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Integral Index of Structural Complexity of Regional Economies*

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ABSTRACT

Current scientific discussions are focused on identifying professions and types of economic activity that will become most in demand in the future and determine priority areas for diversification of regional economies. Analysis of such trends is important for forecasting the dynamics of GRP. The purpose of this work is to construct an integral index of structural complexity on the basis of four basic indices of economic complexity of regional economies, calculated by the authors on the basis of data on the structure of employment, the structure of the distribution of enterprises and the structure of GRP. Two integral indices of structural complexity of regional economies have been constructed. Their advantages and disadvantages are analyzed. It is shown that the structural complexity of the regional economy has an impact on GRP. Moreover, one of the integral indices is significant in the production function of the GRP of 85 regions according to the data of 2019 and 2022

INTRODUCTION

The development of regional economies and the strengthening of the economic security of the regions presuppose an increase in the complexity of production structures and economic systems. Recommendations for the diversification of national and regional economies can be based on approaches focused on increasing economic complexity (Hausmann and Hwang; Rodrik, 2006; Hausmann and Klinger, 2006; Hidalgo and Hausmann, 2009; Hartmann, 2017; Sciarra et al., 2020). At present, the possibilities of assessing the economic complexity of regional economies have been studied based on data on the volume of exports and production volumes, on the number of people employed in various sectors of the economy (Lyubimov et al. 2017; Afanasiev and Kudrov, 2021; Afanasiev, 2023; Afanasiev et al., 2023; Afanasiev and Gusev, 2022; 2023; 2024). For example, in (Afanasiev and Ilyin, 2022) propose an approach to the selection of diversification areas based on recommendations for the development of sectors, aimed at increasing the economic complexity of the regional economy. structural complexity index. The construction of such an index and the analysis of the possibilities of its use is the purpose of this work. To construct an

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integral index, the authors formed various structures of the regional economy: the structure of GRP according to data on production volumes by types of economic activities (TEA); the structure of employment of regions by professional groups; the structure of employment of regions by TEA; the structure of the distribution of enterprises by TEA. Based on the concept of economic complexity, the complexity of each structure is estimated and a corresponding basic index of economic complexity is constructed. The four basic indices are the basis for constructing an integral index of structural complexity. In this paper, two integral indices are proposed, built on a common information basis.

Four basic indices that form the information basis for the construction of integral indices are presented in the authors' previously published works. The approach to assessing the complexity of regional employment structures is described in the paper (Afanasiev et al., 2023). To construct the *ZPRF index* – the complexity of regional employment structures by trade union groups, Rosstat data on the number of employees of organizations on the payroll for 11 professional groups in the constituent entities of the Russian Federation for the period from 2019 to 2022 were used: «On the number and need of organizations for employees by professional groups»¹.

To construct the *ZV index* of the complexity of regional employment structures for 14 TEAs, Rosstat data «distribution of the average annual number of employed by type of economic activity (as a percentage of the total number of employees)²» for the period from 2019 to 2022 were used.

The scheme for calculating and analyzing the *VRPV index* of the complexity of GRP structures based on TEA production data are described in the paper (Gusev, 2024). To assess the economic complexity of 85 regions, the indicators of the GRP structure in 2016 prices for 19 TEA for the period from 2019 to 2022 from the UISS were used: «Gross regional product (in constant 2016 prices; thousand rubles)³».

The *PRV index* of complexity of enterprise distribution structures in the regions by TEA was calculated in accordance with the methodology for assessing economic complexity based on the Rosstat indicator «distribution of the number of enterprises and organizations by type of economic activity (at the end of the year)⁴» for 19 TEA for the period from 2019 to 2022.

On the basis of basic indices of economic complexity, integral indices of structural complexity of regional economies are constructed and their comparative analysis is carried out. Production functions are constructed, including an integral index of structural complexity. It is shown that the structural complexity of the regional economy has an impact on the GRP of the region. Estimates of GRP elasticity based on the integral index of structural complexity are obtained.

1. INTEGRAL INDICES OF THE STRUCTURAL COMPLEXITY OF THE ECONOMY.

1.1 Preliminary stages of calculating integral indices

Various approaches can be used to construct integral indices of the complexity of the structures of regional economies using basic indices. Next, two approaches will be considered and a comparative analysis of the integral indices obtained on their basis will be carried out. Each approach involves the next two preliminary stages of calculations.

Stage 1. Calculation of basic complexity indices. The following four basic complexity indices are used in this study:

VRPV – the index of complexity of GRP structures based on data on production volumes by TEA;

ZPRF – index of complexity of employment structures of regions by trade union groups;

ZV – index of complexity of employment structures of regions by TEA;

¹ On the Number and Needs of Organizations in Workers by Professional Groups / Rosstat. Moscow, 2022 (in Russian).

² EMISS: Average annual number of people employed in the economy (calculations based on data integration) since 2017 URL: <https://www.fedstat.ru/indicator/58994> (accessed 15.03.2024)

³ EMISS: Gross Regional Product in Basic Prices (OCTEA 2). URL: <https://www.fedstat.ru/indicator/61497> (accessed 20.03.2024)

⁴ Regions of Russia. Socio-economic indicators. 2022: Stat. Coll. / Rosstat. Moscow, 2022 (in Russian)

PRV – an index of the complexity of the distribution structures of enterprises in the regions by TEA.

The set of basic indices calculated at this stage can be expanded.

Stage 2. Normalization of the base indices calculated in step 1.

Let *IND* – one of the basic complexity indices calculated in stage 1 with components (*IND*₁, ..., *IND*_{*k*}, ..., *IND*_{*N*}). In here *N* – number of regions, *k* - region number, *IND*_{*k*} – index component corresponding to the region *k*. Let *maxIND* – maximum index component value, *minIND* – minimum value of index components. Components *nIND*_{*k*} normalized index *nIND* are calculated according to the formula:

$$nIND_k = \frac{IND_k - minIND}{maxIND - minIND}.$$

Components of each normalized base complexity index *nVRPV*, *nZPRF*, *nZV*, *nPRV* take values in the range [0; 1].

1.2 Approaches to the construction of integral indices and results based on 2022 data

Integral index INT1.

Integral index *INT1* It is calculated using the principal component method using basic indices. The eigenvalues of the correlation matrix of the basic indices are 2.23; 1.04; 0.38; 0.36. The first main component explains 55.68% of the total variance of the four underlying indices. This is enough to consider the first main component as an integral index (Ayvazyan, 2012, p. 98). Index *INT1* can be represented as a linear function of normalized basic indices (1) with the coefficient values given in Table 1.

$$INT1 = a * nVRPV + b * nZPRF + c * nZV + d * nPRV + const \quad (1)$$

Table 1 also presents the coefficients of function (1) for the normalized (with component values in the interval [0; 1]) integral index *nINT1*. Index correlation coefficients *nINT1* and *INT1* with the basic indices are shown in Table 2. Note that the index normalization we use is a linear transformation. Therefore, the value of the correlation coefficient of the integral index and the basic index does not depend on whether these indices are normalized or not.

Table 1. Weighting coefficients of integral indices.

	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>const</i>
<i>INT1</i>	2.7651	2.4972	2.2116	3.2487	-4.0314
<i>nINT1</i>	0.3228	0.2914	0.2581	0.3792	-0.2330
<i>nINT2</i>	0.2497***	0.2766***	0.2910***	0.3959***	-0.1961***

***The significance of the assessment at the 1% level

Source: own

Table 2. Correlation coefficients of integral and basic indices.

	<i>nVRPV</i>	<i>nZPRF</i>	<i>nZV</i>	<i>nPRV</i>
<i>nINT1</i>	0.6138	0.8317	0.7071	0.8116
<i>nINT2</i>	0.5524	0.8060	0.7486	0.8318

Source: own

Integral index *INT2*.

The idea of constructing the index is presented in the monograph (Ayvazyan, 2012, p. 103) and is based on measuring the distance from a point with coordinates $(nVRPV_k, nZPRF_k, nZV_k, nPRV_k)$, corresponding to each region k in the space of normalized basic indices, to the point – the "standard" with the coordinates (1; 1; 1; 1).

This distance is equal to:

$$D_k = ((1 - nVRPV_k)^2 + (1 - nZPRF_k)^2 + (1 - nZV_k)^2 + (1 - nPRV_k)^2)^{1/2}$$

Normalize the distances calculated for all regions using the formula:

$$nD_k = \frac{D_k - \min D_k}{\max D_k - \min D_k}$$

Calculating the value of the index component *INT2* according to the formula: $INT2_k = 1 - nD_k$. The smaller the distance from the point $(nVRPV_k, nZPRF_k, nZV_k, nPRV_k)$, characterizing the region k in the space of the underlying indices, before the benchmark, the higher the value of the index component *INT2*. At the same time, the components of the index *INT2* take values in the interval [0; 1]. That is, the index is already normalized and $INT2 = nINT2$.

The Pearson correlation coefficient of the *nINT1* and *nINT2* indices is above 0.9940. Spearman's rank correlation coefficient is 0.9871. The *nINT1* integral index constructed by the principal component method is the best way to differentiate regions by complexity estimates, explaining the maximum fraction of the aggregate variance of the underlying indices. The integral index *nINT2*, constructed as a result of calculating the "distances to the standard", differs little from the *nINT1* index. The *nINT2* index does not require special software for calculation and has a simple interpretation – proximity to the standard in the space of normalized basic indices.

Based on the approaches presented above, integral indices based on 2019 data were also calculated.

1.3 Integral indices for 2019

Integral index *nINT1*.

Integral index *nINT1* calculated using the principal component method. The eigenvalues of the correlation matrix are 2.322; 0.813; 0.554; 0.308. The first main component explains 58.07 % of the total variance of the underlying indices. Weights for index calculation *nINT1* according to formula (1) are given in Table 3. Correlation coefficients with basic indices are shown in Table 4.

Table 3. Weights of integral indices according to 2019 data

	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>const</i>
<i>nINT1</i>	0.4097	0.2278	0.2453	0.3211	-0.1331
<i>nINT2</i>	0.3006***	0.2616***	0.2499***	0.3811***	-0.1103***

***The significance of the assessment at the 1% level

Source: own

Table 4. Correlation coefficients of integral and basic indices for 2019

	<i>nVRPV</i>	<i>nZPRF</i>	<i>nZV</i>	<i>nPRV</i>
<i>nINT1</i>	0.8679	0.7067	0.714	0.7334
<i>nINT2</i>	0.8252	0.7121	0.7052	0.763

Source: own

Integral index $nINT2$.

Correlation coefficients of the integral index $nINT2$ and basic indices are shown in Table 4. The last line of Table 3 shows estimates of the linear regression coefficients of the index $nINT2$ on normalized base indices. All scores are significant at the 1% level. Coefficient of determination $R^2 = 0.9908$.

As shown in Table 5, the largest change over a period of 3 years is observed in the employment structure by TEA. Perhaps it is this structure that has been most affected by the impact of the COVID-19 pandemic. At the same time, the structure of professional employment remains highly stable. The structure of the distribution of enterprises by TEA is the most stable, which indirectly indicates the correctness of the estimates obtained. All integral indices are stable over time. The correlation coefficients of integral indices for 2019 and 2022 exceed 0.9. Their stability is higher than most underlying indices.

Table 5. Correlation coefficients of the basic and integral indices of 2019 and 2022

$nVRPV$	$nZPRF$	nZV	$nPRV$	$nINT1$	$nINT2$
0.8397	0.8856	0.6172	0.9570	0.9472	0.9375

Source: own

2. ASSESSMENT OF THE IMPACT OF STRUCTURAL COMPLEXITY ON GRP

A number of foreign publications show that the complexity of the economy has an impact on GDP, the level of income of the population and the socio-economic development of national economies. In this section, we will assess the impact of the structural complexity of the economy on the GRP of Russian regions. At the same time, we proceed from the fact that structural complexity is not only a factor of GRP, but also has a direct impact on it.

Let us consider one-factor regressions (2) of the GRP logarithm for each normalized integral index of structural complexity according to 2022 data:

$$\ln(VRP_k) = s * nINT_k + const + eps_k \quad (2)$$

In here VRP_k – GRP region k for 2022 year in continuous evaluations 2016 year; $nINT_k$ – value of the components of the normalized integral index of structural complexity for the region k (at $k = 1, \dots, n$); $const$ – constant; eps_k – regression error.

The parameter score for each integral index is significant at the 1% level. But to use these estimates to predict the impact of changes in the value of the integral index on GRP with the explanatory ability R^2 at 0.1275 - 0.1658 is not appropriate. Let us include the integral index in the power production function

$$\ln(VRP_k) = \alpha * \ln(L_k) + \beta * \ln(K_k) + s * nINT_k + const + eps_k, \quad (3)$$

where is L_k – number of employees, K_k – cost of fixed assets in the region k . Coefficient of Determination R^2 regression (3) with each integral indices exceeds 0.959. However, the estimates of the coefficients for integral indices for the population of 85 regions are insignificant.

Most regions have an exponential relationship (2). At the same time, as shown in Fig.1, for some regions with small values of the integral index $nINT2$ this dependence is disrupted due to the discrepancy between the relatively high volume of GRP and the relatively low value of the integral index. For these regions, it is possible to indicate the factors that affect GRP and structural complexity in different directions. For example, natural rent⁵. A number of studies provide estimates of the natural rent of some regions specializing in the field of oil and natural gas production. For example, estimates of the share of natural resource rent in GRP obtained in (Ayvazyan et al., 2018; Afanasiev, Kudrov, 2020) exceed 20% of GRP, and for some regions they reach 40%. This is the reason for the disproportion between the integral estimates of the structural complexity of economies and GRP. The regions specializing in oil and natural gas production (Afanasiev and Gusev, 2024) and making the largest contribution to the total GRP of Russian

⁵ In accordance with the generally accepted approach, the additional GRP received in excess of the inputs of production factors is considered as natural rent.

regions include: the Khanty-Mansi Autonomous Area, the Yamalo-Nenets Autonomous Area, the Nenets Autonomous Area, the Krasnoyarsk Territory, the Republic of Tatarstan, the Republic of Sakha (Yakutia), the Orenburg Region, and the Irkutsk Region.

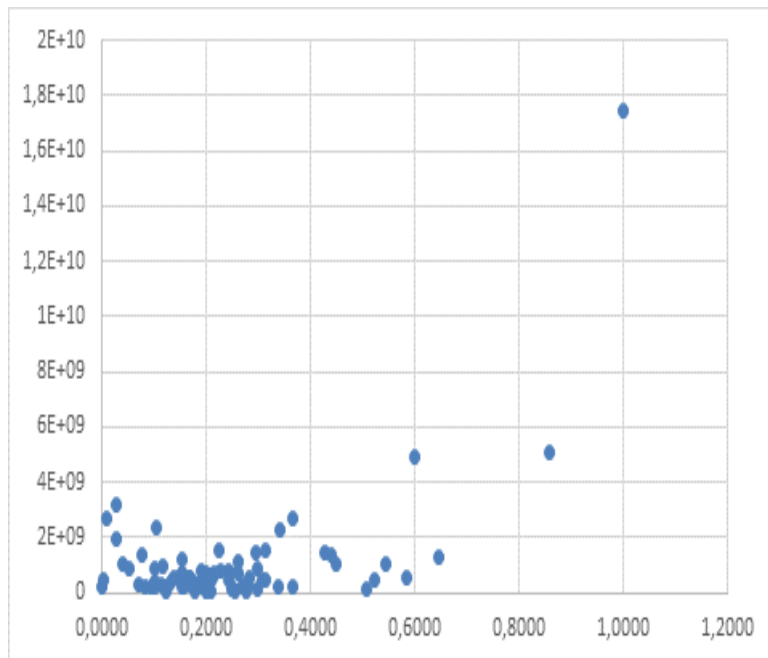


Figure 1. Dependence of GRP (y-axis) on the index $nINT2$ (x-axis)
Source: own

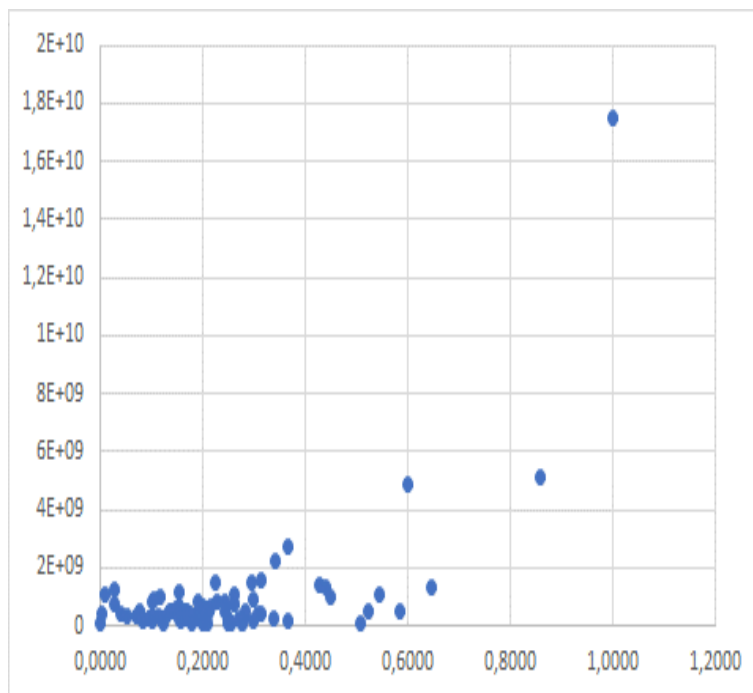


Figure 2. Dependence of GRP with excluded natural rent (y-axis) on the index $nINT2$ (x-axis)
Source: own

Due to the specialization of the economies and geographical features, these eight regions have relatively high GRP with relatively low integral estimates of structural complexity. Excluding eight regions from

consideration leads to an increase in the elasticity of the GRP for labor and a decrease in the elasticity of GRP for capital in the production function estimated without taking into account the integral index. This corresponds to the results of the assessment of elasticity coefficients in the work (Ayvazyan et al., 2016; Afanasiev, Kudrov, 2020) for extractive and evenly developed regions. Estimates of coefficients for integral indices $nINT1$ and $nINT2$ (columns (2), (3) of Table 6) in the production function (3) are significant at the 5% level.

Elasticity of the GRP of the region k on the integral index at the value of INT_k equals $sINT_k$. In our case, each index is normalized and takes values in the interval $[0; 1]$. Thus, the elasticity of the GRP of Russian regions according to the integral index of structural complexity takes values in the interval $[0; s]$. When the value of the integral index is changed to $x\%$, the change in the GRP of a region that does not specialize in oil and natural gas production is estimated at $sINT_k x\%$. It should be emphasized that the GRP growth estimated here is relative, that is, additional to the GRP growth due to the influence of other factors (time, scientific and technological progress, etc.). For a region specializing in neti and gas production, the growth of the structural complexity of the economy may be caused by the emergence of new strong TEAs due to the development of the extractive sector. In this case, the share of natural resource rent in GRP may be preserved, and the elasticity of GRP in terms of the integral index of structural complexity will be the same as that of a non-extractive region. However, for the eight regions specializing in oil and natural gas production, the increase in the structural complexity of the economy is not necessarily accompanied by an increase in the volume of production that generates natural rents. It may be a consequence of the emergence of new strong TEAs in the region that are not related to mining and do not bring natural rent. In this case, the assessment of the elasticity of GRP on the integral index will be $\exp(-r_k)snINT_k$, where is

$$r_k = \ln(VRP_k) - (\alpha \ln(L_k) + \beta \ln(K_k) + snINT_k + const)$$

– valuation of natural resource rent, $\exp(-r_k)$ – share of the region's GRP excluding natural resource rent, and $1 - \exp(-r_k)$ – Share of natural resource rent in GRP. Therefore, for the region, receiving natural rent from oil and natural gas production, the value of $snINT_k$ should be considered as a top-down estimate of the elasticity of GRP in terms of structural complexity. And the value $\exp(-r_k)snINT_k$ – as a bottom-up score. However, the assessment of natural rent in the form of r_k takes into account the impact on GRP of many factors that do not reflect the specialization of regional economies. At the same time, the main circumstance uniting these regions in our case is their specialization in oil and natural gas production. In this study, we do not consider the task of estimating the natural rent of each region. affects the elasticity of GRP by the value of the integral index. And, also to substantiate on this basis the choice of the parameter s for the purposes of forecasting and a priori assessment of the impact of the complexity of employment structures on GRP. Therefore, we will consider an alternative approach to assessing the impact of the complexity of employment structures on GRP, which takes into account the presence of natural rent, which is the general result of the specialization of a group of regions. Let's consider the modification of the production function (3):

$$\ln(VRP_k) = \alpha * \ln(L_k) + \beta * \ln(K_k) + s * nINT_k + r * d_k + const + eps_k, \quad (4)$$

in which d_k - boolean variable that takes values of 1 for a group of regions with general specialization, based on the aggregate of which natural rent is estimated. r - assessment of natural rent. A similar approach to the assessment of natural rent of extractive regions was used in (Ayvazyan et al., 2018; Afanasiev, Kudrov, 2020). Having evaluated the parameters of this function, we can estimate the elasticity of GRP by the value of the index $nINT$ structural complexity for the entire set of regions under consideration. At the same time, the share of GRP of each of the eight regions, excluding natural rent, is $\exp(-r)$, and the share of natural resource rent in GRP is $1 - \exp(-r)$.

The assessment of the parameter s with the integral index $nINT2$ is significant at the 5% level and is equal to 0.298 (see column (5) of Table 6). The assessment of the parameter s with the integral index $nINT1$ is significant at the 10% level (column (4) of Table 6). With this value, the score $1 - \exp(-r)$ natural resource rent for eight regions is equal to 0.258 and does not exceed the share of natural rent of the extractive regions estimated in the works (Ayvazyan et al., 2018; Afanasiev, Kudrov, 2020). Estimated

share $\exp(-r)$ GRP after excluding natural rent is 0.742. Dependence of the GRP of 85 regions with excluded natural rent of eight regions on the index $nINT2$ shown in Fig. 2.

Let us now consider the power production function (5) with time-dependent parameters to estimate the cumulative effect of integral indices of structural complexity constructed from data for 2019 and 2022 on GRP.

$$\ln(VRP_{kt}) = (\alpha + \alpha_1 * t) * \ln(L_{kt}) + (\beta + \beta_1 * t) * \ln(K_{kt}) + (s + s_1 * t) * nINT_{kt} + (r + r_1 * t) * d_k + c * t + const + eps_{kt} \quad (5)$$

For 2019 $t = 0$, for 2022 year $t = 3$. Estimates of the parameters of function (5) are presented in columns (6) and (7) in Table 6. Parameter estimates $\alpha_1, \beta_1, s_1, r_1$ are insignificant for each integral index and are not given in Table 6.

Table 6. Assessment of the parameters of production functions

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Parameters	$nINT1$	$nINT2$	$nINT1$	$nINT2$	$nINT1$	$nINT2$
α	0.319***	0.325***	0.208***	0.210***	0.211***	0.212***
t-stats	(5.28)	(5.44)	(4.73)	(4.82)	(6.27)	(6.32)
p-value	0.000	0.000	0.000	0.000	0.000	0.000
β	0.651***	0.641***	0.759***	0.753***	0.762***	0.759***
t-stats	(12.45)	(12.24)	(19.01)	(18.78)	(25.32)	(25.18)
p-value	0.000	0.000	0.000	0.000	0.000	0.000
s	0.378**	0.416**	0.252*	0.298**	0.216*	0.249**
t-stats	(2.28)	(2.53)	(1.70)	(2.02)	(1.82)	(2.12)
p-value	0.025	0.014	0.094	0.047	0.070	0.036
r			0.279***	0.284***	0.269***	0.273***
t-stats			(3.21)	(3.32)	(4.10)	(4.22)
p-value			0.002	0.001	0.000	0.000
c					-0.035***	-0.034***
t-stats					(-3.27)	(-3.21)
p-value					0.001	0.002
const	6.080***	6.138***	6.080***	6.057***	6.041***	6.057***
t-stats	(16.19)	(16.30)	(16.19)	(18.83)	(25.14)	(18.83)
p-value	0.000	0.000	0.000	0.000	0.000	0.000
N	77	77	85	85	170	170
R ²	0.9613	0.9618	0.9699	0.9702	0.9650	0.9652

***Significance of the assessment at the 1% level

**Significance of the assessment at the 5% level

* Significance of the assessment at the 10% level

Source: own

Index $nINT2$ shows the best statistical characteristics when evaluating the production function (5) according to the data of 2019 and 2022, as well as when evaluating the production function (4) according to the data of 2022. Therefore, we will consider it as the main integral index of the structural complexity of regional economies. At the 5% level, the assessment of the parameter is significant only with the integral index $nINT2$. It is equal to 0.249 and slightly lower than the one obtained when assessing the production function (4). However, the estimate of 0.249 is based on the use of two years of data and appears to be more reliable. We will consider it when estimating the elasticity of GRP by the integral index $nINT2$. Namely, as an assessment of the elasticity of the impact of structural complexity on the GRP of a region that does not specialize in oil and natural gas production, we will consider the value of 0.249 $nINT2$. For example, for the Vologda Oblast with a value in 2022 $nINT2 = 0.279$ a relative increase in the integral assessment of complexity by 10% to a value of 0.3 leads to an estimate of the relative growth of GRP by about 0.7%. And for the Moscow region, with the value of $nINT2 = 0.598$ a relative increase in the integral estimate of complexity by 10% to 0.648 leads to a relative increase in GRP by about 1.5%.

Value $1 - \exp(-r)$ of the share of natural resource rent for eight regions is 0.238. Estimated share $\exp(-r) \exp(-r)$ GRP after excluding natural rent remains 0.761. For regions that receive natural rent

from neti and natural gas production, we will use the elasticity estimate from above $0.249 * nINT2$ and estimation of elasticity from below $0.761 * 0.249 * nINT2$. For example, for the Orenburg region, when the value $nINT2 = 0.065$ a relative increase in the integral estimate of complexity by 70% to the value of 0.111 leads to an estimate of the relative growth of GRP in the range [0.8%; 1.1%].

CONCLUSION

According to Rosstat data for 2019 and 2022, four basic complexity indices were formed for 85 regions: the index of complexity of GRP structures based on data on production volumes by TEA; the index of complexity of regional employment structures by occupational groups; the index of complexity of regional employment structures by TEA; the index of complexity of enterprise distribution structures in the regions by TEA. The leading positions in the four corresponding ratings are occupied by Moscow, St. Petersburg, the Novosibirsk Region, and the Moscow Region.

On the basis of basic indices of economic complexity, integral indices of structural complexity of regional economies are constructed and their comparative analysis is carried out. Despite the different methods of construction, integral indices are statistically strongly interrelated. At the same time, in specific problems of forecasting and mathematical modeling, their features are manifested. Therefore, noting the significant advantages of the integral index, which assesses the distance from the point characterizing the region in the space of basic indices to the standard, the authors consider it premature to exclude alternative index, as it allows for its potential usefulness.

An approach to assessing the impact of the structural complexity of regional economies on GRP is proposed. Production functions are constructed, including an integral index of structural complexity. It is shown that the structural complexity of the regional economy has an impact on the GRP of the region. Estimates of GRP elasticity based on the integral index of structural complexity are obtained.

The integral index of structural complexity of regional economies makes it possible to comprehensively assess the economic potential of territories, identify the most promising industries and industries, as well as identify areas of diversification that fit into the existing regional specialization. This creates the basis for the formation of sound spatial development strategies aimed at increasing the economic complexity and sustainability of regional economies.

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