www.gi.sanu.ac.rs, www.doiserbia.nb.rs
J. Geogr. Inst. Cvijic. 2023, 73(1), pp. 33–48

Original scientific paper

UDC: 911.372.7:711.2
https://doi.org/10.2298/IJGI2301033C

Received: October 18, 2022
Reviewed: February 21, 2023
Accepted: April 1, 2023

CATCHING-UP REGIONAL STRATEGY AS A TOOL TO REDUCE SPATIAL INEQUALITY

Natalia Chistyakova[1], Alexander Mikhalchuk[2], Yulia Bocharova[1], Ekaterina Akerman[3], Valeria Tatarnikova[1]*

[1]National Research Tomsk Polytechnic University, School of Engineering Entrepreneurship, Tomsk, Russia; e-mails: worldperson@mail.ru; j.bocha@yandex.ru; tvv0907@yandex.ru
[2]National Research Tomsk Polytechnic University, School of Basic Engineering Training, Department of Mathematics and Informatics, Tomsk, Russia; e-mail: aamih@tpu.ru
[3]National Research Tomsk State University, Institute of Economics and Management, Tomsk, Russia; e-mail: akerman-ekaterina@rambler.ru

Abstract: The article is devoted to the problem of spatial inequality of regions caused by centripetal or centrifugal forces because of agglomeration effects and interaction costs. It corresponds with the main idea of new economic geography. A differentiated approach to regional development strategizing is proposed in the study as a tool for reducing the level of spatial imbalance. Herein the use of technological arbitrage (catching-up) strategy is proposed for peripheral regions by strengthening interregional interaction. In the paper, two hypotheses are investigated: (1) The economic growth of territories, caused by industry diversification, positive externalities from Research and Development, the quality of human capital, which are typical of the "center" type of regions and (2) The formation of a unified macroeconomic space is possible due to strategies of technological arbitrage (catching-up strategy) for peripheral regions. Its implementation is possible through innovation, industrial-technological, and trade-technological complementarity development of peripheral regions with the central regions. The research methods are: panel regression with fixed effects, Data Envelopment Analysis method, and Malmquist Productivity Index, paired interregional complementarity indices. The study focuses on 10 regions of Siberian Federal District in the Russia, which differ in scale, structure, and level of innovative economic development. The study results confirm the possibility of reducing the level of spatial inequality using catching-up strategies and innovation complementarity of the regions. These strategies proved only for technical efficiency leading regions with high index of complementarity. In regions with a low complementarity index and different industry profile, large-scale interregional cooperation has not been confirmed.

Keywords: Data Envelopment Analysis method; Malmquist Productivity Index; catching-up strategy; innovation complementarity; new economic geography

1. Introduction

The problem of spatial inequality of regions and countries is widely discussed in academic circles over the last decade (Combes et al., 2011). This problem is typical for particular regions of the European Union (Rosés et al., 2010), the People's Republic of China (Herzfeld, 2008; Vuković et al., 2012; Vuković & Wei, 2010), and post-Soviet countries (Berkowitz & DeJong,

*Corresponding author, e-mail: worldperson@mail.ru

2005) including the Russian Federation (Carluer & Sharipova, 2004) with its own specifics. In Russia, for example, the main concentration of the population falls on the northern regions of Russia and, artificial underestimation in the data of statistical observations of migration and economic activity in the western regions (Hill & Gaddy, 2003).

New Economic Geography (NEG) explains unequal spatial development by a number of assumptions that differ from the ones made by the theory of economic growth and international trade theory (Combes et al., 2008). The NEG proves that the relationship between agent interaction costs and agglomeration forces is not linear, but bell-shaped (Krugman et al., 1999). Thus, studies based on long-term historical data confirmed the conclusion about the bell-shaped relationship between the costs of interaction between actors (Kolomak, 2013) and models of the spatial organization of the economy for the United States, France, and Spain (Combes et al., 2008). According to the studying of these processes, when transaction costs fall below a certain level, centrifugal tendencies begin to increase (high costs for the location of production, strong competition, etc.) and deconcentrating occurs (Paluzie et al., 2004). In Russia however, the opposite trend is observed—the country is on the left side of the bell-shaped curve linking interaction costs to the decision to locate enterprises. Centripetal trends are experienced by both western and eastern regions of the country (Kolomak, 2013). Often the role of a center is played by metropolitan regions, which attract better human capital, have a more efficient combination of resources, which leads to technological and innovative leadership (Anokhin et al., 2015). These regions are "magnets" for attracting the best resources from neighboring regions and thus reinforce disparities in spatial inequality, which is typical for European countries as well (Feldman & Audretsch, 1999). It leads to the necessity to form different strategies for regional development for different types of regions. Metropolitan regions have a better prospect of achieving breakthrough technology changes and organizational practice, and they are increasingly characterized by "challenge cultures" (Cooke & Morgan, 1998). Actors in these regions have the potential to become dominant technological leaders. These regions use aggressive policies, benefiting from agglomeration effects and maximizing outcomes while using available resource potential, consistent with "creative destruction" (Schumpeter, 1934). Peripheral regions, in contrast, have fewer development opportunities, tend to have lower Research and Development (*R&D*) outcomes, which lead to a focus on catch-up innovation, and thus, they need their own development strategy.

One of the alternatives for choosing a development strategy for peripheral regions is the model of catching-up (imitative) strategy. Interregional interaction based on knowledge spillovers allows reducing the level of spatial inequality for peripheral regions. It is possible through technologies imitating or purchasing from regions with high level of technical efficiency (TE; Berglund & Johansson, 2007; Garofoli, 1994). Although catching-up strategy may seem simple, it is actually quite a complex process, as knowledge sharing between regions depends on the interaction which can be limited by poor infrastructure, lack of quality human capital, and weak receptivity to innovation (Anokhin et al., 2015). As a result, a high concentration of regional actors—a kind of innovation environment—cannot be formed (Cornett, 2009; Doloreux & Dionne, 2008). It is possible that the peripheral regions adjacent to the central one, will not be able to move to a technological catch-up trajectory. This conclusion determines the logic and choice of methods for this study.

The structure of the article contains the following issues. The first part is devoted to the verification of hypothesis whether diversification, specialization, and interregional knowledge spillover affect the economic growth of peripheral regions in Russia, as well as the influence of interregional interaction potential on regions' development. The study uses a Multiple Panel Regression model, where the listed factors are dependent variables, and Gross Regional Product (GRP) is the independent one. The second part deals with the peculiarities of technological development of the regions, their competitive advantages, opportunities for technological leadership, and catching-up strategies. In the study, the Data Envelopment Analysis (DEA) method is used by making a production function of the regions, identifying the leaders, "nearest neighbors", and calculating TE of the regions. These strategies aroused as recommendations for the regions based on the DEA results. The third part contains calculations of interaction opportunities between regions and determines the areas of technological cooperation. For this purpose, the study uses paired indices of regional complementarity comparing the profiles of innovation output and the production one of the regions. The aim of the study is to consider models of regions' catching-up strategies based on an assessment of their TE and selection of an appropriate interregional cooperation strategy to reduce spatial inequalities.

2. Literature review

Traditionally, the spatial aspects of economic relations management (including integration and innovation processes) are combined in the regional (spatial) economy. The basic theoretical foundations of interregional integration are theories of spatial location and development of regional factors of production (Lösch, 1954; Weber, 1929). These theories were developed in studying the integration of territories to improve the competitiveness of countries (regions), which became the basis of integration processes in Europe. Theoretical background to interregional interaction are the works on the theory of absolute and relative advantages (Smith, 1776). According to the theory, some countries (regions) can produce goods more efficiently than others, and as a result, they have an absolute advantage and sell them through trade. Later, scientists developed the theory of comparative advantage and interregional trade not only in terms of exchange, but also the possibility of reducing gaps between territories (Heckscher & Ohlin, 1991; Samuelson & Barnett, 2007). This direction is reflected in the formation of the concept of NEG (Krugman et al., 1999), which explores the formation of centers and peripheries around them. It is such "centers" that become the sources of growth to which industry moves, generated by the causality of supply and marketing connections (centripetal forces).

Bordering "center" regions gradually become agrarian periphery, have immobile factors of production—fertile lands for agriculture, natural resources etc., there are no economic externalities (by centrifugal forces). Economic externalities (human capital, investment in *R&D*) are not present at the national, but at the local levels and form competitive advantages that can lead to global competitiveness. It is the local level that the foundations of the global competitiveness of countries and economic blocs are laid. Thus, study proves the hypothesis that the concentration of human capital (Griliches, 1979), level of its education, and the share of highly qualified personnel (Rodriguez-Pose, 2011) affects the growth of a country's GDP.

The development of the concept of knowledge spillover highlighted the influence of the factor of knowledge transfer between regions, which is possible in the presence of powerful research centers, concentration of universities in the central regions, which can be used by peripheral regions, using catch-up strategies. The exchange of explicit and tacit knowledge, depending on the degree of proximity, is a significant factor affecting economic growth (Leamer & Storper, 2001) and the concentration of researchers in an area (Tolbert & Zucker, 1996).

As a result, fundamentally different determinants of regional competitiveness emerge: the quality of human capital and living environment, the development of diversified production, and increased confidence. In addition, modern studies of spatial development take into account the acceleration of technological discoveries, globalization, the growing openness of economies, and note the following as additional factors:

- Increasing economies of scale from the concentration of industry within a particular geographic area facilitates knowledge spillovers between companies in the same industry and promotes innovation (Marshall-Earrow-Romer externalities). Sahdev (2016) has shown that inter-industry knowledge spillovers are a source of considerable innovation;
- Positive externalities, in the form of *R&D* expenditure in complementary (related) industries when interacting, contribute to the growth of innovative products and economic growth in the region (Audretsch & Feldman, 2004); and
- Positive externalities in the form of human capital, possibly heterogeneous across regions, play a significant role in firm localization and productivity growth.

One of the emerging approaches to identify suitable development strategies for central and peripheral regions is the method of technological arbitrage (Kirzner, 1997; Shane, 2000; Troutt et al., 2007; Vandenberg & Lance, 2000). According to these theories, economic actors can choose two strategies of innovative behavior to survive in the market: either the development of a new product or production method for the market—breakthrough innovations (Schumpeter, 1934), or a technology arbitrage strategy that allows them to imitate technologies developed by others that can be discovered and are involved for retention in the market (Kirzner, 1997).

Views of Schumpeter (1934) have evolved over time to his assumptions about the impact of regional policy on the activities of entrepreneurs. Regional policies can promote the economic growth of regions by enacting regulations that encourage free enterprise on the part of individuals and corporations. Achieving greater results at lower costs through the recombination of resources, attracting more qualified human capital, increases the efficiency of the region. Considering the development of peripheral regions from this complex point of view, which emphasizes the effectiveness of resource combinations, one can distinguish two main types of a region's strategy: (1) technological expansion, which, through a better combination of resources, expands the best national technologies (Schumpeter's creative destruction), and (2) catch-up (imitation) strategy that allows to imitate the best national technologies (Kirzner, 1997). To evaluate and select the type of strategy for the central and peripheral regions, it is proposed to use the DEA method (Anokhin et al., 2011). DEA allows us to build a production frontier (technological arbitrage curve), which is a way to combine regional resources. Regions that are central and define the very frontier will only have breakthrough innovations as an alternative. Regions that do not have the status of an innovation leader can benefit from studying the innovation strategies of the leading regions by imitating certain elements of the strategy, i.e., using the strategy of catch-up development (imitation).

The main hypotheses addressed in this study are:

- The economic growth of the territories is conditioned by the degree of diversification, positive externalities from *R&D* for the border regions and the quality of human capital, and
- Creating of a unified macro-regional space is possible using technological arbitrage (catching-up) strategies for peripheral regions, whose strengthening can be realized through sectoral innovation, industrial-technological, and trade-technological complementarity with stronger regions.

Thus, this paper explores the possibility of increasing efficiency and, thereby, reducing the level of spatial inequality for peripheral regions. It is possible by using of a catch-up development (imitation) strategy based on Kirzner's approaches through the construction of a technological arbitrage curve.

3. Data and research methodology

3.1. Spatial factors affecting the economic growth of peripheral regions of Russia

A panel regression with fixed effects was used to estimate and identify the key factors influencing economic growth in regions through the diffusion (spillover) of knowledge and resources to neighboring regions (regardless of their level of innovation development). The spatial concentration of gross output in the regions of Siberian Federal District (SFD) was estimated using the production function (Equation 1) with the inclusion of innovative and service variables (Equation 2):

$$Y_{rt} = f(K_{rt}, L) \quad (1)$$

$$Y_{rt} = f(K_{rt}, DENS_{rt}, SPEC_{rt}, MP_{rt}, Kspill_{rt}, HH_{rt}, CUL_{rt}, SER_{rt}) \quad (2)$$

where K_{rt}—the cost of fixed assets of the region, $DENS_{rt}$—the density of economic activity in the region (population per 1 km^2); $SPEC_{rt}$—the level of specialization of the region's economy; HH_{rt}—the Herfindahl index reflects the degree of diversification of the regional economy. It is calculated as the sum of the squares of the shares of sectors in the economy of the region *r*. Calculated as the square of the shares employed in the industry in the total economy of the region r; MP_{rt}—the market potential of the region (Equation 3). It is calculated as the sum of releases of border neighbors weighted s by the shortest distance between them (as the distance $DIST_{rs}$ from region *r* to neighbors regions *s*, the minimum length of the road path from one regional center to another is used).

$$MP_{rt} = \sum\nolimits_{s \neq r} (Y_{rt}/DIST_{rs}) \quad (3)$$

$Kspill_{rt}$—knowledge flows between regions at time *t*. The accessibility index is used. It is calculated as the amount of *R&D* $costs_{rt}$ from the innovation-active regions *r* at time *t*. (Novosibirsk, Tyumen, Tomsk regions, and Krasnoyarsk Krai) to the other regions bordering them *s*, weighted by the distance between the regions (Equation 4)

$$Kspill_{rt} = \sum\nolimits_{s \neq r} (R\&D\ costs_{rt}/DIST_{rs}) \quad (4)$$

The production function (Equation 2) is used as a modified Cobb-Douglas function (Kolomak, 2013). As a result of the logarithm of this function, an econometric model is obtained (Equation 5):

$$\begin{aligned} lnY_{rt}(GRP_{rt}) = \alpha + \beta_1 \cdot lnDENS_{rt} + \beta_2 \cdot lnHH_{rt} + \beta_3 \cdot lnK_{rt} + \beta_4 \cdot lnSPEC_{rt} \\ + \beta_5 \cdot lnMP_{rt} + \beta_6 \cdot lnKspill_{rt} + \beta_7 \cdot lnSER_{rt} + \beta_8 \cdot lnCUL_{rt} + \beta_9 \cdot lnL_{rt} \end{aligned} \quad (5)$$

where GRP_{rt}—the dependent variable of the region *r* at time *t*; similarly SER_{rt}—the level of those employed in services in the total volume of employment in the economy of the region at time *t*. Assessment of the degree of influence of environmental quality on the economic growth of the region *r*; CUL_{rt}—the quality of the environment (the number of theater spectators and the number of museum visits) in the region; L_{rt}—the level of employed in the economy with higher education in the region *r*. The results of the Wald, Breusch-Pagan, and Hausman tests showed that panel regression with fixed effects is a better fit for this study than simple regression or panel regression with random effects (Kolenikov, 2003).

3.2. DEA method as a tool for measuring TE of the regions

The DEA method is used to assess each stage of the innovation process of SFD regions relative to the technological frontier, which allows to judge the efficiency of regions depending on the types and combination of resources used. One emerging approach to assessing the performance of a region's economy and determining the appropriate type of strategy is the technology arbitrage method (Shane, 2000; Vandenberg & Lance, 2000). Models for evaluating regions based on this method are presented in: Stochastic Frontier Analysis (SFA) (Sharma et al., 2007) and DEA (Lin et al., 2021; Ouyang & Yang, 2020) with Malmquist index to evaluate technological development. The DEA methodology is extensively used followed by truncated Tobit regression. The use of the complementary advantages of DEA and SFA methodologies is discussed in papers (Lin et al., 2021). It is implemented by constructing a production function of the regions and in the analysis of basic resources (labour and capital) allows us to identify different regional strategies. The DEA method uses two types of models: input-oriented models to evaluate the effectiveness of minimizing resource use and output-oriented models to evaluate the effectiveness of maximizing the result.

The DEA methodology offers a short-term dynamic characteristic of the two-year progress (regression) of efficiency—the Malmquist productivity index (*MPI*). The values of $MPI < 1$, $MPI = 1$ and $MPI > 1$ correspond to a decrease, constancy or increase in the efficiency of the region during the study period (Malmquist, 1953). The *MPI* is calculated using the formula (Equation 6):

$$MPI = EFF \cdot TECH \tag{6}$$

where *EFF* (Catch-up Effect) is equal to the ratio of the TE_{crc} in period *t*+1 to the TE_{crc} in period *t*, which will be higher than one if there is an increase in the efficiency of the region. TECH (Frontier Shift Effect) is a measure of frontier shift according to technological improvement between periods. A *TECH* member is greater than, equal to, or less than one when technological best practice improves, does not change, or worsens, respectively (Alimohammadlou & Mohammadi, 2016). In the case of several pairs of years on period *T*, the long–term dynamics of *MPI* is estimated by the linear trend $\alpha^*t + b$, $\alpha > 0$ determines progress, and $\alpha < 0$, regression (Jafari, 2014). Calculations are performed using software products: DEAP (Coelli, 1998) and STATISTICA (Khalafyan et al., 2016; TIBCO Software Inc., 2020). Statistical indicators of socio-economic and innovative development of the regions were used for the calculation:

- Indicators characterizing the level of human capital development in the region:
  - HC—The share of researchers engaged in scientific R&D in the total employment structure of the population, in %.
- Indicators characterizing the innovative activity of companies in the region:

  – IA1—Internal R&D costs, million rubles;
  – IA2—The costs of innovative activities of organizations, taking into account prices, million rubles;
  – IA3—The share of innovative goods, works, services in the total volume of goods shipped, works performed, and services, in %.
- Indicators characterizing the accumulation of knowledge in the region:
  – CIA—Coefficient of inventive activity (the number of domestic patent applications for inventions filed in Russia, per 10 thousand people of the population).
- Indicators characterizing investments in the region:
  – IFC—Investments in fixed assets, taking into account prices (with a lag per year), billion rubles.
- The final indicator:
  – GRP—Gross regional product including deflator, billion rubles.

3.3. Different types of interregional complementarity for creating unified macroeconomic space

Paired interregional complementarity indices allow us to assess the potential of interregional cooperation in the field of innovation and technological import substitution, taking into account the industry profiles of the regions. In order to quantitatively substantiate the choice of partner regions in order to form a single macroeconomic space of SFD, a modification of the Economic and Social Commission for Asia and the Pacific trade complementarity index was carried out. The index is based on data on exports and imports of countries for various goods and serves as a characteristic of how the export profile of one country corresponds to the import profile of another. The calculations allow us to conclude how promising the trade and integration relations between the pairs of countries are.

The index is 0 if the countries are absolute trade competitors, and one country does not import any goods exported by the other. The index is equal to 1 if this pair of countries is completely complementary in trade, i.e., one country imports exactly the goods that the other exports. For the purposes of our research, based on the modification of this index (Equation 7), it is possible to estimate:

- Innovative complementarity of regions. Comparing the industry profile of innovative output in different regions allows us to assess the prospects for joint *R&D*;
- Production and technological complementarity of the regions. Comparing the industry profile of innovative output of one region with the industry profile of industrial output of another region allows us to assess the prospects of scientific and industrial cooperation; and
- Trade and technological complementarity of the regions. Comparing the industry profile of technology imports from one region and the industry profile of innovative output from another region allows us to assess the prospects for technological import substitution, which is especially important in the conditions of sanctions regimes. Interregional Complementarity Index ($Icomp_{AB}$) is calculated using the Equation 7:

$$Icomp_{AB} = 1 - \left[\left(\sum_i \frac{x_{iA}}{X_A} - \frac{y_{iB}}{Y_B}\right) / 2\right] \quad (7)$$

where x_{iA}—the value of indicator 1 for industry in region A; X_A—the total value of indicator 1 in region A; y_{iA}—the total value of indicator 2 in region B; and Y_B —the total value of indicator 2 in the region in B.

Primary data on innovative and industrial output are presented for 2020 for 23 types of economic activity (EMISS. Government statistics, n.d.-a, n.d.-b). The choice of these types of activities is due to the following: (1) the most detailed groups of activities were determined from among those that coincide in the compared indicators; and (2) the types of activities in which only one region appears according to this indicator were excluded.

4. Results and discussion

4.1. Hypothesis 1

The economic growth of the territories is due to the degree of industrial diversification, positive externalities from *R&D* in the border regions, and the quality of human capital. According to Krugman et al. (1999), economic growth is achievable in regions with high industrial diversification, market potential, high population density, which actually perform the function of a "center". The study of the main postulates of NEG in Russian reality was carried out by identifying the factors affecting GRP through the construction of multiple panel regression.

The object of the study is 10 regions of SFD: Krasnoyarsk Krai (KK), Altai Krai (AK), Omsk region (OR), Irkutsk region (IR), Novosibirsk region (NR), Tomsk region (TR), Kemerovo region (KR), Republics of Khakassia (RKH), Republics of Altai (RA), and Republics of Tyva (RT). The results of multiple panel regression of SFD regions for 2010–2020 are displayed in Table 1.

Table 1. Assessment of the influence of independent variables on GRP

Name of the independent variable	The value of *β*k
Population density (*lnDENS*)	–0.08 (0.02)
Herfindahl Index (*lnHH*)	0.32*** (0.102)
Specialization (*lnSPEC*)	0.16** (0.07)
Market potential (*lnMP*)	–0.002 (0.45)
Main production assets (*lnK*)	0.73*** (0.03)
Knowledge spillovers (*lnKspill*)	0.06 (0.019)
Services (*lnSER*)	–0.62 (0.05)
Culture (*lnCUL*)	0.11*** (0.13)
Number of people with higher education (*lnL*)	0.71 (0.13)
Number of observations	110
R^2	.91

Note. Standard errors are indicated in parentheses. ***Significance at level 1 %;
**significance at level 5 %; *significance at level 10 %,
R^2—regression determination coefficient.

The results of the regression analysis indicate the high explanatory power of the model (R^2 = .91). Thus, more than 90% of the observed variation can be explained using the resulting regression equation. Four significant variables affecting GRP in the regions of SFD have been identified: *HH, SPEC, K*, and *CUL*. All the variables have a positive impact on the economic growth of the territories. Thus, the elasticity of total output according to the *HH* was 0.32, i.e., an increase in diversification by 1% will lead to an increase in GRP by 0.32%. Ensuring the economic growth of the regions due to the high diversification of the economy and the increase in production assets may indicate disintegration processes in the economic space of SFD since the regions seek to localize as many types of production as possible and ensure development mainly at the expense of internal resources. According to the obtained model, choosing between multidirectional processes—diversification and specialization—preference should be given to diversification (β_{HH} = 0.32 against β_{SPEC} = 0.16).

Statistically insignificant were: *DENS, MP, Kspill, SER*, and *L*. Thus, the indicators embedded in the model for assessing interregional interaction (market potential and knowledge flows) currently do not affect the economic growth of the regions. Services also do not make a significant contribution to regional development, which means that the main output in SFD is provided by those employed in the primary and secondary sectors of the economy. Consequently, the key factors of centripetal forces in SFD, according to the provisions of NEG (a developed environment and a larger market than that of neighboring regions) do not play a big role.

Hypothesis 1 does not generally hold, except for the strong impact of diversification on economic growth. Such trends are associated with a lower level of development of the tertiary sector of the economy, the dominance of capital-intensive traditional production and insufficient realization of human capital. This determines the need to adjust regional policy and take into account the possibility of regional growth due to complementary development within a single macro-regional space.

4.2. Hypothesis 2

The formation of a single macro-regional space is possible with the use of technological arbitration strategies for peripheral regions, the strengthening of which can be implemented through industry innovation, industrial-technological and trade-technological complementarity with stronger regions. The novelty of the proposed approach lies in the use of a three–stage model "Knowledge generation—Commercialization of knowledge—Innovation", in contrast to the classical model, which uses two types of resources (labor and capital). This approach allows us to see the role of the region in the macro-regional space (knowledge producer; creator–technology simulator–industrial center; agricultural or tourist region). To study the models of innovative development of SFD regions, a three stage assessment of DEA–dynamic efficiency was carried out, reflecting the three proposed types of regional development (Table 2):

- Technological expansion, with the leading factor of change—"Knowledge generation" (Model 1);
- Catching-up development, with the leading factor of change—"Commercialization of knowledge" (Model 2); and
- Technological shift, the leading factor of change—growth due to innovative modernization (Model 3).

Table 2. Indicators of the DEA method of three types of models of innovative development of SFD regions

Indicators	Model 1	Model 2	Model 3
Resources	HC and IA1	H31 and IA2	IA3 and IFC
Results	CIA	IA3	GRP

4.2.1. Model 1: "Knowledge generation"

The distribution of regions in the two-dimensional coordinate space (HC; CIA) relative to the leading regions in TE calculated by the variable returns to scale (VRS) model (Sharma et al., 2007) forming efficiency frontiers (broken lines) for 2010 and 2020 (Figure 1). The leading regions in terms of TE, taking into account its dynamics (*MPI*) in 2010, are: TR—relatively high resource costs (HC) and relatively high result (CIA); KR—relatively average resource costs (HC) and relatively low result (CIA); RKH—relatively low resource costs (HC) and relatively low result (CIA). In 2020, KK entered the group of leaders—relatively average resource costs (HC) and relatively low result (CIA). Model 1—Resource indicators (Input–Input indicators)—indicators (HC) and (IA1), performance indicator (output–output indicator)—(CIA) for the period 2010–2020 have been presented in Figure 1.

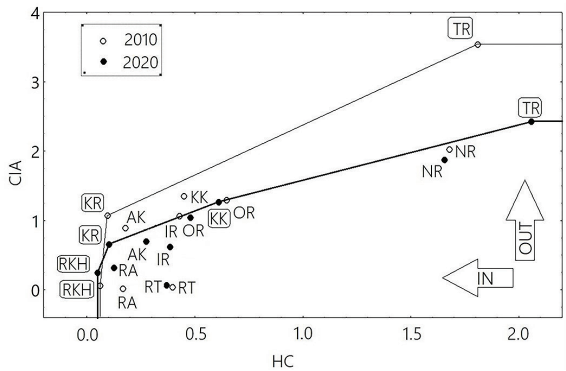

Figure 1. The dispersion diagram of SFD regions relative to the frontiers, indicators for 2010 and 2020, Model 1 "Knowledge generation".
Note. The regions in squares are the leading regions that form the frontier with the value of TE = 1.

In the Model 1 "Knowledge generation", TR and NR have the maximum TE, which indicates the role of these regions as knowledge generators capable of working at the level of frontier scientific tasks. Other regions can enter into active cooperation on this type of resources with these regions in order to strengthen their own technological developments. The results of the TE of the regions for the first stage of the innovation process are presented in Table 3.

4.2.2. Model 2: "Commercialization of knowledge"

Model 2—Resource indicators (CIA and IA2) and performance indicator (IA3) for 2010 and 2020. The leading regions in TE, taking into account its dynamics (*MPI*) in 2010, are: OR—relatively average costs (IA2) and relatively high results (IA3); NR—relatively low costs (IA2) and relatively high results (IA3); RA and AK—relatively low costs (IA2) and relatively average results (IA3); RKH—relatively low costs (IA2) and relatively low results (IA3). The results of the TE of the regions for the second stage of the innovation process are presented in Table 3. For these regions, the model of technological arbitration is applicable, when using resources (patents and internal costs of companies for innovation), results are achieved relatively efficiently. The leadership of NR in the models of "Knowledge generation" and "Commercialization of knowledge" indicates the absence of gaps in the innovation process of the region. The region produces knowledge that is introduced into the technological process. The leading region is TR in the "Knowledge generation" model, because it can use imitation strategies in relation to NR, since it is located in close proximity to this region. Agricultural and tourist regions (RT, RA, and RKH) have a low level of resources with a low result, which indicates a low innovation activity and a different role of the region in the macro-regional economic space.

4.2.3. Model 3: "Implementation of innovations"

Model 3—Resource indicators (IA3 and IFC) and performance indicator (GRP) for 2010 and 2020. The leading regions in terms of TE, taking into account its dynamics (*MPI*) in 2010, in the case of resource use (IA3) and result (GRP) are: KK—relatively low resource costs (IA3) and relatively high result (GRP); and RKH—relatively low costs resource (IA3) and relatively low result (GRP). In 2020, an additional leader appeared: IR—relatively low resource costs (IA3) and relatively average result (GRP). The leading regions in terms of TE, taking into account its dynamics (*MPI*) in 2010, in the case of resource use (IFC) and result (GRP) are: KK—relatively high resource costs (IFC) and relatively high result (GRP); RKH and RT—relatively low resource costs (IFC) and relatively low result (GRP); NR and AK—relatively average resource costs (IFC) and relatively average result (GRP). AK and NR lost their leadership in 2020. The results of the TE of the regions for the third stage of the innovation process are presented in Table 3.

Table 3. TE of regions by stages of the innovation process in 2020

Regions	Model 1		Model 2		Model 3	
	TEin	TEout	TEin	TEout	TEin	TEout
RA	0.591	0.467	1	1	0.909	0.58
RT	0.188	0.062	1	1	1	1
RKH	1	1	1	1	1	1
AK	0.669	0.898	0.337	0.314	0.876	0.887
KK	1	1	0.297	0.362	1	1
IR	0.256	0.642	0.163	0.092	1	1
KR	1	1	0.321	0.289	0.594	0.627
NR	0.827	0.89	0.158	0.333	0.86	0.866
OR	1	1	1	1	0.664	0.684
TR	1	1	0.103	0.238	0.796	0.816

The most effective region in terms of resource use in the absence of innovation gaps is NR which implements a full innovation cycle from knowledge generation to introduction into production, which is reflected in the growth of GRP. The gap in the innovation process is observed in KK, where there is low efficiency of knowledge generation, but at the same time, high efficiency of implementation into production and economic growth at the expense of industry. TR is the most effective in generating knowledge, but at the same time, it is low-effective in their commercialization and introduction into production.

In order to assess the potential for the formation of a single macroeconomic space of SFD, the calculation of paired indices of innovation, production-technological, and trade-technological complementarity was carried out according to the formula specified earlier. The industries promising for innovative interaction of regions in Model 1 and 2 are presented in Table 4.

Table 4. Innovative complementarity of regions with the closest leaders (*pr*) in Model 1 "and Model 2

Region	*pr 1*	*Icomp*AB	*pr 2*	*Icomp*AB	Region	*pr 1*	*Icomp*AB	*pr 2*	*Icomp*AB
Model 1									
TEin (max CIA)					TEout (min HC or IA1)				
RA	RKH	0.595	KR	0.014	RA	TR	0.176	KR	0.014
RT	RKH	0.526	KR	0.013	RT	KR	0.013	TR	0.149
RKH	RKH	1	-	-	RKH	RKH	1	-	-
AK	TR	0.302	KR	0.047	AK	KR	0.047	TR	0.302
KK	TR	0.356	KR	0.549	KK	KR	0.549	TR	0.356
IR	TR	0.206	KR	0.176	IR	KR	0.176	TR	0.206
KR	KR	1	-	-	KR	KR	1	-	-
NR	TR	0.548	KR	0.293	NR	KR	0.293	TR	0.548
OR	TR	0.159	KR	0.176	OR	TR	0.159	KR	0.266
TR	TR	1	-	-	TR	TR	1	-	-
Model 2									
TEin (max IA3)					TEout (min CIA or IA2)				
RA	RA	1	-	-	RA	RA	1	-	-
RT	RT	1	-	-	RT	RT	1	-	-
RKH	RT	0.526	RA	0.595	RKH	RA	0.595	NR	0.133
AK	AK	1	-		AK	AK	1	-	-
KK	AK	0.167	RA	0.050	KK	AK	0.167	NR	0.432
IR	RA	0.080	RT	0.073	IR	AK	0.085	NR	0.183
KR	RA	0.014	RT	0.013	KR	AK	0.047	NR	0.293
NR	NR	1	-	-	NR	NR	1	-	
OR	AK	0.164	NR	0.177	OR	NR	0.177	AK	0.164
TR	RA	0.176	NR	0.548	TR	NR	0.548	-	-

If we consider the matrix of innovative complementarity in isolation from the simulation model, then a highly complementary pair of RA–RT should be distinguished (0.864), and the main industry is the "Information and Communication Technology Sector". In Model 3 "Implementation of innovations", which characterizes growth due to investment/innovation, the indices of production and technological complementarity of regions and the nearest leaders are compared, and only two pairs of complementary regions are found (KR–KK; KR–RKH). This indicates the heterogeneity of the industrial specialization of the regions of SFD, especially when considering an innovative issue. KK and RKH are leaders in Model 3 and have high intraregional indices, which indicates a high potential for the development of intraregional scientific and industrial cooperation.

In the matrix of industrial-technological complementarity, half of SFD regions have *Icomp*AB innovation output (by column) that is higher than within the region (but most of them do not exceed 50%). KR, RKH, and KK have high *Icomp*AB. Thus, it is possible to see in which regions the demand for innovation in certain industries can be found, or which activities can be the sphere of development of projects for scientific and production cooperation between regions. In terms of industrial output (line by line), KR–KK; KR–RKH could be involved in the development of cooperation.

These regions have the largest number of potential regions-partners with innovative companies operating in the same industries that are developed in these regions and can be the sphere of development of projects on science and production cooperation between the regions.

Trade-technology complementarity is presented separately from the simulation models due to a lack of data and low overall complementarity of this type. The import indicator study (by row), identifies partner regions that produce innovative products in the same activities for which other regions import technologies from abroad. Consequently, this type of index serves to assess the potential for technology import substitution through interregional collaboration. If interpreted from the innovation output side (by columns), one searches for partner regions where there is a demand for innovation (a market) in the respective activities. Therefore, the potential for interregional trade and technology relations can be assessed. According to the trade and technology complementarity matrix, a high index (0.569) is observed for KR and KK. KR can act as a producer of innovation, and KK as a consumer. OR and TR have high intraregional indices (0.837 and 0.635), which indicates the potential for in-house technological import substitution. The results indicate that the potential of SFD regions for joint innovation and industrial-technological projects is greater than in the field of trade-technological relations. For certain types of $Icomp_{AB}$, a narrow range of regions are complementary, which indirectly indicates the heterogeneity of SFD innovation space. At the same time, for most regions (RA, RT, RKH, KK, KR, NR, and TR) the feasibility of developing innovation processes on the basis of their interregional integration is confirmed.

The assessment of complementarity makes it possible to identify potential partner regions and promising sectors of innovative interaction for each region, as well as to assess the potential of inte-regional joint innovation projects, inter- and intra-regional research and production projects, and technological import substitution. Thus, the second hypothesis is fully confirmed by substantiating the degree of complementarity of the regions and highlighting the types of economic activities most promising for the development of interaction.

5. Conclusion

The study made it possible to identify the features of the economic growth of the Siberian regions and reject the hypothesis of its connection with the positive externalities from *R&D* in the border regions and the quality of human capital. The results of the study indicate the untapped potential of interregional cooperation in the field of *R&D* and ensuring economic growth through internal sources—diversification and increasing capital-intensive traditional industries. Insufficient realization of human capital and development of the tertiary sector of the economy have been revealed. This determines the need to change regional policy and take into account additional opportunities for regional growth due to complementary development within a united macro-regional space.

Technology expansion model—new combinations of resources and, as a result, new materials, goods, and markets (Schumpeter, 1934) is being implemented in TR and NR. State support measures are widely represented in the regions, the priorities of regional strategies are aimed at implementing advanced innovative development. The model of catching-up development (Kirzner, 1973) is implemented in KK, IR, KR, and OR. The technological shift model is the change of the technological base and the sectoral structure of the region's economy to a more progressive one (Hayek, 1945) is implemented in AK, RA, RKH, and RT.

The peculiarities of interregional sectoral complementarity of the regions of SFD lie in the fact that innovative complementarity is revealed exclusively in the regions within the framework of one model. This complicates the possibilities of simulation strategies at the stage of "Knowledge generation" between regions of different models. The production and technological complementarity have been revealed in the regions within the catch-up development model, as well as between the regions of the catch-up development and technological shift models. This opens up the possibilities of simulation strategies at the stage of "Commercialization of knowledge" and "Implementation of innovations".

The results of the study confirm the possibility of forming a single macro-regional economic space of SFD, taking into account simulation strategies and innovative complementarity of the regions. However, such strategies regarding TE leaders are implemented only in half of the regions of SFD (with high complementarity). In other regions, there is too different industry profile of innovative (industrial) output (low $Icomp_{AB}$), which does not allow for large scale interaction, but does not exclude local projects. The task of finding opportunities for such projects in the regions requires the development of additional analytical tools and the availability of a statistical base in narrow technological areas.

The limitation of this approach is based on the supposition that effectiveness of the regions can only be evaluated in relation to other economic units included in the sample, which is absolute efficiency and not relative ones. This shows how successful these regions are in comparison with other regions included in the sample, but not compared to theoretically achievable maximum. This restriction can be removed in further research by including all the regions of the Russian Federation that are similar in economic development and institutional characteristics of the country.

Acknowledgements

The study was carried out under a grant from the Russian Science Foundation "Global competitiveness and technological leadership of the regions: Rethinking approaches of the macroregional economic space formation", Agreement No. 22-28-01325.

References

Alimohammadlou, M., & Mohammadi, S. (2016). Evaluating the Productivity Using Malmquist Index Based on Double Frontiers Data. *Procedia – Social and Behavioral Sciences*, *230,* 58–66. https://doi.org/10.1016/j.sbspro.2016.09.008

Anokhin, S., Wincent, J., & Autio, E. (2011). Operationalizing opportunities in entrepreneurship research: use of data envelopment analysis. *Small Business Economics*, *37*, 39–57. https://doi.org/10.1007/s11187-009-9227-1

Anokhin, S., Wincent, J., & Ylinenpää, H. (2015). Technological Expansions, Catching-Up Innovations and Technological Shifts at the Regional Level: Conceptual Considerations and Empirical Illustration. *Regional Studies*, *50*(8), 1433–1448. https://doi.org/10.1080/00343404.2015.1027886

Audretsch, D. B., & Feldman, M. P. (2004). Knowledge Spillovers and the Geography of Innovation. *Handbook of Regional and Urban Economics*, *4*, 2713–2739. https://doi.org/10.1016/S1574-0080(04)80018-X

Berglund, K., & Johansson, A. W. (2007). Operationalizing opportunities in entrepreneurship research: use of data envelopment analysis. *Entrepreneurship & Regional Development*, *19*(6), 499–525. https://doi.org/10.1080/08985620701671833

Berkowitz, D., & DeJong, D. N. (2005). Entrepreneurship and Post-Socialist Growth. *Oxford Bulletin of Economics and Statistics*, *67*(1), 25–46. https://doi.org/10.1111/j.1468-0084.2005.00108.x

Carluer, F., & Sharipova, E. (2004). The unbalanced dynamics of Russian regions: Towards a real divergence process. *East-West Journal of Economics and Business*, *7*(1), 11–37. https://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=7313903F6DA04063DA9B4EB72F9AB59C?doi=10.1.1.605.6225&rep=rep1&type=pdf

Coelli, T. (1998). *A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program* (Working Paper No. 96/08). https://www.owlnet.rice.edu/~econ380/DEAP.PDF

Combes, P.-P., Lafourcade, M., Thisse, J.-F., & Toutain, J.-C. (2011). The rise and fall of spatial inequalities in France: A long-run perspective. *Exploration in Economic History*, *48*(2), 243–271. https://doi.org/10.1016/j.eeh.2010.12.004

Combes, P.-P., Mayer, T., & Thisse, J.-F. (2008). *Economic Geography: The Integration of Regions and Nations*. Princeton University Press. https://doi.org/10.2307/j.ctvcm4h9k.7

Cooke, P., & Morgan, K. (1998). *The Associational Economy: Firms, Regions, and Innovation*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198290186.001.0001

Cornett, A. (2009). Aims and strategies in regional innovation and growth policy: A Danish perspective. *Entrepreneurship & Regional Development*, *21*(4), 399–420. https://doi.org/10.1080/08985620903020078

Doloreux, D., & Dionne, S. (2008). Is regional innovation system development possible in peripheral regions? Some evidence from the case of La Pocatière, Canada. *Entrepreneurship & Regional Development*, *20*(3), 259–283. https://doi.org/10.1080/08985620701795525

EMISS. Government statistics. (n.d.-a) *Otgruženo tovarov sobstennogo proizvodstva, vipolneno rabot i uslug sobstvennimi silami s 2017 g* [Output goods of own production, performed works and services on its own since 2017]. https://www.fedstat.ru/indicator/58554

EMISS. Government statistics. (n.d.-b) *Otgruženo innovacionnih tovarov sobstvennogo proizvodstva, vipolneno rabot i uslug sobstennimi silami* (bez NDS, akcizov i drugih analogičnih platežey) s 2017 g [Output innovative goods of own production, performed works and services on its own (excluding VAT, excises and other similar payments) since 2017]. https://www.fedstat.ru/indicator/58761

Feldman, M. P., & Audretsch, D. B. (1999). Innovation in cities: Science-based diversity, specialization and localized competition. *European Economic Review*, *43*(2), 409–429. https://doi.org/10.1016/S0014-2921(98)00047-6

Hill, F., & Gaddy, C. G. (2003). *The Siberian Curse: How Communist Planners Left Russia Out in the Cold*. Brookings Institution Press.

Garofoli, G. (1994). The industrial district of Lecco: innovation and transformation processes. *Entrepreneurship & Regional Development, 6*(4), 371–393. https://doi.org/10.1080/08985629400000022

Griliches, Z. (1979). Issues in Assessing the Contribution of Research and Development to Productivity Growth. *The Bell Journal of Economics*, *10*(1), 92–116. https://doi.org/10.2307/3003321

Hayek, F. A. (1945). The Use of Knowledge in Society. *The American Economic Review*, *35*(4), 519–530. https://statisticaleconomics.files.wordpress.com/2013/03/the_use_of_knowledge_in_society_-_hayek.pdf

Heckscher, E. F., & Ohlin, B. G. (1991). *Heckscher-Ohlin Trade Theory*. The MIT Press.

Herzfeld, T. (2008). Inter-regional output distribution: a comparison of Russian and Chinese experience. *Post-Communist Economies, 20*(4), 431–447. https://doi.org/10.1080/14631370802444658

Jafari, Y. (2014). Malmquist Productivity Index for Multi Time Periods. *International Journal of Data Envelopment Analysis, 2*(1), 315–322. https://ijdea.srbiau.ac.ir/article_7070.html

Khalafyan, A. A., Borovikov, V. P., & Kalaidina, G. V. (2016). *Teoriya veroytnostei, matematičeskaya statistika i analiz dannih: Osnovi teorii i praktika na kompjutere* [Probability theory, mathematical statistics and data analysis: Fundamentals of theory and practice on the computer]. URSS.

Kirzner, I. (1973). *Competition and Entrepreneurship*. University of Chicago Press.

Kirzner, I. M. (1997). Entrepreneurial Discovery and the Competitive Market Process: An Austrian Approach. Journal of Economic Literature, 35, 60–85. https://www.jstor.org/stable/2729693

Kolenikov, S. (2003). *Prikladnoj ekonometričeskij analiz v statističeskom pakete Stata* [Applied econometric analysis in the statistical package Stata]. Russian School of Economics.

Kolomak, E. A. (2013). Neravnomernoe prostranstvennoe razvitie v Rosii: obysneniya novoj ekonomičeskoj [Uneven Spatial Development in Russia: Explanations of New Economic Geography]. *Voprosy Ekonomiki*, *2*, 132–150. https://doi.org/10.32609/0042-8736-2013-2-132-150

Krugman, P. R., Masahisa, F., & Anthony, J. V. (1999). *The Spatial Economy: Cities, Regions, and International Trade*. The MIT Press.

Leamer, E. E., & Storper, M. (2001). The Economic Geography of the Internet Age. *Journal of International Business Studies*, *32*(4), 641–665. https://www.jstor.org/stable/3069470

Lin, S., Lin, R., Sun, J., Wang, F., & Wu, W. (2021). Dynamically evaluating technological innovation efficiency of high-tech industry in China: Provincial, regional and industrial perspective. *Socio-Economic Planning Sciences*, *74*, Article 100939. https://doi.org/10.1016/j.seps.2020.100939

Losch, A. (1954). *Profit Maximisation*. Temple University.

Malmquist, S. (1953). Index numbers and indifference surfaces. *Trabajos de Estatistica*, *4*, 209–242. https://doi.org/10.1007/BF03006863

Ouyang, W., & Yang, J.-b. (2020). The network energy and environment efficiency analysis of 27 OECD countries: A multiplicative network DEA model. *Energy*, *197*(15), Article 117161. https://doi.org/10.1016/j.energy.2020.117161

Paluzie, E., Pons, J., & Tirado, D. A. (2004). The geographical concentration of industry across Spanish regions, 1856-1995. *Review of Regional Research*, *24*(2), 143–160. https://www.semanticscholar.org/paper/The-geographical-concentration-of-industry-across-Paluzie-Novell/e6430aef416fcf242fbd447a9191d6c1aed65257

Rodriguez-Pose, A. (2011). Economists as geographers and geographers as something else: on the changing conception of distance in geography and economics. *Journal of Economic Geography*, *11*(2), 347–356. https://www.jstor.org/stable/26162225

Rosés, J. R., Martínez-Galarraga, J., & Tirado, D. A. (2010). The Upswing of Regional Income Inequality in Spain (1860–1930). *Exploration of Economic History*, *47*(2), 244–257. https://doi.org/10.1016/j.eeh.2010.01.002

Sahdev, N. K. (2016). Do knowledge externalities lead to growth in economic complexity? Empirical evidence from Colombia. *Palgrave Communications*, *2*, Article 16086. https://www.nature.com/articles/palcomms201686

Samuelson, P. A., & Barnett, W. A. (Eds.). (2007). *Inside the Economist's Mind: Conversations with Eminent Economists with William A. Barnett*. Blackwell Publishing.

Schumpeter, J. A. (1934). *The Theory of Economic: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*. Harvard University.

Shane, S. (2000). Prior Knowledge and the Discovery of Entrepreneurial Opportunities. *Organization Science*, *11*(4), 448–469. https://www.jstor.org/stable/2640414

Sharma, S. C., Sylwester, K., & Margono, H. (2007). Decomposition of total factor productivity growth in U.S. States. *The Quarterly Review of Economics and Finance*, *47*82, 215–241. https://doi.org/10.1016/j.qref.2006.08.001

Smith, A. (1776). *An Inquiry into the Nature and Causes of the Wealth of Nations*. Liberty Fund.

TIBCO Software Inc. (2020). *Data Science Textbook*. https://docs.tibco.com/data-science/textbook

Tolbert, P. S., & Zucker, L. G. (1996). The Institutionalization of Institutional Theory. In S. R. Clegg, C. Hardy, & W. R. Nord (Eds.), *Handbook of organization studies* (pp. 175–190). SAGE Publications Ltd.

Troutt, M. D., Ehie, I. C., & Brandyberry, A. A. (2007). Maximally productive input-output units. *European Journal of Operational Research*, *178*(2), 359–373. https://doi.org/10.1016/j.ejor.2006.03.017

Vandenberg, R. J., & Lance, C. E. (2000). A Review and Synthesis of the Measurement Invariance Literature: Suggestions, Practices, and Recommendations for Organizational Research. *Organizational Research Methods*, *3*(1), 4–70. https://doi.org/10.1177/109442810031002

Vuković, D., Jovanović, A., & Đukić, M. (2012). Defining competitiveness through the theories of new economic geography and regional economy. *Journal of Geographical Institute "Jovan Cvijić" SASA*, *62*(3), 49–64. https://doi.org/10.2298/IJGI1203049V

Vuković, D., & Wei, L. (2010). Regional competitiveness: the case of Western China. *Journal of Geographical Institute "Jovan Cvić" SASA*, *60*(1), 107–124. https://doi.org/10.2298/IJGI1001107V

Weber, A. (1929). *Theory of the Location of Industries*. University of Chicago Press.