LIFE QUALITY AND HUMAN POTENTIAL OF TERRITORIES

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ASSESSMENT OF THE RELATIVE EFFECTIVENESS OF INCREASING LIFE EXPECTANCY IN RUSSIAN REGIONS: NONPARAMETRIC APPROACH

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Life expectancy is a key indicator of the quality of public administration and at the same time one of the goals of the national development. In conditions of limited budgetary resources and significant territorial differentiation of the socio-economic development of Russian regions, it becomes critically important to assess the effectiveness of the transformation of available regional resources into an increase in life expectancy. The pandemic crisis of 2020–2021 has actualized the need to identify sustainable models for increasing life expectancy in regions that demonstrate best management practices in the face of external shocks. Thus, the aim of the study is to assess the relative effectiveness of 79 regions of the Russian Federation in achieving high life expectancy over the period 2005–2023, to typologize them according to productivity dynamics and identify key trajectories of change. Using the DEA (Data Envelope Analysis) method, the relative efficiency coefficients of the regions were calculated; then, using the Malmquist index, the temporal dynamics was analyzed with a decomposition into a component of changes in efficiency and technological progress. It was revealed that 83.5% of regions are characterized by a simultaneous improvement in efficiency and technology, however, 16.5% of regions showed a decrease in efficiency with technological progress. We established that the long-term growth in life expectancy is due not only to the volume of resources, but also to the quality of management, a balance between the efficiency of using determinants and technological development,

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which determines the need for a differentiated demographic policy to ensure a sustainable increase in life expectancy throughout the country.

Life expectancy, DEA analysis, efficiency, region, Malmquist index, regional policy, typology of regions.

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Introduction

Demographic dynamics constitute one of the most sensitive indicators of a nation's socio-economic development, reflecting both the quality of life and the effectiveness of social policy. In present-day Russia, achieving higher life expectancy has been designated a strategic priority for national development. Under Presidential Decree 309 of May 7, 2024, "On the National Development Goals of the Russian Federation for the Period up to 2030 and the Long-Term Outlook up to 2036"[1], the attainment of specific life-expectancy targets serves as a key criterion for assessing the performance of government bodies at all levels.

Meeting this goal, however, encounters a number of systemic challenges. The Russian Federation is characterized by pronounced population aging, which places an increasing burden on the health and social security systems. High regional differentiation remains a major concern: the gap in life expectancy between the leading and lagging regions reaches ten years[2], pointing to unequal opportunities for citizens' health depending on their place of residence. The situation was further aggravated by the COVID-19 pandemic, which caused a substantial drop in life expectancy in 2020–2021, followed by a period of demographic recovery.

Given fiscal constraints and the need to optimize public spending, a simple, extensive path of increasing healthcare and social program funding is no longer the sole solution. There is a compelling need to shift the focus from the volume of resources spent to an assessment of how efficiently those resources are used. The critical question becomes not how much funding a region receives, but how effectively that funding is transformed into the preservation of human life and health.

Despite a vast body of research on mortality factors and life expectancy, existing studies are often limited to correlation analyses of the influence of socio-economic determinants on life expectancy, without addressing the key question of how efficiently regions transform their available resources – financial, human, and infrastructural – into population longevity. High spending does not always guarantee high life-expectancy indicators, which points to efficiency reserves within the system.

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[1] On the National Development Goals of the Russian Federation for the Period up to 2030 and the Long-Term Outlook up to 2036: Presidential Decree 309 of May 7, 2024. Available at: http://www.kremlin.ru/acts/bank/50542 (accessed: 27.03.2026).

[2] Calculated from the data of the Unified Interdepartmental Statistical Information System (EMISS). Available at: https://www.fedstat.ru/indicator/31293 (accessed: 12.03.2026).

In addition, a methodological limitation of many studies is the inertia inherent in demographic processes. Ignoring the time lags between resource allocation and the resulting demographic effect can distort efficiency assessments. Moreover, Russia's spatial landscape is highly heterogeneous in terms of economic scale, population density, geography, and climate. The use of methods that assume constant returns to scale is, in this case, inappropriate. There is a need for approaches that allow for variable returns to scale, which would make it possible to compare the efficiency of regions of a similar type and to avoid systematic errors in the assessment of both small and large federal subjects.

Accordingly, the aim of this study is to assess the relative efficiency of the regions of the Russian Federation in achieving high life expectancy over the period 2005–2023, using the non-parametric method of Data Envelopment Analysis (DEA), with a subsequent typology based on productivity dynamics and the identification of key trajectories of change.

The novelty of the study lies in its comprehensive approach to efficiency assessment. This approach includes accounting for regional heterogeneity through a model with variable returns to scale – which improves the quality of estimates for subjects with different population sizes – identifying the benchmark regions that form the "best-practice frontier" and assessing the degree of lag among inefficient subjects, and conducting a dynamic analysis of efficiency change based on the decomposition of the Malmquist index. This decomposition separates the contribution of technological progress (which reflects nationwide trends and federal initiatives) from that of local management efficiency (the "catch-up" effect). Such an approach subsequently allows for the development of differentiated regional policy recommendations that take into account both the reserves for internal improvement and the need to introduce advanced health-preservation technologies.

Theoretical review

Research into the factors that determine life expectancy rests on a number of established theoretical concepts that help explain both the historical dynamics of mortality and present-day interregional differences.

A key concept is the epidemiological transition theory, developed by A. Omran and later elaborated in the work of R. Rogers. According to this theory, the structure of morbidity and mortality shifts systematically in the course of socio-economic development: from a predominance of exogenous causes (infectious and parasitic diseases) to endogenous ones (cardiovascular and oncological diseases), and, at the current stage, to factors associated with lifestyle and the quality of medical care. This theory provides a rationale for the view that, in developed and transition economies, the key determinants of life expectancy are no longer so much sanitary and epidemiological safety as the level of development of the healthcare system, behavioral risks, and socio-economic conditions (Omran, 1971; Rogers, Hackenberg, 1987).

An important theoretical foundation is the concept of human potential and social capital, developed in the work of A. Sen and empirically embodied in the Human Development Index (HDI) of the United Nations Development Programme. This approach treats life expectancy not merely as a result of economic growth, but as an integral indicator of the quality of institutions, the accessibility of education and healthcare, and the level of social inequality. Research conducted within this paradigm demonstrates that achievements in life expectancy are determined by the set of opportunities available to the population, not only by the volume of resources at their disposal (Sen, 1999; Chatterjee, 2005).

In order to justify the application of efficiency analysis methods, an important role is played by the theory of resource efficiency in the social sphere, which adapts the microeconomic theory of production to the analysis of social systems. Within this theory, regions, countries, or social programs are treated as production units (decision-making units, DMUs) that transform multiple resources ("inputs") into demographic and social outcomes ("outputs"). This approach makes it possible to quantitatively assess how efficiently the resources used – healthcare financing, human resources, the population's income level – are converted into increased life expectancy and quality of life (Hashimoto, Ishikawa, 1993; Mariano, Rebelatto, 2014).

From this perspective, it is useful to draw on the concept of "health production" developed by M. Grossman (Grossman, 1972). According to this concept, health is viewed not as an exogenous biological given but as a form of capital that is accumulated and maintained over the life course through the investment of time, financial resources, medical services, education, and behavioral practices. Grossman formalized this process through a health production function in which "healthy time" is the output and various resources serve as input factors. In a macro- and regional context, life expectancy can be interpreted as the cumulative result of demographic development – that is, as a measurable output of a production process carried out by the healthcare system, the socio-economic and institutional environment, and the behavior of the population as a whole (Volkova, Volkova, 2024).

The contemporary scholarly literature identifies several groups of factors that exert a significant influence on life expectancy, while recognizing that their contribution varies considerably depending on a country's level of development and its regional specificities. The influence of healthcare factors on life expectancy has been widely covered in the literature. Numerous studies confirm the importance of the availability of medical personnel and hospital beds. In a study by L. Asandului and co-authors, based on an analysis of 30 European countries, it was shown that the number of physicians and hospital beds per capita, together with public health expenditure, are significant input variables that determine the efficiency of healthcare systems in achieving high life expectancy and low infant mortality (Asandului et al., 2014). At the same time, the literature points to the non-linearity of this relationship: once a certain saturation threshold is reached, an increase in the number of beds and physicians ceases to yield a commensurate gain in life expectancy, indicating an effect of "excess capacity" (Cetin, Bahce, 2016).

Socio-economic conditions are likewise key determinants of demographic well-being, as confirmed by studies demonstrating a stable link between income inequality, poverty levels, and mortality. Thus, an empirical analysis of 28 developed countries conducted by E. Neumayer and T. Plümper showed that market-income inequality is positively correlated with inequality in life expectancy, whereas income redistribution through the fiscal system helps reduce disparities in longevity (Neumayer, Plümper, 2016). Similar results were obtained in a study by R. Rogers and co-authors, which established that differences in education, income, and employment mediate a substantial part of the educational gradients in adult mortality (Rogers et al., 2013).

Behavioral patterns and environmental conditions have a substantial impact on mortality. Alcohol-related mortality is of particular significance for Russia. Studies by

A.V. Nemtsov and A.T. Terekhina confirm that a high level of alcohol consumption, especially in the form of strong spirits, makes a decisive contribution to excess mortality among working-age men (Nemtsov, Terekhina, 2007). For this reason, indicators such as mortality from accidental alcohol poisoning are often used in models for assessing the efficiency of regional demographic policy, serving as a proxy variable for the prevalence of risky behavior (Timonin et al., 2016).

The influence of urbanization on life expectancy is ambiguous. On the one hand, urbanization provides better access to specialized medical care and social services. On the other hand, the urban environment is associated with elevated stress levels, air pollution, and the prevalence of behavioral risks. Empirical research for China, conducted using geographically weighted regression, has confirmed that the contribution of urbanization to life expectancy varies across space and over time, which makes it necessary to take regional specificities into account when formulating public demographic policy measures (Jiang et al., 2018).

The specificities of Russian regions call for a separate examination in the context of the present study. Russia is characterized by significant disparities between central and peripheral territories – a particularly distinctive situation has taken shape in the North Caucasus, where high life expectancy is traditionally recorded alongside relatively low economic indicators – as well as by specific challenges facing the regions of the Far East and the Arctic, associated with extreme climatic conditions and low population density (Shchur, Timonin, 2020; Rodionova, Kopnova, 2020; Trofimova et al., 2023).

The need to assess the efficiency of regional socio-economic systems in achieving high life expectancy is thus driven by several key factors. First, the resources channeled into healthcare, social policy, and human capital development are invariably limited, which demands that they be used as productively as possible. Second, the existence of substantial interregional differentiation in life-expectancy indicators across Russia points to heterogeneity in conditions and management practices, making it imperative to identify leading regions and to disseminate their experience. Third, efficiency assessment not only makes it possible to rank territories but also to establish quantitative target benchmarks for inefficient regions, showing what outcomes can be achieved with the existing level of resource provision (Mariano et al., 2015; Storto, 2020). The application of efficiency measurement methods thus serves as a tool for informing managerial decisions aimed at improving the quality of life and reducing spatial inequality.

A broad range of methodological approaches is employed in international practice to assess the efficiency of social progress and development:

1. Multidimensional indices, such as the Human Development Index (HDI), which combines indicators of health, education, and income (Herrero et al., 2010). Despite their visual appeal, these indices do not make it possible to assess the resource efficiency of the outcomes achieved.

2. Index-based methods and principal component analysis, used to construct aggregated indicators of social well-being (England, 1998). These methods allow information to be condensed but do not provide insights into the "inputs" and "outputs" of the process.

3. Dynamic productivity indices, above all the Malmquist index, which decomposes performance change into technical efficiency change and technological change (Pastor, Lovell, 2005; Färe et al., 1994). This approach is valuable for analyzing changes over time, but does not yield a static assessment of efficiency at a particular point in time.

4. Parametric methods of Stochastic Frontier Analysis (SFA), which account for random error and require the specification of a functional form (Coelli et al., 2005).

5. Non-parametric methods of Data Envelopment Analysis (DEA), which make it possible to assess the relative efficiency of decision-making units without assumptions about the functional form (Charnes et al., 1978; Banker et al., 1984).

Each group of methods has its own advantages and limitations. Parametric methods (SFA), for instance, have the advantage of being able to account for stochastic error, which makes it possible to separate inefficiency from random shocks. Their application in the analysis of social systems, however, is constrained by the need for a rigid specification of the functional form of the production function, which can lead to specification errors when analyzing complex, multi-component processes (Coelli et al., 2005).

The present study gives preference to the non-parametric DEA method, which was originally proposed by A. Charnes, W. Cooper, and E. Rhodes (Charnes et al., 1978) and later modified by R. Banker, A. Charnes, and W. Cooper to account for variable returns to scale (the BCC model) (Banker et al., 1984). The DEA method makes it possible to assess how efficiently given input resources are transformed into socially meaningful outputs without the need to set price or a priori weighting parameters, which is particularly important for intangible and multi-criteria social indicators. Although the method was initially designed for the market sector, its adaptation to healthcare, education, and demographic research is methodologically well founded and has been confirmed by an extensive body of empirical literature (Kohl et al., 2019; Emrouznejad, Yang, 2018). When the model is correctly specified, DEA demonstrates high relevance for the analysis of social production processes, thereby making it possible to move from a descriptive assessment of demographic indicators to the measurement of how effectively resources are used in achieving socio-demographic goals.

The choice of DEA is thus dictated by the following characteristics of the method: first, its ability to handle multiple input and output variables without reducing them to a common unit of measurement; second, the absence of any need to assign weights a priori; and third, the capacity to identify benchmark regions for inefficient units.

The application of DEA in Russian research on social efficiency is represented by a number of studies. In the work of M.V. Bikeeva and co-authors, the DEA method was used to analyze the effectiveness of the implementation of the "Demography" national project (Bikeeva, Sysoeva, 2023). At the same time, M.V. Frants emphasizes the need to take spatial effects into account when assessing the efficiency of regional healthcare systems, since the results of neighboring regions can influence the achievements of a particular subject (Frants, 2025).

A specific methodological problem when modeling the determinants of life expectancy is the presence of time lags. Demographic processes are highly inertial: investments in healthcare, education, and social infrastructure do not lead to an immediate change in mortality indicators. The effect of investment in healthcare fixed assets or in prevention programs materializes with a time lag that can range from several years to a decade (Poças et al., 2020).

Existing studies employ various approaches to accounting for lags: the inclusion of lagged values of input variables in the model, the use of distributed lags, and panel data aggregation. However, including lagged variables in a standard DEA model increases the dimensionality of the input space, which, given a limited number of observation units (regions), reduces the discriminatory power of the method and can lead to an unreasonably high number of efficient regions (Marshall, Shortle, 2005; Despotis, 2005). A critical review of alternative methods – dynamic DEA, window analysis, the use of lags as part of inputs – shows that they either do not solve the problem of accounting for the inertia of demographic processes in a static model or lead to a loss of degrees of freedom and a decline in the reliability of the results.

The application of DEA analysis to demographic research, therefore, runs into the problem of accounting for time lags while preserving the discriminatory power of the model, which rules out the mechanical inclusion of multiple lagged variables. For this reason, the Malmquist index (MI) is used within the present approach to analyze the dynamics of efficiency over time. The MI makes it possible to decompose efficiency change into two components: technical efficiency change (catch-up effect, EC) and technological change (frontier shift, TC) (Färe et al., 1994). In the context of demographic analysis, the EC component is interpreted as the ability of regions to catch up with the leaders by improving the use of existing resources, while the TC component is seen as the result of the introduction of new medical technologies, the digitalization of healthcare, and improvements in prevention and treatment methods. Such a decomposition analysis provides a deeper understanding of the sources of life expectancy growth than a static efficiency assessment (Briec et al., 2013).

Data and methods

The empirical basis of the study consists of official data from the Federal State Statistics Service (Rosstat) for the period 2005–2023, organized as a panel database. The initial set of variables included 50 socio-economic indicators reflecting the key determinants of public health and living conditions. To ensure the methodological validity of the analysis, which depends critically on the homogeneity of the sample and the completeness of the time series, regions with incomplete or incomparable data were excluded from the set of objects. In particular, the following were removed from the analysis: the Chechen Republic, the Republic of Crimea, the City of Sevastopol, as well as subjects with a complex administrative structure that includes autonomous areas (the Arkhangelsk Region excluding the AA; the Nenets Autonomous Area; the Khanty-Mansi Autonomous Area – Yugra; the Yamal-Nenets Autonomous Area; and the Tyumen Region excluding the AA). This filtering was prompted by the need to minimize statistical noise and gaps in reporting, thereby ensuring the correctness of the comparative efficiency assessment.

The methodology of Data Envelopment Analysis (DEA) is a non-parametric approach to assessing the relative efficiency of homogeneous decision-making units (DMUs) that use multiple inputs to produce multiple outputs. Unlike stochastic frontier models, DEA does not require the a priori specification of the functional form of the production frontier, constructing it empirically on the basis of best practices in the sample (Charnes et al., 1978). The basic CCR model, proposed by A. Charnes, W. Cooper, and E. Rhodes, assumes constant returns to scale (CRS). For the analysis of socio-economic systems such as regions, however, it is more appropriate to use the BCC model with variable returns to scale (VRS), developed by R. Banker and co-authors, which makes it possible to separate technical efficiency from scale efficiency (Banker et al., 1984). To assess productivity dynamics over time, the Malmquist index is used, which allows the decomposition of total productivity change into its components:

efficiency change and technical change (Färe et al., 1994).

In the present study, a panel DEA model was constructed to assess the efficiency of the regions of the Russian Federation in raising the life expectancy of the population. The specification of the model is determined by the goal of maximizing the target indicator for a given set of socio-economic conditions, as well as by the heterogeneity of the regions and the need to assess efficiency relative to the local production possibility frontier.

From a mathematical point of view, the DEA model is a linear programming problem. Suppose there are *N* regions (decision-making units, DMUs), each of which uses *M* types of resources (inputs *xij*) to produce *K* outputs (outputs *yrj*) (1):

$$\min_{\theta,\lambda} \theta$$

subject to:

$$\sum_{j=1}^{N} \lambda_j y_{rj} \geq y_{ro}, r = 1, \dots, K(\text{output constraints});$$

$$\sum_{j=1}^{N} \lambda_j x_{ij} \leq \theta \cdot x_{io}, i = 1, \dots, M(\text{input constraints});$$

$$\sum_{i=1}^{N} \lambda_j = 1(\text{convexity condition / VRS});$$

where

θ is the scalar efficiency score ($0 < \theta \leq 1$); a value of $\theta = 1$ indicates that the region lies on the efficiency frontier;

λ_j is a vector of weights that identifies the benchmark region for an inefficient unit;

the constraint $\sum \lambda_j = 1$ ensures variable returns to scale, making it possible to separate pure technical efficiency from scale efficiency.

Life expectancy at birth was chosen as the sole output parameter. The selection of input variables was carried out through a multi-stage procedure designed to strike a balance between the explanatory power of the model and the preservation of its discriminatory capacity. To ensure content validity, the strength of the linear association between each indicator and the target variable was first assessed using Pearson's correlation coefficient; only statistically significant predictors were included in further analysis. A key constraint was the requirement that there be no multicollinearity among the input factors, since high inter-factor correlation distorts the weights in the DEA model. To address this, a greedy selection algorithm was applied: the variables were ranked in descending order of their correlation with the target variable and then sequentially added to the model on the condition that their correlation with the already selected factors did not exceed a threshold value of 0.7.

At the final stage, three alternative sets of input variables were formed (with 7, 8, and 10 factors). To verify the absence of multicollinearity in each specification, the variance inflation factor (VIF) was calculated. The diagnostic analysis confirmed the statistical admissibility of all three variants: the maximum VIF values were 2.73, 3.79, and 4.10, none of which exceeded the critical threshold of five. The specification with eight factors (max VIF = 3.79, mean VIF = 2.21) was chosen for the main analysis. This choice stems from the search for an optimal compromise between statistical reliability and the substantive completeness of the model: the eight-factor specification preserves a sufficient margin of robustness while, at the same time, providing a more comprehensive description of socio-economic conditions than the minimalist model.

The final input group comprises eight selected indicators:

X1 – number of mid-level medical personnel per 10,000 population;

X2 – mortality from diseases of the circulatory system, per 100,000 population;

X3 – spending from the budgets of territorial compulsory health insurance funds, million rubles;

X4 – share of the working-age population, %;

X5 – poverty rate, %;

X6 – retail trade turnover per capita, rubles;

X7 – mortality from road traffic accidents, per 100,000 population;

X8 – mortality from external causes, per 100,000 population.

Thus, the resources of regional systems for increasing life expectancy can be identified as: (a) the supply and accessibility of healthcare services (X1, X2, X3); (b) the standard of living (X5, X6); and (c) lifestyle and self-preservation behavior (X4, X7, X8).

The use of cause-specific mortality indicators is justified by the fact that they serve not as "explanations by the thing itself" but as integral indicators of the effectiveness of regional socio-economic systems in the context of raising life expectancy (Ivanova et al., 2024). This represents an important diagnostic finding, confirming that regional differences in life expectancy depend not only on socio-economic and institutional conditions but are also channeled through a limited number of causes of excess mortality that exert the greatest influence on overall population mortality.

Given the heterogeneous nature of the variables – where indicators X3 and X6 exert a positive influence on the target variable (resource provision), while the remaining ones exert a negative influence (morbidity, pollution) – an inversion procedure was applied to the positive factors in order to comply with the monotonicity axiom of DEA. The choice of an output-oriented model is justified by the fact that, for regions, the priority task is to maximize life expectancy for the existing level of socio-economic development. The model was estimated under the assumption of variable returns to scale (VRS) in order to take regional heterogeneity into account.

As a result of the calculations, the following metrics were obtained for each region and year: efficiency scores, which make it possible to identify the leaders on the efficiency frontier; target values and slacks, which show the deviation of the current level of life expectancy from the efficient level; and lambda weights, which define the reference group (benchmark regions) for inefficient regions.

Within the DEA methodology, the *Malmquist Productivity Index* (MPI) was calculated to assess productivity dynamics over time, with decomposition into the *efficiency change* (EC) component and the *technical change* (TC) component (Färe et al., 1994).

The Malmquist index for a particular region between periods *t* and *t*+1 is calculated using the formula:

$$M_O^{t,t+1} = \underbrace{\frac{D_O^{t+1}(x^{t+1},y^{t+1})}{D_O^{t}(x^{t},y^{t})}}_{\text{Efficiency Change (EC)}} \times \underbrace{\left[\frac{D_O^{t}(x^{t+1},y^{t+1})}{D_O^{t+1}(x^{t+1},y^{t+1})} \times \frac{D_O^{t}(x^{t},y^{t})}{D_O^{t+1}(x^{t},y^{t})}\right]^{1/2}}_{\text{Technological Change (TC)}}, \quad (2)$$

where

$D_O^t(x^t, y^t)$ is the distance function (the reciprocal of the efficiency score θ), calculated relative to the technology of period *t* for observations from period *t*;

$D_O^t(x^{t+1}, y^{t+1})$ is the distance function for observations from period *t* + 1, calculated relative to the technology of period *t* (a mixed-period measure).

An index value above one indicates productivity growth, while a value below one signals a decline. In the context of this study, MPI productivity is understood as the ability of a regional system to deliver an increase in life expectancy. It consists of the efficiency of using the available resources (EC), described by variables X1–X8, and technological progress (TC), which reflects the expansion of the system's capabilities – for instance, through the introduction of technological or managerial innovations.

With the aim of producing an integral assessment of each region's dynamics, the accumulated (geometric mean) values of the MPI and its components were calculated over the entire study period. Using the combination of the EC and TC component values, a typology of regions by source of life expectancy growth is proposed. To analyze the temporal stability of development trajectories, the number of years each region fell into a given type during the observed period was also assessed. This level of detail made it possible to move from merely registering changes in efficiency to assessing the stability of regional policies: identifying stable leaders provides a basis for replicating best practices, while identifying volatile regions grounds the need for a systematic analysis of the causes of instability.

All computational procedures, including the calculation of efficiency scores and the Malmquist index, were implemented in the statistical programming environment R, version 4.3.2. The packages *Benchmarking* (for DEA models) and *prodlim* (for the Malmquist index) were used. The application of these specialized packages provided the necessary flexibility when working with panel data and ensured the reproducibility of the study's findings.

At the same time, the present study has a number of limitations that should be taken into account when interpreting the results. First, an assumption of a zero time lag was employed. In the model, the current year's resources were matched with life expectancy for the same period, which is justified by the nature of life expectancy as an indicator that is sensitive to current conditions. The use of single-year variables is also consistent with the annual cycle of budget planning and monitoring of the effectiveness of regional programs and is widely applied in empirical DEA research on the social sphere and healthcare, where the focus is shifted to assessing the current technical efficiency of resource use (Emrouznejad, Yang, 2018; Kohl et al., 2019). Undoubtedly, some of the input indicators (for instance, healthcare indicators) may have a prolonged effect; however, introducing arbitrary lags without a theoretically grounded delay length for each resource, and under the conditions of the structural changes of recent years, could introduce additional specification error and reduce the sample size.

Second, the assessment of regional efficiency was performed without taking spatial dependence into account. The classic DEA model identifies benchmarks based on the structural similarity of parameters, not geographic proximity, which makes it possible to assess the internal efficiency of resource use. Accounting for interregional influence requires the calibration of a spatial weights matrix and the application of specialized methods (Spatial DEA), which lies beyond the scope of this study.

Third, the study relies on deterministic efficiency estimates within the framework of the classic DEA model, which assumes the absence of a stochastic component in the formation of the production possibility frontier. Thus, the obtained efficiency scores are not accompanied by confidence intervals. Bootstrapping, which provides statistical inference in DEA, was not applied owing to the study's focus on comparative typologization rather than on the testing of statistical hypotheses. A systematic analysis of the determinants of efficiency and the profiling of clusters using external socio-economic determinants (GRP, institutional indicators, human capital) with the application of econometric methods (spatial models, Tobit regression) constitutes a self-contained task, the solution of which is planned as a continuation of the research.

Results and discussion

The dynamics of life expectancy in Russian regions over the period 2005–2023 were characterized by a lengthy stage of growth, a subsequent structural shock, and an accelerated post-crisis recovery *(Fig. 1)*. Over fourteen years, average life expectancy rose from 64.4 years in 2005 to 72.4 in 2019, reflecting a systemic improvement in socio-economic conditions and the quality of life of the population, including the enhanced effectiveness of the healthcare system. In the pandemic period of 2020–2021, however, the average life expectancy fell dramatically to 69.3 years (a decline of 3.1 years) owing to excess mortality, both directly from COVID-19 and as a result of the overload on the healthcare system during that period and the substantial reduction in the accessibility of medical services for the population. The following two years, nonetheless, demonstrated the regions' high resilience to this type of challenge: thanks to compensatory mechanisms and the normalization of the epidemiological situation, the indicators returned to pre-crisis levels, and in 2023 the average life expectancy stood at 72.3 years.

Despite the nationwide trend toward rising life expectancy, a significant differentiation among Russian regions persists with respect to this indicator, and it shows no signs of substantial convergence throughout the entire period under review. The interquartile range, which reflects the variability of values within the core set of regions, has remained stable within 5–7 years, while the gap between the maximum and minimum values reaches 10–13 years – something that is obviously linked both to the socio-economic inequality of the regions and to inequalities in the quality of managing socio-demographic processes.

The DEA analysis showed that, on average over the observed period, 29% of the regions lay on the efficiency frontier; in the inefficient regions, life expectancy was, on average, four years lower – that is, with better resource utilization, the inefficient regions could have raised the population's life expectancy by an average of 6% *(Fig. 2)*.

These indicators are unstable over time, however. A gradual improvement was observed

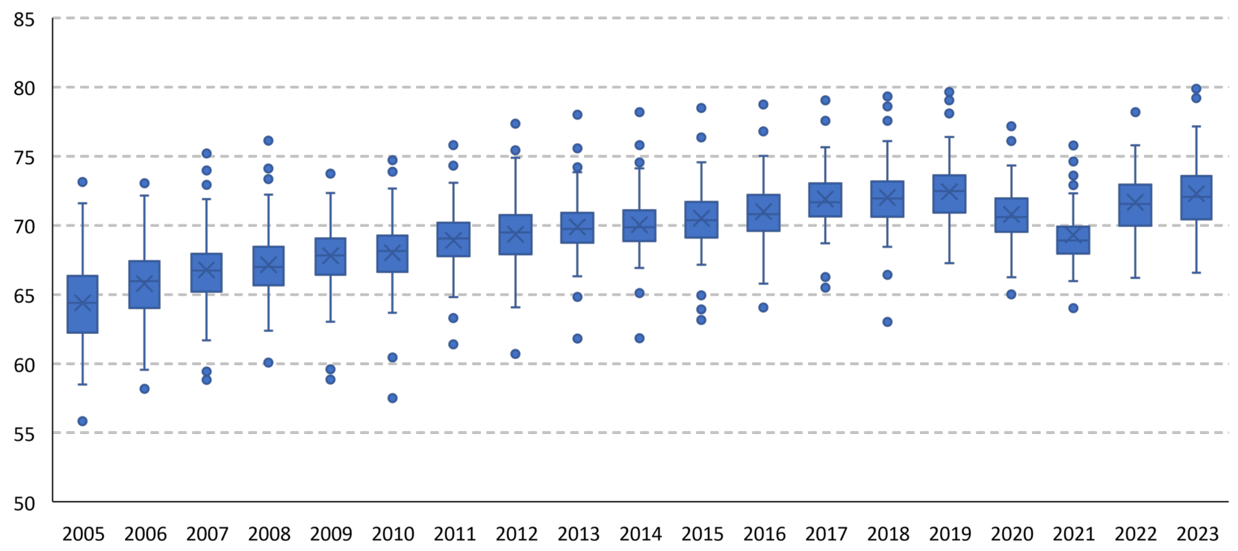

Figure 1. Dynamics of life expectancy in Russian regions, 2005–2023

Calculated from: Regions of Russia. Socio-Economic Indicators. 2025.
Available at: https://rosstat.gov.ru/folder/210/document/13204 (accessed: January 29, 2026).

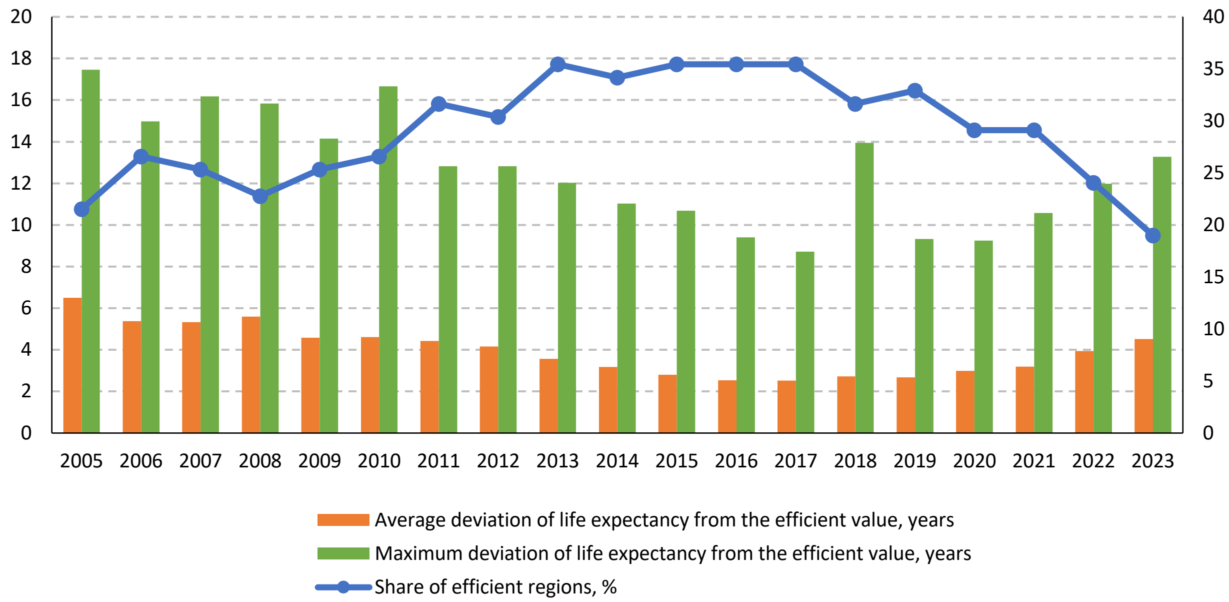

Figure 2. Average efficiency scores of Russian regions in raising population life expectancy, 2005–2023, based on DEA analysis

Calculated from: Regions of Russia. Socio-Economic Indicators. 2025. Available at: https://rosstat.gov.ru/folder/210/document/13204 (accessed: January 29, 2026).

up to 2017, after which the trend reversed: the share of efficient regions declined substantially, and both the average and the maximum deviation of life expectancy values from the efficient level began to increase, indicating a growing disparity in demographic processes among Russian regions that began during the pandemic and has continued in subsequent years.

Throughout the entire period 2005–2023, only six regions lay on the efficiency frontier every year: the City of Moscow, the Moscow Region, the Krasnodar Territory, the Republic of Tatarstan, the Republic of Dagestan, and the Republic of Ingushetia. Clearly, these are four regions with the most favorable socio-economic situation and a developed healthcare system, as well as two regions where high life expectancy stems from entrenched genetic and socio-cultural specificities, which determines their leading positions.

The least efficient regions over the period under review were the Far Eastern regions (the Jewish Autonomous Region, the Amur and Magadan regions, the Khabarovsk and Primorye territories), where more efficient resource use could have raised life expectancy by 8–10 years, as well as a number of Siberian regions (the Irkutsk Region, the Komi Republic, the Republic of Buryatia, the Republic of Sakha (Yakutia), the Krasnoyarsk Territory), where the effect could have amounted to 7–8 years *(Fig. 3)*.

The application of the DEA methodology made it possible to identify ten benchmark regions – the Vologda, Volgograd, Kaliningrad, Vladimir, Kaluga, Leningrad, Voronezh, and Kostroma regions, the Karachayevo-Circassian Republic, and the Kamchatka Territory – that form the efficiency frontier in the space of socio-economic determinants of life expectancy and can serve as benchmarks for other regions in the task of effectively raising the population's life expectancy. A comparative analysis showed that, when self-preservation practices are comparable, belonging to the group of benchmarks is associated with statistically significantly lower values of healthcare accessibility *(Table)*. In this case, however, it is

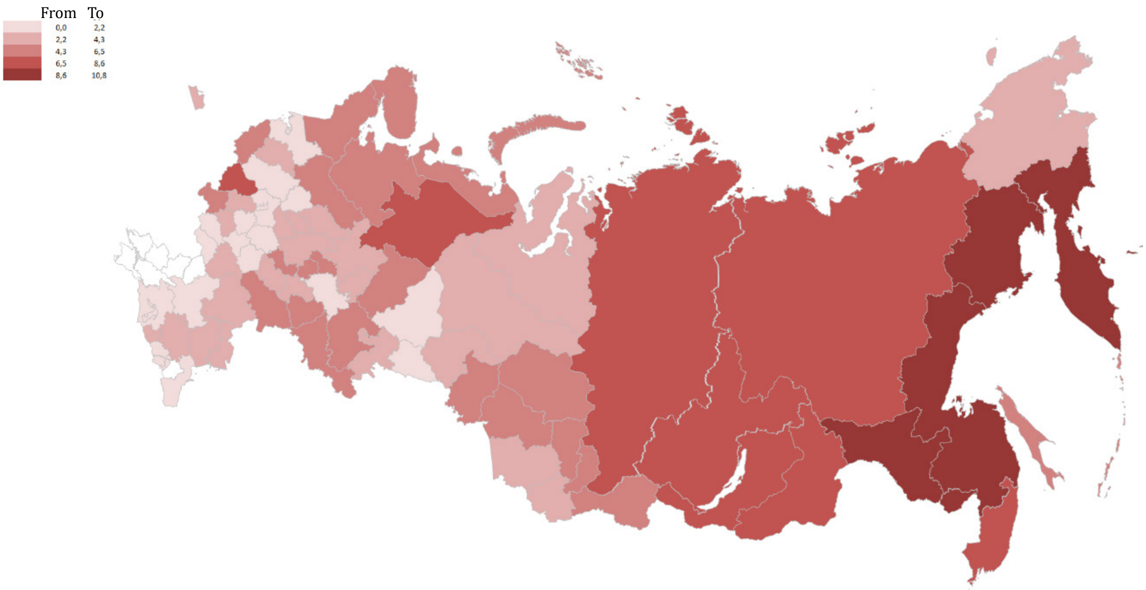

Figure 3. Deviation of life expectancy from the efficient level in Russian regions, average for 2005–2023**

Calculated from: Regions of Russia. Socio-Economic Indicators. 2025.
Available at: https://rosstat.gov.ru/folder/210/document/13204 (accessed: January 29, 2026).

Table. Ratio of the mean values of life expectancy determinants in the benchmark regions and the other regions (differences are statistically significant at p < 0.05)

"Resource" indicator*		Benchmark regions	Other regions	Deviation
Number of mid-level medical personnel, per 10,000 people	X1	102.83	112.69	-9.86
Mortality from diseases of the circulatory system, per 100,000 people	X2	776.16	700.43	75.73
Spending from the budgets of territorial compulsory health insurance funds, million rubles	X3	10951.45	19106.82	-8155.37
Poverty rate, %	X5	14.54	15.29	-0.75
Retail trade turnover per capita, rubles	X6	135315.98	148588.56	-13272.58
Mortality from road traffic accidents, per 100,000 people	X7	21.12	19.51	1.61
Mortality from external causes, per 100,000 people	X8	138.61	152.94	-14.33

* For the indicator "Share of the working-age population," the differences between the benchmark regions and the other regions are not statistically significant.
*Calculated from: Regions of Russia. Socio-Economic Indicators. 2025. Available at: https://rosstat.gov.ru/folder/210/document/13204 (accessed: January 29, 2026).

more appropriate to conclude that higher and more efficient indicators of life expectancy and health require a smaller volume of medical care, which is what the statistical data reflect.

At the same time, the heterogeneity identified among the benchmarks (the coefficient of variation across factors ranged from 15 to 45%) points to a multiplicity of optimal configurations of socio-economic factors for achieving high efficiency in the healthcare system. For instance, the Karachayevo-Circassian Republic is characterized by the optimal use of minimal resources; the Leningrad Region achieves high life-expectancy indicators thanks to a higher standard of living, which compensates for the relatively higher values of avoidable mortality (from road traffic accidents and external causes); the Kaliningrad and Kaluga regions show average life expectancy with an average level of resources; and the Kamchatka Territory demonstrates that, even with low life expectancy, a region can be efficient relative to its own capacity to shape it.

It should be noted separately that the leading regions in terms of DEA efficiency do not belong to the group of benchmark regions. From the standpoint of the DEA methodology, this result indicates that efficiency is not identical to being a benchmark. A region can be efficient without, however, serving as a useful reference point for others, because of incomparable scale (the City of Moscow), specific contextual features (the republics of the North Caucasus), or a unique combination of factors (the Republic of Tatarstan, the Krasnodar Territory). The ten benchmark regions listed above thus represent an "attainable ideal" – that is, they use effective practices that can be adapted and introduced in other regions – whereas the formal leaders with an efficiency score of 1 may represent an "unattainable ideal", useful for understanding the limits of what is possible but not for practical emulation. The lack of overlap between these two groups indicates that the most efficient regions achieve their results through unique, non-replicable mechanisms, while the regions that serve as practical benchmarks demonstrate efficiency through the optimization of available resources under conditions that are relevant for the majority of the subjects of the Russian Federation.

In addition to the static analysis, the dynamics of the efficiency of raising life expectancy in the regions of the Russian Federation over the period 2005–2023 were analyzed using the Malmquist index (MPI) and its decomposition into the efficiency change (EC) and technical change (TC) components. This analysis revealed a stable positive trajectory in life expectancy improvement, while substantial regional differentiation persists.

The cumulated Malmquist index across the entire set of regions stood at 1.0784, which attests to a cumulated productivity growth[3] of the regional systems in raising the population's life expectancy of 7.84% relative to 2005, with the "catch-up" effect serving as the main source of this growth: the efficiency change component (EC = 1.0417) made a larger contribution to the overall dynamics than did technical change (TC = 1.0352), indicating that processes of optimizing the use of available socio-economic resources have predominated over the expansion of the technological frontier of the possibilities for raising the population's life expectancy *(Fig. 4)*.

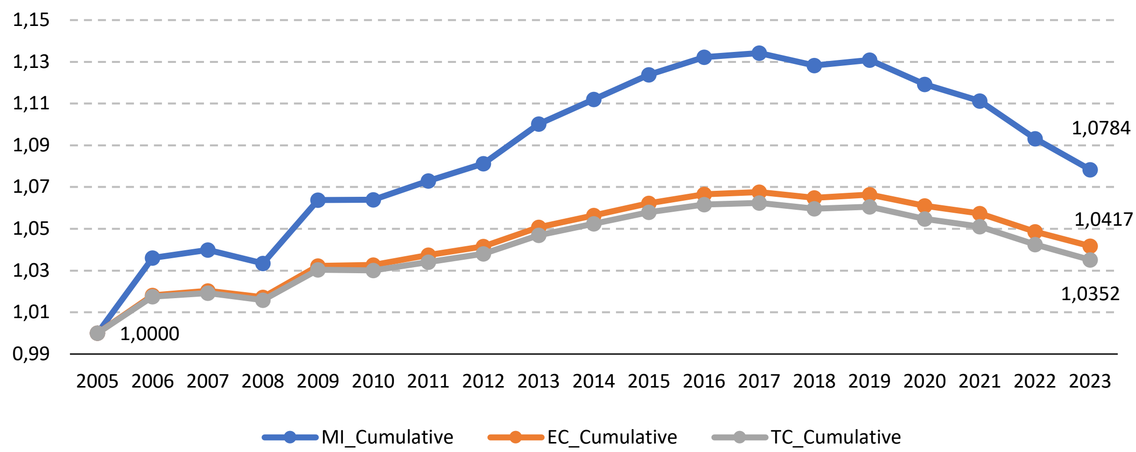

Figure 4. Dynamics of the cumulated Malmquist index and its components for Russian regions, 2005–2023 (2005 = 1)

Calculated from: Regions of Russia. Socio-Economic Indicators. 2025.
Available at: https://rosstat.gov.ru/folder/210/document/13204 (accessed: January 29, 2026).

[3] It should be recalled that, in the present study, MPI productivity is understood as the ability of a regional system to deliver an increase in life expectancy.

It is evident that the Malmquist index showed a tendency to decline during the pandemic period, which corresponds to the fall in life expectancy at that time. It should be noted, however, that the recovery-driven rise in the population's life expectancy in 2022–2023 was not supported by an improvement in the performance of the regional systems – the annual values of the MPI, EC, and TC have all been below one since 2020, pointing to a deterioration both in the efficiency of the regional systems themselves and in the contraction of the technological and institutional opportunities for raising life expectancy. Yet the ability of the majority of regions to preserve the cumulated positive effect over the entire observation period testifies to the existence of adaptive capacity and institutional resilience.

A structural analysis of the distribution of Russian regions across the quadrants of the matrix formed by efficiency change (EC) and technical change (TC) shows that all regions are characterized by technological growth – that is, at the national level, an improvement is observed in the institutional and infrastructural conditions that support higher life expectancy (TC > 1). At the same time, four qualitatively distinct trajectories for raising the population's life expectancy can be identified, each characterized by a unique combination of managerial and infrastructural determinants *(Fig. 5)*.

The first group – "growth driven by efficiency" – encompasses 39 regions (49.4% of the sample) and represents a model of balanced development in which the improved utilization of existing resources serves as the dominant factor in raising life expectancy. These regions are characterized by the efficiency component exceeding the technical change component (EC > TC) while both indicators are positive, which attests to the priority given to organizational innovations in healthcare management, improvements in the quality of life, and the formation of stable patterns of self-preservation behavior. The mean value of the Malmquist index in this group is 1.122, indicating the highest rates of productivity growth among regional socio-economic systems in converting the resources they use into increases in the population's life expectancy. The regions in this category demonstrate that, even with a relatively lower standard of living and high avoidable mortality, it is possible to achieve meaningful demographic results through high-quality management and the introduction of effective organizational practices, making their experience a priority for replication.

The second group – "growth driven by technology" – includes 27 regions (34.2%) and reflects a development model in which the main contribution to the dynamics of life

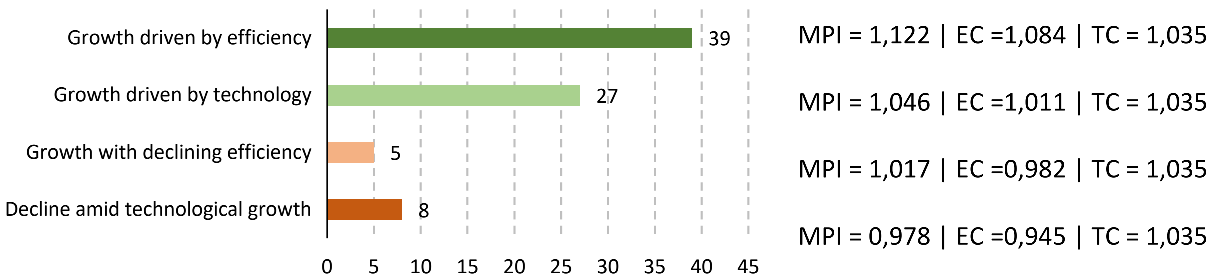

Figure 5. Distribution of regions by type of life-expectancy efficiency dynamics in Russian regions, 2005–2023

Calculated from: Regions of Russia. Socio-Economic Indicators. 2025. Available at: https://rosstat.gov.ru/folder/210/document/13204 (accessed: January 29, 2026).

expectancy comes from the technical change component, which exceeds the catch-up effect (TC > EC). The efficiency of resource use remains at a stable level (EC ⩾ 1) but does not serve as a driver of growth. The mean value of the Malmquist index in this group is 1.046, which is somewhat below the indicators of the first category and points to the existence of reserves for improving the returns from the healthcare system and further raising the standard of living through the improvement of management processes.

The third group characterized by productivity growth with declining efficiency is represented by five regions (6.3%) and reflects a situation in which the development of infrastructural and institutional capacity does not compensate for the deterioration in the quality of resource use. Formally, the Malmquist index in this group remains above one (the mean value is 1.017), but this is achieved exclusively through the positive contribution of the technical change component, whereas efficiency exhibits negative dynamics (EC < 1). Such a trajectory signals imbalances in the management system: possible causes include a decline in the accessibility of medical services for certain population groups, the insufficient development of prevention programs, or staffing imbalances in the healthcare system. The key risk of this model lies in its unsustainability: when the potential for infrastructural growth is exhausted, life expectancy may begin to decline, since the organizational foundation of the regional system does not ensure the conversion of resources into demographic outcomes.

The fourth and most problematic group – "decline amid technological growth" – encompasses eight regions (10.1%) and reflects a critical situation in which the negative dynamics of resource-use efficiency completely offset the positive effect of infrastructural development. The mean Malmquist index in this category is 0.978, which points to a cumulative decline in the productivity of the regional socio-economic systems in this group in the sphere of raising life expectancy relative to the base period. These territories are characterized by systemic management problems: the inefficient use of healthcare-system resources against a background of an average standard of living and a high prevalence of self-preservation behavior. Despite the formal presence of technological progress (TC > 1), its potential is not realized owing to organizational barriers, which leads to the stagnation or decline of life expectancy.

A supplementary analysis of the stability of regional trajectories, based on an assessment of the frequency with which regions fell into the favorable quadrants of the EC/TC matrix (the first and second groups) throughout the entire observation period, reveals substantial heterogeneity not only in the levels but also in the stability of the results achieved. Only 39.2% of the regions exhibit a stable positive dynamic, with an average frequency of falling into the full-growth quadrant exceeding 55%, whereas the overwhelming majority of subjects (60.8%) are characterized by volatile trajectories, in which periods of improved efficiency and technological progress alternate with phases of regression, which reduces the average stability to 40.1%. The instability of managerial decisions, or dependence on conjunctural factors, thus creates additional risks and reduces the predictability of demographic outcomes. At the same time, the regions that are leaders in terms of stability (the Kirov and Kostroma regions, the Krasnodar Territory, and the republics of Tatarstan and Dagestan) demonstrate that long-term growth in life expectancy is secured not by one-off achievements but by the ability of a regional system to maintain a balanced dynamic of the efficiency and technological development components over a long period.

Conclusion

The study of the efficiency of raising life expectancy in the regions of the Russian Federation over the period 2005–2023, conducted on the basis of the DEA methodology and the Malmquist index, has yielded comprehensive findings of both theoretical and practical significance for regional policy in the sphere of increasing the population's life expectancy.

Summarizing the results of the study, it can be stated that the DEA methodology makes it possible to assess the efficiency of regional socio-economic systems in raising the population's life expectancy using non-parametric methods, treating the regions themselves as production units that transform resources into demographic outcomes, and taking into account both the limited nature of the resources themselves and the high interregional differentiation of the socio-economic characteristics of Russia's regions. This method enables work with multiple inputs and outputs without a priori assumptions about the functional form of the production function, the construction of relative efficiency on the basis of an empirical production possibility frontier, the identification of leading regions and regions requiring improvement, and the decomposition of the sources of inefficiency.

A statistical analysis of various indicators of the socio-economic development of Russian regions for 2005–2023 made it possible to select eight of them as input variables for the DEA analysis. These reflect the accessibility of healthcare services, the standard of living, and the population's lifestyle and self-preservation behavior as the resources for raising life expectancy. The efficiency assessment carried out on this basis shows that the dynamics of life expectancy in Russian regions are highly sensitive to external shocks, while at the same time being compensated for by the substantial adaptive capacity of the regional systems.

The DEA analysis of regional efficiency in raising the population's life expectancy revealed considerable heterogeneity among the efficient regions. Moreover, the formal leader regions with an efficiency score of 1 do not appear on the list of the most sought-after benchmark regions, which testifies to the difference between efficiency as such and the ability to replicate best practices.

The analysis of temporal dynamics showed a stable positive trend toward improved performance of the regional socio-economic systems in raising life expectancy. The main source of this growth was the "catch-up" effect, which outweighed the contribution of technological progress, indicating that processes of optimizing the use of available resources have predominated over the expansion of the technological frontier. The proposed typology of regions by type of life-expectancy dynamics shows that long-term growth in life expectancy is determined not so much by the absolute volume of resource provision as by the quality of governance and the balance between the efficiency of the use of available resources and technological development (both infrastructural and institutional). The most sustainable results are demonstrated by regions that combine both components, whereas imbalances in their dynamics create risks for achieving the target indicators of demographic development, a fact that confirms the persistent asymmetry in the distribution of demographic outcomes and the disparities in the resources available across Russian regions.

Thus, the scientific novelty of the study lies in the adaptation of a non-parametric approach (DEA and the Malmquist index) to the assessment of the relative efficiency of Russian regions in attaining life expectancy as a key indicator of demographic development. The work quantitatively separates the resource and management components of the productivity dynamics over the period 2005–2023, offering a reproducible benchmarking methodology and an empirical basis for the transition from unified federal programs to targeted strategies for socio-economic development and a differentiated demographic policy. This will make it possible to ensure sustainable progress in raising the population's life expectancy across the entire territory of the country.

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ОЦЕНКА ОТНОСИТЕЛЬНОЙ ЭФФЕКТИВНОСТИ ПОВЫШЕНИЯ ПРОДОЛЖИТЕЛЬНОСТИ ЖИЗНИ НАСЕЛЕНИЯ В РОССИЙСКИХ РЕГИОНАХ: НЕПАРАМЕТРИЧЕСКИЙ ПОДХОД

Ожидаемая продолжительность жизни выступает ключевым индикатором качества государственного управления и одновременно одной из целей национального развития. В условиях ограниченных бюджетных ресурсов и существенной территориальной дифференциации социально-экономического развития российских регионов критически важной становится оценка эффективности трансформации доступных региональных ресурсов в повышение продолжительности жизни. Пандемийный кризис 2020–2021 гг. актуализировал необходимость выявления устойчивых моделей повышения ожидаемой продолжительности жизни населения в регионах, демонстрирующих наилучшие практики управления в условиях внешних шоков. Таким образом, цель исследования – провести оценку относительной эффективности 79 регионов Российской Федерации в достижении высокой ожидаемой продолжительности жизни за период 2005–2023 гг., типологизировать их по динамике производительности и выявить ключевые траектории изменений. Методом DEA (Data Envelopment Analysis) рассчитаны коэффициенты относительной эффективности регионов; затем с помощью индекса Малмквиста проанализирована временная динамика с декомпозицией на компонент изменения эффективности и технологического прогресса. Выявлено, что для 83,5% регионов характерно одновременное улучшение эффективности и технологий, однако 16,5% регионов показали снижение эффективности при технологическом прогрессе. Установлено, что долгосрочный рост ожидаемой продолжительности жизни обусловлен не только объемом ресурсов, но и качеством управления, сбалансированностью между эффективностью использования детерминант и технологическим развитием, что определяет необходимость дифференцированной демографической политики для обеспечения устойчивого повышения продолжительности жизни населения на всей территории страны.

Продолжительность жизни, dea-анализ, эффективность, регион, индекс Малмквиста, региональная политика, типология регионов.

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