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Spatial convergence of population ageing in Poland's provinces in a retrospective and prospective analysis

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Abstract. Poland's central statistical office, Statistics Poland, forecasts that the populations of most Polish provinces will decline by 2060, as will the share of young people, while the share of old-age population will increase. The population structure across Poland's provinces is visibly disproportionate, and population ageing has two different dimensions: it is both a top-down and a bottom-up process.
Aim. This study was designed to assess the advancement rate and diversity of population ageing in Poland's provinces in the past – and in the future (up to 2040). This study used data on the share of five age groups in the overall population, referring to both the past (2002–2022) and the future (by 2040). To determine the convergence of population ageing, beta-convergence (absolute and conditional) and sigma-convergence models were employed.
Results and conclusions. In the past and by 2040, Poland's provinces have been and will continue to be homogenising in terms of the indicators that describe adult groups of the population. That being said, by 2040, the shares of children and the old-age population in Poland's provinces will continue to diverge.

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1. Introduction

Since the 1990s, the age structure of Poland's population has changed considerably, as evidenced by the declining share of children (aged 0–14) and the increasing share of old-age population (aged 65+) in the total population. The share of old-age population is projected to increase even further by 2060, with a decline in the share of adults (aged 15–64) and a relatively stable percentage of children.

When analysing the specificity and dynamics of population ageing, researchers use various indicators to capture this process. Usually, these are indicators appropriate for assessing top-down population ageing because they refer to older age groups. They include relational demographic indicators that can be applied in a static approach, such as old-age population indicators, double-ageing indicators, demographic supply or demographic burden indicators (Podogrodzka, 2016a; Wasilewska, 2018), and synthetic indicators (Káčerová et al., 2014; Dehnel et al., 2020). Population research covers various geographic areas, including European countries and their provinces, and accounts for the urban–rural division. Researchers use various methods: graphical methods, agglomeration approaches, spatial analysis (Kurek, 2014; Zeug-Żebro, 2020), rank analysis (Wasilewska, 2018), and convergence models (Kashnitsky et al., 2017).

In Poland, the process of population ageing is spatially diverse and can be traced back to demographic changes that reflect the first and second demographic transition (Kowalewski & Majdzińska, 2012; Kurek, 2014; Szukalski, 2020). Podogrodzka (2016b) analysed the similarity of population structures and how they changed over time. She thus demonstrated that, between 1991 and 2011, population ageing was progressing in all provinces of Poland, but at different intensity levels. Wasilewska (2018) confirmed that, between 1992 and 2016, Poland experienced progressive population ageing, while the rate of demographic ageing was visibly spatially diversified.

According to research on ageing at a regional level that covered prospects for the future, the rate of ageing was forecasted to be higher by 2020 for provinces that in the past were characterised by a moderately low rate of demographic ageing (Długosz, 2007; Majdzińska, 2017). Additionally, by 2050, the intensity of population ageing is expected to vary regionally (Kowaleski & Majdzińska, 2012; Trzpiot, 2016). A study of population ageing in 263 provinces of EU27 confirmed beta-convergence in the past (2003–2012) and in the future (2013–2022, 2033–2042) (Kashnitsky et al., 2017).

It is noteworthy that demographers and population geographers have studied the ageing process of the Polish population at various layers of territorial administration: subregions (Antczak & Lewandowska-Gwarda, 2018; Zeug-Żebro, 2020), counties (Kurek, 2008; Kurek et al., 2021; Szukalski, 2020), and communes (Kurek, 2003, 2006; Szymańska & Biegańska, 2014; Rakowska, 2016; Kula & Wójcik, 2017; Wiśniewski et al., 2020). The intensity of demographic processes (vital statistic of population and migration) in the regions influences the unification of the age structures of the population in Poland. In the first two decades of the 21st century, positive natural increase was characteristic of voivodeships in the west and north of the country, especially the areas surrounding the agglomerations whose populations are growing most quickly. On the other hand, the inflow of people due to migration was observed only in five voivodeships with the largest agglomerations (*Government Population Council*, 2021: 115–58).

Demographic processes affect the level of regional socio-economic development; so too *vice versa*, the level of regional development affects population processes. Societal ageing is one such process (Wiśniewski et al., 2020). If the population's age structure changes, e.g. the share of old-age population increases and the number of young people decreases, this may result in a scarcity of labour resources and a growing burden on the social security fund. The study presented in this paper was designed to assess the rate and diversity of population ageing in the provinces of Poland – in the past and by 2040. Based on these changes, the emerging threats to the socio-economic development of provinces can be identified, and, consequently, remedial measures can be formulated that can be incorporated into social policies.

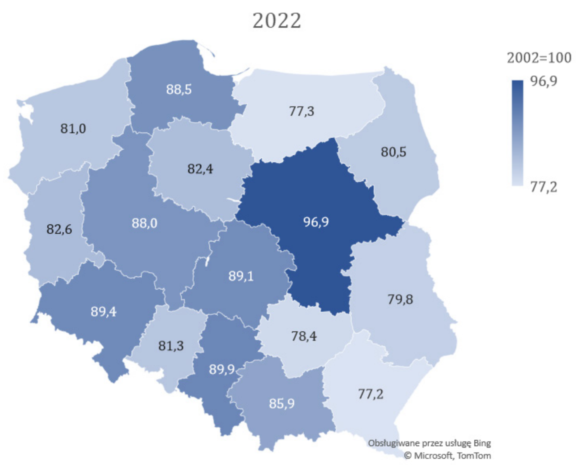
2. Research materials and methods

As evidenced by the literature review, researchers explore changes in both the overall population structure and selected age groups to formulate conclusions regarding the process of population ageing. This study was focused on partial changes in the population structure, because it analysed population ageing from "top-down" and "bottom-up" perspectives. In an analysis of the spatial diversity of population structures in Poland, Poland's population was divided into five groups based on biological age: children (aged 0–14), younger adults (aged 15–34), older adults (aged 35–64), old-age population (aged 65+) and oldest-age population (aged 80+). Two similar time intervals were taken into account: the past (2002–2022) and the future (2022–2040; within this time interval, the 2022 data were real numbers, combined with forecasts for 2023–2040). Poland's provinces (voivodeships) were compared. The real numbers for the period 2002–2022 were collected from the Statistics Poland (SP) databases (SP 2023a), and the predictions for 2040 originated from the SP population projection for 2023–2060 according to the middle scenario (SP 2023b).

The population of Poland decreased by 1.2% from 38.219 million people in 2002 to 37.766 million people in 2022. In most (10) provinces, the population decline was above average; the populations of the provinces of Opolskie and Świętokrzyskie were reduced the most (by 11.2% and 9.1%, respectively). Only four provinces saw increases in their populations, the largest being in Pomorskie and Mazowieckie (of 8.0% and 7.4%, respectively) (Fig. 1). In 2040, compared to 2022, Poland's population is projected to decrease by 6.6% to 35.289 million people. Every province will experience a decline in population. The population decline is projected to be below average in five provinces. Population decline will be most severe in the provinces of Świętokrzyskie and Lubelskie (at 14.0% and 11.8%, respectively) and least severe in Mazowieckie and Pomorskie (at 0.7% and 0.7%, respectively).

Figures 1 to 5 present changes in the population structure according to biological age groups in the provinces in Poland over two time periods: 2002–2022 and 2022–2040; the basic descriptive characteristics for 2002, 2022 and 2040 are summarised in Table 1. Each figure represents one age group only, and the number shown in each province on each map represents the change in share size of that age group over the 20 years of 2002–2022 or the 18 years of 2022–2040. Accordingly, "100" would represent no change in share size, 50 would represent that the share size has halved, and 200 would represent a doubling of share size.

Based on the most recent data, the decrease in the share of children and younger adults was accompanied by an increase in the share of old-age population and the oldest-age population. This direction of changes is reflected in Statistics Poland's predictions, which demonstrates that both top-down and bottom-up population ageing are well advanced across the provinces. In 2002, the province of Podkarpackie had the largest share of children (aged 0–14) in the total population. This region also experienced the largest decline in the proportion of children in the first two decades of the 21st century. By 2040, the largest decline in the share of the children is forecasted in Świętokrzyskie – a region that will also have the smallest share of children in its population (Fig. 1). Wielkopolskie had the highest fraction of younger adults (aged 15–34) in 2002. In 2040, the voivodeship with the highest share of younger adults will be Pomorskie. The largest changes in the percentage share of younger adults by 2022 were observed in Opolskie and the largest such future changes by 2040 are projected to take place in Małopolskie (Fig. 2). Until 2022, there was an increase in the share of older adults (35–64) in each province: the highest in Podkarpackie



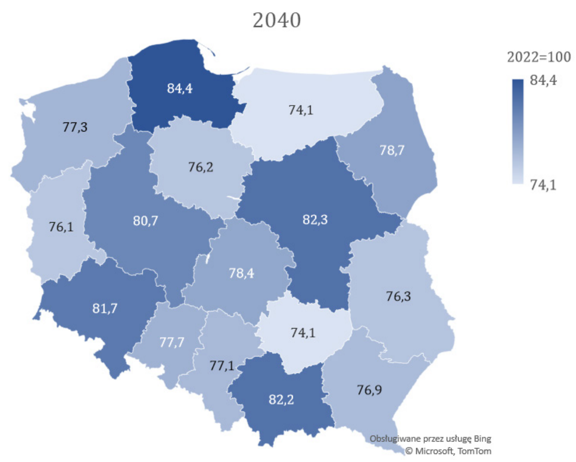


Fig. 1. Dynamics of the share of population aged 0–14 in Poland's provinces in 2022 and 2040
Source: Own calculations on the basis of (SP 2023a, 2023b)
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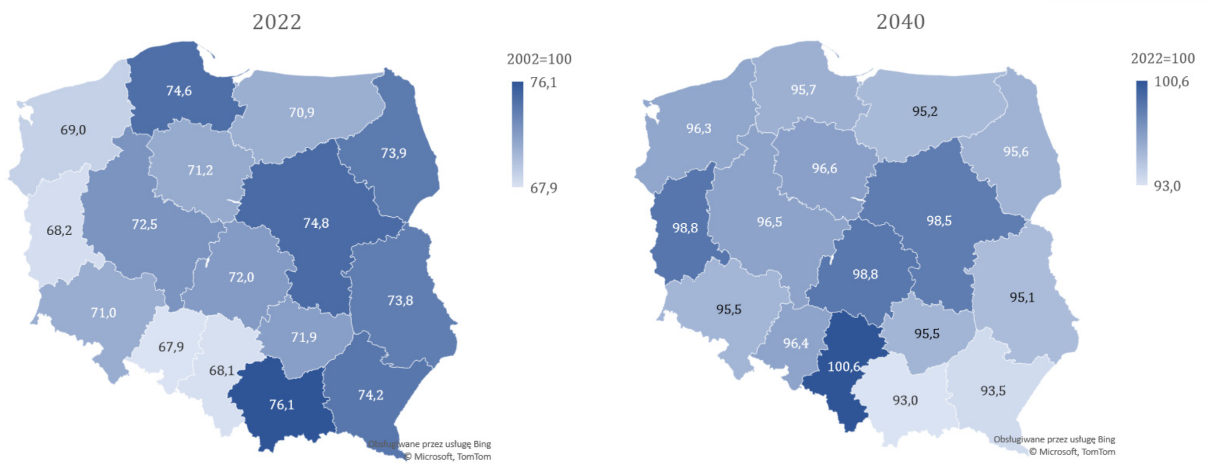

Fig. 2. Dynamics of the share of population aged 15–34 in Poland's provinces in 2022 and 2040
Source: Own calculations on the basis of (SP 2023a, 2023b)

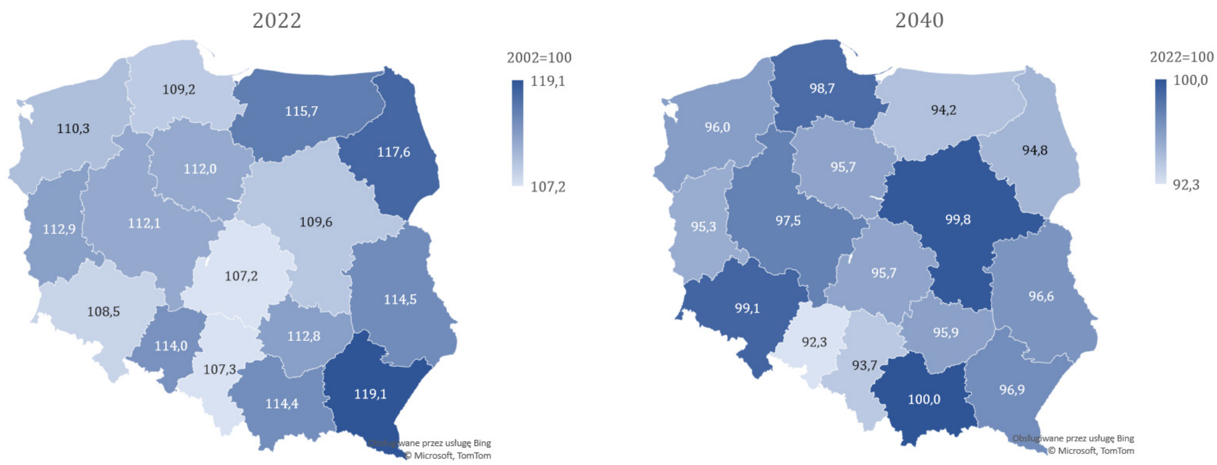

Fig. 3. Dynamics of the share of population aged 35–64 in Poland's provinces in 2022 and 2040
Source: Own calculations on the basis of (SP 2023a, 2023b)

and the lowest in Łódzkie (Fig. 3). By 2040, the share of older adults in the total population will be reduced in every province, with the largest decline taking place in Opolskie. In Małopolskie, the share of older adults will remain stable. In 2002, the share of old-age population (65+) exceeded 7% in most of Poland' provinces, but did not reach the level of 14%. According to the latest UN old-age scale (Jurek 2012), when the share of persons aged 65+ reaches 14%, the region's population can be categorised as an "aged" society. In 2022, all of Poland's provinces were "aged" in demographic terms, and by 2040, all provinces will be considered "hyper-aged" (the share of persons aged 65+ will exceed 21%). The highest indicators were recorded for Łódzkie (in 2002) and Świętokrzyskie (in 2022 and 2040). The most notable changes were observed in Zachodniopomorskie in 2022 and projected for 2040 for Warmińsko-Mazurskie (Fig. 4). The advancement of population ageing is also evidenced by the high percentage share of the oldest-age population (80+). In 2002, the share of the oldest-age population was lowest in Zachodniopomorskie and highest in Łódzkie. By 2040, the lowest percentage share of the oldest-

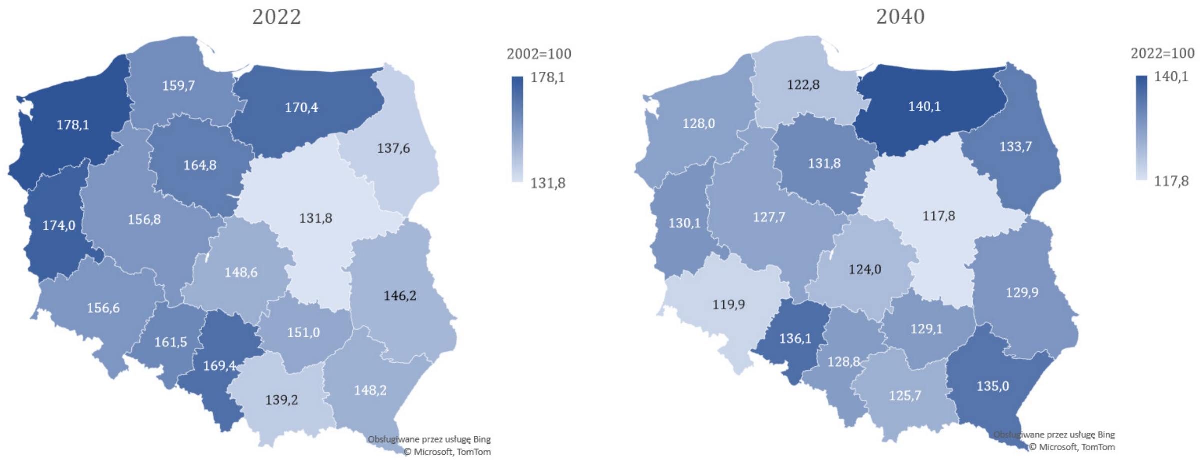

Fig. 4. Dynamics of the share of population aged 65+ in Poland's provinces in 2022 and 2040
Source: Own calculations on the basis of (SP 2023a, 2023b)

age population is forecasted for Małopolskie and the highest one for Świętokrzyskie. Over four decades, the share of the oldest-age population in Poland's provinces will increase three- to five-fold. Between 2022 and 2040, the highest rise in the oldest-age population is expected to take place in Lubuskie, Zachodniopomorskie and Warmińsko-Mazurskie (Fig. 5).

The value range (i.e., the difference between the maximum and the minimum value) of individual population structure indicators – and the median (average) values – will have changed between 2002 and 2040 (Table 1). An increasing range of values is characteristic of two of the five structure indicators (people aged 65+ and 80+), and a decrease in the range of values was reported for older adults. In 2040 compared to 2002, the highest increase in the value range is forecasted for the old-age population (65+), and the greatest decrease in the value range will be seen for older adults. With the varying degree of dispersion in the values of population indicators, a decreasing median is observed for the population structure indicators characterising the share of the youngest population and younger adults. Average indicator values have been increasing for the share of old-age population and oldest-age population.

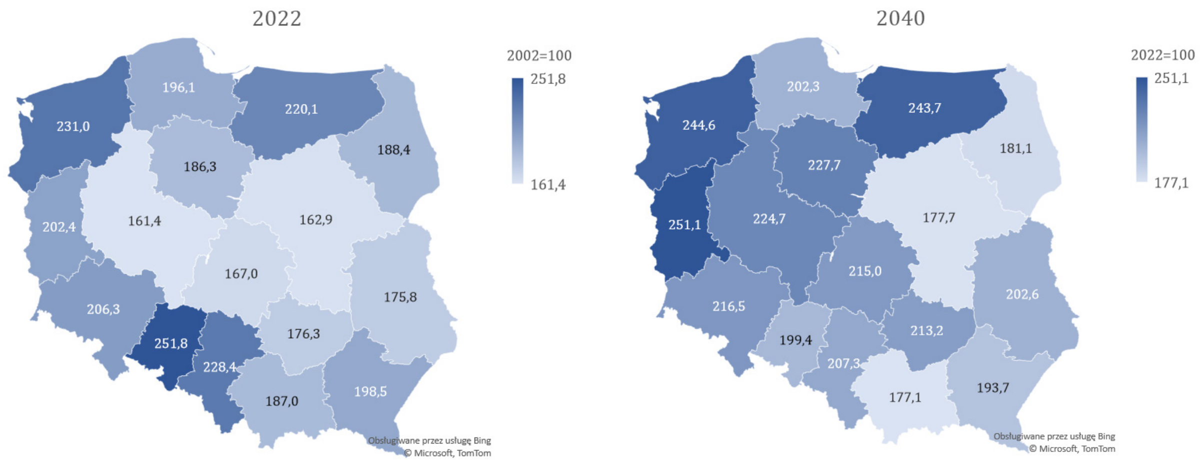

Fig. 5. Dynamics of the share of population aged 80+ in Poland's provinces in 2022 and 2040
Source: Own calculations on the basis of (SP 2023a, 2023b)

Judging by the multidirectional changes in the average and the diversified values of population structure indicators, it can be inferred that the structural ageing applies to all age groups included in the analysis, and it takes place from the base to the top of the population age pyramid. The only limitation of this conclusion is the uncertainty as regards population regeneration, specifically in terms of fertility and migration assumptions included in the Statistics Poland Population Projection by 2060.

Absolute and conditional beta-convergence and sigma-convergence models were used to study the similarities in spatial changes within population structures (Barro & Sala-i-Martin, 1992, Sala-i-Martin, 1996; Boyle & McCarthy, 1997). Absolute beta-convergence means that objects (provinces) with a lower value of the variable in the initial period show a faster growth rate than objects with a higher value in the initial period, and that therefore the growth rate of the variable depends only on the baseline value. As for conditional beta-convergence, the growth rate depends on the baseline value of the variable and other explanatory variables; as a result, objects (provinces) that share similar impacts of factors become similar to each other. Sigma-convergence occurs when variation in the value of a variable between provinces decreases over time. This method of analysis has been used primarily to investigate similarities in changes within economic phenomena, but it is also applied in demographic research (Dorius, 2008; Borges, 2018).

Absolute beta-convergence was verified on the basis of regression model (1), whereas conditional beta-convergence was validated on the basis of regression model (2):

$$ln\left(\frac{y_{iT}}{y_{i0}}\right) = a + b \cdot ln(y_{i0}) \qquad (1)$$

Table 1. Descriptive characteristics of population structure indicators in the provinces of Poland, in selected years

Variables	Year	Minimum value	Maximum value	Median
Share of population aged 0–14	2002	16.2 Łódzkie	20.3 Podkarpackie	18.4
	2022	13.9 Opolskie	16.6 Pomorskie	15.1
	2040	10.4 Świętokrzyskie	14.0 Pomorskie	11.5
Share of population aged 15–34	2002	29.5 Łódzkie	32.2 Wielkopolskie	31.2
	2022	20.9 Śląskie	24.2 Małopolskie	22.4
	2040	20.4 Świętokrzyskie	22.8 Pomorskie	21.4
Share of population aged 35–64	2002	35.7 Podkarpackie	40.9 Śląskie	38.2
	2022	41.5 Pomorskie	44.7 Opolskie	42.9
	2040	40.6 Podlaskie	42.6 Dolnośląskie	41.1
Share of population aged 65+	2002	11.0 Warmińsko-Mazurskie	14.7 Łódzkie	12.5
	2022	17.9 Małopolskie	21.8 Świętokrzyskie	19.6
	2040	22.1 Mazowieckie	28.1 Świętokrzyskie	25.8
Share of population aged 80+	2002	1.7 Zachodniopomorskie	2.8 Łódzkie	2.2
	2022	3.6 Wielkopolskie	4.8 Podlaskie	4.2
	2040	7.5 Małopolskie	10.3 Świętokrzyskie	9.2

Source: Own calculations on the basis of (SP 2023a, 2023b)

$$ln\left(\frac{y_{iT}}{y_{i0}}\right) = a + b \cdot ln(y_{i0}) + \sum_{j=1}^{k} b_j \cdot \ln(x_{j0}) \quad (2)$$

where: $ln\left(\frac{y_{iT}}{y_{i0}}\right)$ – the rate of changes of the variable in the initial and the final period of analysis; y_{iT} – value of the variable in the final period of analysis; y_{i0} – value of the variable in the initial period of analysis; x_{j0} – value of the explanatory variable in the initial period of analysis; a, b, b_j – model parameters; i – object of analysis, $i = 1, \ldots, N$.

Sigma-convergence was verified based on the regression model of variation measure over time (Friedman, 1992):

$$s_t = a + b \cdot t \quad (3)$$

where: s_t – standard deviation in the logarithms of the examined variable in period t; a, b – model parameters; t – period of analysis, $t = 1, \ldots, n$.

The parameters of models (1) to (3) were estimated by the least squares method. The significance of the parameter b was examined by Student's t-test. In models (1) and (2), a statistically significant negative value of parameter b translates into beta-conversion. In turn, a statistically significant positive value of the parameter b indicates beta-divergence. In model (3), a statistically significant negative value of parameter b signifies sigma-convergence. In turn, a statistically significant positive value means sigma-divergence.

Sigma-convergence was also confirmed using the F-test for two variances:

$$F = \frac{\hat{\sigma}_0^2}{\hat{\sigma}_T^2}, \quad (4)$$

where: $\hat{\sigma}_0^2$ – variance of the logarithms of the tested variable in the initial period; $\hat{\sigma}_T^2$ – variance of the logarithms of the tested variable in the final period.

If sigma-convergence is suspected, the decrease in variance in the compared periods is tested for statistical significance. If sigma-divergence is suspected, a test is performed to determine whether the increase in variance is significant. A test of the significance of the parameter b in the sigma-convergence model (3) provides information about changes in the variation of the variable values in the examined period, while the F-test of variance examines the significance of such changes in the extreme (initial and final periods).

3. Research results

3.1. Beta-convergence

Using the values of demographic indicators for population structures in the provinces of Poland, models of absolute beta-convergence (1) and conditional beta-convergence (2) were constructed for two time ranges: 2002–2022 (retrospective approach) and 2022–2040 (prospective approach). The estimation and verification of model parameters using Student's t-test are presented in Tables 2 an 3.

The values of the parameter b were negative in the absolute beta-convergence models of all indicators characterising population structures in the past, in the period 2002–2022 (Table 2). Provinces that in 2002 had a low share of population aged 0–14, 35–64, 65+ and 80+ showed a high rate of changes in the share of these age groups in the period 2002–2022. At the significance level of 0.05, the parameters b were statistically significantly lower than zero, which indicates convergence for all of the four structure indicators listed above. This means that, in 2022 compared to 2002, the provinces of

Table 2. Parameters of absolute beta-convergence models of demographic structure indicators in the provinces of Poland, 2002–2022 and 2022–2040

Variables	Retrospectively, 2002–2022			Prospectively, 2022–2040		
	b	a	R^2	b	a	R^2
Share of population aged 0–14	-0.599*	1.560*	0.398	0.425*	-1.399*	0.406
Share of population aged 15–34	-0.009	-0.299	0.000	-0.302*	0.901*	0.417
Share of population aged 35–64	-0.716*	2.725*	0.705	-0.970*	3.608*	0.710
Share of population aged 65+	-0.698*	2.211*	0.585	-0.023	0.320	0.001
Share of population aged 80+	-0.636*	1.161*	0.624	-0.612*	1.626*	0.308

Explanation: * statistically significant at α = 0.05

Source: Own calculations on the basis of (SP 2023a, 2023b)

Poland became more homogeneous in terms of the percentage share of oldest-age population (80 years and over), old-age population (aged 65+), older adults (aged 35–64 years) and children (aged 0–14 years old).

In the prospective approach, i.e. between 2022 and 2040, negative values of the parameters *b* were obtained in the absolute beta-convergence models for four structure indicators, but three of them were statistically significant. Provinces with a low share of the oldest-age population (aged 80+), as well as both groups of adults (aged 15–34 and 35–64 years) in 2022 showed a prospective high rate of changes in the share of these age groups by 2040. Therefore, in the future, the provinces in Poland will become more homogeneous in terms of the share of population representing these three age groups. In contrast, in provinces with a low share of children (0–14 years old) in 2022, this indicator is unlikely to change by 2040, which means that the differences between provinces will deepen.

In the conditional beta-convergence models (2), the explanatory variables were taken to be the value of the examined variable (Y_0, structure indicator in the initial period), demographic dynamics (X_1, the ratio of the number of births and the number of deaths in the initial period) and migration dynamics (X_2, the ratio of population inflow and population outflow in the initial period). The initial period is 2002 in the retrospective approach and 2022 in the prospective approach. The variables X_1 and X_2 are the equivalents of population increase and the balance of migration that affect the population figures and the population structure. Migration flows incorporate both internal and cross-border migration. The variables X_1 and X_2 need to be used as relative variables because the logarithms of the variables can only be determined for positive values of the variables.

The negative values of the parameter *b* (at variable Y_0) were statistically significant in five conditional beta-convergence models of regional population structures referring to the past and in four models referring to the future (Table 3). In provinces with a low percentage share of population aged 15–34, 35–64, 65+ and 80+ in the initial period, the share of these population groups were changing dynamically until 2022 and are forecasted to continue to change by 2040. The results (of parameter *b* sign for variable Y_0) are consistent with those obtained from the absolute beta-convergence model, except for the models of the population aged 0–14 years. Moreover, the determination coefficients R^2 indicate that the fitting of (2) conditional beta-convergence models for each of the structure indicators is better than the corresponding models (1) of absolute beta-convergence.

In a retrospective approach, the parameter b_1 for the variable of demographic dynamics is negative in the models for old-age population (65+) and oldest-age population (80+) (Table 3). Provinces with low demographic dynamics in 2002 are characterised by a high rate of changes in the share of people aged 65+, and of people aged 80+ in the period 2002–22. Although a statistically significant value of this parameter was reported for the old-age population model, i.e. for people aged 65+, provinces that reported more deaths than births experienced faster top-down population ageing in the past. However, in the models for children, younger adults and older adults, the parameter b_1 has a positive sign. However, the parameter b_1 in the younger adult model (aged

Table 3. Parameters of conditional beta-convergence models of demographic structure indicators in the provinces of Poland, 2002–2022 and 2022–2040

Model variables (2)	Retrospectively, 2002–2022 Share of population aged					Prospectively, 2022–2040 Share of population aged				
	0–14	15–34	35–64	65+	80+	0–14	15–34	35–64	65+	80+
Const	2.178*	4.285*	2.777*	3.290*	1.138*	0.445	2.697*	2.816*	3.074*	2.016*
Y_0	–0.805*	–1.339*	–0.733*	–1.128*	–0.647*	–0.232	–0.859*	–0.761*	–0.992*	–1.048*
X_1	0.097	0.218*	0.026	–0.371*	–0.158	0.115	0.157*	–0.021	–0.280*	–0.553*
X_2	0.302*	0.162*	–0.105*	–0.150*	–0.391*	0.261*	0.008	0.108*	–0.309*	–0.111*
R^2	0.857	0.582	0.905	0.889	0.855	0.854	0.665	0.881	0.925	0.992

Explanation: Y_0 – value of the variable in the initial period; X_1 – demographic dynamics in the initial period; X_2 – dynamics of migration in the initial period; R^2 – determination coefficient; * statistically significant at α = 0.05

Source: Own calculations on the basis of (SP 2023a, 2023b)

15–34) is statistically significant. This means that provinces with high demographic dynamics (the number of births exceeding the number of deaths) in the initial period demonstrate a high rate of changes in the share of this age group between 2002 and 2022.

In the prospective approach, the parameter b_1 had negative signs in the models of old-age population and oldest-age population and positive signs in the models of children and younger adults. This confirms that the direction of changes observed in the past will continue. The sign of parameter b_1 changed for the demographic dynamics in the model of older adults (aged 35–64).

Statistically significant negative values of the parameter b_2 (with the variable determining the dynamics of migration) were obtained for three models in the retrospective approach. Provinces with low migration dynamics in 2002 showed a high rate of changes in the share of people aged 35–64, 65+ and 80+ in the period 2002–2022. Consequently, provinces where population outflow was higher than population inflow will age faster "from the top to the bottom" of the population structure. However, a statistically significant positive value of the parameter b_2 in the models for the youngest population (aged 0–14) and younger adults (aged 15–34) indicates a high rate of changes in the share of these age groups in provinces with high migration dynamics (population inflow prevailing over population outflow).

In the prospective approach, the signs of parameter b_2 did not change in the four models of population structure indicators, and a change in sign (from negative to positive) was reported for the group of older adults. The parameters b_2 remained statistically significant in four models. The rate of changes in the share of old-age population and oldest-age population will continue to be high until 2040 in provinces with low migration dynamics in 2022. As a result, top-down population ageing will be consolidated in provinces where population outflow exceeds population inflow. A statistically significant positive parameter b_2 in the model for children (aged 0–14) and older adults (aged 35–64) means that a high rate of changes in the share of these two age groups can be expected by 2040 in provinces with high migration dynamics (excess of migration inflows over migration outflows) in 2022.

3.2. Sigma-convergence

The parameters of model (3) were estimated to determine whether there is sigma-convergence of demographic indicators describing population structures. An increase in variance in the analysed time intervals was also tested for significance. The results are listed in Tables 4 and 5.

Standard deviation in the period 2002–2022 was shown to decrease, as evidenced by the negative values of the parameters b in four models (Table 4). The parameters b of models of population structure indicators referring to the share of children, older adults, old-age population and oldest-age population were statistically significant, which confirms the existence of sigma-convergence, i.e. decreasing variation in the indicators between Poland's provinces in the first two decades of the 21st century. The F-test confirms a statistically significant (0.05) decrease in variance in 2022 compared to 2002 for two population structure indicators: older adults (34–64) and oldest-age population (80+) (Table 5). However, an increase in the standard deviation of the share of younger adults (15–34) indicates sigma-divergence. The parameter b of model (3) is positive and statistically significant (Table 4), and the F-test confirms a statistically significant (0.05) increase in the variance of this population structure indicator in 2022 compared to 2002 (Table 5). This means that

Table 4. Parameters of sigma-convergence models of demographic structure indicators in Poland's provinces, 2002–2022 and 2022–2040

Variables	Retrospectively, 2002–2022			Prospectively, 2022–2040		
	b	a	R^2	b	a	R^2
Share of population aged 0–14	-0.0004*	0.067*	0.600	0.0019*	0.062*	0.827
Share of population aged 15–34	0.0011*	0.020*	0.901	-0.0007*	0.043*	0.803
Share of population aged 35–64	-0.0009*	0.036*	0.929	-0.0003*	0.016*	0.396
Share of population aged 65+	-0.0020*	0.099*	0.889	0.0008*	0.065*	0.891
Share of population aged 80+	-0.0029*	0.152*	0.934	-0.0003	0.096*	0.038

Explanation: * statistically significant at α = 0.05
Source: Own calculations on the basis of (SP 2023a, 2023b)

Table 5. Variance and F-test of demographic structure indicators in Poland's provinces, 2002–2022 and 2022–2040

Variables	Variance			Retrospectively, 2002–2022		Prospectively, 2022–2040	
	2002	2022	2040	F	p-value	F	p-value
Share of population aged 0–14	0.0047	0.0033	0.0076	1.419	0.261	2.295	0.066
Share of population aged 15–34	0.0006	0.0019	0.0012	3.103	0.021	1.627	0.187
Share of population aged 35–64	0.0013	0.0004	0.0002	3.386	0.015	2.595	0.043
Share of population aged 65+	0.0093	0.0041	0.0060	2.287	0.067	1.478	0.237
Share of population aged 80+	0.0264	0.0099	0.0098	2.661	0.039	1.007	0.495

Source: Own calculations on the basis of (SP 2023a, 2023b)

the share of younger adults in Poland's provinces was becoming increasingly varied in the past.

In the next two decades of the 21st century, between 2022 and 2040, two population structure indicators: younger and older adults will become less dispersed over time. The parameters b of sigma-convergence models were negative and statistically significant (Table 4). However, the F-test indicates a statistically significant decrease in the variance only for the share of older adults (35–64) in 2040 compared to 2022 (Table 5). All the same, an increasing dispersion of values over time was demonstrated for the youngest population and the old-age population (aged 65+). The parameter b is positive and statistically significant at 0.05 in models (3) for these two indicators; however, an increase in variance over time was not confirmed by the F-test (Tables 4 and 5). The ambiguity of conclusions about the decreasing (or increasing) variation of the indicator values can be partially explained by the analysis of changes in the standard deviation of the population structure indicators. In the long term, uniform and unidirectional changes in the value of the variation measure are not always observed. By the mid–2030s, the variation in the percentage share of younger adults, older adults and oldest-age population will decrease, and it will then start to increase.

4. Discussion and conclusions

Retrospective and prospective analysis of selected indicators revealed that the population in Poland will systematically age over time. These findings are consistent with the results of research on changes in population structure indicators referring to people aged 65+ and to people aged 80+ in the period 2002–2020, which indicated regional differences in the advancement of population ageing (Majdzińska, 2017). The ageing process in the past, as described by Podogrodzka (2016a), is to some extent consistent with this analysis. Podogrodzka demonstrated sigma-convergence of the old age index (calculated at different older age thresholds) in Poland's provinces in the period 1996–2011 but did not identify any beta-convergence. This difference in findings can be attributed to the fact that the models used involved a graphical attribute, and that the convergence or divergence of the old age index depends on the construction of the relative measure itself.

This analysis of population ageing convergence in Poland's provinces revealed that, both in the past (in 2002–2022) and in the future (by 2040), the provinces of Poland have been and are becoming increasingly homogeneous as the levels of the analysed variables for adult population have been evening out. This is evidenced by the confirmed absolute or conditional beta-convergence for the oldest-age population (80+), old-age population (65+) and older adults (35–64) (Table 6). This means that, by 2040, the population ageing across Poland's provinces will be further strengthened.

Regional variations in the share of older adults is the only parameter that both decreased in the past and will continue to decrease in the future. This trend was confirmed in both sigma-convergence tests. In other age groups, convergence was found to change into divergence or *vice versa* over time. Variation in the share of younger adults (aged 15–34) between the provinces has increased in the past, and it will decrease in the future, as evidenced by the confirmed sigma-divergence of this variable; nonetheless, it was validated in only one prospective sigma-convergence test (Table 6). Alternatively, the dispersion in the share of the youngest population (0–14 years) and the old-age population (aged 65+) between the provinces decreased in the past but is expected to increase in the future.

Table 6. Confirmation of the type of convergence (divergence) of population structure indicators in Poland's provinces, 2002–2022 and 2022–2040

Variables	Retrospectively, 2002–2022				Prospectively, 2022–2040			
	Type of convergence							
	absolute beta	conditional beta	sigma		absolute beta	conditional beta	sigma	
	test 1	test 1	test 1	test 2	test 1	test 1	test 1	test 2
Share of population aged 0–14	yes	yes	yes	–	(yes)	–	(yes)	(–)
Share of population aged 15–34	–	yes	(yes)	(yes)	yes	yes	yes	–
Share of population aged 35–64	yes	yes	yes	yes	yes	yes	yes	yes
Share of population aged 65+	yes	yes	yes	–	–	yes	(yes)	(–)
Share of population aged 80+	yes	yes	yes	yes	yes	yes	–	(–)

Explanation: test 1 – significance test of parameter *b*; test 2 – *F*-test; yes – convergence confirmed; (yes) – divergence confirmed; – no confirmation of convergence; (–) – no confirmation of divergence
Source: own study

The analysis of prospective data demonstrated that population ageing will continue in all provinces, which makes it necessary to step-up efforts to satisfy the needs of the elderly population. This involves supplying products and services intended for the old-age population and safeguarding decent living conditions. In the latter case, this is not only a matter of financial support, but also of proper care. In Poland, it is difficult to secure a place at a nursing home, and there is a considerable shortage of geriatricians. Satisfying these needs is primarily the responsibility of the central government. Local government bodies can also contribute, as they are responsible for running social welfare homes and organising free time activities for the old-age population.

As the Polish population ages, variations in the population age structure in Poland's provinces will become even greater. This specifically applies to the subpopulation of people aged 0–14 and 65+. In provinces with a lower share of children and young people, expenditure on education will be capped, and in provinces with a larger share of old-age population, expenditure on healthcare is expected to increase, etc. This will be reflected in local government budgets and will affect prospects for economic development. Local governments with few children in the total population will still be forced to maintain redundant infrastructure, such as kindergartens or schools, but these will be attended by fewer children. Demographic changes will slow economic development, which will negatively affect population-related processes, leading to a vicious circle. These threats may be reduced by measures aimed at creating jobs or a conducive business environment that are competitive with those in other provinces, which would increase the revenue of local government units. According to research (Wiśniewski et al., 2020), local government bodies at various levels are aware of the threats arising from demographic changes but are showing little initiative to prevent these threats.

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