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MODELING THE DEMOGRAPHIC POTENTIAL OF RUSSIAN REGIONS CONSIDERING THEIR SOCIAL AND ECONOMIC DIFFERENCES

ANI G. SUKIASYAN
Plekhanov Russian University of Economics
Moscow, Russian Federation
e-mail: sukiasyan.ag@rea.ru
ORCID: 0000-0002-9628-0275; ResearcherID: O-8985-2014

One of the key problems in Russia and its regions remains the problem of demographic decline, which is reflected in the low fertility rate that has persisted for several decades and is aggravated by the high rate of premature mortality among young people and the working-age population. However, in the long term, the demographic policy measures implemented have not led to significant changes in the trend of the demographic process taking place in the country. This determines the aim of this study, which is to identify the social and economic factors that have the greatest impact on changes in the demographic potential of Russian regions using modern statistical and mathematical tools. At the same time, the problem of defining the concept of "demographic potential" is of particular importance, caused by differences in the interpretation of its content. The article provides an overview of the most common approaches to determining and assessing the demographic potential of territories. The net reproduction rate is chosen as an indicator of demographic potential, since it characterizes both the specifics of fertility and premature mortality in the Russian regions. To identify the patterns of this indicator, an econometric model is constructed that describes the dependence of demographic potential on the social and economic development of regions, the results of which are presented in this article. The main problem at this stage was to determine the set of social and economic characteristics that have the greatest impact on demographic potential, which was proposed to be solved using methods

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of correlation analysis, as well as a posteriori selection of factors. Based on the obtained model, a scenario analysis was carried out, confirming the high sensitivity of demographic potential to changes in socio-economic conditions in the country's regions. The practical significance of the study lies in the possibility of using the results of modeling by state and municipal authorities to assess the effectiveness of measures aimed at developing the demographic process, as well as to develop a demographic policy strategy.

Regional development, demographic potential, net reproduction rate, regression, multicollinearity, scenario analysis.

Introduction

The demographic decline, characterized by a low birth rate, high rates of premature mortality, and, as a result, aging population, has remained one of Russia's most pressing problems over the previous few decades. The problem becomes particularly relevant given the fact that in the general population structure there is a decrease in the proportion of the population younger than the working-age and population of working-age, since these age groups form the demographic potential of the country and are the basis of its well-being.

The state implements and constantly improves demographic policy, the goals of which are to overcome depopulation, stimulate natural population growth and maintain a balance of labor resources (Arkhangel'skii et al., 2016). In particular, measures are being taken to provide social support to families with children[1], reduce premature mortality[2], including from socially significant causes of death, ensure access to high-tech medical care for the population, promote a healthy lifestyle, create conditions for physical education and sports[3], etc. However, despite all the measures taken and implemented within the framework of government programs, the population continues to decline in Russia. This indicates the insufficient effectiveness of the existing demographic policy in the country.

To implement effective measures aimed at the transition from depopulation to expanded reproduction, it is necessary, first of all, to obtain objective and adequate estimates of the level of development of the country's demographic potential, on the basis of which econometric models can later be built to identify the factors that have the greatest impact on the level of the country's demographic potential, and therefore to make informed management decisions in the field of demographic policy. The complexity of obtaining such estimates is due to the multidimensional nature of the concept of "demographic potential".

[1] State Programs of the Russian Federation (2025). Targeted state support for families with children, older citizens, as well as certain categories of citizens, as well as the modernization of social services. The state program "Social support". Available at: https://programs.economy.gov.ru/gp/-/subject/-/direction/7/gp/18/gpVersion/10374

[2] State Programs of the Russian Federation (2025). Innovative methods of diagnosis, prevention and treatment, personalized medicine, training of medical personnel, export of medical services, digitalization of healthcare. The state program "Healthcare Development". Available at: https://programs.economy.gov.ru/gp/-/subject/-/direction/7/gp/1/gpVersion/10395

[3] State Programs of the Russian Federation (2025). Development of sports infrastructure, equipping with sports equipment, mass sports and high-performance sports. The state program "Development of physical culture and sports". Available at: https://programs.economy.gov.ru/gp/-/subject/-/direction/7/gp/36/gpVersion/10400

To date, many approaches have been developed to assess the state of the demographic process, based on various principles of defining this term (Rybakovskii, 2023). The existing methods of assessing the level of demographic potential of regions allow not only recording the current state, but also making forecasts, taking into account the influence of various social, economic and environmental factors. The development of digital technologies and the working out of methods for processing and modeling big data open up new opportunities for more accurate assessment and modeling of demographic processes (Sukiasyan, 2024).

Demographic research uses the concept of potential to identify hidden resources contained in the population structure based on various demographic characteristics. The analysis of existing methods for assessing demographic potential has shown that two main approaches are used in scientific practice: one is based on obtaining estimates of the volume of demographic potential (a quantitative approach), the other is based on assessing its quality (Tikhomirov, Tikhomirova, 2022).

Quantitative approaches to assessing demographic potential make it possible to analyze demographic processes and population development trends through various statistical and mathematical tools. Demographic potential is most often associated with the influence of macro-economic factors on capital accumulation, investment, employment, and projected population growth in a particular area (Zvereva, 2006). This takes into account the relationship between employment and labor surplus with financial policy and psychological factors of migration and natural growth through the concept of "expected income" (Yakovets, Golubkov, 2018).

Statistical, econometric, and demographic methods are among the most common quantitative approaches to studying demographic potential. Statistical methods are useful for describing and monitoring demographic trends, econometric methods are useful for identifying factors and making forecasts, and demographic models are useful for studying the age structure and reproduction. These models make it possible to identify patterns, predict trends, and develop measures to stimulate fertility, reduce mortality, and regulate migration flows. To form a comprehensive understanding of these approaches, their advantages and limitations should be studied in detail.

Statistical methods are widely used in the analysis of demographic processes, as they are based on the processing of empirical data. Statistical methods allow studying demographic potential through the construction of tables of fertility, mortality, marriage, and divorce rates with the calculation of the probabilities of relevant events. Demographic grids are traditionally used, which were improved in the 20th century and used in domestic research to analyze typical demographic events. Modern three-dimensional technologies allow reflecting demographic data about a person's life cycle, including location and ethnicity.

The existing methodology of combined demographic tables enabled researchers to predict changes in family types, which was used to develop social programs, especially in the field of housing construction in large Russian cities and urban agglomerations. These tables also allow calculating mortality and life expectancy based on a person's marital status.

According to the statistical approach, fertility is a key factor in assessing demographic potential. Cole's approach is widely used in international practice, but its upper limit on fertility is controversial for Russia, since it is based on the birth rate in the most prolific Hutterite communities, which reached 12 children per married woman over her entire life in a prosperous social environment. In this regard, an alternative method of hypothetical minimum natural fertility (HMNF) has been proposed, applicable to living conditions in the USSR. The method is based on an analysis of the fertility of Uzbek women aged 20–24 who lived in conditions of natural fertility. These women demonstrated the highest possible fertility rate in real Soviet conditions without the intervention of birth control factors. However, this method has become obsolete due to the shift in the average age of mothers to 30–34 years in large cities, as well as changes in the model of reproductive activity – women marry later and use contraception more often.

As improved statistical methods for assessing the current demographic situation in the regions of the Russian Federation, it is proposed in the scientific literature to use standardized total fertility, mortality, and migration rates, which allow for standardized depopulation indicators and are characterized by the ease of use of spreadsheets (Rybakovsky, 2024).

To date, the approach based on the construction of integral indicators has become the most widespread for assessing demographic potential, since it is based on obtaining a single quantitative assessment of the level of development of demographic potential, taking into account not only the characteristics of the demographic process, but also the possibilities of its development. One of these indicators was proposed by the French researcher L. Henri, who developed a method for estimating the intensity of generational substitution in the case of sustainable natural reproduction of the population based on the calculation of the net reproduction coefficient (Valentei, 2016; Makarov, 2019).

This technique allows estimating the average number of daughters that a woman can give birth to in her lifetime, taking into account age-related fertility and mortality rates (Tikhomirov, Tikhomirova, 2023). The net coefficient takes into account mortality in various age groups and shows how many of the girls born on average live to their mother's age (Rostovskaya, Sitkovskii, 2024; Dawidowicz, Poskrobko, 2009).

According to experts in the field of demography, it is the net coefficient that more accurately characterizes the patterns of demographic potential of the population in comparison with other proposed approaches (Rybakovsky, 2024). In addition, the values of this indicator are quite easy to interpret. For example, to achieve expanded reproduction of the population, it is necessary that the values of these coefficients exceed one, which means that on average there is more than one daughter per woman (Balbo et al., 2013). If the indicators do not reach unity, this indicates the presence of depopulation.

It is important to note the following: since age-specific mortality rates for five-year age groups are used in calculating the net reproduction rate, this indicator also characterizes the state and trends of premature mortality in the population. Given that diseases of the circulatory system, external causes and neoplasms predominate among the main causes of premature mortality in the country's regions, we can assume that their reduction can be achieved, among other things, by improving the socio-economic well-being of the regions (Tikhomirova, Sukiasyan, 2018).

The above causes the choice of the net coefficient of population reproduction in the framework of this study as an indicator of the level of demographic potential development and its quantitative assessment.

A comparative analysis of the five-year estimates of the net reproduction rate for Russia and its regions for the period from 1995 to 2023 indicates their high differentiation, which in 1995 amounted to 20.9%, and in 2023 – 16.6% *(Tab. 1)*. To identify the causes of the observed differences and identify the factors having the greatest impact It is proposed to apply econometric methods to the development of demographic potential, which is necessary when developing strategies for the socio-economic development of regions.

Econometric methods provide an opportunity not only to analyze the current state of demographic potential, but also to build forecasts based on the identified patterns, which can be obtained using time series analysis, which allows tracking changes in the level of development of demographic potential in the long term. In particular, correlation and regression analysis reveals the relationship between indicators of demographic status and socio-economic characteristics of regions. Spatial econometrics models, in turn, make it possible to assess inter-regional differences and the spread of demographic trends.

Currently, in the scientific literature, the authors propose a variety of regression models developed to assess the impact of various socio-economic factors on the level of demographic potential. In contrast to the approach presented in this study to determining and quantifying demographic potential, most studies use certain individual statistical indicators as characteristics of demographic potential: birth rates, mortality rates, population size, natural growth, etc. (Roy, 2018; Makarova, 2021), which, as already noted, cannot fully reflect the state and variability of demographic potential. At the same time, sometimes the study of this problem is limited to identifying and describing correlations between demographic indicators and socio-economic characteristics (Bezverbny et al., 2025), while a number of researchers propose to build separate econometric models for each of the characteristics of the demographic potential to analyze the demographic state of the region (Paley, Pollak, 2017; Fattakhov et al., 2020). Despite the undoubted practical value of the proposed approaches, the choice of mutually correlated indicators as explanatory factors characterizing various aspects of the socio-economic situation of the region (country) is criticized.

Table 1. Comparative analysis of the net reproduction rate in the Russian regions

Year	Statistical characteristics	Net reproduction rate
1995	Arithmetic mean	0.662
	Standard deviation	0.138
	Coefficient of variation, %	20.9
2023	Arithmetic mean	0.680
	Standard deviation	0.113
	Coefficient of variation, %	16.6

According to: Center for Demographic Research of the Russian School of Economics (2025). The Russian database on fertility and mortality (RosBRiS). Available at: https://www.nes.ru/demogr-fermort-data?lang=ru (accessed: 07.07.2025).

The above determines the scientific novelty of the presented study, which uses an integral indicator as an indicator of demographic potential – the net reproduction coefficient, which, as already noted, is a more complete description of the demographic process of the region and its development potential, and a set of socio-economic indicators explaining its variability has been previously studied to eliminate correlations. At the same time, the study pays special attention to indicators of the state of the healthcare system and its accessibility, since, according to the author, the development of the demographic potential of the country and its regions is possible, first of all, by improving the quality of public health by providing affordable and timely highly qualified medical care.

Research methodology

Despite the demographic policy measures being implemented in Russia, the country continues to have a declining and aging population (Rybakovsky, 2024). This, in turn, has a negative impact on the economy (Livshits et al., 2023; De Santis, Salinari, 2023), the labor market (Sukiasyan, 2024), industry and other areas of government activity, since, according to modern views of economic scientists, the population forms the development potential of the state (Rybakovskii, 2023; Baeva, Urazova, 2020). In the regions of Russia, the demographic problem is becoming particularly relevant due to their significant differentiation in terms of gender and age composition of the population and socio-economic status (Sukiasyan, 2022). This article is devoted to the problem of constructing an econometric model describing the patterns of influence of indicators of socio-economic development of Russian regions on the level of demographic potential.

The net population reproduction rate is estimated based on the following indicators for five-year age groups:

– number of children born per 1,000 women of the five-year age group *k* in region *j* in year *t*, $f_k^j(t)$;

– number of women who died per 1,000 people in the five-year age group *i* in region *j* in year *t*, $m_i^j(t)$.

Based on the available fertility rates, the age-related fertility rates of girls for the five-year-old age groups of the mother are calculated according to formula 1:

$$b_k^j(t) = \frac{f_k^j(t)}{200} \cdot 0.488, \qquad k = \overline{4{,}10}, \quad (1)$$

where 0.488 is the share of girls among newborns, *k* corresponds to the mother's age group.

The mortality rates of the female population were used to obtain survival coefficients using formula 2:

$$p_i^j(t) = 1 - \frac{m_i^j(t)}{200}, \qquad i = \overline{1{,}10}, \quad (2)$$

where *i* corresponds to the mother's age group.

The net reproduction coefficients for each region *j* in year *t* are determined according to formula 3 (Notestein, 1960):

$$HKB^j(t) = \sum_{k=4}^{10} \left[b_k^j(t) \cdot \prod_{i=1}^{k-1} p_i \right], \ i = \overline{1{,}10}; \ k = \overline{4{,}10}. \ (3)$$

Based on the presented methodology, net population reproduction coefficients were calculated for 79 regions of Russia, exception for the Nenets Autonomous Area, the Khanty-Mansi Autonomous Area – Yugra, and the Yamal-Nenets Autonomous Area, which are geographically part of the Arkhangelsk and Tyumen regions, respectively, as well as the republics of Crimea and Chechnya, and Sevastopol due to the lack of sufficient statistical data on the considered indicators.

The estimates obtained for the period from 1995 to 2023 are characterized by rather high dynamics and differentiation by regions of Russia (Kalabikhina et al., 2022). In general, during the period under review, the average value of the net reproduction coefficient of the Russian population increased from 0.662 to 0.680, i.e. by 2.7%. At the same time, the dynamics of the indicator increased from 1999 to 2015 to a peak value of 0.879, followed by a decrease of 22.7% to a level almost comparable to the level of 1995. In turn, the differentiation of regions by the level of the net reproduction coefficient varies from 14.0% in 2003–2004 to 18.9 and 20.9% in 2011 and 1995, respectively.

The above, as well as the fact that the value of the net reproduction coefficient of the population in the study period does not exceed one, testifies to the ongoing depopulation process in the country (Aivazian et al., 2019; Rybakovsky, Fadeeva, 2020), determine the need to identify the interdependencies between the indicator of demographic potential and the characteristics of the socio-economic situation of regions (Jagger et al., 2008) to identify the factors that have the greatest impact on the change in the value of the net reproduction coefficient, which will allow applying the results obtained to justify strategies to equalize regional differences and develop measures aimed at increasing the level of this indicator, and therefore, the transition from depopulation to extended reproduction (Ivanova et al., 2023).

The initial set of characteristics of the socio-economic situation of the regions included 21 indicators, which were divided into several blocks characterizing various spheres of life: economic, welfare of the population, social, the state of the health system and the environment. The economic block included the index of industrial production, the average per capita size of GDP, investments in fixed assets, etc. The financial well-being of the population was assessed on the basis of such indicators as average per capita monetary income, the amount of paid services, bank deposits, retail trade turnover, the total area of residential premises, museum attendance, and some others. The social sphere was characterized by the number of crimes, the ratio of the number of divorces to the number of marriages, the unemployment rate, the migration growth rate, etc. The state of the healthcare system is represented by the expenditures of consolidated healthcare budgets per capita, the average per capita expenditure of the population on medical services, the number of doctors and nursing staff, the number of beds in medical institutions, etc. The ecological situation of the region was assessed on the basis of the volume of pollutants released into the atmosphere from stationary sources.

After a preliminary analysis of an expanded set of different indicators of the level of socio-economic development of Russian regions for the presence of statistically significant correlations, as well as sufficient variability, the following indicators for the period from 1995 to 2023 were selected for further modeling:

– number of doctors per 10,000 people (x_1);

– ratio of divorces and marriages (x_2);

– crime per 10,000 people (x_3);

– total area of living quarters per person, m^2/person (x_4);

– number of unemployed people per 10,000 working-age population (x_5);

– migration growth rates per 10,000 people (x_6);

– capacity of outpatient clinics for 10,000 people (x_7);

– number of museum visits per 1,000 people (x_8);

– paid medical services, rubles per person (x_9);

– expenses of consolidated budgets for healthcare, rubles per person (x_{10}).

The absence of characteristics of the economic situation of the regions among the selected indicators is due to their strong direct correlation with the expenditures of consolidated budgets on healthcare. Thus, the inclusion of health expenditure indicators in the final set makes it possible to take into account not only the state of the health system in the regions, but also their level of economic well-being (Ivanov et al., 2014).

At the first stage, using correlation analysis methods, the relationships between the resulting variable (net reproduction coefficient, *y*) and the above characteristics were revealed. The Pearson pair correlation coefficients and all subsequent stages of data analysis and model construction were based on the values of the resulting and explanatory variables averaged over the time period under review, which made it possible to offset the effect of random fluctuations and noise on the result.

Based on the analysis of the values of the matrix of paired correlation coefficients, conclusions were drawn about a fairly strong relationship between the net reproduction coefficient (*y*) of the population and such indicators as the number of doctors per 10,000 people, the total area of residential premises per person, the number of unemployed, as well as between the number of doctors and the total area of residential premises, the capacity of outpatient clinics and health care costs.

The strongest negative correlation is observed between the net reproduction rate and the ratio of divorces and marriages (coefficient value -0.55). An even more pronounced negative relationship is observed between the area of residential premises (coefficient -0.71), due to the continuing decline in the population with increasing rates of residential commissioning.

Attention should also be paid to the positive relationship between the net reproduction rate and the number of unemployed per 10,000 working-age population, which is explained by the low involvement of women caring for children in the labor market (Arkhangel'skii et al., 2016; Ivanova, 2022).

Attention should also be paid to the positive relationship between the net-In order to identify hidden relationships due to the simultaneous influence of several indicators on the resulting variable, as well as possible relationships between explanatory variables, multiple correlation coefficients were calculated, which turned out to be significant at the level of 5%. This means that all indicators depend on others quite a lot. The most significant coefficients of multiple correlation were found in the net reproduction rate and the number of divorces. It can be concluded that the remaining indicators explain their variation very qualitatively by the reproduction rate and the number of unemployed per 10,000 people of the working-age population, which is explained by the weak involvement of women caring for children in the labor market (Arkhangel'skii et al., 2016; Ivanova, 2022).

The results obtained allow concluding that it is necessary to check the totality of explanatory variables for the effect of multicollinearity. The analysis used three approaches to assess multicollinearity: VIF variance inflation factors, Fisher statistics, and the criterion χ^2 *(Tab. 2)*.

Despite the fact that Fischer's statistics confirmed the presence of multicollinearity – almost all values $F_{расч}$ turned out to be higher than the tabular value of 2.07, and the calculated value $\chi^2_{\text{расч}} = 86.93$ turned out to be higher than the critical tabular value of 50.99, which indicated the need to reject the null hypothesis of the absence of multicollinearity. Based on the results of calculating the VIF coefficients, each of which does not exceed the threshold value of 10, we can conclude that the effect of multicollinearity on the effectiveness of the parameters of the multiple regression model

Table 2. Calculated values of VIF and Fisher statistics for each explanatory variable

Indicator	VIF	F-Fischer statistics	Value
x_1	1.626	4.798	**
x_2	5.332	33.210	**
x_3	2.593	12.214	**
x_4	3.422	18.572	**
x_5	3.040	15.643	**
x_6	2.352	10.364	**
x_7	2.486	11.395	**
x_8	1.662	5.075	**
x_9	2.424	10.915	**
x_{10}	4.276	25.117	**
According to: Center for Demographic Research of the Russian School of Economics (2025). The Russian database on fertility and mortality (RosBRiS). Available at: https://www.nes.ru/demogr-fermort-data?lang=ru (accessed: 07.07.2025).			

based on the available data is insignificant. This, in turn, allows concluding that it is possible to build a classical linear regression model of the dependence of demographic potential on the socio-economic indicators of the regions under consideration, taking into account the entire set of explanatory variables without the need to introduce additional procedures aimed at eliminating multicollinearity (Wang et al., 2025).

Research result

The parameters of a linear multiple regression equation with a complete list of factors can be written as follows (Tikhomirov, Tikhomirova, 2023):

$$\hat{y} = a_0 + \sum_{p=1}^{10} a_p x_p. \quad (4)$$

Figure 1 shows a limited ("short") multiple regression model for simulating

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Model 2: OLS, using observations 1-79
Dependent variable: y

             coefficient    std. error    t-ratio    p-value
  ----------------------------------------------------------
  const       1.25278       0.0528024     23.73     4.80e-036 ***
  x2         -7.60332e-05   1.11299e-05   -6.831    2.14e-09  ***
  x3          0.000827997   0.000141787    5.840    1.35e-07  ***
  x4         -0.0104054     0.00319018    -3.262    0.0017    ***
  x9         -3.19364e-05   5.61257e-06   -5.690    2.48e-07  ***
  x10         1.24790e-05   1.57708e-06    7.913    2.05e-011 ***

Mean dependent var   0.714460   S.D. dependent var   0.107065
Sum squared resid    0.185162   S.E. of regression   0.050363
R-squared            0.792909   Adjusted R-squared   0.778724
F(5, 73)             55.90029   P-value(F)           1.36e-23
Log-likelihood       127.1148   Akaike criterion    -242.2296
Schwarz criterion   -228.0129   Hannan-Quinn        -236.5339
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Figure 1. Limited model of multiple regression of the dependence of the demographic potential of regions on the level of their socio-economic development

According to: Demographic Yearbook of Russia (2025). Federal State Statistics Service. Available at: https://rosstat.gov.ru/folder/210/document/13207 (accessed: 07.07.2025).

the net coefficient of population reproduction from a reduced number of socio-economic characteristics in Russia's regions on average for the period from 1995 to 2023. The model includes only those explanatory variables that correspond to the statistically significant parameters of the model according to Student's test.

The selection of factors for regression dependence was done using the "a posteriori" method, which implies the step-by-step removal of factors from the regression model with the highest p-value of the corresponding parameter until only factors with significant regression coefficients remain. There are 5 significant indicators left in the model: the number of divorces x_2, the number of crimes x_3, the area of residential premises per person x_4, paid medical services per person x_9, and healthcare costs per person x_{10}. The coefficient of determination of the resulting model is 79.3%, and the model itself is significant according to the Fisher test at the significance level of 1%.

However, to increase the explanatory power of the model and improve the quality of the forecast, it is advisable to exclude from the sample regions that are characterized by abnormal values of indicators compared to other regions or, in other words, can be characterized as gross errors.

In the process of preparing data for building a regression model, special attention was paid to outlier analysis. For this, a step-by-step approach was used, including a combination of one-dimensional and multidimensional methods. At the first stage, the Smirnov – Grubbs criterion was applied, which makes it possible to detect gross errors in each of the indicators separately. As a result, 8 regions were identified characterized by abnormal values of certain signs: Moscow, Saint Petersburg, the Magadan Region, the republics of Dagestan, Ingushetia, and Tuva, the Sakhalin Region, and the Chukotka Autonomous Area.

The Grubbs criterion of variance was used for additional verification. It compares the sample variance with the truncated variance (that is, without the potential outlier). This approach allowed confirming that not all observed deviations are statistically significant, and some could be a consequence of the usual variability of the data. As a result, the presence of abnormal values in the data of three regions (Saint Petersburg, the Republic of Ingushetia, and the Chukotka Autonomous Area) was confirmed.

However, since a one-dimensional analysis does not allow identifying situations where a region differs significantly from the main array of subjects in terms of a combination of factors, multidimensional Hotelling statistics were calculated for each of the marked regions to more fully analyze the initial sample. Statistically significant emissions according to this criterion were Saint Petersburg ($T^2 = 56.35$), the Republic of Ingushetia ($T^2 = 60.32$), and the Chukotka Autonomous Area ($T^2 = 44.91$), whose values exceed the critical value of 24.38. Accordingly, these regions were excluded from the sample to obtain a model with better quality characteristics than the above model.

This modification made it possible to maintain the necessary level of representativeness of the data and ensure an optimal balance between the coefficient of determination and the standard error in the subsequent regression model *(Fig. 2)*.

The non-emission model demonstrates higher quality indicators: the value of the coefficient of determination (R^2) is 0.828 versus 0.793 for the second model, and the normalized coefficient of determination reaches 0.815, which is also higher than 0.779 for the model with emissions *(Tab. 3)*. Additionally, it is worth noting a decrease in the standard error from 0.050 to 0.046, which indicates a higher stable parameter estimates and lower variance of residuals. These differences are not numerically critical, but collectively speak in favor of higher accuracy and interpretability of the outlier-free model.

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Model 2: OLS, using observations 1-79
Dependent variable: y

             coefficient    std. error    t-ratio    p-value
  -----------------------------------------------------------
  const       1.25278       0.0528024     23.73     4.80e-036 ***
  x2         -7.60332e-05   1.11299e-05   -6.831    2.14e-09  ***
  x3          0.000827997   0.000141787    5.840    1.35e-07  ***
  x4         -0.0104054     0.00319018    -3.262    0.0017    ***
  x9         -3.19364e-05   5.61257e-06   -5.690    2.48e-07  ***
  x10         1.24790e-05   1.57708e-06    7.913    2.05e-011 ***

Mean dependent var   0.714460   S.D. dependent var   0.107065
Sum squared resid    0.185162   S.E. of regression   0.050363
R-squared            0.792909   Adjusted R-squared   0.778724
F(5, 73)             55.90029   P-value(F)           1.36e-23
Log-likelihood       127.1148   Akaike criterion    -242.2296
Schwarz criterion   -228.0129   Hannan-Quinn        -236.5339
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Figure 2. Limited model of multiple regression of the dependence of the demographic potential of regions

According to: Demographic Yearbook of Russia (2025). Federal State Statistics Service. Available at: https://rosstat.gov.ru/folder/210/document/13207 (accessed: 07.07.2025).

Table 3. Comparison of regression models of the dependence of demographic potential on the level of development of the socio-economic situation of regions with significant parameters

Emission-free model		Emissions-based model	
Regression statistics		Regression statistics	
Multiple R	0,910	Multiple R	0.890
R-square	0,828	R-square	0.793
Normalized R-square	0,815	Normalized R-square	0.779
Standard error	0,046	Standard error	0.050
According to: Demographic Yearbook of Russia (2025). Federal State Statistics Service. Available at: https://rosstat.gov.ru/folder/210/document/13207 (accessed: 07.07.2025).			

However, it is also advisable to check this model for autocorrelation of residues. For this purpose, the Durbin – Watson statistics were calculated. The resulting value was $DW = 1.91$, which was close to the threshold value of 2. This indicates that there is no pronounced positive or negative autocorrelation. However, since the Durbin – Watson test has an uncertainty zone, it is important to take into account the critical boundaries determined by the number of observations and the number of regressors. With 76 observations and five explanatory variables, the lower critical limit is approximately 1.50, and the upper limit is 1.71. Thus, our value of $DW = 1.91$ is above the upper bound. This allows concluding with confidence that there is no first-order autocorrelation in the model.

To confirm this result, the Breusch – Godfrey test was applied, which has no restrictions on the inclusion of lags of the dependent variable as factors and is more universal when checking autocorrelation of various orders. The results of the Breusch – Godfrey test for first-order autocorrelation are: statistics $LM = 2.12$ p-value (χ^2): 0.145; Fischer statistics $F = 1.84$, p-value (F): 0.18.

Both *p*-values exceed the standard significance level of 5%, which makes it impossible to reject the null hypothesis of the absence of autocorrelation. Thus, both tests consistently showed that there is no autocorrelation in the model. This confirms the correctness of the model specification in terms of the premise of error independence. The absence of autocorrelation also has a positive effect on the accuracy of forecasts and the interpretability of results: there is no need to use alternative estimation methods (for example, generalized least squares) or introduce lags (Tikhomirov, Tikhomirova, 2024).

Based on the above, the emission-free model with selected significant factors seems to be more reliable and appropriate for further analysis and forecasting. Data purification has improved the statistical characteristics of the model without unnecessarily complicating its structure (Abdulrashid et al., 2023; Jindrov et al., 2013).

The model demonstrated the best balance between high explanatory power and low standard error, while maintaining the interpretability of the coefficients and the stability of the model structure. The constructed model adequately reflects the dynamics of the dependent variable and can be used to predict various scenarios, including deterioration and improvement of conditions. Its structure makes it possible to vary the values of factors and assess how possible changes in the social environment will affect the demographic situation in the country.

To demonstrate the applied value of the model, a scenario analysis was carried out, reflecting potential changes in the demographic situation when adjusting socio-economic indicators. The situation was modeled, characterized by an improvement in all socio-economic conditions, taking into account their actual variability. A scenario was considered in which the number of divorces per 10,000 marriages x_2 decreases by 15%, crime per 10,000 people x_3 decreases by 1%, housing conditions x_4 improve by 3%, the capacity of outpatient clinics x_7 increases by 10%, and healthcare x_{10} costs increase by 5%. A detailed analysis showed that varying socio-economic indicators by a smaller amount than indicated individually does not lead to a statistically significant change in the level of the net reproduction coefficient.

This optimistic scenario demonstrated an increase in the projected value of the net reproduction rate in most regions, with a total increase of 8.7%. The increase was most noticeable in the Magadan, Leningrad, and Murmansk regions. However, in some regions, the improvement of social factors had a negative impact on the level of the net reproduction rate. This applies to the republics of Ingushetia, Dagestan, and the Kabardino-Balkarian Republic, which may be due to both the specifics of the regional socio-economic structure and the high sensitivity of these constituent entities to changes in individual factors. This highlights the need for an individual approach when developing social measures and shows that universal improvements are not always effective across the country.

A pessimistic scenario was also considered, in which the number of divorces per 10,000 marriages x_2 increases by 12%, crime per 10,000 people x_3 increases by 4%, housing conditions x_4 worsen by 7%, the capacity of outpatient clinics x_7 decreases by 7%, and healthcare costs x_{10} decrease by 8%. Attempts to alternately vary the considered characteristics by a smaller amount individually did not lead to statistically significant changes in the net reproduction coefficient.

As expected, this scenario had a negative impact on the demographic potential of most regions, with a total decline of 10.4 percentage points. The decline was most affected in the Magadan, Leningrad, and Murmansk regions. In turn, the republics of Ingushetia, Dagestan, and the Kabardino-Balkarian Republic showed an increase, which confirms the specifics of these regions and the need to implement targeted measures aimed at leveling the demographic situation in the country's regions.

Conclusions

In the course of the study, a regression model was built to identify the impact of socio-economic factors on the level of demographic potential in the country's regions, in particular on the value of the net reproduction coefficient. The main attention was paid to the preliminary analysis of the data array for the presence of gross errors (outliers), as well as the effect of the multicollinearity effect on the effectiveness of estimates of the parameters and quality characteristics of the constructed model.

Scenario analysis showed that with an improvement in the values of socially significant factors, most regions demonstrate a positive trend in the model values of the indicator. However, not all regions are experiencing an increase: in some republics of the North Caucasus, a decrease in the projected value has been noted. This is due to the specifics of regional conditions, traditionally high baseline fertility rates, and cultural characteristics that are poorly correlated with the socio-economic variables under consideration.

The practical significance of the work performed lies in the possibility of applying the obtained model to assess the potential effect of changes in social policy. With the correct interpretation of the coefficients, recommendations can be made for managing the demographic situation at the regional level, as well as approaches to standardizing variables in similar studies.

Thus, according to the results of the conducted research, the goal of analyzing the impact of socio-economic factors on demographic processes in Russia was successfully achieved. Modeling and analysis suggest that, despite some deviations, the model reflects general patterns and can serve as a basis for developing effective solutions in the field of demographic policy.

As questions and prospects for further research, the author suggests setting up and attempting to solve problems related to building a model while preserving gross errors in the sample, but correcting them using stable estimation methods (for example, censoring, the Huber model), as well as evaluating the model on panel data to take into account the specifics of regional differences in more detail. Although panel data models are also a useful tool for considering the dynamics of demographic processes, since they allow finding and analyzing changes simultaneously in time and space, the constructed multiple regression model at the stage of identifying common patterns has a number of advantages, primarily related to the simple implementation and interpretation of the results. Also, unlike multiple regression, the panel data model takes into account fixed or random effects, which requires additional computing power.

It is important to emphasize that the Russian Federation is a large multinational country with pronounced regional differences in socio-economic development, population structure and migration trends, which was confirmed by the conducted research. With this in mind, building a single model that reflects the reality of all regions equally well is a very difficult task, so another approach to improving the quality of forecasting demographic potential and justifying the impact of changes in socio-economic conditions on its level may be to solve the problem of building a cluster model that generalizes into clusters similar in their socio-economic and demographic characteristics of the regions. Nevertheless, the results obtained make it possible to use the model as a tool for evaluating the effectiveness of measures aimed at equalizing and ensuring the progressive development of the demographic process.

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INFORMATION ABOUT THE AUTHOR

Ani G. Sukiasyan – Candidate of Sciences (Economics), Associate Professor, Plekhanov Russian University of Economics (36, Stremyanny Lane, Moscow, 115054, Russian Federation; e-mail: sukiasyan.ag@rea.ru)

Сукиасян А.Г.

МОДЕЛИРОВАНИЕ ДЕМОГРАФИЧЕСКОГО ПОТЕНЦИАЛА РЕГИОНОВ РОССИИ С УЧЕТОМ ДИФФЕРЕНЦИАЦИИ ИХ СОЦИАЛЬНО-ЭКОНОМИЧЕСКОГО ПОЛОЖЕНИЯ

Одной из наиболее актуальных проблем в России и ее регионах остается проблема демографического спада, выражающаяся в сохраняющемся на протяжении нескольких десятилетий низком уровне рождаемости и усугубляющаяся высоким уровнем преждевременной смертности среди молодежи и населения трудоспособного возраста. Однако в долгосрочном периоде реализуемые меры демографической политики не привели к существенным изменениям в тенденции происходящего в стране демографического процесса. Это обусловливает цель настоя-

щего исследования, которая заключается в выявлении социально-экономических факторов, в наибольшей степени оказывающих влияние на изменение уровня демографического потенциала регионов России, с использованием современного статистического и математического аппарата. При этом особую значимость имеет определение понятия «демографический потенциал», что вызвано различиями в интерпретации его содержания. В статье представлен обзор наиболее распространенных подходов к определению и оценке демографического потенциала территорий. В качестве индикатора демографического потенциала выбран нетто-коэффициент воспроизводства населения, поскольку он характеризует специфику как рождаемости, так и преждевременной смертности населения регионов России. Для выявления закономерностей развития данного показателя построена эконометрическая модель, описывающая зависимость демографического потенциала от различающихся условий социально-экономического развития регионов. Основная проблема на данном этапе заключалась в определении набора социально-экономических характеристик, оказывающих наибольшее влияние на демографический потенциал. Решить ее предложено с применением методов корреляционного анализа, а также апостериорного отбора факторов. На основе полученной модели проведен сценарный анализ, подтверждающий высокую чувствительность демографического потенциала к изменениям социально-экономических условий в регионах страны. Практическая значимость исследования заключается в возможности использования результатов моделирования органами государственного и муниципального управления для оценки эффективности мер, направленных на развитие демографического процесса, а также для выработки стратегии демографической политики.

Региональное развитие, демографический потенциал, нетто-коэффициент воспроизводства, регрессия, мультиколлинеарность, сценарный анализ.

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ИНФОРМАЦИЯ ОБ АВТОРЕ

Ани Гагиковна Сукиасян – кандидат экономических наук, доцент, Российский экономический университет имени Г.В. Плеханова (Российская Федерация, 115054, г. Москва, Стремянный пер., д. 36; e-mail: sukiasyan.ag@rea.ru)