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DEMOGRAPHIC AGEING AND PUBLIC DEBT IN POLAND. IS THE PUBLIC FINANCE SECTOR ABOUT TO COLLAPSE?

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Abstract. The paper addresses the issue of demographic ageing of the Polish population, with particular emphasis on its impact on the functioning of the national economy. Its main objective was to assess the influence of demographic changes on the public finance sector in Poland. To achieve the main objective of assessing the impact of demographic aging on Poland's public finance sector, a study of correlation and periodic change dynamics was conducted, covering the period from 2000 to 2022. Additionally, a regression analysis was performed using the Classical Least Squares Method. In the research part of the paper, changes in the age structure in Poland are characterized, and the impact of this phenomenon on the economic situation of elderly persons is assessed. Using an econometric model, the impact of factors related to demographic changes, such as natural population growth and the demographic dependency ratio on the post-working-age population, on the value of the state's public debt was assessed. Based on the model, an attempt was made to forecast this variable for the years 2023-2026. The analyses revealed that the consequences of demographic ageing threaten the stability of the public finance sector. The study showed that with a 95% probability, a decrease in natural population growth by 1000 individuals leads to an increase in debt by 0.81 billion PLN, and an increase in the demographic dependency ratio on the post-working-age population results in an increase in public debt by 19.71 billion PLN, with other conditions unchanged. Furthermore, the prediction confirmed that, under the conditions of the values of explanatory variables forecasted by the Central Statistical Office, its value in 2026 will increase by 0.38% compared to 2022.

Keywords: demographic ageing; public finance sector; public debt

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JEL Classifications: H63, J10, J11

1. Introduction

The demographic ageing process is one of the most significant challenges facing the economic systems of many countries worldwide, including the capacity of their public finance sector. It is widely known that activities focused on broadly understood pronatalist policy are highly expensive and their effectiveness is often unsatisfactory for public authorities. These factors influence the relatively broad interest of researchers in the problem of the impact of the demographic ageing process on the condition of the public finance sector in individual countries.

The issue of the impact of the demographic ageing process on public debt has been addressed in many scientific studies. This topic was addressed, among others, by Jensen et al. (1995), Hondroyiannis et al. (2000), Afllatet (2018), Eberstadt & Groth (2010) and Lee et al. (2022).

Popular research directions also concern a slightly more general issue related to the impact of demographic ageing on various components of the public finance sector. Among the key research initiatives, it is worth highlighting the work of Jorgensen et al. (2011), Žokalj (2016), King & Jackson (2000) and Yoshino et al. (2019).

This paper addresses the issue of demographic ageing of the Polish population, with particular emphasis on its impact on the functioning of the national economy. The paper is theoretical-empirical in nature, and its main objective was to assess the influence of demographic changes on the public finance sector in Poland. To achieve the main objective, a study of correlation and periodic change dynamics was conducted, covering the period from 2000 to 2022. Additionally, a regression analysis was performed using the Classical Least Squares Method. Using an econometric model, the impact of factors related to demographic changes, such as natural population growth and the demographic dependency ratio on the post-working-age population, on the value of the state's public debt was assessed. Based on the model, an attempt was made to forecast this variable for the years 2023-2026.

2. Theoretical background

Demographic ageing has been a significant challenge for many countries authorities for years. One of the essential aspects of this phenomenon is the consequences it has for the condition of the public finance sector. The table presents a list of selected publications on this topic along with a brief summary (Table 1).

Table 1. Review of literature

Publication	The main conclusion from the conducted research
Van der Berg (1998)	Van der Berg examines the impact of population ageing on the country's public finances and social security systems. The article highlights the challenges posed by demographic change, including increased demand for pensions and healthcare services. Van der Berg examines the sustainability of the current social security framework in light of these trends, arguing for the need to adapt policies to provide adequate support for older citizens. Overall, the article calls for a comprehensive approach to reform that addresses both the financial sustainability and well-being of older people in South Africa.
King, Jackson (2000)	King and Jackson examine the fiscal challenges of an ageing population. The authors highlight several key areas of concern, including rising costs for health care, pensions, and social services as the proportion of older people increases. They advocate proactive fiscal planning to manage the effects of an ageing population.
Lindh (2003)	Lindh discusses the implications of demographic change, particularly population ageing, for social policy and the public sector. The paper examines how changes in age distribution affect economic and social policy, emphasizing the need for adaptive strategies to cope with these changes. Lindh argues for innovative approaches that incorporate demographic trends into policy planning.
Wolf & Amirkhanyan (2010)	Wolf and Amirkhanyan examine how changing demographic patterns are affecting public sector management and policy. The authors argue that population ageing, changing immigration trends, and changing family structures pose significant challenges to public administration. The article highlights the need for adaptive strategies in public sector organizations to effectively respond to these demographic changes, ensuring that public services remain effective and equitable.
Jorgensen et al. (2011)	Jorgensen, Rocha, and Fruttero examine the multifaceted effects of population ageing in Brazil. The report, published by the World Bank, examines how demographic changes are changing the country's economic landscape and social policies. The authors analyze the implications of population ageing for economic growth, highlighting potential challenges such as a shrinking labor force and increased dependency ratios. They discuss how these demographic changes could exacerbate poverty levels, especially among older people.
Immam (2013)	Immam examines the impact of Japan's ageing population on the stability of its financial sector. The study highlights how demographic changes, characterized by falling birth rates and rising life expectancy, pose significant challenges to economic growth and financial systems. Immam discusses potential risks associated with an ageing population, including a shrinking labor force and rising dependency ratios, which could lead to reduced consumption and investment. The paper emphasizes the importance of addressing the financial implications of an ageing population to maintain stability and promote sustainable economic growth in Japan.

Kluge (2013)	Kluge examines the economic consequences of demographic change, particularly population ageing, for public finances in Germany. The study highlights the growing pressure on the country's welfare system due to rising costs related to pensions, healthcare and social services for the older demographic group. Kluge discusses potential policy responses, including raising the retirement age, adjusting benefit formulas and increasing labor market participation among older people.
Yoshino et al. (2019)	Yoshino, Kim, and Sirivunnabood examine the impact of population ageing on financial stability. The authors discuss how demographic changes, characterized by rising life expectancy and falling birth rates, pose challenges to government budgets and social welfare systems. The article highlights the need to address these challenges, including adjustments to retirement age, tax policies, and social security frameworks.
Lyons et al. (2018)	In their study, Lyons, Grable, and Joo conduct a cross-country analysis of the relationship between population ageing and financial security. This research examines how different nations adapt to the challenges posed by an ageing population, particularly in terms of economic stability and individual financial well-being. The authors identify key factors affecting older adults' financial security, including pension systems, access to health care, and employment opportunities.
Rouzet et al. (2019)	This article examines the fiscal challenges faced by ageing societies and their implications for inclusive growth. It highlights the growing pressure on public finances due to rising healthcare and pension costs associated with ageing populations. The study highlights the need for reforms in taxation, public expenditure and social protection systems to promote sustainable development and inclusiveness.
Mihajlovic & Miladinov (2024)	Mihajlovic and Miladinov analyze the impact of population ageing on the stability of public finances, highlighting the challenges posed by the increasing old-age dependency ratio. The authors emphasize that this demographic trend places a significant burden on pension systems and social care expenditures, negatively affecting economic growth. The article underscores the necessity of implementing policies that support long-term financial stability, such as investments in human capital, promotion of active ageing, and the extension of working life.
Symeonidis et al. (2021)	Symeonidis, Tinios, and Chouzouris examine the impact of implicit pension debt on the stability of public finances using projections from the Ageing Working Group. The authors highlight that in many countries, implicit pension debt exceeds public debt, posing a significant risk to fiscal budgets. The article emphasizes the need for pension system reforms and responsible budget planning, which should account for explicit public debt and implicit pension liabilities to ensure long-term financial stability.
Temsumrit (2023)	This article analyzes the impact of an ageing population on the level of government expenditures and the structure of the state budget. The study points out that an increasing share of elderly individuals in society leads to higher public spending on healthcare, social care, and the environment. At the same time, the share of expenditures on education declines, which may negatively affect the long-term development of human capital.

Source: compiled by the authors

In this context, in addition to those mentioned in the table, it is worth highlighting the important contributions of Auerbach, and Kotlikoff (1985); Auerbach, and Kotlikoff (1987); Hagemann, R., & Nicoletti, G. (1989); Auerbach et al. (1989); Clements et al. (2018).

A brief review of the literature on the impact of demographic ageing on public debt is presented in Table 2.

Table 1. Review of literature

Publication	The main conclusion from the conducted research
Jensen & Nielsen (1995)	Jensen and Nielsen examine the interplay between population ageing and fiscal sustainability. The authors analyze how the growing proportion of older people affects public debt and the ability of governments to maintain sustainable fiscal policies. They emphasize the potential of rising pension and health care costs to create significant fiscal pressures, leading to higher public debt levels.
Eberstadt & Groth (2010)	Eberstadt and Groth examine the long-term implications of demographic trends for the sustainability of public debt. The authors argue that population aging, falling birth rates, and demographic changes in the workforce will significantly exacerbate fiscal challenges for governments, particularly in developed countries. They suggest that these demographic changes could lead to increased public spending on pensions and health care, straining national budgets and raising debt levels.
Afflatet (2018)	Afflatet examines how demographic change, particularly population ageing, affects public debt levels in Europe. The study uses panel data from 18 countries to explore the relationship between demographic ageing and fiscal sustainability. The results indicate that the growing elderly population contributes significantly to the growth of public debt, mainly due to higher spending on pensions and healthcare.

Lee et al. (2022)	Lee, Mason, and Park examine the relationship between population ageing and debt dynamics in Asia. The authors examine how the growing elderly population affects fiscal policy and public debt levels across the region. They discuss the rising costs of pensions, health care, and social services for ageing populations, which can lead to unsustainable debt burdens.
Aspide et al. (2023)	This article examines the impact of population ageing on public debt and fiscal decision-making. The authors emphasize the growing risk of debt accumulation and highlight the differing preferences of various age groups regarding debt reduction. The publication encourages reflection on the influence of social policy and public finance management strategies on the economic situation in the context of demographic ageing.
Judge (2024)	Judge analyzes the relationship between population ageing and public debt. He discusses how the increasing number of elderly individuals impacts fiscal policy and public debt levels in developed countries. The article also addresses the issue of declining tax revenues, which further complicates public finance management.
André et al. (2024)	The authors highlight the substantial impact of demographic ageing on public debt in OECD countries, underscoring the urgency of pension system reforms. They further explore the challenges of refinancing existing public debt amid increasing global interest rates and rising debt servicing costs.
Basso & Rachedi (2021)	The article emphasizes that demographic changes affect public debt by reducing the ability of government spending to generate economic growth, thereby complicating efforts to reduce budget deficits. The authors conclude that population ageing weakens the effectiveness of fiscal policy as a tool for managing the economy and ensuring its stability.

Source: compiled by the authors

3. Research objective and methodology

The study's main objective was to assess the impact of demographic ageing of the Polish population on the public finance sector. The following specific objectives were formulated:

1. Characterization of demographic trends in Poland in 2000-2022 and assessment of the financial standing of senior citizens.
2. Characterization of the impact of demographic ageing of the Polish population on the labor market and the public finance sector.
3. An attempt to forecast Poland's public debt for 2023-2026 based on the predicted natural increase and the projected dependency ratio of the post-working age population.

The principal premise of this research is to ensure that it is thoroughly representative. This was achieved using detailed macroeconomic statistics based on the official data from Statistics Poland (GUS) and Eurostat.

The following research hypotheses were posited:

1. The advancing ageing of the population contributes to increasing public expenditure on healthcare.
2. The components involved in population ageing, i.e. declining birth rate and increasing dependency ratio of the post-working age population, produce an increase in the national public debt.

This study was concerned with Poland, while the empirical analysis focused on the condition of the public finance sector, taking into account demographic ageing factors which affect the economic situation in the country. As regards the timeframe, the study covered the period from 2000 to 2022.

This study analyzed and interpreted the findings from research on the impact of demographic ageing on the financial situation of older people, the labor market and the public finance sector. The research used secondary data published by Statistics Poland, which was contained in the Local Data Bank, Domain Knowledge Bases, and periodic thematic statistical reports.

The issue in question was investigated using statistical analysis and an econometric model. The former involved a quantitative description of economic and social phenomena, relying on a numerical determination of the average level of the analyzed characteristic and the average degree of differentiation between units. Statistical analysis also encompassed the study of the dynamics of phenomena, which included periodic changes and development trends. Meanwhile, the econometric model developed using Gretl software served to carry out

regression analysis to demonstrate the linear relationship between the studied parameters and obtain a macroeconomic econometric forecast based on the classical trend model.

The impact of demographic ageing on the Polish economy was analyzed by predicting public debt in 2024-2026 while relying on the following factors: dependency ratio of the post-working age and natural increase in 2010-2022.

The Classical Least Squares method (CLS) was used to estimate the parameters of the linear model. It consists of determining the values of the estimates $\hat{\beta}_0, \hat{\beta}_1, \dots, \hat{\beta}_t$ of parameters $\beta_0, \beta_1, \dots, \beta_t$, so that the sum of squares of the deviations between the theoretical values and the empirical values is the smallest, which may be expressed as:

$$\sum_{t=1}^n e_t^2 = \sum_{t=1}^n (y_t - \hat{y}_t)^2 \rightarrow \min,$$

where:

e_t – absolute error of *ex-post* projection over period t ,

y_t – empirical value of the variable projected for period t ,

$\hat{y}_t$ – theoretical value of y variable over period t (Nazarko, 2018, p. 14).

Using CLS, the following assumptions were formulated:

1. The model is linear.
2. The anticipated value of the random component equals zero.
3. The random component is not subject to autocorrelation, while its variance is constant over time.
4. Explanatory variables are not random.
5. The random component has a normal distribution (Tatarczuk, 2021, p. 51).

Parameters β_0 i β_1 are estimated using CLS in accordance with the following formulas:

$$\hat{\beta}_1 = \frac{\sum_{t=1}^n (t - \bar{t}) y_t}{\sum_{t=1}^n (t - \bar{t})^2},$$

$$\hat{\beta}_0 = \bar{y} - \hat{\beta}_1 \bar{t},$$

where:

$\hat{\beta}_1$ – estimate value for parameter β_1 ,

$\hat{\beta}_0$ – estimate value for parameter β_0 ,

t – time variable,

$\bar{t}$ – arithmetic mean of variable t ,

y_t – empirical value of the variable projected for period t ,

$\bar{y}$ – arithmetic mean of empirical values of the projected variable (Nazarko, 2018, p. 16).

In order to assess the validity of the estimates, statistical significance was verified using Student's t -test, followed by normality analysis of the distribution of the random component, heteroskedasticity analysis of the distribution of the random component and autocorrelation analysis of the model residuals.

The model was developed based on Statistics Poland data for 2010-2022 and the projected data for 2023-2026. The general econometric model used in this study may be expressed as follows:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \xi,$$

where:

Y – explanatory variable (value of state public debt),

x_1 – explanatory variable (natural increase),

x_2 – explanatory variable (dependency ratio of the post-working age population),

ξ – random component.

The variables Y , x_1 , x_2 are known. Their values were obtained from detailed statistical studies conducted by Statistics Poland. The study estimated the structural parameters β_t . The model's consistency with reality was then tested, and the results were presented. The obtained estimates were interpreted and compared with the posited hypotheses.

4. Results and discussion

Population dynamics are mainly reflected by the ratio of the number of live births to the number of deaths, which has significantly deteriorated in Poland in recent years. It is shown in Fig.1.

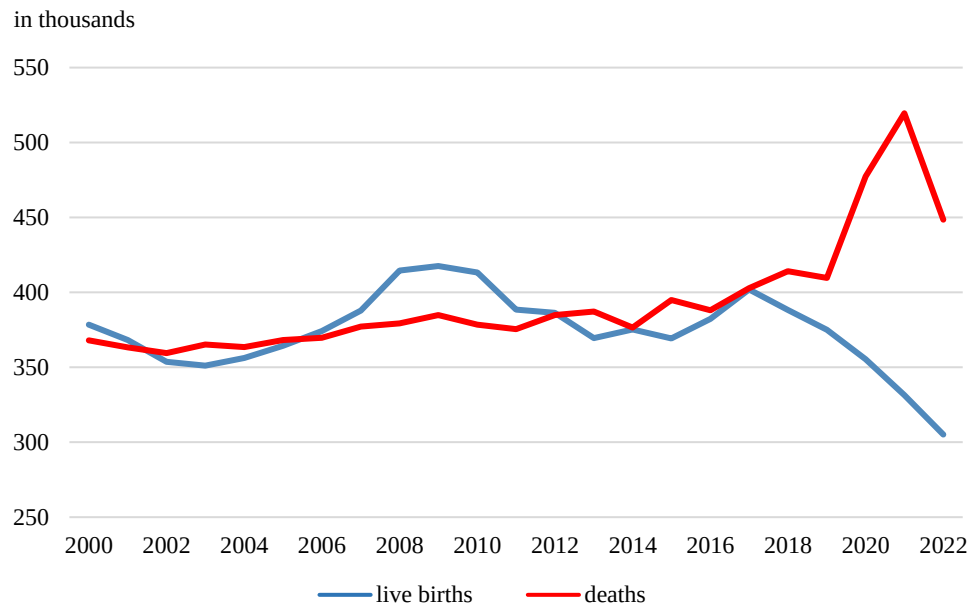


Fig. 1. Number of live births and deaths in Poland in 2000-2022
Source: own elaboration based on data from Statistics Poland

In 2022, approximately 305,000 live births will be recorded, which, compared to 2000 (approximately 378,000), represents an almost 20% decrease. On the other hand, the number of deaths in 2022 reached approximately 448,000, increasing by more than 21% since 2000 (around 368,000). The sudden spike in death rate between 2019 and 2022, as seen in the figure, was undoubtedly due to the COVID-19 pandemic, but it should be noted that the indicator demonstrated an increasing trend throughout the period studied. Another noteworthy element is the small but distinctive increase in the number of births between 2008 and 2010, mainly attributable to the birth of children of persons born during the final stages of the baby boom. Nevertheless, since 2013, Poland has been facing a negative natural increase, which amounted to over 143,000 in 2022.

The changing dynamics of births, deaths and life expectancy have a considerable impact on the Polish pension system, which translates into the quality of life of the senior citizens. Hence, the analysis of the demographic structure provides a foundation for the study of the economic and financial standing of older people, whose livelihood relies chiefly on retirement pay and pensions. Their average level, together with the relation to the average salary in the national economy in 2010-2022, is shown in Fig. 2.

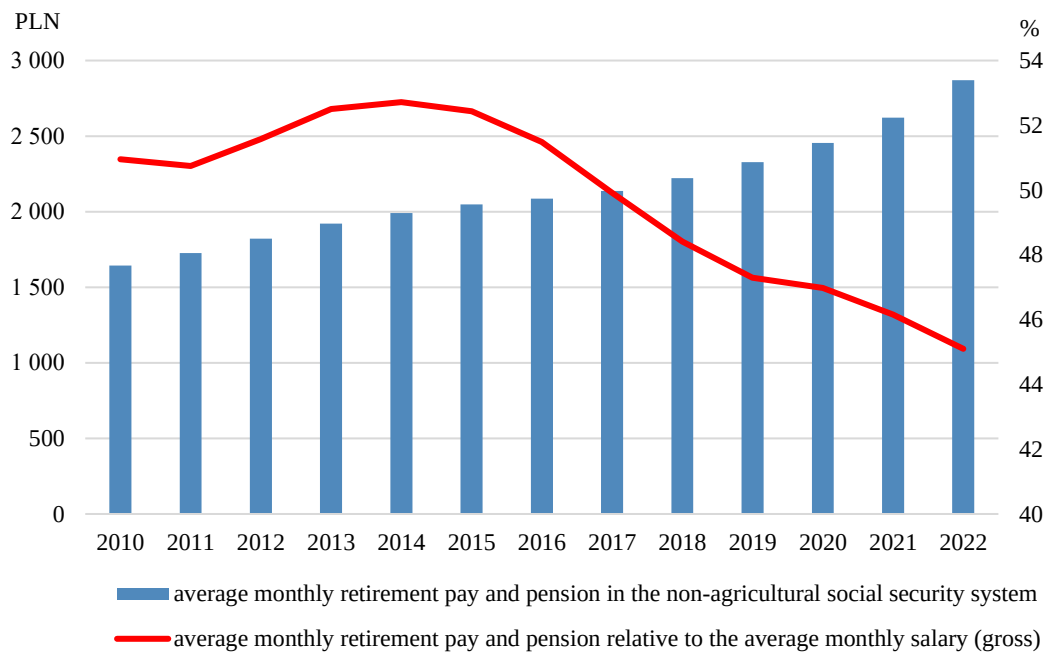


Fig 2. Amounts of gross retirement pay and pensions in the non-agricultural social security system relative to average monthly salary (gross) in Poland in 2010-2022

Source: own elaboration based on data from Statistics Poland

Despite the annual increase in the average monthly gross retirement pay and pensions in the non-agricultural social security system, their relation to the average gross monthly salary in the national economy has seen a significant decline since 2014. In 2022, it reached just over 45%, which, compared to 50-53% in the first half of the studied period, is a worrisome development. The value of average benefits paid by the Social Insurance Institution (ZUS) increased in 2022 by more than 74% compared to 2010, while the value of average salaries in Poland in that period increased by more than 97%. Negative trends may be further illustrated by examining the dynamics of retirement pay and pensions relative to inflation. In 2022, their value increased by 9.4% compared to the previous year. Simultaneously, the prices of consumer goods and services increased by 14.4%, which in practice may mean that the financial standing of older people in Poland worsened.

Moreover, demographic ageing has a significant impact on the labor market. In recent years, the number of people in the post-working age group has considerably increased, and forecasts indicate that this trend will continue in the next decades. At the same time, a decline in the number of people of pre-working age has been observed, heralding a tangible reduction in the labor force's potential. In 2060, the proportion of the post-working-age population is projected to increase by more than 140% compared to 2000, whereas the proportion of working-age persons will fall by almost 20%. In addition, the number of people of pre-working age is expected to drop by approximately 36% in the studied period. When examining the structure of Poland's population by economic age groups, one should also analyze the average annual rate of change, which may be expressed by the following formula:

$$\bar{i}_g = \left(\sqrt[n-1]{i_{\frac{n}{n-1}} * i_{\frac{n-1}{n-2}} * i_{\frac{n-2}{n-3}} * \dots * i_{\frac{2}{1}} * i_{\frac{1}{0}}} - 1 \right) * 100\%,$$

where:

$i_{\frac{n}{n-1}}$ – last chain index,

$i_{\frac{1}{0}}$ – first chain index,

n – number of studied periods.

The average annual rate of change in the number of pre-working-age people between 2000 and 2022 was -1.33%. For those of working age, the rate reached -0.22% and 1.94% for the post-working age population. These values indicate a much faster increase in the number of elderly persons accompanied by a fairly rapid decline in the number of young people. Such trends call for an immediate response, posing a significant challenge to the market, which is to adapt to jobs and employment conditions without delay.

Eurostat projections also provide eloquent data concerning the impact of demographic ageing on the labor market in Poland (Tab. 1). According to the projections, by 2070, the population in Poland will drop by approximately 7 million while life expectancy will increase by 6.5 years for women and 8.9 years for men. In addition, changes in the labor market will be prompted by a significant decline in the proportion of the pre-working age population, reaching nearly 20% between 2025 and 2070. Furthermore, it follows from the projections that if the retirement age does not change, economic growth will be substantially hampered in the coming decades as the baby boom generation of the early 1980s will have left the labor market. An evident slowdown in productivity growth is also anticipated due to changes in the employment structure.

Tab. 1. Eurostat projections of change in the labor market in 2025-2070

	Population (in millions)	Total dependency rate	Labor force (in thousands)	Share of the employed aged 55-74 (%)	Productivity growth rate (%)
2025	37.52	69.72	17.21	16.68	3.28
2030	36.96	70.58	16.78	18.27	3.19
2035	36.30	70.50	16.30	20.69	2.59
2040	35.59	72.21	15.59	22.94	2.25
2045	34.82	78.56	14.68	23.82	2.21
2050	34.02	87.74	13.73	23.64	2.07
2055	33.23	95.86	12.97	22.28	1.94
2060	32.44	100.88	12.44	20.97	1.81
2065	31.64	101.17	12.11	21.72	1.67
2070	30.81	99.46	11.80	22.24	1.54

Source: own elaboration based on Eurostat data

In the Eurostat studies, the total dependency ratio was approached as the ratio of the number of people aged 0-19 and 65+ to the number of persons aged 20-64. It is projected to increase by almost 43% over the period analyzed. According to Eurostat forecasts, by 2070 the labor force will have fallen by more than 31%, more than the population (18%). In contrast, the share of those employed aged 55-74 will increase by around 33% in the period under review. Negative trends are expected with respect to productivity growth, which is anticipated to slow down by more than half. This phenomenon is certain to be influenced by the ageing labor force.

Depopulation poses a significant challenge for the public finance sector. Changes in the demographic structure not only reduce income tax revenue but also necessitate increased spending to minimize the negative consequences of the growing share of the elderly in the population. Even so, when considering the trend of the impact of demographic change on public finances, one should also mention areas where reduced budget expenditure may be anticipated. These include education, pre-school care and maternity benefits. As for the overall impact of population ageing, it is crucial to highlight increased outlays on healthcare services (Fig. 3). Statistics show that the elderly and children account for the majority of the National Health Fund (NFZ) patients. Moreover, the highest mean reimbursement values for healthcare services and medications per patient are generated by people in the oldest age groups.

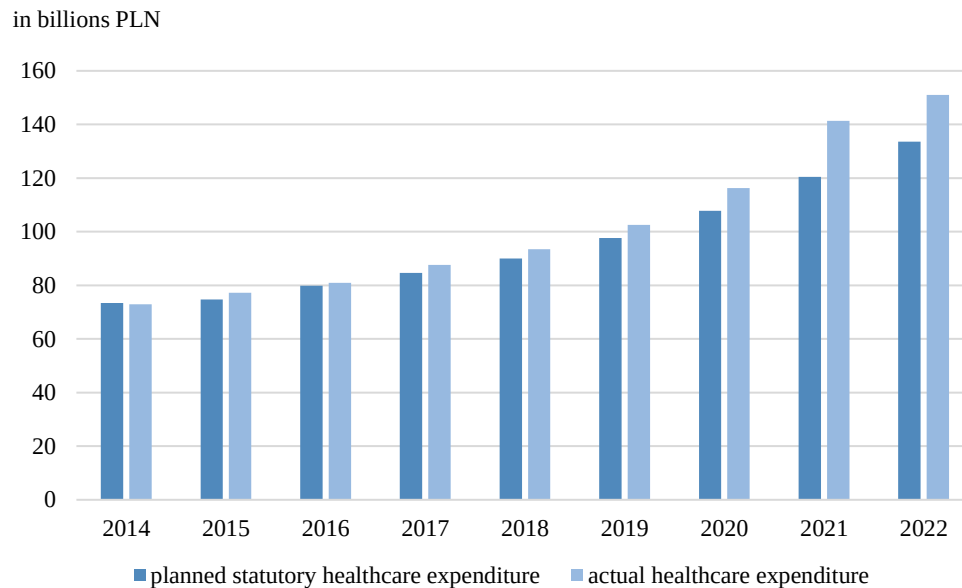


Fig. 3. Planned and actual public expenditure on healthcare in Poland in 2014-2022

Source: own elaboration based on data from Statistics Poland

In 2022, public expenditure on healthcare in Poland amounted to over PLN 133 bn, i.e. 4.9% of the Gross Domestic Product (GDP). This was 107% more than in 2014. A comparison of planned and actual expenditures also yields relevant information about the healthcare system, as only in 2014 was the former greater than the latter. However, the greatest disproportion was observed in the last two years of the studied period, when actual expenditures exceeded planned expenditures by 17% and 13%, respectively. The unfavourable situation faced by the National Health Fund (NHF) may also be inferred from the speed of expenditure growth. Between 2014 and 2022, the medium-term rate of change in public healthcare expenditure was 9.5%, while the rate of change in GDP per capita was 7.9%. The direct impact of population ageing on the public finance sector can be demonstrated by analyzing the Pearson linear correlation coefficient, expressed by the formula:

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}}$$

where:

x, y – variable values,

$\bar{x}, \bar{y}$ – mean variable values,

n – number of periods.

The linear correlation coefficient between the number of persons aged 70 and over and healthcare expenditure between 2014 and 2022 was almost 96%. This means that as the size of the elderly population increases, public expenditure on healthcare increases as well, which is not surprising given that those are seniors who most frequently use services financed by the National Health Fund.

Inquiries into the demographic ageing of the population must not be limited to the current situation but also consider the threats that the Polish economy will have to confront in the future. Again, Eurostat forecasts provide vital information in this respect (Tab.2), indicating that negative demographic trends and their consequences will affect all European Union (EU) countries in the coming years. The data shows that ageing-related changes will result in increased healthcare expenditure, including long-term care. The projected statistics for Europe also estimate the total cost of ageing as a percentage of GDP, which even more clearly illustrates the scale of the issue in question.

Tab. 2. Eurostat forecasts concerning changes in expenditure due to demographic ageing in Poland in 2025-2070

	Healthcare expenditure as % GDP	Long-term care expenditure as % GDP	Total ageing cost as % GDP
2025	6.04	0.92	22.14
2030	6.29	1.13	22.22
2035	6.51	1.33	22.14
2040	6.71	1.45	22.19
2045	6.92	1.52	22.45
2050	7.14	1.62	23.00
2055	7.36	1.79	23.68
2060	7.53	2.01	24.14
2065	7.62	2.20	24.18
2070	7.62	2.30	24.09

Source: own elaboration based on Eurostat data

It is estimated that between 2025 and 2070, the share of healthcare expenditure in GDP will increase by more than 26%. Significant changes are also projected for long-term medical care expenditure, which is expected to increase by 150% as a share of GDP. The average EU rates are 12.4% and 58.7% respectively. As for Poland, the total cost of ageing as a percentage of GDP determined by Eurostat will increase by 8.8% by 2070, with a 4.1% increase for the entire EU. These trends reflect the rapid ageing pace in Poland and the extent of costs resulting from such dynamic demographic changes.

Reflection on the changes in the demographic structure in Poland may be concerned with multiple domains, whereby the public finance sector may be considered one of the most important among them. Therefore, an attempt was made to assess the impact of trends related to demographic ageing on Poland's financial condition. Two explanatory variables were included in the econometric model: natural increase and the dependency ratio of the post-working age population. On the other hand, national public debt was adopted as the explained variable. The data in Tab. 3 demonstrates that Polish society is facing the problem of depopulation. However, the study aimed to measure the actual consequences of this phenomenon, expressed as changes in the value of national public debt. For the purposes of the analysis, it was assumed that the aforementioned variables are the only ones that influence its volume. The study considered actual data from 2010-2022 and the Statistics Poland forecast for 2023-2026.

Tab. 3. Value of national public debt in 2010-2022 and explanatory variables with projection until 2026

	National public debt (in billions PLN)	Natural increase (in thousands)	Dependency ratio of post- working age population
2010	747.90	34.82	26.0
2011	815.35	12.92	26.9
2012	840.48	1.47	27.9
2013	882.29	-17.74	29.0
2014	826.77	-1.31	30.2
2015	877.28	-25.61	31.4
2016	965.20	-5.75	32.7
2017	961.84	-0.87	34.0
2018	984.31	-26.02	35.3
2019	990.95	-34.76	36.5
2020	1111.81	-122.05	37.4
2021	1148.58	-188.01	38.1
2022	1209.50	-143.32	39.0
2023		-123.27	39.9
2024		-128.27	40.7
2025		-132.15	41.4
2026		-139.67	41.9

Source: own elaboration based on data from Statistics Poland

In addition to assessing the impact of the explanatory variables on the explained variable, the analysis also aimed to estimate national public debt in 2023-2026, which is why the table does not include data on its value in the period concerned. As part of the assessment of Poland's demographic situation, it may be worthwhile to consider changes in natural increase, which dropped more than fivefold between 2010 and 2022. At the same time, national public debt rose by more than 60% and the dependency ratio by approximately 50%.

The Classical Least Squares method (CLS) was used to estimate the parameters of the linear model. The formula of the model in question was as follows:

$$Y = 275.26 - 0.81x_1 + 19.71x_2 + \xi,$$

where:

Y – value of the national public debt in billions PLN,

x_1 – natural increase in thousands,

x_2 – dependency ratio of post-working age population,

ξ – random component.

The obtained parameter estimates were interpreted as follows:

1. If the natural increase grows by 1,000 people, national public debt will decrease by an average of PLN 0.81 bn, with a mean error of $\pm$ PLN 0.25 bn *ceteris paribus*.
2. If the dependency ratio of the post-working age population increases by one unit, national public debt will increase on average by PLN 19.71 bn with a mean error of $\pm$ PLN 3.73 bn *ceteris paribus*.

After evaluating the model, its compatibility with the data was analyzed. It was found that the empirical values of the national public debt deviate from the theoretical values by an average of PLN 33.19 bn, which constitutes 3.49% of the mean of this variable. The determination coefficient was also significant, as it demonstrated that the model accounted for 95.26% of the variability of the national public debt. Based on these statistics, the model should be considered to fit the actual data.

To assess the validity of the model, the significance of the structural parameter was verified by positing the following hypotheses:

$$\begin{aligned} H_0: \beta_1 &= 0, \\ H_1: \beta_1 &\neq 0. \end{aligned}$$

The null hypothesis assumes that the structural parameter β_1 equals zero, i.e. it is statistically insignificant. The alternative hypothesis, on the other hand, assumes that the parameter is non-zero, i.e. it is statistically significant. Since the absolute value of the Student's t-statistic (3.29) is higher than the critical value (2.23), the null hypothesis was rejected in favour of the alternative hypothesis. It follows that the parameter β_1 is statistically significant, meaning that population growth significantly affects the value of the national public debt.

The significance of the parameter β_2 was verified in the same manner. The following hypotheses were posited:

$$\begin{aligned} H_0: \beta_2 &= 0, \\ H_1: \beta_2 &\neq 0. \end{aligned}$$

The null hypothesis assumes that the structural parameter β_2 equals zero, i.e. it is statistically insignificant. In contrast, the alternative hypothesis assumes that the parameter is non-zero, i.e. it is statistically significant. Since the absolute value of the Student's t-statistic (5.29) is higher than the critical value (2.23), the null hypothesis was rejected in favour of the alternative hypothesis. It follows that the parameter β_2 is statistically significant, meaning that the dependency ratio of the post-working-age population significantly affects the value of the national public debt.

The following hypotheses were posited to verify the joint significance of the structural parameters of the model:

$$\begin{aligned} H_0: \beta_1 &= \beta_2 = 0, \\ H_1: \beta_1 &\neq 0 \vee \beta_2 \neq 0. \end{aligned}$$

The null hypothesis assumes that both explanatory variables are equal to zero, i.e. they are statistically insignificant. Conversely, the alternative hypothesis assumes that the parameters are non-zero, i.e. they are statistically significant. Adopting significance at a level of $\alpha=0.05$, both parameters were considered significant, and the null hypothesis was rejected in favour of the alternative hypothesis, as the significance of the variables was 0.0082 and 0.0004, respectively. The Fisher-Snedecor test showed that the value of the F-statistic (100.4) is higher than the critical value (4.10), which means that natural increase and the dependency ratio of the post-working age population have a jointly significant impact on the value of the national public debt.

Confidence intervals for the structural parameters were also analyzed, with the following results:

$$\begin{aligned} P &= \{-1.36 \leq \beta_1 \leq -0.26\} = 0.95, \\ P &= \{11.41 \leq \beta_2 \leq 28.02\} = 0.95. \end{aligned}$$

This means that with a probability of $1 - \alpha$, i.e. 0.95, the actual value of the parameters β_1 and β_2 is within the specified intervals.

As regards the interpretation of the structural parameter estimates, it is crucial to verify the stochastic assumptions that are necessary to assess the degree of fit of the econometric model. Consequently, the normality test of residual distribution was performed with the following hypotheses:

$$\begin{aligned} H_0: \xi_t &\sim N(0, \hat{\sigma}_\xi^2), \\ H_1: \xi_t &\not\sim N(0, \hat{\sigma}_\xi^2). \end{aligned}$$

The null hypothesis assumes that the random component has a normal distribution, while the alternative hypothesis is that the random component does not have a normal distribution. This was verified using the Chi-square(2) test statistic, which was 0.45, so at the significance level of $\alpha=0.05$, it was found to be lower than the critical value (5.99). As a result, since there were no grounds to reject the null hypothesis, the random component was assumed to have a normal distribution. This is corroborated by the visualization of the distribution in Fig. 4.

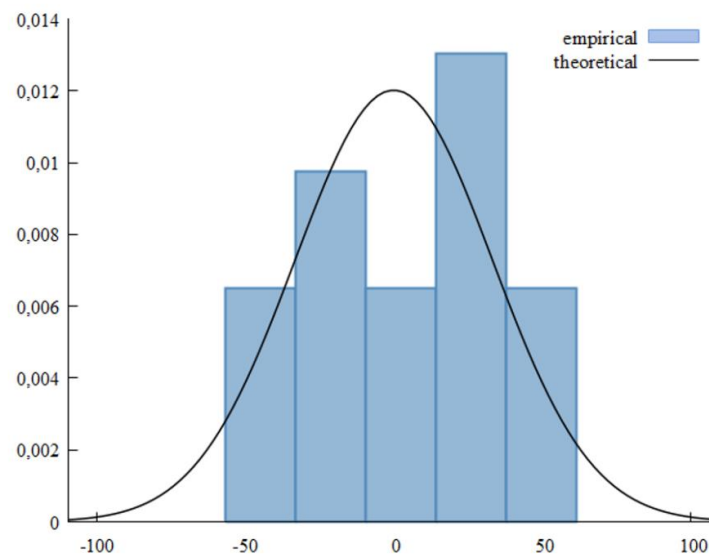


Fig. 4. Results of normality test of residual distribution in Gretl

Source: own elaboration based on data from Statistics Poland

Since the data shown in Fig. 4 indicate that the residuals have a distribution approaching normal distribution, the model should be evaluated positively. The probability of an erroneous verification decision is $\alpha=0.05$.

The test of heteroskedasticity of the random component may also serve to verify the stochastic assumptions of the model. The following hypotheses were thus posited:

$$H_0 : E(\xi_t^2) = \sigma_\xi^2,$$

$$H_1 : E(\xi_t^2) \neq \sigma_\xi^2.$$

The null hypothesis assumes that heteroskedasticity of the variance does not occur, while the alternative hypothesis is that heteroskedasticity does occur, i.e. the variance of the random component is heterogeneous. White's test was performed to verify these assumptions. The p-value of the Chi-square (5) statistic amounted to 0.44, reaching a higher value than the adopted significance level, i.e. $\alpha=0.05$. Consequently, there were no grounds to reject the null hypothesis, and the variance of the random component was considered to be homogeneous.

Finally, the validity of the model was analyzed using the Durbin-Watson (DW) test to examine the autocorrelation of the random component. The following hypotheses were put forward:

$$H_0 : \rho = 0,$$

$$H_1 : \rho > 0.$$

The null hypothesis assumes that there is no autocorrelation of the random component, whereas the alternative hypothesis is that there is significant positive autocorrelation. The DW statistic was 1.96, which is higher than the critical values d_L and d_U , which, at the significance level $\alpha=0.05$ reached 0.86 and 1.56, respectively. This means that there are no grounds for rejecting the null hypothesis, i.e. autocorrelation of the random component does not occur. It should be noted that the closer the DW statistic is to 2, the better the model is. This study closely approached that value, which implies the model's high validity.

All the above tests demonstrate that the developed econometric model is valid and explains the relationship between the studied variables with high probability. The study shows that reduced natural increase and rising dependency ratio of the post-working age population significantly increase the national public debt. The analyses highlight the negative impact of demographic ageing on the stability of the public finance sector in recent years. As part of this inquiry, it may also be worthwhile to consider this process in terms of the corollaries which the Polish economy will face in the coming years.

To illustrate the scale of these challenges, a forecast of changes in the national public debt 2023-2026 was developed using the econometric model described above. The obtained results are presented in Tab. 4.

Tab. 4. Projected national public debt in 2023-2026

	Projected national public debt (in billions PLN)	<i>Ex ante</i> error (in billions PLN)	95% confidence interval (in billions PLN)
2023	1161.46	37.857	1077.11 – 1245.81
2024	1181.28	38.668	1095.12 – 1267.43
2025	1198.21	39.468	1110.27 – 1286.15
2026	1214.14	39.964	1125.10 – 1303.19

Source: own elaboration based on data from Statistics Poland

Assuming that the natural increase and dependency ratio of the post-working age population will reach the levels projected by Statistics Poland while other conditions remain unchanged, the national public debt in 2023 will amount to PLN 1161.46 bn and will continue to increase year on year by an average of 1.5%. The accuracy of the forecast at its formulation stage is expressed by the relative *ex-ante* error, which may be described using the following formula:

$$V_t = \frac{\sqrt{S^2(e) + x_t D^2(a_j) x_t^T}}{y_t^P} * 100,$$

where:

$S^2(e)$ – residual variance,

x_t – value of explanatory variables in the projected period,

$D^2(a_j)$ – variance and covariance matrix for structural parameter estimates,

x_t^T – value vector of the explanatory variable in the projected period,

y_t^P – value of point forecast.

Relative errors of acceptability of the forecast for 2023-2026 ranged between 3.26% and 3.29%, which, with the adopted significance level $\alpha=0.05$, indicates the validity of the prediction and a slight deviation of the actual value of the phenomenon from the forecast. The accuracy of the estimates is illustrated by the data in Fig. 5.

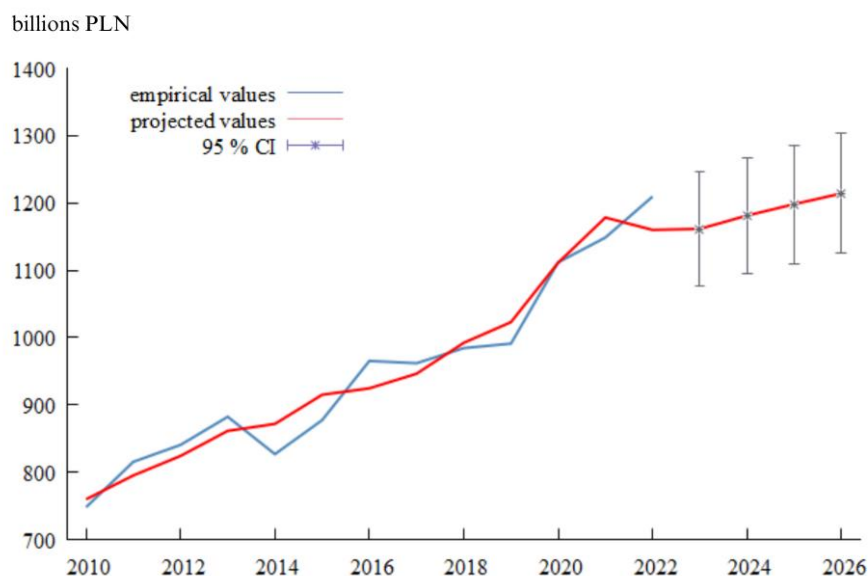


Fig. 5. Projected national public debt in Gretl

Source: own elaboration based on data from Statistics Poland

In line with the accuracy of the *ex-ante* prediction, the estimated values of the national public debt for 2023-2026 should be considered accurate. The obtained forecast suggests that demographic ageing will significantly affect the future condition of the public finance sector, causing a 0.38% increase in the debt in 2026 compared to 2022.

Conclusions

The demographic ageing of Poland's population should be recognized as a major challenge to the economic system. The advancing demographic changes are a threat to the labor market and the condition of the public finance sector. Negative trends have been confirmed both by archival data and parameters projected by statistical institutions.

As a result of the study, the following conclusions were obtained:

1. The demographic situation in Poland is deteriorating dynamically, while forecasts indicate further negative trends. The number of births between 2000 and 2022 fell by more than 20 %, and the natural increase has been negative since 2013.
2. Between 2000 and 2022, the dependency ratio of the post-working-age population increased by more than half. Projections suggest that after 2055, the ratio of the working-age population to the non-working-age population will be 1:1. The fact that the labor force aged in the period from 2013 to 2022 is shown in the 66% rise in the number of employees aged 60 and over.
3. In 2022, public finance sector expenditure on healthcare more than doubled compared to 2014 and amounted to almost 5% of GDP at that time. During the analyzed period, those outlays grew on average 20% faster than GDP per capita.
4. The increase in the number of elderly people in Poland translates into increased public expenditure on healthcare. Pearson's linear correlation coefficient between these outlays and the number of persons aged 70 and over in 2014-2022 was almost 96%, indicating a very high correlation between the variables in question. This confirms the hypothesis that the progressing ageing of the population causes public expenditure on healthcare to increase.
5. From 2010 – 2022, the natural increase in Poland dropped more than fivefold. Linear regression analysis indicated a significant impact of changes in the natural increase and dependency ratio of the post-working age population on the national public debt, which was corroborated by significance tests on the structural parameters and stochastic assumptions of the econometric model. With a probability of 95%, if the natural increase diminishes by 1,000 people, the debt increases by an average of PLN 0.81 bn, with a mean error of $\pm$ PLN 0.25 billion, while a one-unit increase in the dependency ratio will cause the national public debt to rise by PLN 19.71 bn, with an average error of $\pm$ PLN 3.73 bn *ceteris paribus*. This supports the hypothesis that the components of population ageing, i.e. reduced natural increase and greater dependency ratio of the post-working age population, contribute to increased national public debt.
6. Taking into account the predictions of Statistics Poland, the changes in natural increase and dependency ratio of the post-working age population will cause the national public debt in 2026 to increase by 0.39% compared to 2022, with a probability of 95%.

This research constitutes a novel contribution by quantitatively demonstrating the strong correlation between demographic changes and public debt using localized data and precise econometric model. Unlike other studies, this analysis provides detailed projections specific to Poland, highlighting its unique demographic dynamics and fiscal implications.

Nonetheless, the findings must be considered in light of certain limitations. For instance, the projections rely on current trends, which may be altered by technological advancements, digitalization, or policies promoting the integration of older adults into the workforce. These factors could potentially mitigate some of the anticipated fiscal challenges and warrant further investigation.

The results of this study are consistent with broader findings in the literature, which also emphasize the significant fiscal challenges posed by demographic ageing. Numerous studies have highlighted the impact of

population ageing on public debt, particularly through rising expenditures on pensions and healthcare. This research builds upon these insights by providing a more detailed, localized perspective focused on Poland, offering specific quantitative results and projections. The alignment of findings with prior research underscores the universality of issues stemming from demographic ageing while emphasizing the distinctive pressures faced by Poland due to its rapid demographic changes.

Future research should explore strategies to address the economic and fiscal consequences of demographic ageing. Promising avenues include promoting active ageing, increasing the retirement age, and enhancing the participation of older individuals in the labor market. Additionally, evaluating the impact of technological innovations and improvements in healthcare delivery on public expenditure could provide valuable insights into mitigating these challenges.

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