Human capital development in the global-knowledge economy

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Abstract. The national economy is as competitive as its human capital is effectively capitalized in modern hypercompetitive global markets. The world digital technologies contribute to the globalization of the economy and accelerate the accumulation of human capital by digitizing jobs, providing the population and households with electronic services and data mining technologies. The article analyzes the structure of multivariate data on the factors of human capital development, e-education and the use of ICT by households in Russian regions. The average annual values of the relevant factors of monitoring the development of the information society in the Russian Federation for the period from 2010 to 2017 were selected as factors of each object of analysis. The reliability of the research results is ensured by applying standardization and rationing of the initial matrix of factors, reducing the dimension of the normalized matrix of factors using the PCA method, cluster analysis using the method of EM-maximizing expectations and the hierarchical clustering method. The author has built a rating of regional clusters of the Russian Federation, differing in the quality of human capital depending on the development of electronic infrastructure, availability of digital resources and the features of the social environment.

1 Introduction

Functioning of the global knowledge-based economy is largely driven by the synchronous development of information and communication technologies (ICT), software, digital platforms and services. Globalization of the knowledge economy and digital technologies render a significant impact on the state and dynamics of human capital development. On the one hand, firms can get an access to human capital around the world while using a global network of information portals, on the other hand, the employees obtain access to the global labor market as well. Creating a new generation of workforce equipped with modern high-performance competencies for the efficient and advanced labour to obtain high professional mobility under the influence of informatization is becoming possible not only in the process of formal education, training and learning-by-doing, but is being determined by life

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conditions, Internet and network information resources, as well as ICT implementation, by households and population[1,2].

Supranational digital technologies contribute to the economy globalization and accelerate the development of new qualities of human capital through the jobs digitalization, providing people and households with electronic services, IoT capabilities and big data processing technologies. The empirical research has proved that human capital and ICT have a positive impact on the organization performance efficiency [3,4,5], social development and the knowledge production sphere growth rate acceleration [6].

The entry of human capital into the digital age started with the organization of open digital portals, which change the way people interact with the spheres of education, health care, training, culture, leisure and other social services provided in electronic form. Richard D. Johnson and Hal J. Hugh pointed out that the transition to digital interfaces and e-services had a profound impact on the human capital economy [7,8,9]. Computer analysis process based on business results renders information to HR managers about the expected business results of specific actions related to human capital management or specifies actions necessary to achieve a certain business result. „This will free the staff from performing routine tasks. More time will be devoted to engaging employees and managers in high-impact business processes including recruitment, hiring, succession provision, planning, training and career development [10].”

Human capital development takes place through knowledge accumulation and new skills mastering, essential for successful progress in ever changing society, whereas the development of ICT takes place through the digitalization of social change [11,12,13], economic growth and social progress [14]. Thus, generally recognized consequences of ICT implementation turn out to be: interactivity intensification, increase in markets efficiency, reduction of information asymmetry and costs for obtaining and using information as well as the global coverage of markets by information services [15].

Training and professional development are priorities in the models of the digital development of the society. These activities are considered key measures for human development [16]. At mastering any skills it is important to develop measures, which express the state of readiness to expand the use of information and new technologies to develop knowledge. It is offered even to consider measuring the integral indicator of such readiness - the basic literacy level / illiteracy rate [17,18]. Fundamental digitalization framework is formed by the R&D activity aimed at public goods production growth and acquisition of competitive advantages. Being an integral part in the process of new knowledge generating, research activity provides facilities for the digital economy development [19].

Some empirical studies of economic growth have attempted to assess the role of human capital and ICT as the determinants of long-term economic growth effectiveness reasoning from indicators of human capital and ICT-based literacy [20,21]. Such indicators usually include: school enrolment comprising secondary special and higher education [22]; education costs; years of study; the employees' educational level and the degree of ICT implementation by households and the population, ICT application infrastructure, development of e-services. This statistical approach is reflected in the system of indicators Monitoring the Development of the Information Society in the Russian Federation [23].

2 Methods

The initial statistical data of the information society development monitoring in the Russian Federation (RF) are presented in the form of "object-property" matrix:
\[
\begin{pmatrix}
  x_1^{(1)}(t) & x_1^{(2)}(t) & \ldots & x_1^{(p)}(t) \\
  x_2^{(1)}(t) & x_2^{(2)}(t) & \ldots & x_2^{(p)}(t) \\
  \vdots      & \vdots      & \ddots & \vdots      \\
  x_n^{(1)}(t) & x_n^{(2)}(t) & \ldots & x_n^{(p)}(t)
\end{pmatrix}
\]

where \( x_i^{(j)}(t_k) \) - the value of the \( j \)-th analyzed factor characterizing the state of the \( i \)-th subject of the RF at the time \( t_k \). Matrix (1) forms a space-time sample, where \( n \) subjects of the RF are subjected to statistical survey. And the values \( p \) characterizing the subjects of the RF are fixed in successive moments of time \( t_1, t_2, \ldots, t_n \). It is obvious that record (1) defines a certain statistical series (namely \( n \) pieces) "object-property" matrixes. We can also say that the matrix data contains realizations of \( p \)-dimensional time series \( \{ x_1^{(1)}(t), x_1^{(2)}(t), \ldots, x_1^{(p)}(t) \} \).

For the purpose of the statistical structuring and identification of the interrelations between the analyzed factors, such big data of multidimensional observations, as a rule, are subjected to statistical processing with the aim of reducing dimensionality of the investigated factor space for concise explanations of the nature of the analyzed multidimensional data. The potential for such reduction of the analyzed multivariate data is based on the assumption, according to which there is a small (in comparison with the numeral \( p \) of the initial analyzed factors \( x_1^{(1)}, x_1^{(2)}, \ldots, x_1^{(p)} \)) the numeral \( p' \) of factors-determinants (e.g., principal components) which can be accurately described both as the observed variables of constituent entities of the RF, i.e. all the elements of the matrices (1) as well as all the elements determined by these variable properties (characteristics) of the analyzed statistics population.

Statistical studies have shown that a system using fewer factors, each of which is a combination of a large number of factors directly measured at the object, leads to a quite satisfactory classification of objects in terms of specificity. These fundamental settings are inherent in the essence of the linear transformation of the original system of factors reducing the dimension, and this transformation is carried out by the principal component analysis (PCA).

We will choose the average values of the Human capital and E-education factors in information society development monitoring in the RF for the period of 2010-2017 as values of factors for each subject of the Russian Federation. Implementation of the PCA method to reduce the dimensionality of the analyzed factor space enables to obtain preliminary structuring of multidimensional data. Software implementation of the RSA method is made in the integrated development environment RStudio.

### 3 Results

Let us first reduce factors for "Human capital" group. The resulting biplot graph shows the scatterplot of the RF regions in the space of the first two principal components. The analysis of the scattering graph made possible to implement pre-visualization of clusters for the RF constituent entities. Serial numbers of the RF subjects are presented in Appendix 1. A
number of objects with numbers: 10, 24, 18, 28, 42, 47, 64, 66, 69, 74, 75, 84 are located apart. This means that they differ from other subjects of the RF by the special characteristics of human capital.

Fig. 1. Biplot Graph plotted according to the factors in "Human capital" group

Human capital development can be accelerated through the implementation of cluster policies based on a differentiated approach to individual regional clusters to improve the skills and abilities of employees and to achieve competitive advantages in terms of human capital. Therefore, it seems expedient to conduct a cluster analysis of the RF subjects by the selected factors of "Human capital" set. Several probabilistic models are used to determine the optimal number of clusters. The evaluation of the BIC (Bayesian Information Criterion) is carried out for selecting the best model. Data structuring through cluster analysis has been made by means of the expectation maximization method (EM-Expectation Maximization) and Ward Hierarchical Clustering method. The scatterplot with the localization of three clusters is shown in figure 2.

Further on, a dendrogram with 4 clusters has been constructed using Ward's Hierarchical Clustering Method, (Fig.3).

Fig. 2. Scatterplot (visualization of cluster analysis results by EM method)

This classification procedure of hierarchical type "at the output" is not completed by the final version of dividing the population of the RF subjects into classes. With its help, it is possible to form a general visual representation of the stratification structure of the RF subjects' population in the form of a specially arranged graph - dendrogram.
Now we proceed to reduce the group of factors "E-education". Visualization of the factors contribution to the principal components is represented in the biplot graph by the corresponding factor loads (Fig. 4).

The resulting image shows a scatterplot of the objects under examination. These are RF regions in the space allocated to the first two principal components. Let us move on to clustering of the RF subjects by E-education factors. Clustering by five clusters turns out to be the most informative (Fig. 5).

Then we move on to hierarchical clustering by Ward's Hierarchical Clustering Method (Fig. 6).
4 Conclusions

The application of the PCA method which leads to a decrease in the dimension of the factor space, makes possible to give a brief explanation of the nature of multidimensional data under analysis and solve a number of applied problems of statistical analysis and modeling. Among such decisions, it is necessary to distinguish primarily the following:

- visualization of the initial data by projecting them onto a specially constructed plane;
- simplification of modeling and interpretation of the statistical conclusions obtained due to the desire for conciseness of the models under study.

Social and economic development cannot be achieved without accelerated digital technologies accumulation and effective use of human capital. Digital technologies are creating a new institutional mechanism effectively promoting growth of total factor productivity, high staff mobility and reducing the shortage of highly skilled workers.

The exposed clusters substantiate the impact of digitalization on improving the quality of human capital in the subjects of the RF which differ in the level of development of electronic infrastructure, social conditions and features of the business environment. Digital technologies support human development and provide competitive advantages for regions being the part of clusters with a high level of human capital development. The availability of highly developed human capital focused on certain areas makes possible to attract international investment in such regions and poses new challenges. This research project is aimed at studying regional human capital development strategies of domestic areas to find out how regional institutions respond to the challenges of the global economy. The results of the given study can serve as the guidelines for the formation of domestic regional cluster networks aimed at improving the international competitiveness of the RF subjects.

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| No | Subject of Russian Federation       | No | Subject of Russian Federation       |
|----|-----------------------------------|----|-----------------------------------|
| 1  | the Belgorod Region               | 43 | the Stavropol Region              |
| 2  | the Bryansk Region                | 44 | the Republic of Bashkortostan      |
| 3  | the Vladimir Region               | 45 | the Republic of Mari El           |
| 4  | the Voronezh Region               | 46 | the Republic of Mordovia          |
| 5  | the Ivanovo Region                | 47 | the Republic of Tatarstan         |
| 6  | the Kaluga Region                 | 48 | the Udmurt Republic               |
| 7  | the Kostroma Region               | 49 | the Chuvash Republic              |
| 8  | the Kursk Region                  | 50 | the Perm Territory                |
| 9  | the Lipetsk region                | 51 | the Kirov Region                  |
| 10 | the Moscow region                 | 52 | The Nizhny Novgorod region        |
| 11 | the Oryol Region                  | 53 | the Orenburg Region               |
| 12 | the Ryazan region                 | 54 | the Penza Region                  |
| 13 | the Smolensk region               | 55 | the Samara Region                 |
| 14 | the Tambov region                 | 56 | the Saratov Region                |
| 15 | the Tver region                   | 57 | the Ulyanovsk Region              |
| 16 | the Tula region                   | 58 | the Kurgan Region                 |
| 17 | the Yaroslavl region              | 59 | the Sverdlovsk Region             |
| 18 | the city of Moscow                | 60 | the Khanty-Mansijsk Autonomous District |
| 19 | the Republic of Karelia            | 61 | the Yamalo-Nenets Autonomous District |
| 20 | the Republic of Komi               | 62 | the Tyumen Region (not Autonomous District) |
| 21 | the Arkhangelsk region             | 63 | the Chelyabinsk Region            |
| 22 | the Vologda region                | 64 | the Republic of Altai             |
| 23 | the Kaliningrad region            | 65 | the Republic of Buryatia          |
| 24 | the Leningrad region              | 66 | the Republic of Tuva              |
| 25 | the Murmansk region               | 67 | the Republic of Khakassia         |
| 26 | the Novgorod region               | 68 | the Altai Territory               |
| 27 | the Pskov region                  | 69 | the Zabaikalye Territory          |
| 28 | the city of St. Petersburg         | 70 | the Krasnoyarsk Region            |
| 29 | the Adygeya republic              | 71 | the Irkutsk Region                |
| 30 | the Republic of Kalmykia           | 72 | the Kemerovo Region               |
| 31 | the Republic Of Crimea            | 73 | the Novosibirsk Region            |
| 32 | the Krasnodar region              | 74 | the Omsk Region                   |
| 33 | the Astrakhan region              | 75 | the Tomsk Region                  |
| 34 | the Volgograd region              | 76 | the Republic of Sakha (Yakutia)   |
| 35 | the Rostov region                 | 77 | the Kamchatka Region              |
| 36 | the city of Sevastopol             | 78 | the Primorye Territory            |
| 37 | the Republic of Dagestan           | 79 | the Khabarovsk Territory          |
| 38 | the Ingush Republic               | 80 | the Amur Region                   |
| 39 | the Kabardino-Balkar Republic      | 81 | the Magadan Region                |
| 40 | the Karachay-Cherkess Republic     | 82 | the Sakhalin Region               |
|   | the Republic Of North Ossetia-Alania | 83 | the Jewish Autonomous Region |
|---|-------------------------------------|----|----------------------------|
| 42 | the Republic Of Chechnya             | 84 | the Chukotka Autonomous District |