Modeling of Demographic Changes in Ukraine Based on Information Before the War and Possible Directions of Their Deterioration

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Abstract. The demographic crisis in Ukraine at the beginning of the 21st century was associated with a decrease in the birth rate in 1991-2000. Subsequently, this caused a significant reduction in labor resources and increased retirement-age population. Halting the decline in birth rates after 2000 did not improve the situation. According to the forecast based on the model of demographic changes, the total population of Ukraine tended to decrease by almost 37% until 2045. Russian aggression in 2014 led to the occupation of the territories of Ukraine, namely the annexation of Crimea and the capture of parts of the Donetsk and Luhansk regions. It caused mass migration of the population from the occupied territories to the territory controlled by Ukraine. However, part of the population remained in the occupied territory. A military invasion in February 2022 further worsened the demographic situation. It is still impossible to fully determine the consequences of the war, but it is already possible to classify the trends of such changes. The conducted research provides a population forecast by age groups and regions of Ukraine, provided there are no population losses and migrations to other countries during the war years, and can serve as an estimate of the possible demographic state of the regions.

Keywords: Modeling, Demographic changes, Ukraine, War, Labor resources, Demographic crisis, Human capital.

1 Introduction

Population is an essential strategic resource of any country. Countries with larger populations always have more significant potential to increase gross domestic product (GDP). The ratio of GDP to population size, namely the share of GDP per capita, determines the country's ability to improve the welfare of its population. On the other hand, GDP is the product of labor only for the working population.

It is the working population that creates GDP through their work. *Labor productivity* is defined as the share of GDP produced by one person without a disability and is an assessment of the potential of the country's labor resources. Labor productivity depends on many components and varies significantly in different countries. The most developed countries have higher labor productivity.

GDP growth can be associated not only with the growth of labor resources. Another factor in GDP growth is increased labor productivity due to technological development. It is possible to identify a group of countries that increase their GDP due to the production and export of oil, gas, and other energy resources, which are necessary for the functioning of the industries of many countries at this level of technological development. The GDP of countries that create GDP due to oil and gas production depends not on the population but on the volume of exports and prices.

Therefore, both the increase in the population and labor productivity positively affect the increase in GDP. The best option is the simultaneous growth of the population and labor productivity. Investments in human capital development make it possible to increase labor productivity.

The interdependence study of the demographic change factors, labor productivity, and gross domestic product requires analytical information on the country in which changes in these factors are widespread. One of such countries is Ukraine. In Ukraine, throughout history, the population has changed dynamically, both in the direction of increase and decrease; labor productivity changes, and the gross domestic product from 1991 to 1996 dropped by 60%. By comparison, during the Great Depression in the United States, the gross product fell by only 40%. That is why studying these processes and changes in labor productivity in the example of Ukraine can enrich the theory of the demographic changes' impact on economic development.

Territorially, Ukraine occupies a central place on the European continent. Ukraine is the geographical center of the European continent. Ukraine borders Russia to the east, Belarus to the north, and Poland, Slovakia, Hungary, Romania, and Moldova to the west. By area, Ukraine is the largest country on the European continent. The area of Ukraine is larger than the area of France and smaller than the area of Turkey. At the same time, the population of Ukraine is smaller than the population of Germany, France, Italy, and Spain and is almost equal to the population of Poland, whose area is almost half the size of Ukraine.

Ukraine has a relatively high educational potential and possesses macro-technologies in the field of aircraft construction and the construction of missile carriers. However, the transitional economic processes of the formation of the new country, which began almost from the time of gaining statehood in 1991, led to a significant drop in GDP and a decrease in the welfare of the population. As a result of the influence of these factors, the birth rate began to fall, which became a threat of a demographic crisis. That is, two trends affecting the GDP are observed in Ukraine simultaneously. On the one hand, these are structural-demographic shifts that cause a decrease in the number of the working-age population and, on the other hand, efforts to increase labor productivity through improving the quality of human capital.

However, the growth of labor productivity is also related to the size of the working population. Therefore, studying the Ukrainian population's demographic structure and identifying trends in structural changes are becoming particularly relevant.

The peculiarities of the demographic crisis in Ukraine and its consequences were determined in the scientific studies of many authors. Deserves attention to fundamental research by scientists from the M.V. Ptukha Institute for Demography and Social Studies [1]. Many publications stated the existence of a demographic crisis in Ukraine [2] [3] [4] [5]. After the beginning of the war, the study of demographic changes determined the increase in population migration flows [6] [7]. Recently, publications devoted to the revival of Ukraine began to appear [8] [9]. Issues of demographic development modeling were also considered in publications [10] [11] [12].

The general state of population development in the world's countries is given in UNDP publications [13].

The studies mostly consider Ukraine as a whole and do not focus on its regions. The scientific novelty of the study consists of developing a simulation model for forecasting changes in population size by age group for any territorial grouping and its application for determining structural shifts in labor resources.

Based on the lag method of population size changes in different age groups, the author's mathematical model was used to forecast structural changes in the population's demographic composition in this study. The main elements of the model are the module for calculating the birth rate of boys and girls and the module for the natural decline of the population by different age groups. Based on the official results of the 2001 population census of Ukraine and considering changes in the population before the start of forecasting, the model made it possible to predict demographic changes in Ukraine as a whole and in individual regions and regions for the period up to 2050. In the measured time before the start of Russia's military aggression, the annexation of Crimea, and the occupation of part of Ukraine, population migration was not of significant importance. However, with the beginning of the military aggression of the Russian Federation, the uncertainty of migrations, as well as the loss of the population of working age in the conditions of the war, increased significantly. These processes require additional study.

2 Information Theory Methodology

2.1 Labor resources in models of economic growth

Labor resources are the main factor in models of economic growth. In modern studies, the influence of this factor is constantly being clarified depending on the nature of the work. The level of qualification into skilled and unskilled differentiates labor. Physical and intellectual works are considered separately. Investments in the development of labor resources make it possible to acquire new knowledge and skills and form human capital. However, the dynamics of changes in this factor are most often defined as the result of natural population growth and are not specified. Thus, the central block in R. Solow's cyclical model of economic dynamics [14] is the production function (PF). PF results are divided between consumption and accumulation (Fig. 1). Accumulation becomes a source of investment and forms capital gains in the next cycle. Capital also decreases due to wear and tear. The recycling rate is set to regulate the wear rate μ . According to the definition of R. Solow, labor resources have a natural increase with a coefficient ν . The corresponding economic-mathematical model of R. Solow with a discrete definition of time has the form of a system of equations:

$$\begin{cases} Y_t = F(K_t, L_t), \\ Y_t = I_t + C_t, \\ K_t = (1-\mu)K_{t-1} + I_{t-1}, \\ L_t = (1+\nu)L_{t-1} \end{cases}, \qquad (1)$$

where: $t = 1,2,\ldots,T$; $t=0$ – base year; $t=T$ – final year of the period under investigation; K_0, I_0, L_0 - are considered given.

The first equation is PF for finding GDP based on the values of resources - the main production assets (MPA) and the number of employees. The second equation is the distribution of GDP between investments and consumption. The third equation is a recurring relationship for determining the following year's MPA based on the current year's values. This equation reflects that the investments made in the current year are materialized in the MPA of the following year; that is, the lag of capital investments is equal to one year. The fourth equation is a recurring relationship for determining the number of employees in the next year. This equation is based on the hypothesis of constancy of the annual growth rate of the number of employees ν .

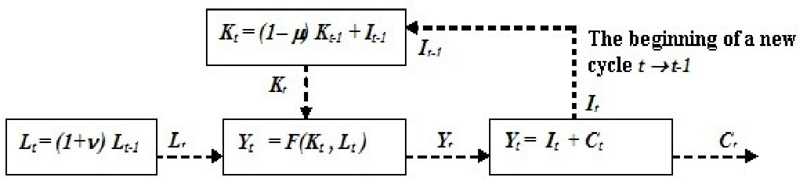


Figure 1. R. Solow's model of economic dynamics

According to the classification into static and dynamic elements, the first equation is a nonlinear static element, the second is a linear static element, and the third and fourth are a linear dynamic element. Thus, the economy in the form of the Solow model is a dynamic system because there are dynamic elements in its composition.

Exemplary models with the endogenous influence of scientific and technological progress are the models of P. Romer [15], F. Aghion, and P. Howitt [16].

P. Romer divides the economy into three main sectors. In the first research sector, "new knowledge is carried out". In the second sector, knowledge is transformed into means of production (technological equipment). With the help of means of production, labor costs, and human capital, the third sector ensures the production of final products. Capital in P. Romer's model is represented as the sum of its components spent on the purchase of the necessary means of production:

$$Y\left(H_y, L, x\right) = H_y^{\alpha} L^{\beta} \sum_{i=1}^{\infty} x_i^{1-\alpha-\beta} \qquad (2)$$

where: x_i – a list of i of production means used by one firm for the production of final products; α, β - some technological parameters.

In the model of F. Aghion and P. Howitt, growth is achieved due to competition between firms carrying out technological innovations. An increase in the intensity of the flow of innovations, the scale of the impact of innovations on the economy, and the share of skilled labor associated with the production of intermediate goods (human capital in the field of R&D) will lead to the growth and development of the economy.

However, modernity provides new incentives for research and forecasting the dynamics of structural changes in the population's demographic composition, based on the results of which the potential of labor resources is determined, which forms the basis of forecasting models of economic growth or decline.

The most effective method of researching various scenarios of economic process development is using simulation models.

This study aims to construct a simulation model of the population's demographic composition development and study changes in labor resources in Ukraine and its regions.

The result of modeling will allow for the determination of the main problems of the demographic structure of Ukraine, which can be used in the construction of the state policy of formation and development of human capital.

The dynamics of changes in the demographic structure determined by the simulation model are a basis for accounting for the population losses in Ukraine due to the war.

2.2 The model of structural-demographic shift formation

To assess the state of the demographic structure, the population can be divided into groups:

- population up to working age;
- the population of working age;
- population of retirement age.

Usually, the entire population is divided into age groups from 0 to 4 years, from 5 to 9, from 10 to 14, and further up to 99 years. Men and women are treated separately in each group.

Such information can be obtained from the results of the population census. Therefore, this information will have a static character and determine the demographic structure during the census.

To determine the dynamics of changes for the previous period, you can use actual values based on the results of statistical accounting. When forecasting economic development, it is necessary to forecast the dynamics of changes in the working-age population. To perform such forecasting, trend extrapolation methods do not provide an accurate result. Therefore, to perform such forecasting, a mathematical model is needed to consider population development's main features.

To forecast structural demographic shifts, the study used a simulation model built according to the author's methodology. The essence of the main aspects of building the model is contained in the following.

The model combines the following modules:

the module for determining the number of births;

the module for determining the natural decline of the population for each age group;

the module for the transition between groups based on the lag method.

The lag method was used to develop a simulation model, the essence of which is contained in the following.

The observation research period is chosen from the beginning - one year, five years, ten years. According to this period, the lag of changes in the population size is chosen, and model-1Y, model-5Y, and model-10Y are formed accordingly.

Depending on the selected lag, the population is divided into groups separately for women and men. For example, if the lag is five years, then we should use the distribution of the population, which was formed in previous periods, by the following age groups: 0-4; 5-9; 10-14; 15-19; 20-24; 25-29; 30-34; 35-39; 40-44; 45-49; 50-54; 55-59; 60-64; 65-69; 70-74; 75-79; 80-84; 85-89; 90-94; 95-99 years old.

Forecasting defines periods with the selected model lag. For each subsequent period, the composition of age groups is calculated based on the values of the previous period. The prediction module works according to the following algorithm. In each age group (except the first group 0-4), the number is calculated according to the formula:

$$N_t = F(N_{t-1}), \text{ or } N_t = N_{t-1} * K_t, \quad (3)$$

where N_t is the population in age group *t*;

N_{t-1} - the population of the previous age group;

K_t - the rate of population decline (including mortality and migration).

The formula is used separately for men and women. The mortality rate is determined for each age group separately for men and women.

The module for determining the number of births allows you to calculate the number of boys and girls for the age group 0-4. The number of births is determined as a linear function of the number of women of childbearing age in the corresponding period and is calculated separately for boys and girls:

for girls $N_{0G}=N_{G15-49}\times K_G$, for boys $N_{0M}=N_{G15-49}\times K_M$, (4)

where: N_{G15-49} - the number of women of childbearing age (from 15 to 49 years old);

K_G - birth rate of girls;

K_M - birth rate of boys.

When finding birth rates for boys and girls, the birth ratio of 105 boys per 100 girls is considered.

The initial information for forecasting using the model is the demographic composition of the population (men and women separately) by age group according to the results of the 2001 census. The information was obtained from the state website of Ukraine, "Data Bank of the State Statistics Service of Ukraine" [17].

The mortality and migration rate by age group (men and women separately) is calculated based on information from previous periods. From (3) we get:

$K_t=N_t/N_{t-1}$. (5)

According to the information from the previous periods, the average values of the coefficients for men and women in each age group are determined. The number of births in five years is calculated as a linear function of the number of women of childbearing age in the previous period.

The input information for the described model is formed from population groups at the beginning of forecasting. The birth rates are determined separately for boys and girls using the basis of previous periods. These parameters are laid down for the formation of various scenarios of demographic development. Based on the results of previous periods, population mortality rates are also calculated for each age group separately for men and women.

The module for determining the number of births and calculating the number of the population in the first age group of 0-4 years at the beginning of the forecasting process is first executed.

The module for determining the natural decline of the population for each age group is the next executed.

Based on the lag method, the module for the transition between groups transfers the formed and specified number of populations in the group, taking into account the lag, into the next age group. Thus, every five years, the population of group ***N*** is transferred to group ***N+1***, taking into account natural changes. Transition from the last group, 95-99, is not performed.

Such a model allows for predicting demographic changes for almost several decades. This universal model can forecast structural-demographic shifts in any country and even individual territorial groups.

2.3 Modeling and forecasting Ukrainian demography

Before starting the simulation, it is necessary to prepare the input information. First, it is information by age group. This information was obtained from the State Committee of Statistics for 2011 data.

Secondly, information on the birth rate is calculated. This information was determined based on the results of the analysis for the years 1996-2011. The determined coefficients and their average, maximum, and minimum values are given in the table. 1.

Table 1. Calculation of the birth rate

Year	Women of childbearing age (15-49)	Boys were born	Coefficient	Girls were born	Coefficient
1996	12 317 174	1 416 391	0,114993179	1 344 342	0,1091437
2001	12 704 814	1 064 951	0,083822636	1 008 629	0,07938951
2006	12 582 673	1 031 702	0,081993866	973 382	0,07735892
2011	12 342 731	1 250 676	0,101328952	1 178 887	0,09551265
Average value			0,095534658		0,0903512
Max			0,114993179		0,1091437
Min			0,081993866		0,07735892

According to the given data, the birth rate of boys is 1.05737013 times higher than the rate of girls, but the mortality rate of men is higher, so the number of women starting from 25-29 years old already exceeds the number of men. Fertility in the period prior to the study was the worst in 2006 and the best in 1996. The fertility rate is a factor that determines living conditions. It improves when promoting the development of the family and, on the contrary, worsens otherwise.

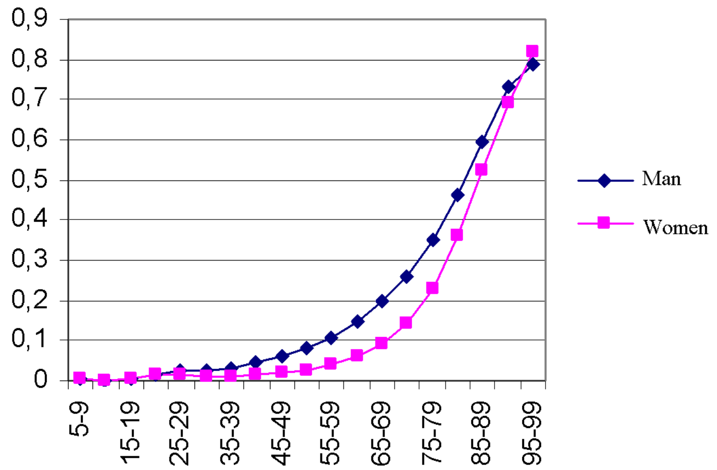
Third is the death rate for each age group. It was also calculated based on information on changes in population size in age groups from 1996 to 2011.

When building the model, based on the analysis of information from previous periods, the dynamics of mortality rates by age (Figure 2) and the value of birth rates (Table 1) were determined.

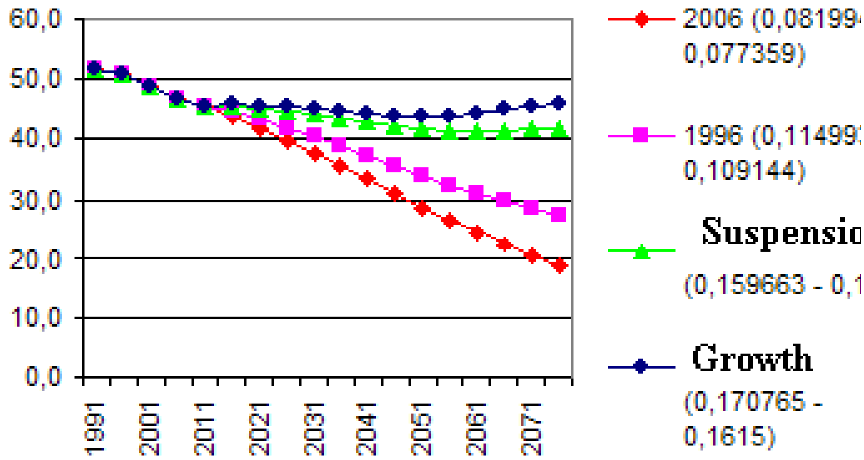
With the help of a simulation model, the dynamics of population changes in Ukraine were determined under the worst scenario of 2006 (Coefficient boys – 0,081993866; girls – 0,07735892) and the best scenario of 1996(Coefficient boys – 0,114993179; girls – 0,1091437). The forecasting horizon is chosen until 2071-2076. This makes it possible to determine the peculiarities of trends in structural-demographic shifts.

The birth rate that will stop the reduction of the population in Ukraine and the rate that will contribute to population growth were also determined (Figure 3).

The scenario of suspension and growth is artificial and is possible only with the participation of state support and stimulation of the increase in the birth rate. Administrative methods cannot do this. For this, it is necessary to create appropriate conditions. Moreover, even in the best case, the positive result of increasing the birth rate to the level of growth will be observed only after 2056.



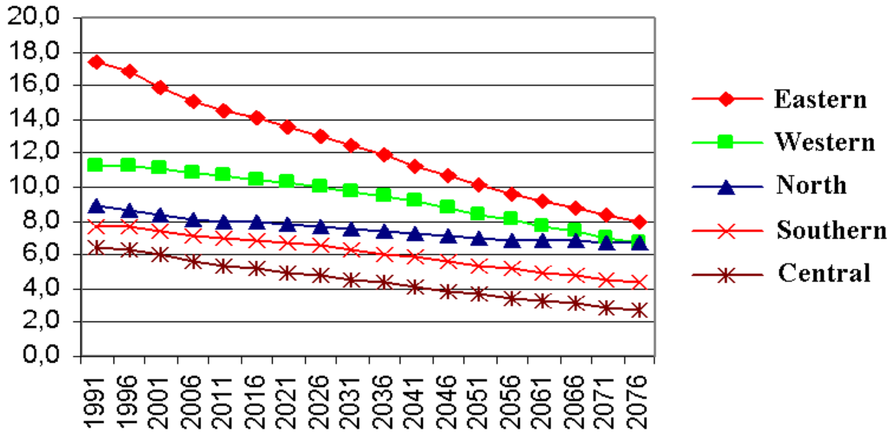
Calculated by the author based on the data of the State Committee of Statistics
Figure 2. Dynamics of mortality rates in Ukraine



Built by the author based on the results of the simulation model

Figure 3. Dynamics of changes in the population of Ukraine according to individual scenarios.

The decline in the population of Ukraine does not occur equally in different regions. According to the scenario with the birth rate at the level of 1996 (boys - 0.114993; girls - 0.109144), changes in the population by region differ significantly for regions (Figure 4).



Built by the author based on the results of the simulation model
Figure 4. Dynamics of changes in the population of Ukraine by region.

The model allows, based on the forecasting results, to determine the dynamics of changes in the population of working age (from 20 to 59 years), before working age (from 0 to 19 years), and above working age (after 60 years), as well as to determine the burden on the working age population to provide for children and pensioners.

The analysis of three development scenarios allows us to identify the following features of Ukraine (Figure 5).

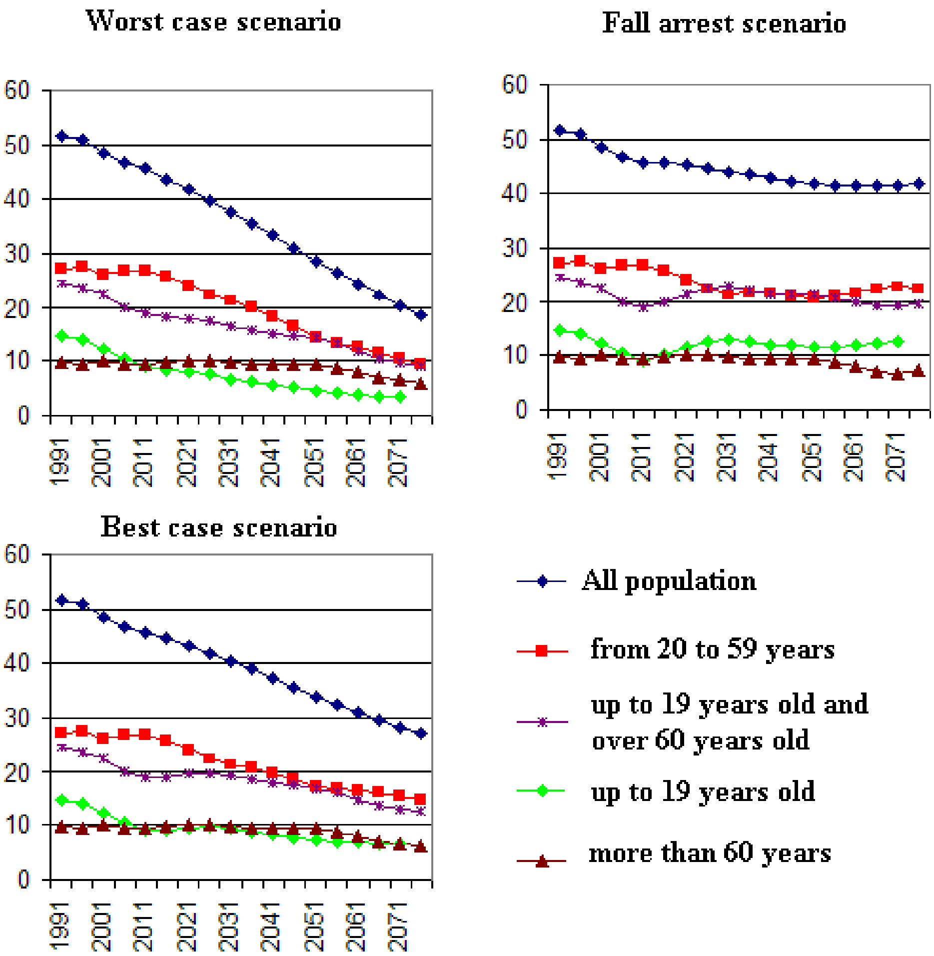
First, according to the first and second scenarios, the number of births continues to decrease, and according to the third, the birth rate increases but does not reach the level of 1991.

Secondly, starting in 2011, Ukraine began reducing the working-age population.

Thirdly, with the birth rate growth around 2028, an excess of the burden is observed. The most significant drop is observed in Donetsk and Dnipropetrovsk oblasts, the largest in Ukraine in population. At the same time, rapid population growth is observed in the city of Kyiv. By region, the worst condition is observed in eastern Ukraine, and the best is in northern Ukraine. Under these conditions, eastern, western, and northern Ukraine regions will have practically the same population.

In the case of achieving the birth rate equation concerning population growth in Ukraine, structural shifts in population groups significantly increase the burden on the working-age population (Figure 6).

The birth rate is gradually increasing, and the working-age population is decreasing. There will be an increase in the population "up to" and "over" the working age over the working-age population starting from 2028. This situation will be observed almost until 2055. Only then will the growth of the working-age population correct the situation. An increase in the working-age population will require more institutions to raise and educate children, which are currently being destroyed. Their establishment requires an increase in budget expenditures.



Built by the author based on the results of the simulation model

Figure 5. The dynamics of changes in specific population groups of Ukraine according to certain scenarios.

Using the proposed simulation model allows us to create and compare different scenarios of the development of situations with the demographic state of the population in Ukraine almost throughout a person's life.

Based on the simulation results, some features of structural shifts in labor potential were revealed.

Until 2011, the business environment functioned in conditions of a surplus of the working population. Starting from 2011, a significant reduction in the working population began, accompanied by an increase in the population "up to" and "older" than the working age. The reduction of the working-age population directly affects the decrease in gross regional product (GRP) levels.

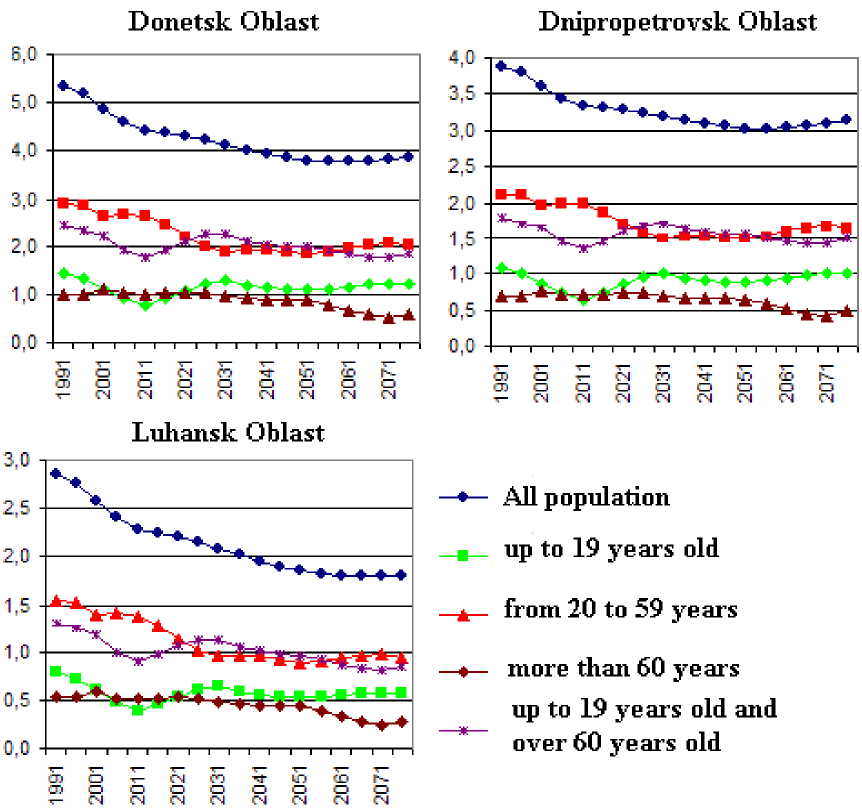


Figure 6. Dynamics of changes in certain population groups of the eastern regions of Ukraine according to certain scenarios.

A decrease in the working population will lead to changes in the labor market. If the number of working people used to be within the number of working places, the situation would gradually change, and the working population would be less than the number of working places. That is, the economy of Ukraine will move from the conditions of cheap labor to the languages of expensive labor. This will lead to competition between technologies. Enterprises with inefficient labor technology will not be able to withstand competition and will cease to exist. Perhaps such a provision will be an impetus for the business environment to step toward technology renewal.

2.4 The war in Ukraine and its impact on demography

The modeling was conducted based on information from 2014. Therefore, such a forecast can be a basis for determining the further impact of the war on demography in Ukraine.

Russia's military operations in Ukraine began in 2014. As a result, Crimea was annexed, as well as occupied parts of Donetsk and Luhansk regions. This caused the beginning of population migration to the territory controlled by Ukraine. In the occupied territories, there remained a population that did not have the opportunity to migrate due to their health, insufficient financial status, or their desire to live in Russia. Such a population is considered Ukrainian but lives according to the laws of the occupying power. The occupying authorities began to resettle the population from the depressed regions of Russia into the occupied territory in the apartments left by the migrants. Moreover, the children will be resettled deep in Russia. In those times, before the start of active aggression from the Russian Federation, the impact on demography was mainly due to the migration of all population strata.

With the beginning of active military aggression by the Russian Federation, missile attacks and destruction, as well as the seizure of new territories, migration flows increased. Migrations from Ukraine to other countries of the world have begun.

Active hostilities are accompanied by injury and death of soldiers. The death of civilians accompanies the shelling of cities.

All these processes significantly affect demography and worsen its condition. Women with children mainly carry out-migration to other countries. In the war, primarily men of the most working-age die.

To determine the current demographic structure of the population by age groups, starting from 2022, it is necessary to add the loss of the population of Ukraine due to emigration and the death of the military.

Loss of confidence in the future and deterioration of welfare also affected the demographic situation. The number of children born in Ukraine was only 87,655 in the first half of 2024. This is 9% less than in the same period last year. At the same time, 250,972 deaths were recorded.

The war in Ukraine continues, and the intensity of hostilities only increases. Now, the troops of the Russian Federation are conducting offensive actions. The Russian Federation had a robust mobilization reserve at the beginning of the war [18]. However, it is lost every day. According to the military, the daily loss of Russian occupiers reaches more than 1,000. Since the beginning of the war, the total amount on the part of Russia is already approaching a million dead. Currently, statistics do not provide information on the number of dead from the Ukrainian side. However, this is a war with casualties on both sides.

The expected consequences of the war for Ukraine are catastrophic [19]. Already today, this is the loss of occupied and annexed territories with a population that cannot work in the economy of Ukraine. A substantial share of losses is the death of soldiers at the front. The destruction, shelling, and destruction of the Kakhovka Dam have already led to the death of a large number of civilians. Those who migrated abroad should be added to this list. Also, during the war, the birth rate decreased, and the mortality rate increased among the population.

3 Conclusion(s)

Studying any country's demographic structure and population dynamics provides information about changes in the working-age population, which is the leading resource for forming the country's GDP.

Capital investments are necessary to increase the rate of economic growth and investments in the development of labor resources. Such investment is required to acquire education and competencies, maintain a person's physical health, and meet other needs. Such investments form human capital, which can influence economic growth.

For forecasting structural-demographic shifts, it is advisable to use the simulation modeling mechanism based on the example of the proposed model. The most appropriate is the 5Y model, which is based on age groups of the population of 5 years and uses a lag of 5 years. Using such a model provides an opportunity to significantly expand the forecasting horizon and perform forecasting for countries as a whole and individual territorial groups, too.

The modeling of structural-demographic shifts conducted in Ukraine made it possible to identify demographic problems and their impact on future development.

Forecasting provides more adequate information in peacetime and in the absence of natural disasters. The results of such forecasting can become the basis for determining the state policy for forming the country's human capital.

The impact of wars and disasters hurts demographic shifts. In this case, the proposed forecasting mechanism allows determining the basis for loss accounting and also provides information for decision-making at the state and regional level.

The use of the model can make it possible to obtain a complete picture of the dynamics of changes in the demographic structure of the territorial community when forming a strategy for the recovery of territorial communities. Before starting forecasting using the model, it is necessary to determine the actual state of the population of the territorial community with age groups. Based on information from the pre-war period, birth and death rates can be calculated. Forecasting structural changes in labor resources can be used as a basis for forming a strategic plan to restore the territorial community.

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