Economic Assessment of the Development Level of the Central Federal District Regions of the Russian Federation: Econometric Approach

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Abstract

The article is devoted to assessment of the development level of the Central Federal district, based on the study of gross domestic product by region by Russian Classification of Economic Activities grouped by institutional sector of the economy. We apply the author's methodological toolkit that includes the formation of individual and integrated indicators of the functioning of complex systems, considered as socio-ecological and economic systems. The algorithm of constructing indicators is based on aggregate data and econometric modeling and takes into account both individual assessment indicators and specific conditions for these systems functioning (factors of condition and impact). We present the methodology of forming the harmonic coefficient characterizing the equilibrium of socio-ecological and economic systems economic development by activities, the latter is one of the criteria of complex systems stability. This approach was tested on the example of Central Federal district regions using Russian Federation Federal State Statistics Service data for 2007–2015.

Keywords	JEL code
Regional economy, socio-ecological and economic systems, econometric modeling, integral indicators, balance	*C10, P25, R11, R15*

INTRODUCTION

Assessment of the state of the regions, the features of their functioning, development and resistance to the impact of external negative processes requires further development of existing approaches, the construction of refined or the creation of new models based on traditional and time-tested solutions

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in the study of complex systems existing in Russian and worldwide practice. The region as an administrative--territorial unit is a socio-ecological and economic system (SEES), and its study is connected with a set of methodological, conceptual, descriptive and interpretational problems inherent in most objects in the modern world. The identification of SEES, their analysis and assessment depend on the viewpoint, used approaches, methods of data processing and their presentation, that's why we can observe their wide variety. Modern economists, sociologists and geographers chose the indicators for assessing the state of the regions according to their applied tasks, research objectives as well as the generality of the category under study and expert conclusions (Aivazian, 2012). It determines a wide variety of approaches, techniques, models, as well as the use of private and integral indicators. The study of the economic component of the SEES in conjunction with various factors (conditions) of its functioning enables to take an objective approach to the formation of integrated strategies for the socio-economic and ecological development of the region, thereby ensuring reliable positions of the state in the world political arena.

The aim of this paper is to assess the level of economic development of the Central Federal district (CFD) regions taking into account the specific factors of their operation and also to evaluate the balance of economy by the study of certain types of economic activities.

The key method is supposed to use the author's approach presented in the part Data and Methods. It is based on the methods of system analysis, econometric modeling, correlation and regression analysis and the convolution algorithm of data.

1 SURVEY AND LITERATURE REVIEW

Economic evaluation of the region includes a number of indicators, the gross domestic product by region (GDP by region), usually calculated per capita at purchasing power parity, belongs to the most generalized ones.. The System of National Accounts (SNA) (Zander, 2012) is a commonly used methodology for calculating GDP by region. Econometric approach to clustering and regional estimation of GDP by region is considered in the work by (Aivazyan et al., 2016). Other macroeconomic indicators (indicators of economic potential use) estimating the economy of a subject of the Russian Federation include unemployment rate, consumption of fixed capital, capital productivity, material and capital intensity (Arzhenovskiy, 2014). A more detailed assessment can be made by studying the particular spheres of goods and services production, the first of them includes industry, agriculture and forestry, construction (Morozova, 2012). Service industries are divided into transport and communication services, trade and procurement, public catering and other services (market, non-market, including science, health, education, defense, management). Kolesnikov et Tolstoguzov (2016) put forward the plan of studying the regional economy state by the index of added value (the ratio of gross value added per capita to the average for Russia) for certain economy sectors and the sections included herein (types of activities according to Federal State Statistics Service of the Russian Federation – ROSSTAT). Within the framework of the integrated model of the regional economy functioning, where attention is paid to the mechanism of relations between economic entities, Bozo (2012) adduces 6 blocks that reflect the production of goods, market and non-market services, demography, government revenues and expenditures, basic balance relations, as well as the indicators of socio-economic development. A number of scientists use a cluster approach to the economic development assessment (Enright, 1996).

In a number of recent studies, the assessment of the regional economy condition is replaced by a study of its potential,i.e. hidden opportunities to ensure the production of goods and services within the economic activities of economic entities in order to meet the needs of the population. So the Ministry of Economic Development of the Russian Federation (formerly the Ministry of Economic Development and Trade of the Russian Federation) offered the methodology to assess the economic potential of the region that has 12 indicators including GDP by region per capita at purchasing power parity (Chernitsky, 2014).

The methodology of the Expert RA (Russian rating agency) contains 9 indicators estimating the investment potential and appeal of the regions.[2] However, the level of economic potential can only give an idea of the possible state of the region, provided rational use of its resources, but does not allow to assess the real state of the economy. At the same time, GDP by region and its derivatives characterize the functioning of the region and its results but not the potential, therefore, they should not be regarded as evaluation indicators. So, the study of the region's economic potential should be aimed at solving problems related to the analysis of conditions or factors of economic growth that form its investment appeal.

Another approach to the analysis of the state of economy is connected with the study of economic growth (Akerlof et al., 2001; Rothschild et Stiglitz, 1976; Schumpeter, 1935; Solow, 1956). The economic growth or sustained increase in the country's (or region's) production capacity, meaning the production of goods and services, is determined by many significant factors that make up the socio-economic and natural resource potential (Lipsits, 2006).

Lipsits (2006) distinguishes five indicators: capital-labor ratio (the average cost of physical production capital per person employed in economic activities); used technologies; the educational level of employees; methods for the allocation of limited resources; scale of production and its effect.

According to the proposed methodology of the United Nations Development Program (UNDP), indicators of sustainable development are divided into 3 categories on the basis of their target: driving force, state and response.[3] A similar analytical scheme of "impact – changes – consequences" was offered by Muhina et al. (1978) for the study of complex systems. The Organization for Economic Cooperation and Development (OECD) scheme included a theme, subtopic and indicator (Tarasova et Kruchina, 2006).

The development of the methodologies studying the sustained growth at the mesolevel leads to a change in the indicators of the state of complex systems. Gurban et al. (2016) use the growth rate measures of the corresponding indicators (GDP by region, price index, imports and exports, investments), when they treat the region as a socio-economic system according to the scheme "ecology – population – economy". Shabashev et al. (2016) identified 5 macroeconomic factors closely connected to social and demographic indicators that affect the development of the Russian Federation (RF) subjects. They are considered within the framework of a structural model formed with the help of multidimensional statistical analysis method SEPATH. Meanwhile the problem of choice of the productive and factor attributes remained open (the cause-effect relations were studied). Chichkanov et Belyaevskaya-Plotnik (2016) define indicators in terms of their threat to economic security (obsolete structure, technologies, renewal of fixed assets, profitability and energy costs).

The analysis of modern research has shown that there is no common approach to the choice of indicators of the regional economic condition. The wide variety of the latter and sometimes the confusion of the used indicators of regional economic assessment make it difficult to evaluate the state and the prospects of SEES development.

The first of such inaccuracies is to unite in a group the indicators that characterize different elements of one of the schemes divided by the target, for example, "driving force, state and response," or using the same indicator to describe the various blocks of the triad.

The second is the incorrect use of static and dynamic indicators while studying either the state (for example, the growth rate of GDP by region per capita) or the development of the complex system under study (for example, the unemployment rate).

The third problem is the simultaneous use of indicators, some of which are conditions (factors), and others are the result of the functioning of the system under consideration, and this situation leads to a violation of the cause-effect relationships characteristic of the SEES. Meanwhile, the performance

[2] The Rating Agency «Rating of RA» [online]. <http://raexpert.ru/ratings/regions/2015/regions_2015.pdf>. [cit. 18.9.2017].
[3] The United Nations development programme (UNDP) [online]. <http://www.undp.ru>. [cit. 18.9.2017].

indicators of socio-ecological-economic systems and the factors (conditions) for their achievement often belong to one and the same group, that is, the latter also act as an assessment, not being it in fact. Some of them are the derivatives from other indicators (for example, GDP by region, gross output and intermediate consumption are assessed simultaneously, and the aim of the study is not the formation and composition of the gross domestic product by region), so we can make a conclusion that the selected characteristics of the assessment are redundant.

The factorial and productive features of the SEES should be strictly differentiated according to the directions of cause-effect relationships (direct or inverse). So the growth of GDP by region depends on the investment amount. In its turn, the high GDP by region influences the investment appeal of the region. Therefore, their interrelation should be described by a ratio that takes into account the degree and direction of this dependence.

The fourth aspect is related to the use of absolute and relative characteristics in one group, because it makes it difficult to analyze and make managerial decisions.

The fifth problem deals with the substitution of the concept of the economic state of the system by economic or investment potential, as well as the level of economic development or economic growth. Herewith, both economic security and stability of the SEES can be studied.

The sixth group combines the ways of forming integrated indicators, where there is no common methodology for their design. In most of the works dealing with the integral assessment the arithmetic or geometric mean approaches are used (for example, while studying the quality of life) (Mishra et Nathan, 2013). A number of researchers use the weights of each of the individual indicators, but their weights are determined by experts. The FEA (Functioning Environment Analysis) method, which is a Russian analogue of the DEA (DEA – Data Envelopment Analysis) method (Charnes et al., 1978) makes it possible to construct an integral index by solving the non-linear programming problem (determine the weight of subindexes) (Krivonozhko et Lychev, 2010). However, their usage violates the conditions of dimensionlessness and normalization.

2 DATA AND METHODS

To eliminate the identified inconsistencies and misunderstandings of the goals and results of ongoing research, and to select indicators for assessing the state and functioning of complex systems it is important to adhere to the following recommendations.

Determine the object of research, the level of detailed elaboration of its structural features and the existing cause-effect relationships according to the model and the hypothesis.

Choose (form) a scheme for studying the system and determine the direction of the research (state, dynamics, result of functioning, potential, safety, stability, integrated assessment, etc.).

Describe and justify the choice of factor and performance indicators. Divide them into groups (social, ecological, economic), corresponding to the chosen scheme and taking into account the available information base. The research information base must meet the criteria of reliability, veracity, completeness (sufficiency) and relative availability.

Justify the choice of the method and construct the integral index. The integral indicator and the process of its construction must have the following properties:

Universality. The possibility of using the approach in any field of activity.

Dimensionlessness. It allows you to compare characteristics that are of a different nature and refer to different processes (for example, ecological, economic and social). Dimensionlessness can be achieved through the procedure of standardization.

Normalization. Bringing the indicators to a scale from 0 to 1 provides a visual representation of the data.

Normability. It provides the ability to compare the actual data with the norm, that is calculated for a particular SEES functioning under its specific conditions.

Take into account the nexus between private performance indicators. The necessity is justified by considering the object of research as a complex system.

Consider the specific conditions of functioning. It assumes the account of the SEES state in the quantitative assessment of private and integral indicators.

The approach can prevent the mistakes that are common while studying the SEES.

The individual performance indicator is determined as the ratio of the actual and normative indicator values for the selected region (Zhuravlev et al., 2013):

$$\xi_{k,i}(t) = \frac{y^0_{k,i}(t)}{\hat{y}^0_{k,i}(t)}, \tag{1}$$

where $y^0_{k,i}(t)$, $\hat{y}^0_{k,i}(t)$ are actual and normative values of standardized individual performance indicators which are specific for explored region, k is the region number, t is the time parameter (t = 1..T), i = 1..m, m is the amount of individual performance indicators, the index "0" indicates that the normalization procedure has been carried out (bringing to the scale from 0 to 1), and after standardization:

$$y^0_{k,i}(t) = \frac{y^*_{k,i} - \min\{y^*_{k,i}, \hat{y}^*_{k,i}\}}{\max\{y^*_{k,i}, \hat{y}^*_{k,i}\} - \min\{y^*_{k,i}, \hat{y}^*_{k,i}\}}, \tag{2}$$

$$\hat{y}^0_{k,i}(t) = \frac{\hat{y}^*_{k,i} - \min\{y^*_{k,i}, \hat{y}^*_{k,i}\}}{\max\{y^*_{k,i}, \hat{y}^*_{k,i}\} - \min\{y^*_{k,i}, \hat{y}^*_{k,i}\}}. \tag{3}$$

Here $y^*_{k,i}, \hat{y}^*_{k,i}$ are standardized individual performance indicators, defined by the formulas:

$$y^*_{k,i}(t) = \frac{y_{k,i} - M(y_i(t))}{\sigma(y_i(t))}, \tag{4}$$

$$\hat{y}^*_{k,i}(t) = \frac{\hat{y}_{k,i} - M(\hat{y}_i(t))}{\sigma(\hat{y}_i(t))}, \tag{5}$$

where $M(y_i(t))$, $M(\hat{y}_i(t))$, $M(y_i(t))$, $\sigma(\hat{y}_i(t))$ are expected value and standard deviation, respectively.

A generalized performance indicator is calculated as the ratio of individual performance indicators (actual and normative) (Zhukov, 2014):

$$\xi_k(t) = \frac{\sqrt{\sum_{p=1}^{m}\sum_{q=1}^{m} r_{pq} \cdot y^0_{k,p}(t) \cdot y^0_{k,q}(t)}}{\sqrt{\sum_{p=1}^{m}\sum_{q=1}^{m} \hat{r}_{pq} \cdot \hat{y}^0_{k,p}(t) \cdot \hat{y}^0_{k,q}(t)}}, \tag{6}$$

where r_{pq} and $\hat{r}_{pq}$ are the corresponding paired correlation coefficients.

If $\xi_k(t) \geq 1$, then we can assume them satisfactory otherwise we are to take measures aimed at the achievement of the norm that is calculated for each k of the object.

The application the proposed approach makes it possible to meet all the requirements for integrated assessment indicators.

The harmonic coefficient characterizing the balance of the system's functioning results can be determined by the formula (Zhukov, 2016, 2017):

$$K_k = 1 - \frac{\sigma(\xi_{k,i})}{M(\xi_{k,i})}, \tag{7}$$

where $M(\xi_{k,i})$ is expected value, $\sigma(\xi_{k,i})$ is standard deviation. The closer to the one K_k, the more harmonic the functioning of the object under research is. This indicator does not characterize its specialization, but shows the degree of compliance of the indicators under consideration with the norms, taking into account specific conditions.

The standardized models of the additive form were chosen as the models for forming the norms:

$$\hat{y}_i^* = \sum_{j=1}^{n} C_{i,j} \cdot x_j^* + \sum_{s=1}^{s} D_{i,s} \cdot z_s^*, \tag{8}$$

where n is the number of state factors, s is the number of impact factors, $C_{i,j}$, $D_{i,s}$, are corresponding weight coefficients between i productive (result of functioning of system) and j and s standardized factors of x_j^* state and z_s^* impact. When substituting actual values x_j^* and z_s^* in (8) for k region you can get a individual norm. Herewith:

$$x_j^* = \frac{x_j - M(x_j)}{\sigma(x_j)}, \tag{9}$$

$$z_s^* = \frac{z_s - M(z_s)}{\sigma(z_s)}, \tag{10}$$

where x_j, z_s are the actual values of factors of state and impact in absolute units of measurement.

As the alternatives to (8) their logarithmic analogs were considered:

$$\ln(\hat{y}_i^*) = \sum_{j=1}^{n} C_{i,j} \cdot \ln(x_j^*) + \sum_{s=1}^{s} D_{i,s} \cdot \ln(z_s^*), \tag{11}$$

that is the equivalent to the representation of non-linear models, and in case of using labor and capital – to the explanatory variables in the form of Cobb-Douglas (Cobb et Douglas, 1928):

$$\hat{y}_i^* = \prod_{j=1}^{n} x_j^{*C_{i,j}} \cdot \prod_{s=1}^{n} z_s^{*D_{i,j}}. \tag{12}$$

The coefficients of the model are determined with the help of a step-by-step least squares method (determination of important factors).

So, the actual indicator means real index value which characterizes the level of development of the region. The normative indicator is value which is calculated using the model for the region (Formula (8), (11) or (12)). When substituting actual and normative values in Formula (1) or (6) you can get individual performance indicator or generalized performance indicator correspondingly.

The information base of the research is represented by the ROSSTAT data for the regions of the Central Federal district in 2007–2015,[4] that also embrace:

- performance indicators (private assessment indicators) that include GDP by regions by economic activities (Russian Classification of Economic Activities (NACE (OKVED)) was used in the Russian Federation till 2015)[5] grouped by institutional sector of the economy;
- factors of state and impact from the qualitative point of view, they have a social, economic and socio-economic meaning.

[4] Federal State Statistics Service of the Russian Federation (ROSSTAT) [online]. <http://www.gks.ru>. [cit. 20.6.2017].

[5] Russian Classification of Economic Activities (NACE (OKVED)) [online]. <http://www.gks.ru/bgd/free/b02_60/Main.htm>. [cit. 18.6.2017].

"Section B. Fisheries", was not included in the analysis due to its small share (less than 0.1%) in the GDP by region structure for the regions of the Central Federal district. The variables that we use are grouped according to the division offered by Kolesnikov et Tolstoguzov (2016) and their descriptive statistics is represented in Table 1 to Table 3.

Table 1 Descriptive statistics (private assessment indicators)

№	Variables	Description	№	Variables	Description
1	y_1, y_1^*, $\hat{y}_1$, $\hat{y}_1^*$	Commodity institutional sector	4.3	$y_{4.3}$, $y_{4.3}^*$, $\hat{y}_{4.3}$, $\hat{y}_{4.3}^*$	Section I. Transport, storage and communications (H, J)
1.1	$y_{1.1}$, $y_{1.1}^*$, $\hat{y}_{1.1}$, $\hat{y}_{1.1}^*$	Section A. Agriculture, hunting and forestry (A)	4.4	$y_{4.4}$, $y_{4.4}^*$, $\hat{y}_{4.4}$, $\hat{y}_{4.4}^*$	Section J. Financial intermediation (K)
1.2	$y_{1.2}$, $y_{1.2}^*$, $\hat{y}_{1.2}$, $\hat{y}_{1.2}^*$	Section C. Mining and quarrying (B)	4.5	$y_{4.5}$, $y_{4.5}^*$, $\hat{y}_{4.5}$, $\hat{y}_{4.5}^*$	Section K. Real estate, renting and business activities (L, M, N)
2	y_2, y_2^*, $\hat{y}_2$, $\hat{y}_2^*$	Manufacturing institutional sector	5	y_5, y_5^*, $\hat{y}_5$, $\hat{y}_5^*$	Institutional sector of non-market services
2	y_2, y_2^*, $\hat{y}_2$, $\hat{y}_2^*$	Section D. Manufacturing (C)	5.1	$y_{5.1}$, $y_{5.1}^*$, $\hat{y}_{5.1}$, $\hat{y}_{5.1}^*$	Section E. Electricity, gas and water supply (D, E)
3	y_3, y_3^*, $\hat{y}_3$, $\hat{y}_3^*$	Construction institutional sector	5.2	$y_{5.2}$, $y_{5.2}^*$, $\hat{y}_{5.2}$, $\hat{y}_{5.2}^*$	Section L. Public administration and defence; compulsory social security (O)
3	y_3, y_3^*, $\hat{y}_3$, $\hat{y}_3^*$	Section F. Construction (F)	5.3	$y_{5.3}$, $y_{5.3}^*$, $\hat{y}_{5.3}$, $\hat{y}_{5.3}^*$	Section M. Education (P)
4	y_4, y_4^*, $\hat{y}_4$, $\hat{y}_4^*$	Institutional sector of market services	5.4	$y_{5.4}$, $y_{5.4}^*$, $\hat{y}_{5.4}$, $\hat{y}_{5.4}^*$	Section N. Health and social work (Q)
4.1	$y_{4.1}$, $y_{4.1}^*$, $\hat{y}_{4.1}$, $\hat{y}_{4.1}^*$	Section G. Wholesale and retail trade: repair of motor vehicles, motorcycles and personal and household goods (G)	5.5	$y_{5.5}$, $y_{5.5}^*$, $\hat{y}_{5.5}$, $\hat{y}_{5.5}^*$	Section O. Other community, social and personal services activities (R, S)
4.2	$y_{4.2}$, $y_{4.2}^*$, $\hat{y}_{4.2}$, $\hat{y}_{4.2}^*$	Section H. Hotel and restaurants (I)			

Note: Variables without any extra characters are variables in absolute units, * standardized variables, ^ model (calculated) variables, () NACE Rev. 2. sections.
Source: ROSSTAT, own construction

The non-market sector includes kinds of activities which are implemented in markets with regulated pricing mainly.

Table 2 Descriptive statistics (state factors)

№	Variables	Description	№	Variables	Description
6	The cost of fixed production assets at full accounting value at the end of the year by types of economic activity		7.4	$x_{3,2}$, $x^*_{3,2}$	Section F
6.1	$x_{1.1,1}$, $x^*_{1.1,1}$	Section A (A)	7.5	$x_{4.1,2}$, $x^*_{4.1,2}$	Section G (G)
6.2	$x_{1.2,1}$, $x^*_{1.2,1}$	Section C (B)	7.6	$x_{4.2,2}$, $x^*_{4.2,2}$	Section H (I)
6.3	$x_{2,1}$, $x^*_{2,1}$	Section D (C)	7.7	$x_{4.3,2}$, $x^*_{4.3,2}$	Section I (H, J)
6.4	$x_{3,1}$, $x^*_{3,1}$	Section F (F)	7.8	$x_{4.5,2}$, $x^*_{4.5,2}$	Section K (L, M, N)
6.5	$x_{4.1,1}$, $x^*_{4.1,1}$	Section G (G)	7.9	$x_{5.1,2}$, $x^*_{5.1,2}$	Section E (D, E)
6.6	$x_{4.3,1}$, $x^*_{4.3,1}$	Section I (H, J)	7.10	$x_{5.3,2}$, $x^*_{5.3,2}$	Section M (P)
6.7	$x_{5.1,1}$, $x^*_{5.1,1}$	Section E (D, E)	8	x_3, x^*_3	Average annual population
7	Average annual number of persons employed by types of economic activities		9	Transport	
7.1	$x_{1.1,2}$, $x^*_{1.1,2}$	Section A (A)	9.1	$x_{4.1}$, $x^*_{4.1}$	Passenger turnover of public buses
7.2	$x_{1.2,2}$, $x^*_{1.2,2}$	Section C (B)	9.2	$x_{4.2}$, $x^*_{4.2}$	Departure of passengers by public railway transport
7.3	$x_{2,2}$, $x^*_{2,2}$	Section D (C)	10	x_5, x^*_5	Morbidity per 1 000 of population, registered diseases diagnosed in patients for the first time in life

Note: Variables without any extra characters are variables in absolute units, * standardized variables, ^ model (calculated) variables, () NACE Rev. 2. sections.
Source: ROSSTAT, own construction

Table 3 Descriptive statistics (impact factors)

№	Variables	Description	№	Variables	Description
11	Investments in fixed capital by kinds of economic activities		12	z_2 , z_2^*	Organic fertilizers per 1 ha of agricultural crops (in terms of 100% nutrients)
11.1	$z_{2,1}$, $z_{2,1}^*$	Section D (D)	13	Consolidated budget expenditures (by object)	
11.2	$z_{4.1,1}$, $z_{4.1,1}^*$	Section G (G)	13.1	$z_{5.2,3}$, $z_{5.2,3}^*$	Social policy
11.3	$z_{4.2,1}$, $z_{4.2,1}^*$	Section H (I)	13.2	$z_{5.3,3}$, $z_{5.3,3}^*$	Education
11.4	$z_{4.5,1}$, $z_{4.5,1}^*$	Section K (L, M, N)			

Note: Variables without any extra characters are variables in absolute units, * standardized variables, ^ model (calculated) variables, () NACE Rev. 2. sections.
Source: ROSSTAT, own construction

The model includes only substantial factors, significant at the level of no more than 5%. At the first stage, all the factors of state and impact were analyzed according to the sections of the annual statistical compendium ROSSTAT (more than 20 variables). The number of observations for each variable made 153 (input data as of 2007–2015 for 17 CFD regions).

We used least square method (backward selection) to select them.

Every absolute indicator represented in terms of value was adjusted according to purchasing power parity (PPP) in US dollars so that we could make a comparison with the international level.

3 RESULTS AND DISCUSSION

The conducted research resulted in the corresponding models in Formulas (8) and (11), whose specification is represented in Table 1 to Table 3 using author's expert system (beta version) (Zhukov, 2015):

$$\hat{y}_{1.1}^* = \underset{(0.001)}{0.668} \cdot x_{1.1,1}^* + \underset{(0.001)}{0.259} \cdot x_{1.1,2}^* + \underset{(0.035)}{0.611} \cdot z_2^* , (R^2 = 0.874), \tag{13}$$

$$\ln(\hat{y}_{1.1}^*) = \underset{(0.073)}{0.706} \cdot \ln(x_{1.1,1}^*) + \underset{(0.087)}{0.241} \cdot \ln(x_{1.1,2}^*) + \underset{(0.030)}{0.006} \cdot \ln(z_2^*) , (R^2 = 0.824), \tag{14}$$

$$\hat{y}_{1.2}^* = \underset{(0.001)}{0.604} \cdot x_{1.2,1}^* + \underset{(0.025)}{0.346} \cdot x_{1.2,2}^* , (R^2 = 0.889), \tag{15}$$

$$\ln(\hat{y}_{1.2}^*) = \underset{(0.090)}{0.707} \cdot \ln(x_{1.2,1}^*) + \underset{(0.111)}{0.243} * \cdot \ln(x_{1.2,2}^*) , (R^2 = 0.879), \tag{16}$$

$$\hat{y}_2^* = \underset{(0.001)}{0.396} \cdot x_{2,1}^* + \underset{(0.002)}{0.395} \cdot x_{2,2}^* + \underset{(0.001)}{0.226} \cdot z_{2,1}^* , (R^2 = 0.964), \tag{17}$$

$$\ln(\hat{y}_2^*) = \underset{(0.047)}{0.492} \cdot \ln(x_{2,1}^*) + \underset{(0.052)}{0.271} \cdot \ln(x_{2,2}^*) + \underset{(0.031)}{0.324} \cdot \ln(z_{2,1}^*) , (R^2 = 0.928), \tag{18}$$

$$\hat{y}_3^* = \underset{(0.001)}{0.170} \cdot x_{3,1}^* + \underset{(0.003)}{0.786} \cdot x_{3,2}^* , (R^2 = 0.888), \tag{19}$$

$$\ln(\hat{y}_3^*) = \underset{(0.076)}{0.391} \cdot \ln(x_{3,1}^*) + \underset{(0.121)}{0.464} \cdot \ln(x_{3,2}^*)\,, (R^2 = 0.664), \tag{20}$$

$$\hat{y}_{4.1}^* = \underset{(0.001)}{0.715} \cdot x_{4.1,1}^* + \underset{(0.003)}{0.168} \cdot x_{4.1,2}^* + \underset{(0.001)}{0.121} \cdot z_{4.1,1}^*\,, (R^2 = 0.966), \tag{21}$$

$$\ln(\hat{y}_{4.1}^*) = \underset{(0.058)}{0.662} \cdot \ln(x_{4.1,1}^*) + \underset{(0.093)}{0.180} \cdot \ln(x_{4.1,2}^*) + \underset{(0.039)}{0.126^*} \cdot \ln(z_{4.1,1}^*)\,, (R^2 = 0.844), \tag{22}$$

$$\hat{y}_{4.2}^* = \underset{(0.001)}{0.758} \cdot x_{4.2,2}^* + \underset{(0.001)}{0.229} \cdot z_{4.2,1}^*\,, (R^2 = 0.942), \tag{23}$$

$$\ln(\hat{y}_{4.2}^*) = \underset{(0.001)}{0.711} \cdot \ln(x_{4.2,2}^*) + \underset{(0.001)}{0.244} \cdot \ln(z_{4.2,1}^*)\,, (R^2 = 0.781), \tag{24}$$

$$\hat{y}_{4.3}^* = \underset{(0.001)}{0.171} \cdot x_{4.3,1}^* + \underset{(0.004)}{0.553} \cdot x_{4.3,2}^* + \underset{(0.001)}{0.138^*} \cdot x_{4,1}^* + \underset{(0.001)}{0.141^*} \cdot x_{4.2}^*\,, (R^2 = 0.968), \tag{25}$$

$$\ln(\hat{y}_{4.3}^*) = \underset{(0.047)}{0.182} \cdot \ln(x_{4.3,1}^*) + \underset{(0.109)}{0.391} \cdot \ln(x_{4.3,2}^*) + \underset{(0.040)}{0.205} \cdot \ln(x_{4.1}^*) + \underset{(0.037)}{0.260} \cdot \ln(x_{4.2}^*), (R^2 = 0.895), \tag{26}$$

$$\hat{y}_{4.4}^* = \underset{(0.001)}{0.969} \cdot x_3^*\,, (R^2 = 0.940), \tag{27}$$

$$\ln(\hat{y}_{4.4}^*) = \underset{(0.054)}{0.976} \cdot \ln(x_3^*)\,, (R^2 = 0.853), \tag{28}$$

$$\hat{y}_{4.5}^* = \underset{(0.004)}{0.576} \cdot x_{4.5,2}^* + \underset{(0.001)}{0.408} \cdot z_{4.5,1}^*\,, (R^2 = 0.959), \tag{29}$$

$$\ln(\hat{y}_{4.5}^*) = \underset{(0.066)}{0.576} \cdot \ln(x_{4.5,2}^*) + \underset{(0.045)}{0.167} \cdot \ln(z_{4.5,1}^*)\,, (R^2 = 0.898), \tag{30}$$

$$\hat{y}_{5.1}^* = \underset{(0.001)}{0.567} \cdot x_{5.1,1}^* + \underset{(0.004)}{0.418} \cdot x_{5.1,2}^*\,, (R^2 = 0.929), \tag{31}$$

$$\ln(\hat{y}_{5.1}^*) = \underset{(0.055)}{0.507} \cdot \ln(x_{5.1,1}^*) + \underset{(0.086)}{0.465} \cdot \ln(x_{5.1,2}^*)\,, (R^2 = 0.860), \tag{32}$$

$$\hat{y}_{5.2}^* = \underset{(0.001)}{0.250} \cdot x_3^* + \underset{(0.001)}{0.749} \cdot z_{5.2,3}^*\,, (R^2 = 0.979), \tag{33}$$

$$\ln(\hat{y}_{5.2}^*) = \underset{(0.042)}{0.475} \cdot \ln(x_3^*) + \underset{(0.032)}{0.534} \cdot \ln(z_{5.2,3}^*)\,, (R^2 = 0.942), \tag{34}$$

$$\hat{y}_{5.3}^* = \underset{(0.001)}{0.225} \cdot x_{5.3,2}^* + \underset{(0.001)}{0.781} \cdot z_{5.3,3}^*\,, (R^2 = 0.982), \tag{35}$$

$$\ln(\hat{y}_{5.3}^*) = \underset{(0.039)}{0.370} \cdot \ln(x_{5.3,2}^*) + \underset{(0.024)}{0.597} \cdot \ln(z_{5.3,3}^*)\,, (R^2 = 0.950), \tag{36}$$

$$\hat{y}^*_{5.4} = \underset{(0.001)}{0.993} \cdot x^*_3 + \underset{(0.001)}{0.054} \cdot x^*_5, (R^2 = 0.962), \tag{37}$$

$$\ln(\hat{y}^*_{5.4}) = \underset{(0.037)}{0.963} \cdot \ln(x^*_3) + \underset{(0.117)}{0.051} \cdot \ln(x^*_5), (R^2 = 0.887), \tag{38}$$

$$\hat{y}^*_{5.5} = \underset{(0.001)}{0.466} \cdot x^*_3 + \underset{(0.001)}{0.518} \cdot z^*_{5.5,3}, (R^2 = 0.958), \tag{39}$$

$$\ln(\hat{y}^*_{5.5}) = \underset{(0.078)}{0.416} \cdot \ln(x^*_3) + \underset{(0.058)}{0.563} \cdot \ln(z^*_{5.5,3}), (R^2 = 0.883). \tag{40}$$

Here is denoted: () standard errors, * the statistical significance at 5% level, other coefficients show statistical significance at 1% level, ln(..) logarithmic model, R^2 determination coefficient.

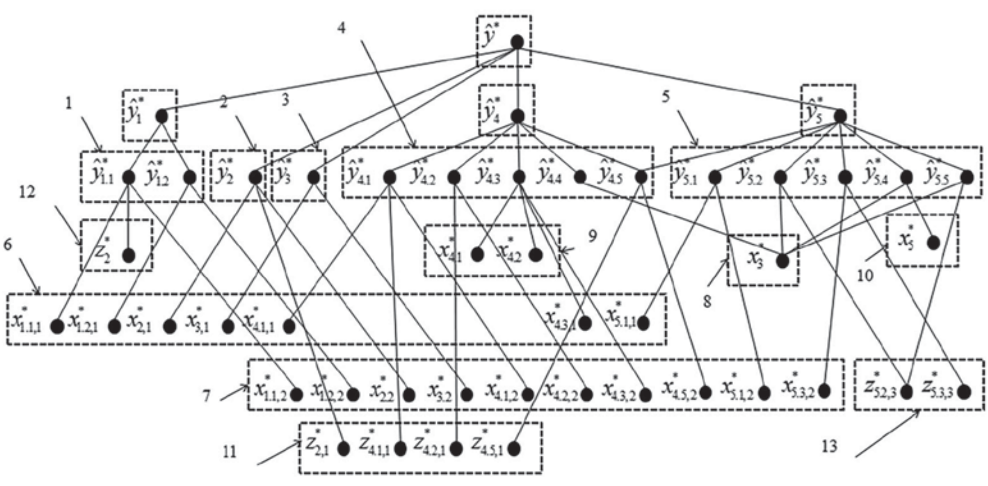
For these models the coefficient of determination are statistically significant at 1% level. For assessment the F-test was used. For minimal $R^2 = 0.664$ from these model (Formula (20)): F = 147.920 >> critical F = 4.749 ($p_1 = 2$, $p_2 = 150$, $\alpha = 0.01$). Also coefficients of models are statistical significant at 5% level (Formulas (16) and (25)). Coefficients of other models are statistical significant at 1% level. For assessment t-test was used.

The visualization of the detected significant links is shown in Figure 1.

Most of the performance indicators correlate with the size of fixed assets and the employment of the population, which is confirmed by earlier studies (Aivazyan et al., 2016). The market services sector depends on the economic (investments) and socio-economic (employment, population) factors.

While studying the influence of the state and impact factors on the non-market services sector, social (population, morbidity) and socioeconomic factors (passenger turnover and departure of passengers by rail, consolidated budget expenditures (social policy, education)) turn out to be predominant, and from a qualitative point of view, it can be easily explained.

Figure 1 The scheme that reveals the connections of factorial and productive features (performance indicators)



Note: 1 commodity sector, 2 manufacturing industries sector, 3 construction sector, 4 market services sector, 5 non-market services sector, 6 fixed assets value (FA) (by types of activities), 7 average annual number of persons employed (by types of activities), 8 average annual population, 9 passenger turnover and departure of passengers by railway transport, 10 morbidity per 1 000 people, 11 investments in fixed assets (by types of economic activities), 12 introduction of organic fertilizers, 13 expenses of the consolidated budget (under sections).
Source: Own construction

The integrated (generalized) performance indicators for the CFD regions were calculated with the help of Formulas (6) and (8)–(11) (see Table 4 and Table 5).

Table 4 The values of the integral performance indicators ξ_k *(t)* for the regions of the CFD in 2010–2015 years

№	Region/Year	2010	2011	2012	2013	2014	2015	Ranking
1	Belgorod	0.913 / 1.042	1.101 / 1.073	1.026 / 1.079	1.008 / 1.082	1.013 / 1.097	1.016 / 1.073	10
2	Bryansk	0.871 / 0.869	0.895 / 0.923	0.999 / 0.991	1.003 / 0.968	1.049 / 1.002	0.932 / 0.921	14
3	Vladimir	0.740 / 0.903	0.816 / 0.942	0.847 / 0.976	0.817 / 0.939	0.826 / 0.947	0.806 / 0.937	17
4	Voronezh	0.752 / 0.899	0.929 / 0.955	1.034 / 1.015	0.977 / 0.989	1.038 / 0.993	1.06 / 1.003	8
5	Ivanovo	0.827 / 0.811	0.739 / 0.768	0.835 / 0.814	0.883 / 0.819	0.859 / 0.805	0.825 / 0.740	16
6	Kaluga	0.946 / 1.008	1.137 / 1.061	1.102 / 1.062	1.039 / 1.028	1.070 / 1.052	0.962 / 0.967	13
7	Kostroma	1.821 / 1.114	2.606 / 1.416	2.776 / 1.537	3.027 / 1.473	3.047 / 1.552	3.427 / 1.662	1
8	Kursk	1.104 / 0.991	1.116 / 1.001	1.102 / 1.020	1.087 / 1.030	1.141 / 1.054	1.142 / 1.042	5
9	Lipetsk	0.881 / 0.953	0.962 / 1.003	0.955 / 1.019	0.939 / 0.974	1.055 / 1.032	1.061 / 1.019	7
10	Moscow	1.006 / 0.968	1.008 / 0.97	1.037 / 0.982	0.983 / 0.964	0.983 / 0.971	0.996 / 0.965	11
11	Orel	1.358 / 1.018	1.163 / 1.084	1.305 / 1.145	1.419 / 1.247	1.448 / 1.196	1.435 / 1.121	3
12	Ryazan	0.978 / 0.936	1.086 / 0.997	1.210 / 1.080	1.206 / 1.095	1.226 / 1.088	1.146 / 1.023	4
13	Smolensk	0.917 / 0.939	0.977 / 0.991	1.022 / 1.024	1.039 / 1.030	1.018 / 0.999	0.983 / 0.960	12
14	Tambov	0.942 / 0.914	1.104 / 1.004	1.175 / 1.047	1.168 / 1.076	1.343 / 1.135	1.461 / 1.104	2
15	Tver	1.002 / 1.021	1.049 / 1.058	0.959 / 1.023	0.990 / 1.010	1.003 / 1.029	1.060 / 1.015	9
16	Tula	0.749 / 0.852	0.847 / 0.900	0.863 / 0.933	0.848 / 0.922	0.891 / 0.931	0.882 / 0.918	15
17	Yaroslavl	0.891 / 0.944	0.921 / 0.999	0.959 / 1.016	1.007 / 1.015	1.046 / 1.048	1.081 / 1.043	6

Note: / – linear / logarithmic model calculations.
Source: Own calculations

Table 4 shows that the largest value of the indicator belongs to the Kostroma region, and the smallest to the Vladimir region. The value above 1 means that within the current state and impact factors subject's performance satisfies the norm. The differences in the indicator values for the linear and logarithmic models, while preserving a general trend, can be explained by the shift in the norm boundary because of its functional form's choice. Until 2014 inclusive the indicator dynamics is positive for most regions except for the Moscow and Ryazan regions, where there are small fluctuations in the overall trend. In 2015, the integral indicator value that determined the level of regional development decreased due to the stagnation of macroeconomic processes, as well as the unjustified change in purchasing power parity (12.7% in 2015 against 3.8% in 2014). The similar changes characterize the generalized indicators by the economic sector.

Anomalous value for the Kostroma region in the commodity sector ($\xi_1 = 23.102$), is explained by the lack of fixed assets (234 million rubles) and the employment (0.4 thousand people) in the sector, that gives the minimal value for the norm having 0,1% GDP by region in its structure. The corresponding values are in the Belgorod region (the part of GDP by region is 12.4%, fixed assets – 65 505 million rubles, employment – 22.9 thousand people). Logarithmic model allows to smoothen its inheterogeneity ($\xi_1 = 1.851$). A similar situation is observed for the Tambov region in the construction sector ($\xi_3 = 44.005$ / 3.563), which is 13.5% of GDP by region at a relatively low cost of fixed assets (5 664 million rubles) and minimum employment among the regions of the Central Federal district (17.6 thousand people).

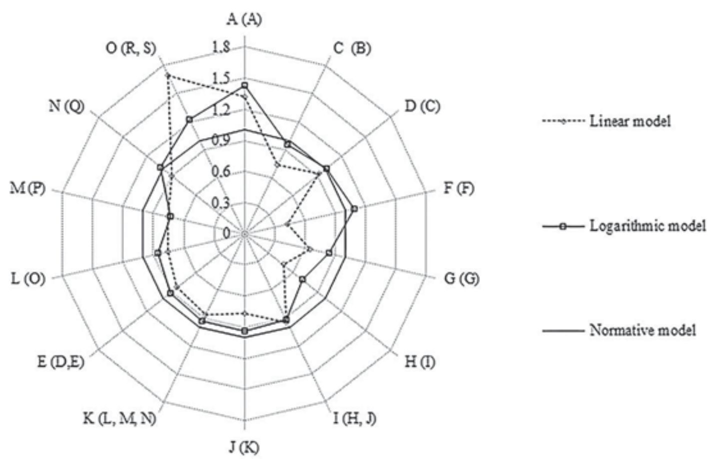
Table 5 The value of the integral performance indicators ξ_k for the CFD by the types of economic activities for 2015

№	Region/Indicator	ξ_1	ξ_2	ξ_3	ξ_4	ξ_5
1	Belgorod	0.953 / 1.077	1.363 / 1.156	1.339 / 1.148	1.232 / 1.159	1.126 / 1.005
2	Bryansk	1.033 / 1.122	1.665 / 1.149	0.978 / 0.813	1.144 / 1.072	0.798 / 0.751
3	Vladimir	1.538 / 1.169	0.924 / 1.013	0.427 / 1.08	0.695 / 0.839	1.01 / 0.937
4	Voronezh	1.449 / 1.137	1.073 / 1.038	1.146 / 1.088	0.968 / 1.013	1.011 / 0.945
5	Ivanovo	1.236 / 0.842	0.372 / 0.388	0.364 / 0.000	0.905 / 0.797	1.034 / 0.873
6	Kaluga	1.638 / 1.208	0.607 / 0.783	0.826 / 0.941	0.885 / 0.849	1.485 / 1.101
7	Kostroma	23.102 / 1.851	1.570 / 0.749	1.383 / 3.909	4.583 / 1.773	3.445 / 1.537
8	Kursk	1.061 / 1.125	3.546 / 1.731	1.849 / 1.455	0.891 / 0.857	1.254 / 1.020
9	Lipetsk	1.182 / 1.105	1.389 / 1.177	1.664 / 1.443	0.774 / 0.931	1.055 / 0.932
10	Moscow	0.810 / 1.002	0.972 / 1.016	1.368 / 1.051	0.989 / 0.966	1.033 / 0.953
11	Orel	1.264 / 1.275	4.268 / 1.016	3.835 / 2.070	1.305 / 0.859	1.785 / 1.092
12	Ryazan	1.615 / 1.162	1.102 / 1.010	0.625 / 0.738	1.237 / 1.127	1.239 / 0.994
13	Smolensk	0.938 / 0.941	0.984 / 0.866	0.643 / 0.809	1.201 / 1.120	1.130 / 0.932
14	Tambov	1.493 / 1.252	1.190 / 0.960	44.005 / 3.563	1.063 / 1.002	1.162 / 0.854
15	Tver	1.048 / 0.866	1.147 / 1.076	0.920 / 0.944	1.300 / 1.162	1.020 / 0.980
16	Tula	1.023 / 1.003	1.164 / 1.077	0.672 / 0.859	0.888 / 0.941	0.860 / 0.858
17	Yaroslavl	1.442 / 1.097	0.869 / 0.947	1.154 / 1.045	1.192 / 1.074	1.199 / 1.048

Note: ξ_1 commodity institutional sector, ξ_2 manufacturing activities institutional sector, ξ_3 construction institutional sector, ξ_4 institutional sector of market services, ξ_5 institutional sector of non-market services.
Source: Own calculations

In 2015 the lowest value of integral performance indicator (ξ = 0.806 / 0.937), it is related to the functioning of individual industries characterized by private indicators by types of economic activity (see Figure 2).

Figure 2 The diagram of individual performance indicators by NACE (OKVED) sections for the Vladimir region



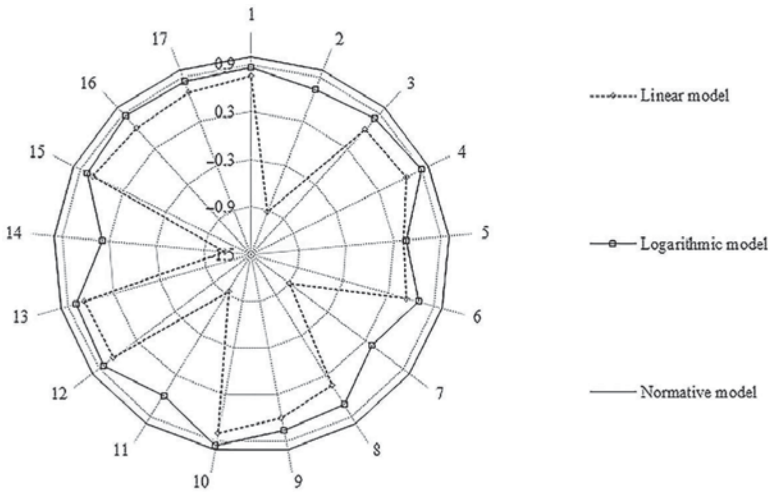
Note: A-O are NACE rev 1.1. sections, () NACE Rev. 2. sections.
Source: Own construction

Figure 2 shows that the norm is not achieved according to all the indicators except for sections A (A), N (Q) and O (R, S) which make the asymmetry of economic development. The worst values for linear and logarithmic models are observed in sections G (G) and H (I) that can be interpreted as the irrational investment, the engagement of fixed assets and wholesale and retail trade workers as well as the hotel and restaurant business. There are some differences of assessment in sector F and they are explained by the disbalance between the usage of fixed assets (shortage, $C_{3,1} = 0.170$) and the construction sector workers (overemployment, $C_{3,2} = 0.786$), they can not be detected while studying the indicator at the logarithmic model $C_{3,1} = 0.391$, $C_{3,2} = 0.464$).

The performance uniformity analysis of SEES functioning showed the differentiation of the harmonic coefficient (see Formula 7) for the CFD regions in 2015 (see Figure 3).

As we can see from figure 3 the greatest disbalance in the economic assessment indicators is observed for Bryansk, Kostroma, Orel and Tambov regions, moreover, the form of the linear representation is identical to the logarithmic mapping. The differences are in numerical values and scaling, that is explained by the oscillations smoothing effect while using the logarithmic procedure.

Figure 3 Harmonic coefficient for the CFD regions in 2015



Note: 1 – Belgorod, 2 – Bryansk, 3 – Vladimir, 4 – Voronezh, 5 – Ivanovo, 6 – Kaluga, 7 – Kostroma, 8 – Kursk, 9 – Lipetsk, 10 – Moscow, 11 – Orel, 12 – Ryazan, 13 – Smolensk, 14 – Tambov, 15 – Tver, 16 – Tula, 17 – Yaroslavl.
Source: Own construction

So we have the grounds to conclude that the use of non-linear models particularly in Cobb-Douglas form is preferable in the study of regions with a strong differentiation of the GRP structure.

CONCLUSION

The main result of the study is the solution how to assess the economic development of the Central Federal District regions using the methodology for the formation of individual and integral (generalized) performance indicators of complex systems, considered as socio-ecological and economic systems. In this regard, further analysis of each object under consideration does not require the comparative evaluation of other systems because each region has its own norms that take into account the specific conditions of its functioning. The methodology includes the data convolution and it considers the mutual influence of performance indicators characteristic for any SEES. It is an advantage over other approaches. At the same time, all the requirements for integral indicators of the object's assessment are met. Within the framework of the study, a generalized economic indicator and performance indicators by economic sectors were calculated for each CFD region, and it enabled to find out both the specific features of SEES functioning and current problems related to state and impact factors.

Also, the generated harmonic coefficient that characterizes the functioning uniformity of the SEES can help management bodies to eliminate the asymmetry of ongoing processes by redistributing the resources at their disposal and changing the factors of state and impact.

The demonstrated approach is applicable to various territorial (economic entity, municipal entity, region, district, state) and sectoral levels. Results of the investigation can be interesting to a wide range of researchers, including the international studies.

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