DOI: 10.63550/ICEIP.2025.92.79.006

Structural Complexity of Regional Economies and Its Impact on GRP

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Key words: regional economy, econometrics, economic complexity, integral index

Abstract: Four integral indices of structural complexity of regional economies are constructed. It is shown that structural the complexity of the regional economy affects the GRP. The estimates of the elasticity of the GRP are obtained using the integral index of structural complexity. The integral index of structural complexity of regional economies allows for a comprehensive assessment of the economic potential of territories, identifying the most promising industries, and identifying areas of diversification that contribute to strengthening the economic security of regions in the context of sanctions pressure. This creates the basis for the formation of sound spatial development strategies aimed at increasing economic complexity and sustainability regional economists .

1 INTRODUCTION

Recommendations for diversification of national and regional economies can be based on approaches aimed at increasing economic complexity (Afanasyev, Kudrov , 2021; Hidalgo , Hausmann , 2009). Currently, the possibilities of assessing the economic complexity of regional economies based on data on export volumes and production volumes, and the number of people employed in various sectors of the economy have been studied (Afanasyev, Gusev, 2023; Afanasyev et al., 2023). Economic complexity indices are used to justify priority areas of diversification. For example, in the work (Afanasyev, Ilyin, 2022), an approach is proposed to choosing diversification areas based on recommendations for sector development, aimed at increasing the economic complexity of the regional economy. The accumulated experience in constructing economic complexity indices makes it possible to approach the problem of a generalized assessment of the complexity of regional economies using an integral index of structural complexity. The construction of such an index and analysis of the possibilities of its use is the goal of this work. To construct the integral index, various structures of the regional economy were formed: the GRP structure based on data on production volumes by types of economic activity; the employment structure of regions by professional groups; the employment structure of regions by types of economic activity; the distribution structure of enterprises by types of economic activity. The basic indices that form the information basis for constructing the integral indices are presented in previously published works. The approach to assessing the complexity of the professional employment structures of regions is described in the work (Afanasyev et al., 2023). To construct the ***ZPRF index - the complexity of the employment structures of regions by professional groups,*** Rosstat data on the list of employees of organizations by 11 professional groups in the constituent entities of the Russian Federation for 2022 were used: "On the number and need of organizations for employees by professional groups". The normalized *ZPRF index* with values in the interval [0; 1] based on data for 2022 is given in column (4) of Table P1 of the Appendix. To construct the ***ZV index of the complexity of the employment structures of regions by 14 types of economic activities*** The Rosstat data “distribution of the average annual number of people employed by type of economic activity” for 2022 were used. The normalized *ZV index* with values in the interval [0; 1] based on the data for 2022 is given in column (5) of Table P1 of the Appendix. The calculation scheme and analysis of the ***VRPV index of the complexity of GRP structures*** based on data on production volumes by types of economic activity are

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described in the work (Gusev, 2024). To assess the economic complexity of 85 regions, the GRP structure indicators in 2016 prices for 19 types of economic activities for 2022 from the Unified International Maritime Statistical Information System (UISIS) were used: “Gross Regional Product (at constant 2016 prices; thousand rubles)”. The normalized *VRPV index* with values in the interval [0; 1] based on the data for 2022 is given in column (3) of Table P1 of the Appendix. Based on the Rosstat indicator "distribution of the number of enterprises and organizations by types of economic activity (at the end of the year)" for 19 types of economic activities for 2022, in accordance with the methodology for assessing economic complexity, the ***PRV index of the complexity of enterprise distribution structures in regions by types of economic activity*** was calculated . The normalized *PRV index* with values in the interval [0; 1] based on data for 2022 is given in column (6) of Table P1 of the appendix.

2 METHODOLOGY: INTEGRAL INDICES OF STRUCTURAL COMPLEXITY OF THE ECONOMY

2.1 Preliminary Stages of Calculating Integral Indices

Below we will consider four approaches to constructing integral indices of the complexity of regional economic structures using basic indices. Each of the four approaches involves performing the following two preliminary stages of calculations.

Stage 1. Calculation of basic complexity indices. The following basic complexity indices are used in this study: $VRPV$– complexity index of GRP structures based on data on production volumes by types of economic activity;$ZPRF$ – index of complexity of regional employment structures by occupational groups; ZV– index of complexity of regional employment structures by types of economic activity; PRV– index of complexity of enterprise distribution structures in regions by types of economic activity.

Stage 2. Normalization of the basic indices calculated in stage 1.

LetIND – one of the basic complexity indices calculated at stage 1 with components (IND_1, …, IND_k, …, IND_N). Here *N* is the number of regions, *k* is the region number,IND_k – the index component corresponding to region k . Let$\max IND$ – the maximum value of the index components,$\min IND$ – the minimum value of the index components. Components $nIND_k$ standardized index $nIND$ are being calculated By formula :

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

The normalized base indices constructed based on 2022 data are presented in columns (3)–(6) of Table P1 of the Appendix.

Integral index $INT1$.

The integral index $INT1$is calculated using the principal component method with the use of basic indices. The eigenvalues of the correlation matrix of the basic indices are 2.23; 1.04; 0.38; 0.36. The first principal component explains 55.68% of the total variance of the four basic indices. This is sufficient to consider the first principal component as an integral index (Ayvazyan, 2012, p. 98). The index $INT1$can be presented as a linear function of the 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 presents the coefficients of function (1) for the normalized (with component values in the interval [0; 1]) integral index $nINT1$. The correlation coefficients of the indices $nINT1$and $INT1$with the base indices are given in Table 2.

Table 1: Weighting coefficients of integral indices.

	a	*B*	*c*	*d*	*const*
INT1	2,7651	2,4972	2,2116	3,2487	-4,0314
nINT1	0.3228	0.2914	0.2581	0.3792	-0.2330
INT2	0.25	0.25	0.25	0.25	-
nINT2	0.3137	0.3137	0.3137	0.3137	-0.2348
INT3	0.4729	0,0609	0.2887	0.1775	
nINT3	0.5733	0.0738	0,3500	0.2152	-0.2077
nINT4	0.2497***	0.2766***	0.2910***	0.3959***	-0.1961***

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

Integral index $INT2$.

The integral index $INT2$is calculated using formula (1) with equal weight coefficients for the normalized base indices $a = b = c = d = 0{,}25$and $const = 0$. Such an integral index can be called an index of "equal investments" of the base indices. The correlation coefficients of the indices $nINT2$and $INT2$with the base indices are shown in Table 2.

Table 2: Correlation coefficients of integral and basic indices.

	$nVRPV$	$nZPRF$	nZV	$nPRV$
nINT1	0.6138	0.8317	0.7071	0.8116
nINT2	0.6018	0.8359	0.7345	0.7876
nINT3	0.7237	0.7237	0.7237	0.7237
nINT4	0.5524	0.8060	0.7486	0.8318

Integral index $INT3$.

When calculating the integral index $INT3$ using formula (1), $const = 0$the weight coefficients are selected in such a way that the correlation coefficients of the integral index $INT3$with the base indices are equal. The values of the weight coefficients are given in Table 1. Such an integral index can be called an index of "equal influences" of the base indices. Table 1 shows the coefficients of function (1) for the index $nINT3$. Table 2 shows the correlation coefficients of the indices $nINT3$and with $INT3$the base indices.

Integral index $INT4$.

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

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

We normalize the distances calculated for all regions using the formula:

$$nD_k = \frac{D_k - minD_k}{maxD_k - minD_k}$$

The normalized integral index $nINT4$with component values in the interval [0; 1] is given in column (7) of Table P1 of the Appendix. The index $nINT4$cannot be presented as a linear dependence (1) on the normalized base indices. The last row of Table 1 presents estimates of the coefficients of linear regression of the index $nINT4$on the normalized base indices. All estimates are significant at the 1% level. The determination coefficient is $R^2 = 0{,}994$. The correlation coefficients with the base indices are given in Table 2.

2.2 Methodology: Assessing the Impact of Structural Complexity on GRP.

A number of types of publications (Hartmann, 2017; Hidalgo, 2021) show that the complexity of the economy affects GDP, the level of inequality in income distribution, and the socio-economic development of national economies. This section assesses the impact of the structural complexity of the economy on the GRP of Russian regions. We will include the integral index in the power production function

$$\ln(VRP_k) = \alpha * \ln(L_k) + \beta * \ln(K_k) + s * nINT_k + const + eps_k, \quad (2)$$

where $L_k$is the number of employed, $K_k$is the value of fixed assets in region k. The coefficient of determination of R^2regression (4) with each of the four integral indices exceeds 0.959. However, the estimates of the coefficients for the integral indices for the set of 85 regions are insignificant.

Most regions are characterized by an exponential dependence of GRP on the values of integral indices, confirmed by the estimates in Table 3. At the same time, for some regions with low values of the integral index $nINT$, this dependence is violated 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 factors that affect GRP and structural complexity in different directions. For example, natural rent. A number of studies provide estimates of natural rent for some regions specializing in oil and natural gas production. For example, estimates of the share of natural rent in GRP obtained in (Ayvazyan et al. , 2018) exceed 20% of GRP, and for some regions 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 (Afanasyev, Gusev, 2023) and making the largest contribution to the total GRP of Russian regions include: Khanty-Mansi Autonomous Okrug, Yamalo-Nenets Autonomous Okrug, Nenets Autonomous Okrug, Krasnoyarsk Krai, the Republic of Tatarstan,

DOI: 10.63550/ICEIP.2025.92.79.006

the Republic of Sakha (Yakutia), Orenburg Oblast, and Irkutsk Oblast.

When the integral index value changes by x%, the change in the GRP of a region not specializing in oil and natural gas production is estimated at $sINT_k x$%. It should be emphasized that the GRP growth estimated here is relative, i.e. additional to the GRP growth due to the impact of other factors. In a region specializing in oil and gas production, the growth of the structural complexity of the economy may be caused by the emergence of new strong types of economic activities due to the development of the extractive sector. In this case, the share of natural rent in the GRP may be maintained and the elasticity of the GRP by the integral index of structural complexity will be the same as in a region not engaged in extraction. 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 extraction generating natural rent. It may be a consequence of the emergence of new strong types of economic activities in the region that are not related to extraction and do not generate natural rent. In this case, the estimate of the elasticity of GRP by the integral index will be $\exp(-r_k)snINT_k$, where

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

– assessment of natural rent, $\exp(-r_k)$ – the share of the region's GRP excluding natural rent, and $1 - \exp(-r_k)$ – the share of natural rent in GRP. Therefore, for a region receiving natural rent from oil and gas production, the value $snINT_k$should be considered as an upper estimate of the GRP elasticity by structural complexity. And the value $\exp(-r_k)snINT_k$– as a lower estimate. In this study, we do not consider the problem of assessing the natural rent of each region. Our task is to establish how accounting for natural rent, reflecting the general specialization of a group of regions, affects the elasticity of GRP by the value of the integral index. Therefore, below 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 a general result of the specialization of a group of regions.

Let us consider a modification of the production function (2):

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

in which $d_k$is a Boolean variable that takes the value 1 for a group of regions with a common specialization, for the totality of which natural rent is estimated. r– estimation of natural rent. A similar approach to estimating natural rent of extractive regions is used in (Ayvazyan et al., 2018). Having estimated the parameters of this function, we can estimate the elasticity of GRP by the value of $nINT$the structural complexity index for the entire set of regions under consideration. In this case, the share of GRP of each of the eight regions excluding natural rent is $exp(-r)$, and the share of natural rent in GRP is $1 - exp(-r)$.

3 CALCULATION RESULTS

The parameter estimate $s$for the integral index $nINT4$is significant at the 5% level and equals 0.298 (see column (7) of Table 3). With this value, the estimate of $1 - exp(-r)$the share of natural rent for eight regions is 0.2558 and does not exceed the share of natural rent of extractive regions estimated in the works (Ayvazyan et al., 2018). The estimated share of $exp(-r)$GRP after excluding natural rent is 0.742.

Table 3 : Estimates of the parameters of function (3) for 85 regions.

(1)	(2)	(4)	(5)	(6)	(7)
		nINT1	*nINT2*	*nINT3*	*nINT4*
α *t* -statistics *p* -value	0.217*** (4.92) 0,000	0.208*** (4.73) 0,000	0.210*** (4.76) 0,000	0.214*** (4.75) 0,000	0.210*** (4.82) 0,000
β *t* -statistics *p* -values	0.770*** (19,34) 0,000	0.759*** (19,01) 0,000	0.759*** (18.94) 0,000	0.766*** (18.79) 0,000	0.753*** (18,78) 0,000
s *t* -statistics *p* -value		0.252* (1.70) 0.094	0.226 (1.56) 0.124	0.105 (0.56) 0.577	0.298 ** (2.02) 0.047
r	0.213***	0.279***	0.273***	0.242**	0.284***

t -statistics *p* -value	(2.70) 0.008	(3.21) 0.002	(3,13) 0.002	(2.55) 0,013	(3.32) 0,001
const *t* -statistics *p* -value	5,790*** (19.53) 0,000	6,080*** (16.19) 0,000	5,985*** (18.74) 0,000	5,865*** (17.97) 0,000	6,057*** (18.83) 0,000
N	85	85	85	85	85
R^2	0.9688	0.9699	0.9697	0.9689	0.9702

*** importance ratings at the 1% level
** importance ratings at the 5% level
* importance ratings at the 10% level

The index $nINT4$shows the best statistical characteristics when assessing the production function (3) based on 2022 data. Therefore, we will consider it as the main integral index of the structural complexity of regional economies. We will use the estimate of 0.298 when assessing the elasticity of GRP by the integral index $nINT4$of the structural complexity of the regional economy. Namely, we will consider the value of 0.298 as an estimate of the elasticity of the influence of structural complexity on the GRP of a region that does not specialize in oil and natural gas production $nINT4$. For example, for the Vladimir region, with a value in 2022, $nINT4 = 0{,}245$a relative increase in the integral assessment of complexity by 10% to a value of 0.27 leads to an estimate of the relative growth of GRP of approximately 0.73%. And for the Kaliningrad region, with a value of , $nINT4 = 0{,}537$a relative increase in the integral assessment of complexity by 10% to a value of 0.59 leads to a relative growth of GRP of approximately 1.6%. For regions receiving natural rent from the extraction of neti and natural gas, we will use the upper elasticity estimate $0{,}298 * nINT4$and the lower elasticity estimate $0{,}742 * 0{,}298 * nINT4$. For example, for the Orenburg region, with a value of $nINT4 = 0{,}065$relative increase in the integral complexity estimate by 70% to 0.111, the estimate of the relative growth of GRP is in the range [1.0%; 1.3%].

4 CONCLUSION

Based on the basic indices of economic complexity, integral indices of the structural complexity of regional economies are constructed. An approach to assessing the impact of the structural complexity of regional economies on GRP is proposed. Production functions are constructed that include the integral index of structural complexity. It is shown that the structural complexity of the regional economy affects the GRP of the region. Estimates of the elasticity of GRP by the integral index of structural complexity are obtained.

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DOI: 10.63550/ICEIP.2025.92.79.006

APPENDIX

Table P 1: Basic and integral indices according to 2022 data.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
N	Region	$nVRPV$	$nZPRF$	nZV	$nPRV$	$nINT4$
1	Moscow	1,0000	0.9364	1,0000	1,0000	1,0000
2	Saint Petersburg	0.8938	0.9364	0.8850	0.7946	0.8754
3	Novosibirsk region	0.9077	0.8605	0.7216	0.3897	0.6137
4	Moscow region	0.8038	0.8326	0.6678	0.4192	0.5979
5	Tomsk region	0.6145	1,0000	0.5903	0.4568	0.5579
6	Tyumen region without ao	0.6145	0.5872	0.6944	0,6050	0.5752
7	Kaliningrad region	0.7290	0.4626	0.7255	0.5221	0.5370
8	Sevastopol city	0.7041	0.8087	0.8105	0,1743	0.4746
9	Seaside edge	0.7339	0.5554	0.6327	0.3173	0.4654
10	Samara region	0.6209	0.3901	0.5913	0.5441	0.4584
11	Nizhny Novgorod region	0.7620	0.5657	0.5297	0.2954	0.4353
12	Kabardino-Balkarian Rep .	0.6743	0.7947	0.4686	0.0749	0.3412
13	Krasnodar edge	0.7944	0.5275	0.5665	0,1107	0.3527
14	Sverdlovsk region	0.7709	0.3901	0.2563	0.3856	0.3228
15	Ivanovskaya region	0.7885	0.4996	0.3710	0,1990	0.3288
16	Kaluga region	0.7465	0.3317	0.6997	0.0746	0.2962
17	Rostov region	0.6668	0.4930	0.3959	0.2193	0.3261
18	Republic Crimea	0.7418	0.4626	0.5197	0.0798	0.3025
19	Rep . Northern Ossetia - Alania	0.7418	0.5867	0.3038	0.1082	0.2811
20	Voronezh region	0.7582	0.5426	0.2698	0.1489	0.2792
21	Chelyabinsk region	0.7304	0,1982	0.5199	0.2640	0.2885
22	Yaroslavskaya region	0.7698	0.3580	0.3292	0,2000	0.2717
23	Republic Karelia	0.6376	0.4154	0.4792	0.1646	0.3002
24	Republic Altai	0,6960	0.5275	0.3038	0,1409	0.2759
25	Republic Adygea	0.7874	0.5807	0.1378	0.1296	0.2317
26	Republic Buryatia	0.6875	0.4052	0.1874	0.3051	0.2621
27	Omsk region	0,6707	0.4296	0.2513	0.2296	0.2637
28	Leningradskaya region	0.6017	0.3329	0.5853	0,1308	0.2777
29	Republic Kalmykia	0.7630	0.5275	0.2809	0,0409	0.2330
30	Chechen Republic	0.6212	0.5762	0.2173	0.1525	0.2477
31	Karachay-Cherkessia Rep .	0.7845	0.5107	0.2173	0.0574	0.2165
32	Republic Dagestan	0.6895	0.5762	0.2173	0.0791	0.2282
33	Vladimirskaya region	0.6859	0.2760	0.5438	0.0876	0.2455
34	Volgograd region	0,6410	0.4238	0.4103	0.1029	0.2576

DOI: 10.63550/ICEIP.2025.92.79.006

35	Stavropol edge	0.6493	0.4236	0.4381	0.0338	0.2358
36	Rep . Bashkortostan	0.6343	0.3522	0.3985	0.1236	0.2408
37	Khabarovsk edge	0.6578	0.2760	0.4651	0.0892	0.2235
38	Murmansk region	0.6359	0.2650	0.3985	0.1557	0.2257
39	Astrakhan region	0.5456	0.4996	0.3594	0.0729	0.2305
40	Jewish autonomous region .	0.6693	0.4402	0.3490	0,0176	0.2109
41	Altaic edge	0.8029	0.2170	0,1750	0,1920	0,1721
42	Pskov region	0.6888	0.3728	0.2261	0.1158	0,1974
43	Republic Tuva	0.6280	0.5807	0.1475	0,0580	0.1846
44	Sakhalin region	0.4489	0.2708	0.5311	0.1838	0.2318
45	Smolensk region	0.7399	0,1586	0.2530	0.2057	0,1767
46	Bryansk region	0.6972	0.2458	0.4237	0.0528	0,1932
47	Ryazan region	0.7003	0.4147	0,0690	0.1564	0,1666
48	Saratov region	0.6589	0.4236	0.2252	0.0764	0,1905
49	Kamchatka edge	0.7444	0.2708	0,1882	0,1403	0.1699
50	Ulyanovsk region	0.7067	0.4268	0.0897	0,1162	0.1636
51	Republic Ingushetia	0,6630	0.5107	0,0000	0,1217	0.1423
52	Tverskaya region	0.7541	0.3552	0.1025	0.0876	0.1444
53	Republic Komi	0.6331	0,1950	0,4100	0,0910	0,1783
54	Lipetsk region	0,6360	0,1950	0.2908	0,1605	0.1715
55	Novgorod region	0,6550	0.3692	0,1306	0.1191	0,1584
56	Penza region	0.7199	0.2792	0.2304	0,0637	0.1544
57	Magadan region	0.5260	0.4094	0.3012	0.0571	0,1797
58	Tula region	0,6360	0.2062	0.3250	0.0952	0,1609
59	Kirov region	0.7381	0.3114	0,0404	0,1200	0.1186
60	Permian edge	0.5043	0,0000	0.6753	0.1254	0,1440
61	Kurgan region	0.6772	0.4031	0,1383	0.0331	0.1394
62	Udmurt Republic	0.5705	0.2170	0.0739	0.3012	0,1382
63	Vologda region	0,6940	0,1586	0.1718	0.1447	0.1225
64	Arkhangelsk region without ao	0.6793	0,0000	0.4474	0.0893	0.1187
65	Chuvash Republic	0.6645	0.1683	0,1963	0,1208	0.1216
66	Chukchi autonomous district	0.5272	0.3062	0.2358	0.0899	0.1438
67	Orlovskaya region	0.6789	0.3661	0,0404	0.0429	0.0975
68	Kemerovo region	0.5604	0.1066	0.2654	0,1793	0.1255
69	Transbaikal edge	0.5528	0,1964	0.3490	0.0542	0.1339
70	Republic Tatarstan	0.4007	0,1586	0.3269	0,1991	0,1344
71	Amurskaya region	0.6005	0.1066	0.3933	0,0176	0.1078
72	Kostroma region	0.7247	0,1964	0,0690	0,0637	0,0730
73	Belgorod region	0.4955	0,1586	0.1199	0.2505	0.1062
74	Republic Mordovia	0.6583	0,1586	0.2189	0.0331	0.0919
75	Republic Khakassia	0.5691	0,1964	0.2397	0.0632	0.1085

DOI: 10.63550/ICEIP.2025.92.79.006

76	Republic Mariy El	0.6677	0,1586	0.1025	0.0714	0.0689
77	Irkutsk region	0.5554	0.1066	0.2930	0.0571	0.0889
78	Tambov region	0.6951	0.2506	0,0244	0,0000	0.0457
79	Orenburg region	0.4598	0.3355	0.0552	0,0607	0.0645
80	Republic Sakha (Yakutia)	0.4035	0,0000	0.3542	0.1352	0.0621
81	Khanty-Mansiysk ao	0.1654	0,0000	0.5319	0,1839	0,0504
82	Krasnoyarsk edge	0.3914	0,1586	0.2476	0.0594	0,0605
83	Yamalo-Nenets ao	0.1654	0,0000	0.5319	0,1361	0.0352
84	Kursk region	0.5772	0.1066	0,0647	0,0000	0,0000
85	Nenets ao	0,0000	0.1048	0.4180	0.2494	0.0274