

Presumably, all the factors indicated in the hypotheses can affect the economic growth of regions. However, it is required to confirm that the influence of each factor is indeed statistically significant or to find

out that it is negligible. Even for the first hypothesis, not all of these factors, as it turned out, have a statistically significant impact on the region's economic growth. Moreover, the assertion of the third hypothesis about the mutual influence of factors from the bordering country's regions on economic growth is not obvious. The calculations show that the hypotheses are valid but not for all factors. We discuss and compare the results with similar studies in section 4 of this paper.

In our study, the main goal is to determine the influence of the factors indicated in the *H3* hypothesis, which corresponds to the paper's title. However, for completeness and comparability of the study results, we included hypotheses *H1* and *H2* in consideration.

The calculations show individual effects, and the Hausman test confirms the preference for using the panel data method with fixed effects over random effects. The results obtained confirm all three hypotheses put forward, but not for all, but some indicators. Moreover, there are differences in the sets of these indicators for the two countries.

The rest of the paper consists of the following sections. The next section provides an overview of the literature on the research topic. Then we describe the data, the economic growth model, and the results of checking the data for stationarity. The following section presents calculations using the panel data model with fixed effects and their discussion. The last section concludes the paper.

LITERATURE REVIEW

Modern studies of the influence of endogenous factors on the country's economic growth originate with theoretical works of the 1950s−1960s. Economic growth has two main drivers: increased labor costs and capital based on knowledge concepts.

Human Capital as a Factor of Economic Growth. The transfer of knowledge from the sphere of science to society occurs based on the education system, and

the knowledge's use to improve the welfare of society is possible through the specialists' interaction in science and business. Human capital, considered at the country level, is a broad interpretation of labor resources in the intellectual sphere. Social capital is a catalyst in the development of human capital.

The works (Becker, 1964; Schulz, 1961) recognize human capital as the driving force behind economic growth. Researches (Lucas, 1988; Romer, 1986; Uzawa, 1965) show that the sources of growth underlying non diminishing returns on capital are knowledge and learning by doing. The works (Barro and Sala-i-Martin, 1991; Baumol, 1986; Romer, 1986) consider the level of human capital as a growth factor.

Mankiw et al. (1992) propose a modified Solow-Swan model with the addition of human capital to a Cobb-Douglas-type production function as a factor in economic growth with diminishing returns on human and physical capital. They prove the importance of human capital among the factors that shape the level of countries' economic development in the intercountry differences' presence in income. Lucas (1988) shows that the impact of migration on the countries' convergence is due to the technology's spread between countries. That is, through the exchange of knowledge.

Grossman and Helpman (1991) argue that countries' economic growth requires innovation as a mixed public good produced due to interaction between the state and the economy's private sector. This model was the first endogenous growth model, linking technological progress with innovative activity. In it, the authors formulate the following premises: through the patenting of innovations, one can receive monopoly rent, which finances R&D; economic growth continues until there is a decrease in the return on R&D concerning the research and development costs. Jaffe et al. (1993) show the crucial role of R&D spending and confirm the positive impact of the collocation of public and private research centers on the growth.

Having identified the increase in research costs as a critical factor in developing innovations (Zemtsov et al., 2016) confirm the main provisions of the theoretical model of the knowledge production function. A significant factor is a cost of acquiring equipment due to its high wear and tear and fundamental research that lays the foundation for new developments. These authors establish that the center-periphery structure of the Russian innovation system contributes to the migration of highly qualified researchers to the leading regions, weakening the donor regions' potential. Restrictions on knowledge spillovers in the form of patents are much less. Therefore, proximity to the center, in this case, is considered a positive factor.

Somewhat later, Aghion and Howitt (1992) developed an econometric model that assumes a three-sector economy, the production of intermediate products, and the implementation of technological innovations by the research sector. This work also tests the U-shaped dependence of innovation activity on the level of competition. The authors call the social processes between individuals "knowledge flows."

Using an inter-regional dynamic panel model, German-Soto et al. (2021) explore the hypothesis that innovation is an essential growth driver. Data from Mexico regions showed that innovation positively affects growth, with significant differences across regions and sectors.

Numerous studies have confirmed the positive impact of innovation and the innovation climate on productivity. Examples of such work are (Hallak and Jagadeesh, 2009; Ito and Lechevalier, 2010), and many empirical studies look at examples from individual countries, industries, and regions. On the other hand, some studies point to the negative effect of innovation on firms' productivity, for example, in (Greenaway and Kneller, 2007). Although relatively minor literature supports this view, there is no consensus on innovation and productivity.

Fleisher et al. (2010) found that human capital has a positive effect on output and productivity growth in a study conducted in the provinces of China. Moreover, they found both direct and indirect effects of human capital on total factor productivity growth.

Akindinova et al. (2017) consider the issue of total factor productivity and note that in the inertial scenario, the quantity of labor contribution to economic growth will be negative over the entire period until 2035. A new approach to analyzing "growth accounts" is proposed in Russia. With the allocation of fundamental and cyclical components, a modified human capital index allows taking into account the impact on the dynamics of GDP of the results achieved in education and the population's health state. In this context, with the prevailing trends in investment and total factor productivity and a moderate external environment, long-term growth rates in Russia will remain close to 1%.

The work of (Bozhechkova et al., 2019) considers a system of measures that can positively affect the rate of economic growth in Russia and the institutional problems. They have accumulated in the education system, which reduces its effectiveness, communication issues of investments in education, and increased human capital.

Spending on education, healthcare, and socioeconomic conditions. The most crucial factor in economic growth is the quality of human capital. The study's main results by Che Sulaiman et al. (2021) in Malaysia from 1990 to 2016 show that economic growth is becoming increasingly inclusive. To achieve inclusive and equitable economic growth, the authors recommend that the government consider fiscal aspects and holistic components, including human capital growth factors such as education and healthcare.

Clarke et al. (2015) note that there is a statistically significant positive relationship between education spending and economic growth in U.S. states and developed countries. They find that what matters for economic growth is not spending but the workforce's education level. Moreover, Ramos et al. (2012) concluded that economic growth in the regions of the European Union in previous years was associated with an increase in over-education.

As shown in (Zemtsov et al. 2016), to the greatest extent, the number of potentially commercialized patents depends on the quality of human capital derived from the number of economically active citizens with higher education.

In addition to the costs of innovation activity, human capital factors and the socioeconomic conditions of the regions are essential for economic growth. Based on the catch-up development model, Leslie and O'hUallachain (2007) found that regional structural indicators and human capital impact is comparable to R&D costs.

At the same time, the authors of some studies find cases where there is no connection between education spending and economic growth. For example, Zhu et al. (2018) conducted an empirical study on six provinces in China from 2003 to 2014. The results show that the contribution of higher education to economic growth was below 5%, which is much lower than the contribution of primary education. Higher education has a significant positive impact on economic growth in central China.

Knowledge spillovers and regional growth. The development and knowledge flow embodied in human capital require communication channels in society to interact with human capital in different areas. The organization of these conditions belongs to the area of the state's responsibility and acts as its function. The concept of (Griliches, 1979) about the knowledge production function (KPF) explains the relationship between "innovation–regional economic growth." These ideas were later developed within the theory of knowledge spillovers, laying the foundation for the spatial econometrics of (Anselin, 1988) innovations. Tobler (1970) formulates the first law of geography, "everything is related to everything else, but near things are more related than distant things," and introduces the concept of "geographical proximity." The merit of this group of scientists is their conclusion that there is an inverse relationship between the intensity of knowledge flows and distances. The possibility of direct communication and knowledge flows decreases with increasing distance, which helps to explain the varying concentration of innovative activity.

Fagerberg (1998) points out that knowledge spillovers are the key to innovation in the knowledge economy, which are the basis of positive externalities and the source of economic growth for countries and regions. Accounting for knowledge spillovers in mod-els that reflect the impact of science and innovation on economic growth is based on the construction of geographic proximity measures, i.e., indices that link R&D costs and a measure of distance between regions between which knowledge flows. Researchers assume that geographical proximity affects the possibility of spreading knowledge, and the influence of cross-flows "fades out" with increasing distance.

One of the well-known knowledge spillover models is the model of Jaffe (1986), which, using patent statistics, interprets knowledge spillovers as R&D spillovers. Griliches (1979) and Jaffe (1986) confirm the positive effects of knowledge spillover on the example of a database of U.S. companies proving that a 10% increase in R&D costs by all firms leads to a 20% increase in the number of patents.

The model of Audretsch and Feldman (1996) reflects an integrated approach to the theory of knowledge spillovers, assuming that the economic characteristics are clustering of economic activity in those industries and in those regions in which active processes of knowledge generation take place. The authors consider three sources of knowledge: R&D, a highly skilled workforce, and basic research. The study hypothesis was confirmed using a regression analysis of the 1982 U.S. patent database.

Kangjuan et al. (2017) examine the impact of education factors on economic growth across China's provinces over the period 1996–2010 and establish that these factors have spatial spillover effects and regional differences in the impact of educational factors.

Zemtsov and Smelov (2018) identify and generalize Russia's regional development factors in 1998–2014: advantageous geographical location, raw materials, and agro-climatic capital.

Empirical country studies provide a mixed picture of the impact of higher education and science spending on regional growth. For example, a study on Russia by Kaneva and Untura (2018) shows that spending on higher education and science generates a flow of knowledge between all regions of Russia, which increases the growth rate of GRP.

However, a study on Kazakhstan (Mukhamediyev and Spankulova, 2020) gives the opposite results. The level of science directly determines the state of higher education, and education, in turn, affects the prospects for the development of science. In general, the factors determining knowledge spillover's impact on regional growth are poorly understandable.

As evidenced by the above literature review, many studies prove the existence of an indirect positive relationship between R&D, technological innovation, and economic growth through technological progress. In contrast, other studies link economic growth through indicators of human capital development. At the same time, some studies reveal cases of negative or insignificant influence of certain factors on the economic growth of regions. Therefore, studying these links con-

cerning specific countries and regions is pretty reasonable.

DATA AND MODEL

Data. For calculations, the authors used data collected for 89 regions, including 73 regions in Russia and 16 regions in Kazakhstan, from 2005 to 2018. Due to incompleteness, they do not use data from the Republic of Crimea, Sevastopol, Nenets, Khanty-Mansi, Yamalo-Nenets autonomos okrugs, or others in the research. The data sources were the Federal State Statistics Service of the Russian Federation's Ministry of Economic Development[1] and Kazakhstan's Bureau of National statistics of the Agency for Strategic planning and reforms.[2]

Leading indicators characterizing the socioeconomic conditions of the region are usually presented as some linear combination of them, called the "Social filter." In (Crescenzi et al., 2007) and in the number of subsequent studies authors estimated it using the principal components factor analysis method. We built social filters for the two countries' regions following this approach. Social filter equation for Russian regions:

$$filtin_{it} = -0.8106 * unempl_{it} + 0.5598 * emplrd_{it} - 0.324 * emplyu_{it} + 0.6803 * emplin_{it},$$

social filter equation for the regions of Kazakhstan:

$$filtin_{it} = 0.6143 * unempl_{it} + 0.0873*emplrd_{it} + 0.7904 * emplyu_{it} - 0.6217*emplin_{it}.$$

Here for region i and year t $unempl_{it}$ is unemployment rate (in %), $emplrd_{it}$ is the number of people employed in R&D (in % of those employed), $emplyu_{it}$ is employed among young people (in % of the employed), $emplin_{it}$ is employed in industry (in % of the employed).

It is natural to believe that such spillovers should be weaker for more remote regions. Taking it into account Schurmann and Talaat (2000) proposed the formula for the spatial weight matrix. Let us number all the regions so that 1, 2, ..., 73 are the numbers of the regions in Russia, and 74, 75, ..., 89 are the numbers of the regions in Kazakhstan. If in the region j indicator h has the magnitude h_j, then its impact on economic growth in the region i inversely proportional to the distance d_{ij} between these regions and is evaluated as a product $h_j f_{ij}$, where

$$f_{ij} = \frac{1/d_{ij}}{\sum_{k=1}^{89} 1/d_{ik}}. \quad (1)$$

[1] https://rosstat.gov.ru/regional_statistics. Accessed 12 May, 2021.
[2] https://stat.gov.kz. Accessed 12 May, 2021.

In this study, we propose to modify this approach for the case of two countries to identify their mutual influence. Let us define the indices of impact:

$$H_i^R = \sum_{j=1}^{73} h_j f_{ij}, \quad H_i^{RK} = \sum_{j=74}^{89} h_j f_{ij}, \quad i = 1,2,\ldots,73, \quad (2)$$

$$H_i^K = \sum_{j=74}^{89} h_j f_{ij}, \quad H_i^{KR} = \sum_{j=1}^{73} h_j f_{ij}, \quad i = 74,75,\ldots,89. \quad (3)$$

Here H_i^R is the influence index on the economic growth in the Russian region i of the indicator h related to the remaining regions of Russia. H_i^{RK} is the influence index on the economic growth in the Russian region i of the indicator h related to all regions of Kazakhstan. The indices H_i^K and H_i^{KR} for Kazakhstani regions are determined similarly. As an indicator of h, the article uses the technological innovation's cost *inno*, the R&D cost *rd*, the index of socioeconomic conditions *filtin*, the healthcare cost *heal* and the education cost *edu* in each region.

Researchers usually measure the distance between regions as the distance between their administrative or business centers. These can be distances by road, rail, or air. It is unclear what distances we should consider in the calculations. First, road or rail travel is often used for short distances, such as between neighboring regions. For large and medium distances, by the standards of Russia and Kazakhstan, it is more acceptable and reasonable to use air transport, mainly since virtually all the centers of the regions are provided with air traffic. And since airplanes usually fly along the shortest routes, their length practically coincides with geodetic distances between regions.

Secondly, there are estimates of the distances between the regions of Russia, made by scientists K.P. Glushchenko and A. Abramov from Novosibirsk State University. The study (Kaneva and Untura, 2018) used these distances. But there are no estimates for the distances between the regions in Russia and the regions in Kazakhstan. If all three types of transport communication are available, it is unclear what combination to use on the route's different sections.

In addition, note that the distance between the centers of regions approximates the distance between regions in a broad sense. Not only do the centers of the regions interact with each other, but also parts of these regions. Since we are only investigating a statistically significant impact on the economic growth of innovation and human capital cost spillovers in this research paper, we consider it appropriate to use geodetic distances. Their use estimates distances between regions uniform.

Let α_i and β_i be the longitude and latitude in radians, respectively, of the center of region i, and let R denote the Earth's radius. The formula for the distance between regions i and j is easy to derive:

$$d_{ij} = 2R\arcsin\left\{\frac{1}{2}\left[(\sin\beta_j - \sin\beta_i)^2\right.\right.$$
$$+ \left(\cos\beta_j \cos\alpha_j - \cos\beta_i \cos\alpha_i\right)^2 \qquad (4)$$
$$\left.\left. + \left(\cos\beta_j \sin\alpha_j - \cos\beta_i \sin\alpha_i\right)^2\right]^{1/2}\right\}.$$

The YandexMaps site[3] provides the coordinates α_i, β_i of the cities of the world. The Earth's radius is approximately 6367.4 km.

Endogenous growth model. After the model of Jaffe (1986), interest in studies of the impact of knowledge spillovers on economic growth has increased. Romer (1986) and Lucas (1988) concluded that spending on science and higher education might be significant endogenous factors of economic growth. In our research, we adhere to the formulation of traditional endogenous growth models, for example, Romer (1986) and Fagerberg (1998). Russia and Kazakhstan have a common border; economic, scientific, and cultural ties remain, creating preconditions for the knowledge spillover between their regions.

Nevertheless, over the past three decades of the separate existence of the two states, differences in their regional development could have formed. Modifying the basic model makes it possible to identify these countries characteristics of these countries. The basic panel data model for country regions:

$$growth_{it} = \alpha + \beta_1 \ln(y_{it-1}) + \beta_2 inno_{it} + \beta_3 rd_{it}$$
$$+ \beta_4 filtin_{it} + \beta_5 heal_{it} + \beta_6 edu_{it} + \beta_7 Sinno_{it}$$
$$+ \beta_8 Srd_{it} + \beta_9 Sfiltin_{it} + \beta_{10} Sheal_{it} + \beta_{11} Sedu_{it} \qquad (5)$$
$$+ \beta_{12} Sinno\_pc_{it} + \beta_{13} Srd\_pc_{it} + \beta_{14} Sfiltin_{pc_{it}}$$
$$+ \beta_{15} Sheal\_pc_{it} + \beta_{16} Sedu\_pc_{it} + u_i + \varepsilon_{it}.$$

Here, for region i and year t, the growth rate of gross regional product per capita in percentage terms is chosen as the dependent variable $growth_{it}$. To test the convergence hypothesis, the explanatory variables include the logarithm of the gross regional product per capita $\ln(y_{it-1})$ with a lag of 1 year. And also, the model contains variables:

$inno_{it}$—it is a technological innovation's cost in region i as a percentage of GRP,

rd_{it}—R&D costs in region i as a percentage of GRP,

$filtin_{it}$—it is the socioeconomic conditions' variable of region i,

$heal_{it}$—healthcare costs in region i as a percentage of GRP,

edu_{it}—it is an education cost in region i as a percentage of GRP,

$Sinno_{it}$—spillovers to region i of costs for technological innovation from the other regions of the country,

Srd_{it}—spillovers of R&D costs to region i from the other regions of the country,

$Sfiltin_{it}$—spillovers of socioeconomic conditions to region i from the country's other regions,

$Sheal_{it}$—spillovers of healthcare costs to region i from the country's rest regions,

$Sedu_{it}$—spillovers of education spending to region i from the country's rest regions,

$Sinno_{it}\_pc$—spillovers to region i of costs for technological innovation from the partner country's regions,

Srd_{it}_pc—spillovers to region i of R&D costs from regions of the partner country,

$Sfiltin_{it}\_pc$—spillovers of socioeconomic conditions to region i from the partner country's regions,

$Sheal_{it}\_pc$—spillovers of healthcare costs to region i from partner country's regions,

$Sedu_{it}\_pc$—spillovers of education spending from the partner country's regions to region i.

Here u_i is the individual effect of region i, ε_{it} is the random error model's term. Model (5) was estimated based on data from Russian and Kazakhstani regions. In contrast, in the notation of variables for Russian regions, the ending *pc* is replaced by *rk*, and for Kazakhstani regions—by *rf*.

There is a knowledge spillover between regions. Rodriguez-Pose and Crescenzi (2008) investigated the fact that a region's socioeconomic conditions impact neighboring regions. The innovation, R&D, education, healthcare, and socioeconomic conditions costs in each region can affect the adjacent and nearby regions of the country and the neighboring countries' regions, thereby affecting their economic growth.

At the same time, we did not intend to study the influence of various factors on regions' economic growth, particularly institutional factors, capital, and labor. Accordingly, the production function in the panel data econometric model is not required. However, the social filter includes the unemployment rate and employment in specific sectors of the economy. The authors take the same approach in (Rodriguez-Poze and Crescenzi, 2008) and (Kaneva and Untura, 2018) and many other studies.

First, there are always some variables not included in the model. The fixed effects panel method reduces the bias of the coefficient estimates due to the exclusion of significant variables from the model of Verbeek (2000, p. 345). Secondly, under the purpose of the study, the value of the estimated coefficient $\widehat{\beta}_i$ at the variable is not so important for us, but the sign of the true coefficient β_i in the model matters. The confi-

dence interval provides a basis for such conclusions when discussing the results in the fourth section of the article.

Health and education are components of the human capital structure. The costs of maintaining and strengthening the population's health and raising education can improve its ability to work and thereby enhance economic growth in the region. But how significant this effect is estimated by calculations using the model.

The regions' convergence means the rapprochement process of their levels of development. It is a process in which rich regions develop more slowly and poor regions develop faster. Many authors (Akhmedjonov et al., 2013; Blochliger and Durand-Lasserve, 2018; Di Bella et al., 2017; Drobyshevsky et al., 2005; Guriev and Vakulenko, 2012; Iwasaki and Suganuma, 2015; Kholodilin et al., 2012) have studied the convergence problem of Russian regions. The hypothesis of regional convergence for model (5) is H_0: $\beta_1 < 0$, i.e., a larger value of y_{it-1} has a stronger decelerating effect on $growt_{it}$.

Model (5) is a variant of the conditional convergence model of regions or countries. In the term $\beta_1 \ln(y_{it-1})$ the coefficient β_1 shows how much the growth rate in region i will decrease with an increase in real GRP per capita by 1 percent in the previous period ($\beta_1 < 0$). The logarithmic function reflects the diminishing returns to the economic growth rate from an additional unit of real GRP per capita as its value increases. Crescenzi et al. (2007) and others used such a form of this term on the equation's right side. Replacing the logarithmic form of this term with its linear form could lead to its excessive negative influence on the economic growth rate for rich regions.

Checking variables for stationarity. It is necessary to check the data for stationarity, especially considering that the number of periods is more than ten (Hadri, 2000). If one uses non-stationary data, the calculations from panel data can be misleading. Performing calculations on non-stationary indicators can lead to false regressions (Baltagi, 2013, p. 275). Therefore, we selected independent variables for calculations based on the data in Table 1. If the variable is stationary, then we use itself in the calculations; if not, we use its first difference under the condition of its stationarity. For example, the variable *inno* is stationary for Russia and Kazakhstan, and we included it in the calculations for both countries. And the variable *rd* is stationary for Russia, but non-stationary for Kazakhstan, but the first difference Δrd is stationary for Kazakhstan. Therefore, we included the variable *rd* in the calculations for Russia and the variable Δrd in the calculations for Kazakhstan.

The Levin-Lin-Chu unit root test, often applied to panel data, assumes the data contains a relatively small number of panels compared to the periods' number.

Alternatively, it is applicable if the data includes a relatively small number of panels and a rather large period's number.

In our case, on the contrary, the number of panels exceeds the periods' number for Russia and Kazakhstan, and this test does not apply to them. We used the Breitung, Im, Pesaran, and Shin, and Fisher-type tests (Baltagi, 2013, pp. 281−285), which do not contain such a requirement for panel data. Table 1 presents the results for these three unit root tests.

They do not reject the null unit root hypothesis for some panels. However, in all cases, the results of Table 1 reject the unit root hypothesis for their first differences. Growth model (5) calculations use stationary variables according to the data in Table 1. When constructing panel regressions, we used the panels themselves as independent variables if they were stationary; if not, we used their first differences instead.

At the same time, if the model includes a variable in levels, then the coefficient reflects its effect on economic growth. If in differences, then the coefficient demonstrates the influence of the increase in this variable on economic growth.

RESULTS AND DISCUSSION

Table 2 contains the calculations according to model (5) based on panel data for 89 regions of Russia and Kazakhstan. The dependent variable $growth_{it}$ is determined by the values of y_{it} and y_{it-1}, i.e. current value and value with a lag of 1 year. Since y_{it-1} and $\ln(y_{it-1})$ are correlated, there will also be a correlation between $growth_{it}$ and $\ln(y_{it-1})$. To exclude the occurrence of simultaneity, in the calculations, we used the GRP per capita logarithm's variable with a lag of 2 years, and we used all other independent variables with a one-year lag.

There are four specifications obtained using the STATA econometric package. Specifications 1 and 2 include all stationary independent variables or their first differences if the independent variable itself is non-stationary, for Russia and Kazakhstan, respectively. Specification 1a contains only those explanatory variables from Specification 1, for which the coefficient estimates are significant at least at the 5% level. Similarly, specification 2a includes only those explanatory variables of specification 2, for which the estimated coefficients are also significant, at least at the 5% level.

Table 3 contains variables' descriptions, Tables 4 and 5 contain descriptive statistics of variables, and Tables 6 and 7 contain pairwise correlations for variables for Russia and Kazakhstan in final specifications Ia and IIa, respectively. One can see from the correlation coefficients that for almost all variables' pairs, the strength of the connection between them is very weak (0−0.3) or weak (0.3−0.5), and only for one variables'

Table 1. Unit root tests: Breitung, Im, Pesaran and Shin, and Fisher-type tests

	Russia				Kazakhstan		
Variables	Breitung	Im-Pes-Sh	Fisher-type	Variables	Breitung	Im-Pes-Sh	Fisher-type
growth	0.0000	0.0000	0.0000	**growth**	0.0001	0.0000	0.0000
lny(−1)	0.0168	0.0032	0.0029	**lny(−1)**	0.0333	0.0001	0.0000
inno	0.0000	0.0000	0.0000	**inno**	0.0001	0.0015	0.0000
Δinno	0.0000	0.0000	0.0000	Δinno	0.0000	0.0000	0.0000
rd	0.0464	0.0006	0.0000	rd	0.2234	0.0008	0.0001
Δrd	0.0000	0.0000	0.0000	**Δrd**	0.0000	0.0000	0.0000
filtin	0.0065	0.1929	0.7844	filtin	0.9985	0.9984	0.9943
Δfiltin	0.0000	0.0000	0.0000	**Δfiltin**	0.0000	0.0000	0.0000
heal	0.5147	1.0000	1.0000	**heal**	0.0004	0.0000	0.0000
Δheal	0.0000	0.0000	0.0000	Δheal	0.0000	0.0000	0.0000
edu	0.0000	0.0002	0.0043	edu	0.2512	0.3083	0.3593
Δedu	0.0000	0.0000	0.0000	**Δedu**	0.0000	0.0000	0.0000
Sinno	0.0000	0.0000	0.0000	**Sinno**	0.0000	0.0000	0.0000
ΔSinno	0.0000	0.0000	0.0000	ΔSinno	0.0000	0.0000	0.0000
Srd	0.0000	0.0000	0.0000	Srd	0.9948	0.3537	0.9078
ΔSrd	0.0000	0.0000	0.0000	**ΔSrd**	0.0000	0.0000	0.0000
Sfiltin	0.0015	0.9998	1.0000	Sfiltin	1.0000	1.0000	1.0000
ΔSfiltin	0.0000	0.0000	0.0000	**ΔSfiltin**	0.0000	0.0000	0.0000
Sheal	1.0000	1.0000	1.0000	**Sheal**	0.0000	0.0000	0.0000
ΔSheal	0.0000	0.0000	0.0000	ΔSheal	0.0000	0.0000	0.0000
Sedu	0.0000	0.0000	0.0547	Sedu	0.6366	0.6937	0.9939
ΔSedu	0.0000	0.0000	0.0000	**ΔSedu**	0.0000	0.0000	0.0000
Sinno_rk	0.0000	0.0000	0.0000	**Sinno_rf**	0.0000	0.0000	0.0000
ΔSinno_rk	0.0000	0.0000	0.0000	ΔSinno_rf	0.0000	0.0000	0.0000
Srd_rk	1.0000	0.0335	0.9891	**Srd_rf**	0.0000	0.0000	0.0000
ΔSrd_rk	0.0000	0.0000	0.0000	ΔSrd_rf	0.0000	0.0000	0.0000
Sfiltin_rk	1.0000	1.0000	1.0000	Sfiltin_rf	0.2166	0.9929	1.0000
ΔSfiltin_rk	0.0000	0.0000	0.0000	**ΔSfiltin_rf**	0.0000	0.0000	0.0000
Sheal_rk	0.0000	0.0000	0.0000	Sheal_rf	0.9945	1.0000	1.0000
ΔSheal_rk	0.0000	0.0000	0.0000	**ΔSheal_rf**	0.0000	0.0000	0.0000
Sedu_rk	0.7851	0.9342	1.0000	Sedu_rf	0.0000	0.0085	0.1737
ΔSedu_rk	0.0000	0.0000	0.0000	**ΔSedu_rf**	0.0000	0.0000	0.0000

Δ means the first difference of variable; *p*-values are shown in the Table 1; variables used in subsequent calculations are in bold.
Source: Authors' calculations.

pair is average for both Russia and Kazakhstan. In particular, the correlation between education and R&D is very weak for Russian regions and Kazakhstani regions; we did not include the R&D variable in the final regression 2a. Therefore, there are no significant reasons for multicollinearity in panel regression. In addition, a sign of multicollinearity is the presence of insignificant coefficients in the estimated regression. There are no such coefficients in the final regressions 1a and 2a for the regions of both countries.

The tests confirmed individual effects for the panel data of the regions of Russia and Kazakhstan. The Hausman test revealed the preference for using the fixed effects panel data method over the random effects panel data method. In addition, the panel data method is usually applied if the objects' set is unchanged, as in our case, and is not selected randomly from the general population of objects.

The confidence interval with a probability of 0.95 covers (contains) the true value of the coefficient β_i in the model. As shown in Table 8, the 95-percent confidence intervals lie entirely in the positive area if the estimated coefficient is positive and in the negative area if the estimated coefficient is negative. It means

Table 2. Panel regressions with fixed effects for dependent variables of the regional growth rate per capita

Variables	Russia		Kazakhstan	
	Specification 1	Specification 1a	Specification 2	Specification 2a
lny(−2)	−22.2*** (2.6)	−22.8*** (2.4)	−18.1*** (4.6)	−20.6*** (2.7)
inno(−1)	0.005 (0.008)		0.44*** (0.09)	0.42*** (0.06)
rd(−1)	465.2* (262.1)	536.2** (260)		
Δrd(−1)			−4.67 (12.24)	
Δfiltin(−1)	0.16 (0.32)		0.73* (0.37)	0.71** (0.31)
heal(−1)			1.96 (2.15)	
Δheal(−1)	0.117 (0.484)			
edu(−1)	1.48*** (0.43)	1.27*** (0.41)		
Δedu(−1)			2.25 (1.84)	1.92** (0.78)
Sinno(−1)	0.31* (0.18)		8.26*** (2.72)	7.84*** (2.61)
Srd(−1)	3243** (1581)	3206** (1497)		
ΔSrd(−1)			−169.3 (129.7)	
ΔSfiltin(−1)	0.30 (0.52)	0.68** (0.28)	14.72** (5.48)	12.23** (5.30)
Sheal(−1)			−28.29 (16.92)	
ΔSheal(−1)	0.23 (0.72)			
ΔSedu(−1)	−3.0*** (1.2)		−2.17 (7.42)	
Sinno_pc(−1)	2.98 (3.16)	5.37*** (2.04)	−4.15 (5.03)	
Srd_pc(−1)			30 787** (11175)	15 991** (5697)
ΔSrd_pc(−1)	−26.33 (136.2)			
ΔSfiltin_pc(−1)	−13.28 (9.39)		−1.65 (1.50)	
Sheal_pc(−1)	−16.46 (13.08)			
ΔSheal_pc(−1)			1.62 (2.30)	
ΔSedu_pc(−1)	3.60* (7.82)		1.29 (4.50)	
Constant	258*** (29.8)	262.2*** (28)	80.90*** (37.5)	94.0*** (14.5)
Number of obs.	876	876	192	192
R²	0.273	0.255	0.277	0.210

Robust standard errors in parentheses (option vce (robust)); ***, **, and * respectively indicate the 1, 5, and 10% significance levels; in the notation of the partner country variables, the ending *pc* means *rk* for specifications 1 and 1a and means *rf* for specifications 2 and 2a.

For specification 1a, the F-test for the significance of individual effects: $F(72, 797) = 4.48$, Prob > F = 0.000, Modified Wald test for group wise heteroskedasticity in fixed effect regression model: chi2(73) = 2411.89, Prob > chi2 = 0.0000, Hausman test: Chi2(5) = 197.17, Prob > chi2 = 0.0000.

For specification 2a, the F-test for the significance of individual effects was: $F(15, 169) = 2.20$, Prob > F = 0.0079, Modified Wald test for group wise heteroskedasticity in fixed effect regression model: chi2(16) = 79.12, Prob > chi2 = 0.0000, Hausman test: Chi2(3) = 25.65, Prob > chi2 = 0.0000.

Source: Authors' calculations.

that the model's estimated and true coefficients, at least with a probability of 0.95, have the same signs. In other words, we can judge the impact direction of the indicator in specifications 1a and 2a by the estimated coefficient's sign in Table 2.

Next, we will analyze the results for specifications 1a and 2a in Table 2. As in (Rodríguez-Pose and Crescenzi, 2008; Kaneva and Untura, 2018; Mukhamediyev and Spankulova, 2020) confirm the convergence hypothesis of each country's regions in economic growth since the coefficients at the logarithm of GRP per capita are negative and significant at the 1%

level. R&D spending has had a positive impact on economic growth in the regions of Russia but not in the regions of Kazakhstan. While the costs of technological innovation had a positive impact on economic growth in Kazakhstan, their significant impact was not revealed for the Russian regions. It is consistent with the results of previous studies (Kaneva and Untura, 2018; Mukhamediyev and Spankulova, 2020) and the results (Rodríguez-Pose and Crescenzi, 2008) regarding the impact on the growth of R&D costs in the European regions. One can explain the difference in influence for Russian and Kazakh regions by the

Table 3. Description of the variables

Variable	Definition
GRP	Gross regional product
growth—dependent variable	The annual growth rate of GRP per capita
ln(y)	Natural logarithm of GRP per capita
inno	The technological innovation's cost in region as GRP percentage
rd	R&D costs in the region as a percentage of GRP
filtin	Social filter, a variable of the region's socioeconomic conditions
heal	Healthcare costs in the region as a percentage of GRP
edu	Cost of education in the region as a percentage of GRP
Sinno	Spillovers to the region of technological innovation's costs from the country's other regions
Srd	Spillovers of R&D costs to the region from the country's other regions
Sfiltin	Spillovers of socioeconomic conditions to the region from the country's other regions
Sheal	Spillovers of healthcare costs to the region from the country's rest regions
Sedu	Spillovers of education spending to the region from the country's rest regions
Sinno_pc	Spillovers to the region of costs for technological innovation from the partner country's regions
Srd_pc	Spillovers to the region of R&D costs from the partner country's regions
Sfiltin_pc	Spillovers of socioeconomic conditions to the region from the partner country's regions
Sheal_pc	Spillovers of healthcare costs to the region from the partner country's regions
Sedu_pc	Spillovers of education spending to the region from the partner country's regions
unempl	The unemployment rate in the region
emplrd	The employed people's share in R&D in the total number of people employed in the region
emplyu	The employed young population's percentage under the age of 30 in the region's population
emplin	The share of those engaged in the industry in the total number employed in the region
d_{ij}	The distance between regions i and j
α_i and β_i	The longitude and latitude in radians, respectively, of the center of region i

Table 4. Descriptive statistics for variables of Russia

Variable	Obs.	Mean	Std. Dev.	Min	Max
growth	1022	3.350392	7.283774	−28.72856	65.70953
lny(−2)	949	12.12035	0.5511222	10.31393	14.00868
edu(−1)	949	5.493414	2.679685	0.4471578	22.44316
rd(−1)	949	0.002233	0.0049104	0	0.0309764
Srd(−1)	949	0.002638	0.0021166	0.0008715	0.0152803
ΔSfiltin(−1)	876	0.113964	0.7822653	−2.468306	4.452761
Sinno_pc(−1)	949	0.100669	0.1321496	0.0049434	1.382423

fact that Russian regions attach great importance to research and development.

In contrast, the regions of Kazakhstan focused on technological innovation in production, and science is underfunded. There was no significant effect from the improvement of socioeconomic conditions in the regions of Russia, but it positively impacted growth in Kazakhstan. Although the study (Kaneva and Untura, 2018) showed a positive effect of socioeconomic conditions on the growth of Russian regions, it was not statistically significant at the 5% level.

Neither healthcare costs in Russian regions nor their growth in the Kazakhstani regions significantly affected their economic growth. It is a consequence of the fact that investments in healthcare appear with a lag exceeding one year. However, the education cost contributed to the economic growth of the regions of Russia. In Kazakhstan, the education cost increase positively influenced the region's economic growth.

Table 5. Descriptive statistics for variables of Kazakhstan

Variable	Obs.	Mean	Std.Dev.	Min	Max
growth	224	4.079647	8.605496	−18.56283	38.32442
lny(−2)	208	5.578449	0.6973	4.227414	7.278901
Δedu(−1)	192	−0.1003754	0.527918	−2.005913	1.193484
inno(−1)	208	0.77178	2.229256	0	25.98407
Δfiltin(−1)	192	−0.4844644	1.74407	−6.205507	8.244154
Sinno(−1)	208	0.2275011−	0.2352903	0.0192646	1.464517
ΔSfiltin(−1)	192	−0.1442319	0.1448993	−0.6882286	0.3285093
Srd_pc(−1)	208	0.0015609	0.0002176	0.0012221	0.002218

Table 6. Pairwise correlations for variables of Russia

	growth	lny(−2)	edu(−1)	rd(−1)	Srd(−1)	ΔSfiltin(−1)	Sinno_pc(−1)
growth	1.0000						
lny(−2)	−0.1423	1.0000					
edu(−1)	0.1083	−0.4699	1.0000				
rd(−1)	−0.0132	0.2867	−0.2475	1.0000			
Srd(−1)	−0.0213	0.2302	−0.2317	0.6111	1.0000		
ΔSfiltin(−1)	0.0829	−0.0463	−0.0016	−0.0400	−0.0672	1.0000	
Sinno_pc(−1)	−0.0790	0.1106	0.0959	−0.1017	−0.1973	0.0719	1.0000

As in the Russian regions themselves and in (Kaneva and Untura, 2018), the flow of R&D costs from Russia's other regions positively affected their economic growth. In the regions of Kazakhstan, the costs flow for technological innovation from Kazakhstan's other regions had a positive impact on economic growth, as was also (Mukhamediyev and Spankulova, 2020) found. The explanation here is the same as for the effect of spending on growth within the regions themselves.

The increase in the spillover of the social filter to the region due to improved socioeconomic conditions in the country's other regions positively impacted its economic growth. It is valid for the regions of both countries. (Kaneva and Untura, 2018) for the spillover of the two social filter options has received conflicting results, with positive and negative impacts on growth in other regions. The results in Table 2 of our study show that in each country, neither the spillover of socioeconomic conditions nor the health spillover and education costs to other regions significantly impacted their economic growth.

Identifying the mutual influence on Russia and Kazakhstan's regional economic growth is interesting. The results of econometric analysis find this mutual influence on two indicators. The spillover of spending on technological innovation in the regions of Kazakhstan has had a positive impact on the Russian regions' economic growth. And R&D expenditures in the regions of Russia had a positive effect on the economic growth of Kazakhstan's regions. The two countries' regions have no significant mutual influence for the

Table 7. Pairwise correlations for variables of Kazakhstan

	growth	lny(−2)	Δedu(−1)	inno(−1)	Δfiltin(−1)	Sinno(−1)	ΔSfiltin(−1)	Srd_pc(−1)
growth	1.0000							
lny(−2)	−0.1934	1.0000						
Δedu(−1)	0.0274	0.1447	1.0000					
inno(−1)	0.0999	0.0097	−0.0474	1.0000				
Δfiltin(−1)	0.0882	0.0329	−0.0327	−0.0378	1.0000			
Sinno(−1)	0.0440	−0.0488	0.0149	0.0817	−0.0730	1.0000		
ΔSfiltin(−1)	0.0489	0.0440	0.1281	−0.0947	−0.1516	−0.5358	1.0000	
Srd_pc(−1)	−0.0308	0.3252	0.0766	−0.0133	−0.0870	−0.2250	0.1505	1.0000

Table 8. 95% confidence intervals for coefficients for specifications 1a and 2a

Russia				Kazakhstan			
Variable	Coef.	[95% Conf. interval]		Variable	Coef.	[95% Conf. Interval]	
$lny(-2)$	−22.8***	−27.60	−17.96	$lny(-2)$	−20.6***	−26.32	−14.79
$rd(-1)$	536.2**	18.61	1053	$inno(-1)$	0.42***	0.29	0.55
$edu(-1)$	1.27***	0.46	2.08	$\Delta filtin(-1)$	0.71**	0.06	1.36
$Srd(-1)$	3206**	222.5	6191	$\Delta edu(-1)$	1.92**	0.26	3.59
$\Delta Sfiltin(-1)$	0.68**	0.13	1.23	$Sinno(-1)$	7.84***	2.28	13.40
$Sinno\_pc(-1)$	5.37***	1.31	9.43	$\Delta Sfiltin(-1)$	12.23**	0.93	23.52
				$Srd\_pc(-1)$	15991**	3847	28 136

***, **, and * respectively indicate the 1, 5, and 10% significance levels; in the notation of the partner country variables, the ending *pc* means *rk* for Russia and means *rf* for Kazakhstan.

Source: Authors' calculations.

rest of the indicators, socioeconomic conditions, healthcare costs and education, and their evolution.

CONCLUSION

This study aims to determine the effective directions for spending on innovation and human capital to support the economic growth of the regions developed in Russia and Kazakhstan from 2005−2018. We considered the costs of technological innovation, R&D, healthcare, education, and the socioeconomic conditions of the regions, their spillovers between regions within each country, and their spillovers between these two neighboring countries' regions. We performed calculations for an economic growth model based on panel data with fixed effects.

The results in Table 2 confirm the *H1* hypothesis for the regions of Russia in terms of R&D costs and education costs and for Kazakhstan's regions—in terms of technological innovation, socioeconomic conditions costs, and growth in education costs.

Also, the results of Table 2 support hypothesis *H2* for Russian regions for R&D costs and socioeconomic conditions spillovers from other regions of Russia; and for Kazakhstani regions—in terms of technological innovation costs and socioeconomic conditions spillovers from Kazakhstan's other regions.

Finally, the results in Table 2 confirm hypothesis *H3* for Russian regions about the costs spillover for technological innovation from Kazakhstan regions. They confirm hypothesis H3 in the spillover of R&D costs from the Russian areas to Kazakhstan regions.

Thus, for the economic growth of Russian regions, the R&D costs and their spillovers between the country's regions are significant, and for Kazakhstani regions' economic growth, the technological innovations' costs and their spillovers between the country's regions have a significant impact. Moreover, R&D costs spillover from the regions of Russia has a signifi-

cant positive impact on growth in the Kazakhstani regions. And conversely, the spillover of costs for technological innovation from the Kazakhstani regions is a positive growth factor in the Russian regions.

Here we do not mean that one country incurs costs to support economic growth in another country's regions. There is a synergistic effect. In particular, R&D results in Russian regions can motivate Kazakhstani enterprises to innovate in technology. In turn, these enterprises can order new equipment and machinery in the regions of Russia to implement technological innovations, thereby stimulating their economic growth.

As an illustration of the impact of R&D results in the Russian regions on the technological innovations caused by them and on the GRP growth in the regions of Kazakhstan and their inverse effect on the GRP growth in Russian regions, one can point out the following examples. The assembly center for the production of special equipment and components for KAMAZ based on the "Akmola Autocentre KAMAZ" company in Kazakhstan, produces 71.000 vehicles per year.[4]

The Ulan-Ude Aviation Plant of the Russian Helicopters Holding delivered the first two Mi-8AMT helicopter kits to Kazakhstan for subsequent assembly in Almaty.[5] In 2022, Russian helicopters and Kalashnikov assault rifles will be assembled in Kazakhstan.

The Russian vaccine "Sputnik V" is produced at the Karaganda pharmaceutical complex.[6]

One of the Akmola region's industrial and technological park's launch modules will use a licensed

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[4] https://tengrinews.kz/kazakhstan_news/tokaevu-pokazali-krupneyshuyu-avtomobilnuyu-korporatsiyu-461718/.
[5] https://bgtrk.ru/news/society/211245/.
[6] https://www.zakon.kz/5057836-pochemu-v-karagande-reportazh-s-zavoda.html.

assembly of ACROS and TORUM combine harvesters and RSM tractors—products of "Rostselmash."[7]

Expenditures on education and improving socioeconomic conditions in Russia and Kazakhstan contribute to the economic growth of the regions. In addition, the region's economic growth in Kazakhstan is also favorably influenced by improving socioeconomic conditions in the country's other regions. At the same time, the calculations did not reveal a statistically significant impact on the economic growth of regions of healthcare costs and their spillovers between regions.

A significant result is a synergistic effect of the mutual influence of R&D and technological innovation costs on economic growth between the Russian and Kazakh regions. It can be viewed as a manifestation of the integration processes between these two countries and used in preparing joint regional development programs for the regional development of neighboring countries, particularly the Eurasian Economic Union countries. The presented approach to the analysis of the mutual influence of regions on their economic growth for two neighboring countries can be generalized to the case of several countries.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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[7] https://www.virazh.kz/news/v-akmolinskoy-oblasti-rasshiryaetsya-proizvodstvo-selhoztehniki-188/.

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