REPORT

Resilience analysis

(of current pension systems to demographic changes)

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FutuRes
Towards a Resilient Future of Europe

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Contents

1 Introduction

Ageing populations, as we currently observe in most of the industrialized countries, imply an increasing number of elderly dependent people in parallel to a shrinking workforce. If current economic and welfare institutions do not adjust to the changing structure of our population, there is a risk that the long-term sustainability of the welfare state will be compromised. At the same time, the economic potentials of people and their level of dependency will be shaped by their education, labor market participation, household dynamics, health, and retirement decisions. These life course events will in turn depend on future demographic circumstances and the prevailing institutional and macroeconomic framework.

To study these feedback mechanisms between the macroeconomy and the demographic structure, we have built up a dynamic general equilibrium model of overlapping generations that integrates the life cycle model of households into a model of an open economy and institutional framework of a pension system which is run by the government.

We apply our model to study the resilience of pension systems in terms of their fiscal sustainability and equity across heterogeneous ageing populations. Since the demographic development is currently in the center of discussions about pension systems and their resilience, we assume different demographic scenarios of fertility, mortality and migration. We apply three projections by EUROSTAT (baseline, higher and lower migration) and add three additional scenarios (constant fertility, ultra-low fertility and ultra-low mortality). Given our model set up, which includes realistic demographic structures at the household level, focusing on demographic scenarios for the resilience analysis constitutes a natural choice and represents the dimension in which our framework adds the most to the current discourse.

Since different pension systems and particularly also their parametric setting (retirement age, replacement rate, contribution period, etc.) are differently affected by population ageing, we have chosen four European countries that differ in their pension system and their generosity in terms of the replacement rate. We take Austria and Germany as representatives of unfunded defined benefit (DB) systems and Poland and Italy as representative of notional defined contribution (NDC) systems. While Austria and Italy allow rather high replacement rates for retirees, the replacement rate level is much lower in Germany and Poland.

One specific focus of our study is to consider the change in the educational attainment together with the changing age structure and its impact on pension costs. All our simulations are therefore not only distinguishing households by age and gender but also by educational attainment and income level. This approach allows us to see whether low socioeconomic status (SES) groups are affected differently by future pension costs compared to high SES groups in different countries and across time. Since pension systems not only depend on the demographic structure, but mainly also on the economic situation in each country, we present how different demographic scenarios affect the labour market and economic growth.

We begin by outlining our quantitative overlapping-generations model in Section 2. The model features heterogeneous households facing life-cycle risks in labor market participation, health, fertility, and mortality; endogenous education and retirement choices; a representative firm operating in competitive international markets; and a government that finances pensions and social insurance through raising contributions. Section 3 then briefly describes the calibration strategy. All demographic processes and transition probabilities are determined by cohort-, gender-, and education-specific data, while parameters related to individual preferences and characteristics are chosen to match observed labor income moments, educational attainment, and retirement behavior across countries.

Section 4 begins the quantitative analysis by describing, on top of the baseline population projections, the five alternative demographic scenarios and their implications for the evolution of population structure. We document how differences in fertility, mortality, and migration translate into distinct paths for population growth, the population's mean age, and the old-age dependency ratio. Constant and ultra-low fertility primarily accelerate population ageing through shrinking cohort sizes, higher migration mitigates ageing by expanding the working-age population, and ultra-low mortality increases ageing pressure by prolonging retirement duration.

Educational attainment is the first decision individuals make as independent economic agents in the model. Section 5 therefore begins the economic analysis by examining how cohort-level educational expansion affects the contribution rate required to finance the pension system. We show that this effect is governed by the relative retiree skill premium—that is, by the comparison between the skill premium during working life and the skill premium embedded in pension benefits—and by the transitional dynamics of educational composition between workers and retirees. We document the evolution of the relative retiree skill premium in Austria, Germany, Italy, and Poland over the period 1960–2100.

Sections 6 and 7 summarize the main quantitative economic implications of the different scenarios of demographic change within our model. Section 6 documents how alternative demographic scenarios shape labor market outcomes and economic growth, while Section 7 translates these dynamics into pension system costs and redistribution across and within generations. Section 8 concludes the paper.

2 Model description

We model three types of agents—households, a representative neoclassical firm, and a government—that interact on the market via prices of labor and capital and taxes and contributions levied on households and distributed by the government.[1]

A household comprises a household head and depending on her age, dependent children that are assumed to leave their parents home at age 18. Initially household heads differ by their gender and year of birth and two unobserved characteristics (learning ability and educational effort). During their lifetime household heads face idiosyncratic risks related to unemployment, health, and mortality, which depend on their initial characteristics. In addition households also face an initial one-time shock related to the total number of children they will have along their lives with cohort, age and education specific fertility rates determining the schedule of children over the life-cycle. Together, initial characteristics, the economic environment, and idiosyncratic shocks will jointly determine the optimal life-cycle decisions regarding consumption, education, and retirement age. We assume two levels of education, household's can choose to become high-skilled (ISCED 5–8) or not (ISCED 0–4). Savings act as precautionary motive also including the retirement phase. The age of retirement is chosen endogenously.

Educational choice plays an important role in our model. It determines not only

[1]The model is based on the dynamic overlapping generations model developed within the FutuRes project.

lifetime labor income, labor productivity and unemployment risk but also private savings, pension benefits, health and life expectancy.

Furthermore, the choice of education also determines a priori the risk of having a specific number of children and the age at childbearing. We assume that having children imposes labor income penalties on women—but not on men—through several channels. First, the presence of a newborn increases the rate of job separation defined as the number of workers leaving their jobs compared to the total number of workers (Kleven et al., 2024). Second, the job separation rate further increases with the number of children under the age of six. The marginal effect of an additional child on the separation rate has been calculated using ILO data. These two effects reduce the employment rate and labor income of women with children, which later on translates into lower pension rights. Since data indicate that per capita consumption does not differ by gender (see Istenič et al., 2016), we assume that men transfer part of their labor income to women until the per capita consumption profiles of both genders are equalized. Over time these transfers will decline as the share of women with tertiary education increases.

We assume a representative firm that produces a final good by combining capital and effective labor under constant returns to scale. The effective labor in each year is calculated as the sum across age, gender and education level, of all employed individuals. The final good can either be consumed by households or saved. The rate of growth of the labor-augmenting technological progress is assumed to be constant at 1.5 percent per year throughout the entire period analyzed. The representative firm maximizes its net cash flow by renting capital and hiring labor from households in competitive markets. The firm operates in an open economy, where both the interest rate and the wage per effective unit of labor are fixed and determined in international markets. The annual interest rate is assumed to be 3.5%. For more details, see FutuRes Deliverable 5.1 (Sánchez-Romero et al., 2023).

The government's role is to balance the pension system together with running the social insurance (unemployment benefits) and government expenditures.[2] To finance these transfers, the government levies social contributions on workers' income. Contribution rates are adjusted annually to cover all benefits claimed. In notional defined contribution (NDC) pension systems, we distinguish between the fixed contribution rate used to accumulate pension rights and the additional contributions required to cover the total cost of the system. We implement this distinction, since in an NDC pension system it is a priori not guaranteed in a non-stable population that a fixed contribution rate can finance all benefits claimed. Government expenditures are financed through taxes on labor income, capital income, and consumption, as well as through a confiscatory tax on accidental bequest.

For the sake of comparability across countries, we have harmonized the mathematical representation of the pension systems. All pension systems are modeled using the pension point system. This allows us to replicate both pensions systems (defined-benefit and defined-contribution) in one framework (see Appendix A). Three assumptions were introduced for computational reasons, which may increase the total cost of the pension system. First, since the actual average labor-augmenting technological progress between 1960 and 2020 was higher than 1.5 percent, our assumption of a constant 1.5 productivity growth implies that the initial cost of the pension system will be initially overestimated—see the influence of productivity on the cost of the pension system in Sánchez-Romero

[2]To better understand the impact of demography on the economic evolution and sustainability of the social security system, we assume no government debt.

and Prskawetz (2019). Second, we assume that all individuals can accumulate pension rights and convert them into pension benefits upon retirement. This assumption increases costs because it includes many individuals who, in reality, would not qualify for contributory pensions. Instead, such individuals often receive non-contributory benefits funded through the general government budget. Third, we do not impose any requirement for years of contribution to qualify for early retirement.

3 Calibration

We apply our model to four countries (Austria, Germany, Italy and Poland) and present simulation results for cohorts born between 1942 and 2047 for each country. To do so, we run the model from year 1960 until 2146. This is because individuals are assumed to leave their parents home at the age of 18 (1942+18) and can live to a maximum of 99 years (2047+99). Demographic data and projections for the four countries, along with all country-specific transition rates for health, employment, and mortality—by birth cohort, number of children, gender, and skill group—are derived from publicly available data from Eurostat (EUROPOP2023) and the Wittgenstein Centre Human Capital Data Explorer. For more details, see Deliverables 5.2 (Sánchez-Romero et al., 2024) and 5.3 (Sánchez-Romero et al., 2025).

For each country, the model is calibrated to target retirement ages and educational attainment by gender and country. We use age profiles derived from publicly available data from Eurostat and the AGENTA data explorer to match the existing labor income profiles observed for each gender, skill group and country. The dynamic overlapping generations model has been built using the Julia Programming Language v1.11.4, which is a general purpose open-source programming language.

4 Demographic trends

A key aspect of the paper is to study the resilience of economic growth and the currently implemented pension systems in Austria, Germany, Italy and Poland to alternative future demographic scenarios which differ in the assumption how fertility, mortality and migration will evolve over time.

This section summarizes the projected paths of the key demographic variables under a baseline, taken from Eurostat (2023), and a set of alternative scenarios. Starting from the baseline, each alternative scenario changes only one demographic component:

1. *Constant fertility*: Age-specific fertility rates are assumed to remain at their 2023 levels throughout the projection horizon.

2. *Lower migration*: Following Eurostat, net migration is 33 percent lower than in the baseline in each year. See Table 6 in the Appendix C.

3. *Higher migration*: Following Eurostat, net migration is 33 percent higher than in the baseline in each year. See Table 6 in the Appendix C.

4. *Ultra-low fertility*: The total fertility rate (TFR) is assumed to decline to 1.0 by 2035 and remain at 1.0 thereafter.

5. *Ultra-low mortality*: Using the Lee–Carter method (Lee and Carter, 1992) applied to Eurostat's projected age-specific mortality rates for 2022–2100, the mortality decline (i.e., the drift term) is assumed to be twice as large as in the baseline.

We next summarize the projected evolution of five demographic indicators—total fertility rate, life expectancy at age 65, the population's mean age, total population size, and the old-age dependency ratio—for each demographic scenario through 2100.

Fertility. Eurostat, similar to UN population projections, assumes a modest rebound in fertility over the 21st century, reaching a total fertility rate (TFR)—the number of births per woman—of about 1.7 by 2100 and converging asymptotically to 1.77 (Eurostat, 2023). Eurostat's national projections also include sensitivity tests in which the TFR is 20 percent lower, while the UN provides probabilistic projection variants for the TFR (UN-DESA, Population Division, 2024). Since these TFR values are higher than current trends suggest, in this report we assume the following three fertility scenarios: (1) baseline, following the assumptions of Eurostat (2) *constant fertility*, in which each country's TFR remains at its current level; and (3) *ultra-low fertility*, in which the TFR declines sharply to 1.0 by 2035 and remains at 1.0 thereafter.

Figure 1 shows the evolution of the TFR for Austria, Germany, Italy, and Poland over 1960–2100 for each scenario: *baseline* (solid blue line), *constant fertility* (dash–dot red line), and *ultra-low fertility* (dash–dot–dot purple line).

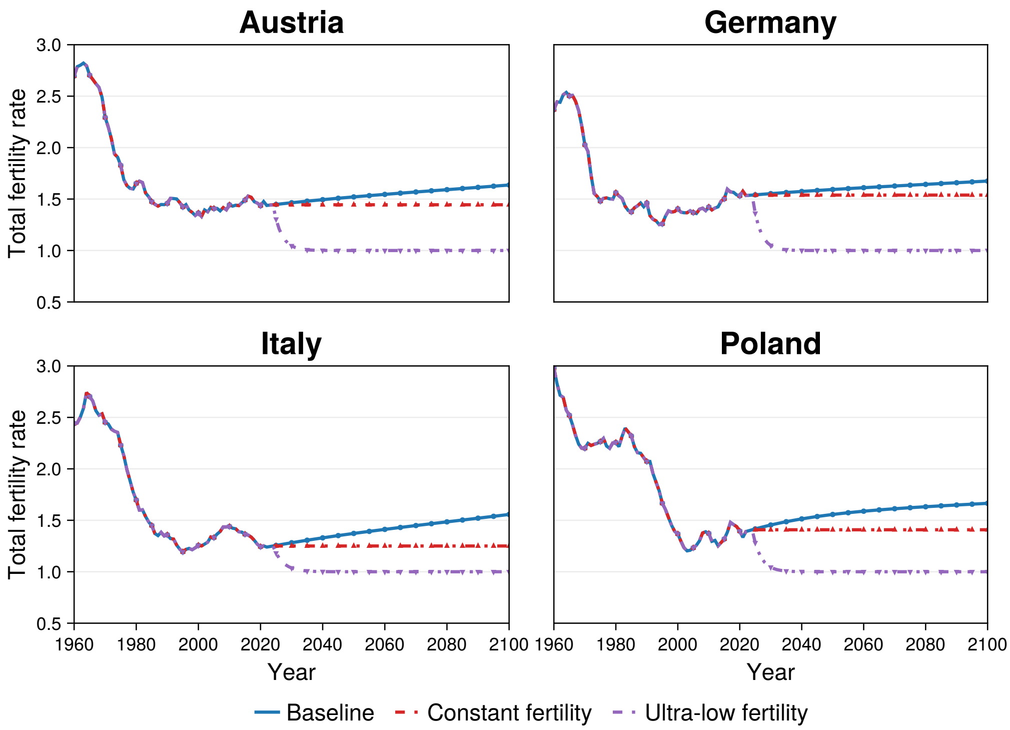

Figure 1: Evolution of the total fertility rate (TFR) in Austria, Germany, Italy, and Poland for the period 1960-2100. *Source*: Eurostat and authors' simulations. *Notes*: Baseline (solid-blue line), *constant fertility* (dashed-dot read line), and *ultra-low fertility* (dash-dot-dot purple line)

Among the four countries, Germany has the highest TFR (1.53) in 2020, followed by Austria (1.44), Poland (1.39), and Italy (1.24). Relative to 2020 levels, the baseline scenario therefore implies a smaller increase in TFR for countries that already start from higher fertility and a larger increase for countries starting from lower fertility. Poland shows the steepest decline in TFR over the last three decades, from above 2.0 in 1990 to 1.39 in 2020. Consequently, while all four countries will experience rapid population ageing, the pace of ageing is expected to be especially pronounced in Poland in the coming decades. In the very long-run, however, Italy will decline faster, as this country has the lowest fertility level.

Mortality. Another key determinant of the sustainability of pension-systems is the number of years retirees receive benefits, which is closely linked to the life expectancy at the age of retirement. Figure 2 shows the expected age at death conditional on reaching age 65—i.e. life expectancy at age 65—by gender (female=opaque, male=transparent) in Austria, Germany, Italy, and Poland over 1960–2100 under two demographic scenarios: *baseline* (solid blue line) and *ultra-low mortality* (dashed brown line). All other simulation scenarios assume the baseline mortality path.

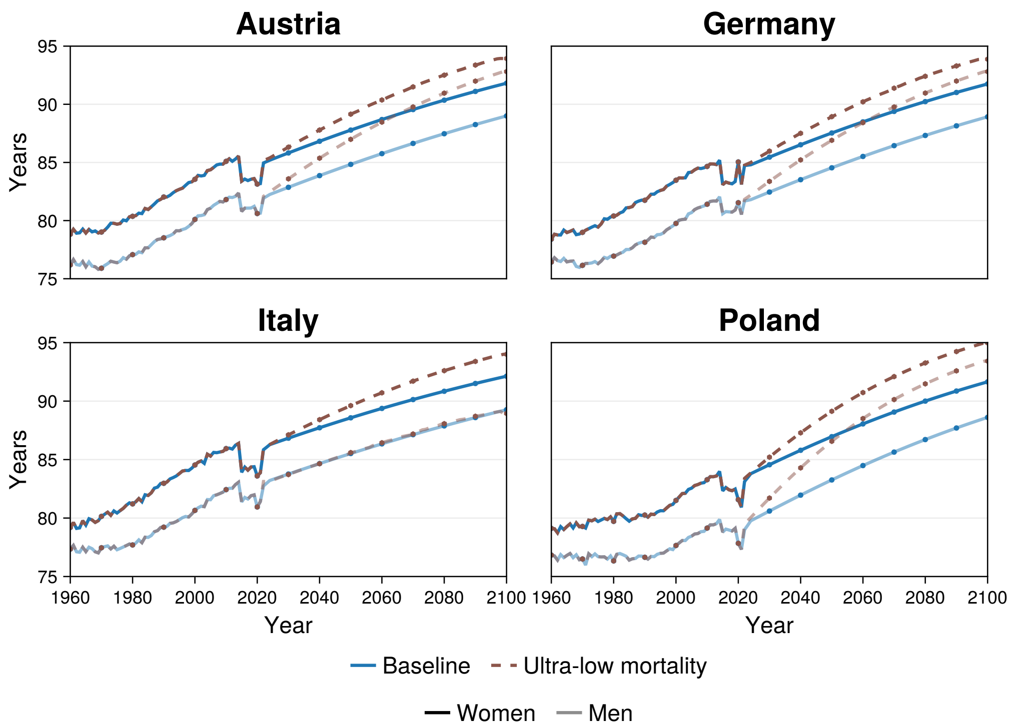

Figure 2: Evolution of the expected age at death for 65 years old by gender in Austria, Germany, Italy, and Poland for the period 1960-2100. *Source*: Eurostat and authors' simulations. *Notes*: Baseline (solid-blue line) and ultra-low mortality (dashed brown line).

For consistency with the economic model, the projected increase in the expected age at death at age 65 is calculated assuming that the maximum age at death is 98 (as assumed in the life cycle model). As a result, Figure 2 underestimates longevity gains for women, particularly under the *ultra-low mortality* scenario, as a higher fraction of women will survive to age 98.

Overall, life expectancy at age 65 increases steadily throughout the last decades and the projection horizon. In the past, we only observed a temporary interruption during the COVID-19 period. On average, the expected increase in the age at death for 65 years old is close to 1 year per decade under the *baseline* and 1.14 years per decade in the *ultra-low mortality* scenario.

In 2025, Italy has the highest life expectancy at age 65 (21.4 years for women and 18.2 for years men), followed by Austria (20.3 and 17.3), Germany (19.9 and 16.9), and Poland (18.9 and 14.9). By 2100, the expected age at death for 65 years old is assumed to converge to above 91 years for women and around 89 for men in all four countries. The *ultra-low mortality* scenario implies a substantial upward shift in the expected age at death conditional on survival to age 65 for both genders across all countries.

Under both scenarios, if the effective retirement age remains 65, retirees would receive pension benefits for more than twenty years on average, thereby putting additional pressure on the pension system. Under the *ultra-low mortality* scenario and assuming that retirement behavior does not change, an expected age at death of 90 by 2060, conditional on reaching 65, will further weaken the sustainability of the pension system by increasing the number of retirees to the working-age population.

Migration. The proportion of people migrating in and out of a country can either slow down or accelerate its ageing process, respectively. We consider two alternative migration scenarios based on Eurostat assumptions for the 2023 population projections: a net migration rate that is 33 percent lower than the baseline (*low migration*) and a net migration rate that is 33 percent higher than the baseline (*high migration*), while keeping fertility and mortality at their baseline levels. All other simulation scenarios assume the baseline migration path.

Figure 3 illustrates the net migration rate (i.e. total net migrants divided by the total resident population) in Austria, Germany, Italy, and Poland over the period 2025–2100 under the baseline and the lower- and higher-migration scenarios. According to the Eurostat's 2023 projections, Italy is expected to exhibit the highest net migration rate (slightly below 0.5 percent per year), followed by Austria and Germany. In contrast, Poland is assumed to have a negative net migration rate of around -0.25 percent in 2025, which gradually converges to the Italian net migration rate by 2100.

Population mean age. The mean age of the population is an important determinant of economic growth and of the average labor income. Growth of labor-income depends on productivity growth, which tends to be higher among younger workers as they accumulate experience and build human capital faster than older workers (Mason et al., 2016; Gordon, 2016). Thus, all else equal, economies with a younger labor force should exhibit faster growth of labor-income for a given path of labor-augmenting technological progress. Simultaneously, a higher mean-age of the working-age population implies higher average labor incomes. This relationship can, however, be strengthened or weakened by labor-market conditions, retirement behavior and labor-force participation (particularly also female labour force participation), which affect the size and composition of the labor force even when prices of production factors are taken as given. To better understand the results displayed later on, Table 1 shows the population's mean age in Austria, Germany, Italy, and Poland in years 1960, 2020 and 2100 under the baseline and the five alternative demographic scenarios.

As shown in Table 1, in 2020, Italy has the highest mean age of the population (45.24 years), followed by Germany (44.03), Austria (42.45), and Poland (41.36). Over the period 2020–2100, the mean age varies substantially across scenarios. It is highest

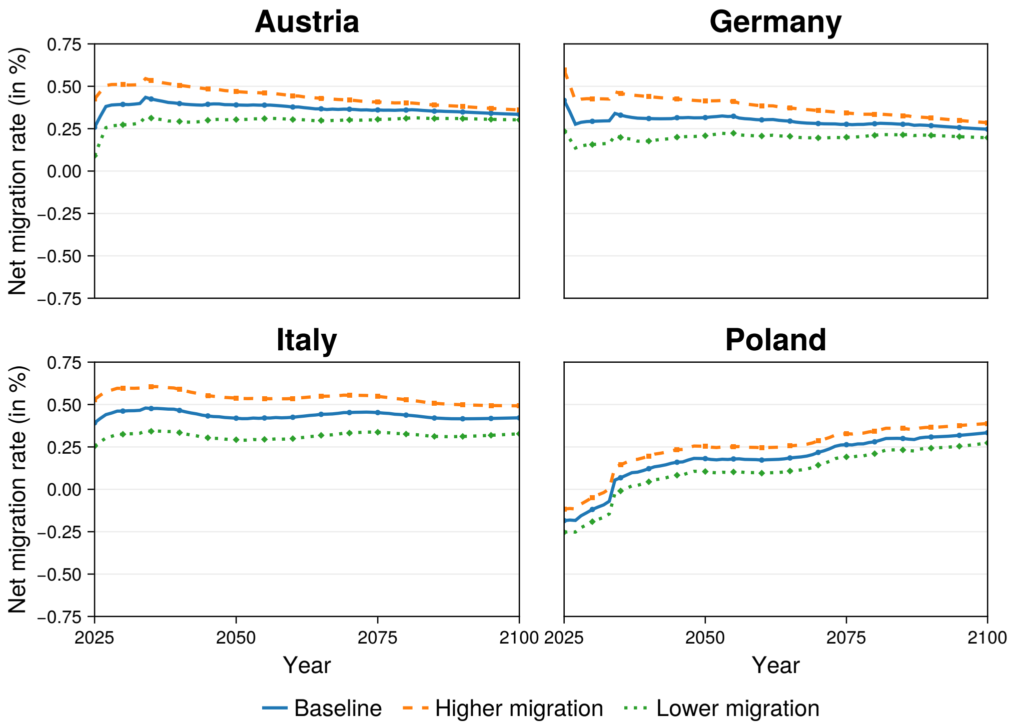

Figure 3: Evolution of the net migration rate in Austria, Germany, Italy, and Poland for the period 2025–2100. *Source*: Eurostat 2023 population projections and authors' simulations. *Notes*: Baseline (solid-blue line), high migration (dashed-orange line), and low migration (doted-green line).

Table 1: Mean age of the population in Austria, Germany, Italy, and Poland in 1960, 2020 and 2100.

		Demographic scenario					
Country	**Year**	**Baseline**	**Const. fert.**	**High migr.**	**Low migr.**	**Ultra-low fert.**	**Ultra-low mort.**
Austria	1960	36.02	36.02	36.02	36.02	36.02	36.02
	2020	42.45	42.45	42.45	42.45	42.45	42.45
	2100	48.03	49.40	47.78	48.33	54.73	49.66
Germany	1960	35.74	35.74	35.74	35.74	35.74	35.74
	2020	44.03	44.03	44.03	44.03	44.03	44.03
	2100	47.38	48.35	47.09	47.75	54.85	49.04
Italy	1960	33.04	33.04	33.04	33.04	33.04	33.04
	2020	45.24	45.24	45.24	45.24	45.24	45.24
	2100	50.20	52.44	49.74	50.82	55.45	50.78
Poland	1960	28.64	28.64	28.64	28.64	28.64	28.64
	2020	41.36	41.36	41.36	41.36	41.36	41.36
	2100	48.14	50.44	47.94	48.36	55.81	50.63

Source: Eurostat and authors' simulations.

under the *ultra-low fertility* scenario, reaching close to 56 years by the end of the century. Depending on initial fertility conditions, either the *ultra-low mortality* or the *constant-fertility* scenario also implies higher mean ages compared to the baseline. *Higher migration* lowers the mean age, whereas *lower migration* increases it.

Population growth. This variable is important for assessing the growth rate of an economy, which is frequently used by many institutions as an indicator for whether an economy is in a recession. In 2020, the population was slightly below 9 million in Austria, around 82 million in Germany, close to 60 million in Italy, and close to 38 million in Poland. Together, these four countries account for approximately 42 percent of the total EU-27 population in 2020. To isolate the contribution of each demographic scenario—i.e. changes in fertility, mortality, and migration—to the evolution of the population size in each country, Table 2 shows total population size in 1960, 2020, and 2100 relative to its 2020 level.

Table 2: Total population size—measured relative to the population in year 2020 (2020 = 100)—across six alternative demographic scenarios in Austria, Germany, Italy, and Poland, years 1960, 2020 and 2100

		Demographic scenario					
Country	**Year**	**Baseline**	**Const. fert.**	**High migr.**	**Low migr.**	**Ultra-low fert.**	**Ultra-low mort.**
Austria	1960	79.00	79.00	79.00	79.00	79.00	79.00
	2020	100.00	100.00	100.00	100.00	100.00	100.00
	2100	107.70	102.00	118.00	97.50	77.50	112.60
Germany	1960	87.30	87.30	87.30	87.30	87.30	87.30
	2020	100.00	100.00	100.00	100.00	100.00	100.00
	2100	101.30	97.40	113.20	89.50	69.20	106.00
Italy	1960	82.80	82.80	82.80	82.80	82.80	82.80
	2020	100.00	100.00	100.00	100.00	100.00	100.00
	2100	84.20	77.40	96.10	72.30	66.80	85.50
Poland	1960	77.40	77.40	77.40	77.40	77.40	77.40
	2020	100.00	100.00	100.00	100.00	100.00	100.00
	2100	78.50	71.10	84.80	72.30	53.80	84.40

Source: Eurostat and authors' simulations.

Under the *baseline* scenario, Austria's population increases by about 8 percent by the end of the century, Germany's population remains broadly stable, and Italy's and Poland's populations decline by roughly 16 percent and 21.5 percent, respectively. In Austria and Germany, population growth (or stability) despite below-replacement fertility is driven by net migration and continued increases in life expectancy. Poland's comparatively faster decline reflects past net out-migration together with below-replacement fertility.

Holding fertility constant at its current level (*constant fertility*) implies a population level that is between four and seven percentage points below the *baseline* by 2100. Under the *higher* (respectively, *lower*) *migration* scenario, the population level by 2100 is more than 11 percentage points above (respectively, below) the *baseline* in Austria, Germany, and Italy, and around 6 percentage points in Poland. Under the *ultra-low fertility* scenario, the population declines between 2020 and 2100 by more than 22 percent in Austria, 30 percent in Germany, 33 percent in Italy, and 46 percent in Poland. In contrast, under the *ultra-low mortality* scenario, the population level is about 5 percentage points above the *baseline* by 2100 in Austria, Germany, and Poland, and less than 2 percent points above the *baseline* in Italy.[3]

Old-age dependency ratio (OADR). A commonly used demographic indicator that accounts for age only (and not the economic characteristics at each age) is the OADR, defined as the ratio of the population aged 65 and older to the population aged 15–64. In this sense, it proxies the size of the potential retired population relative to the potential working-age population and shows the pressure on the financial sustainability of the pension system. Figure 4 reports the OADR for 1960–2100 in Austria, Germany, Italy, and Poland under the baseline and the five alternative demographic scenarios.

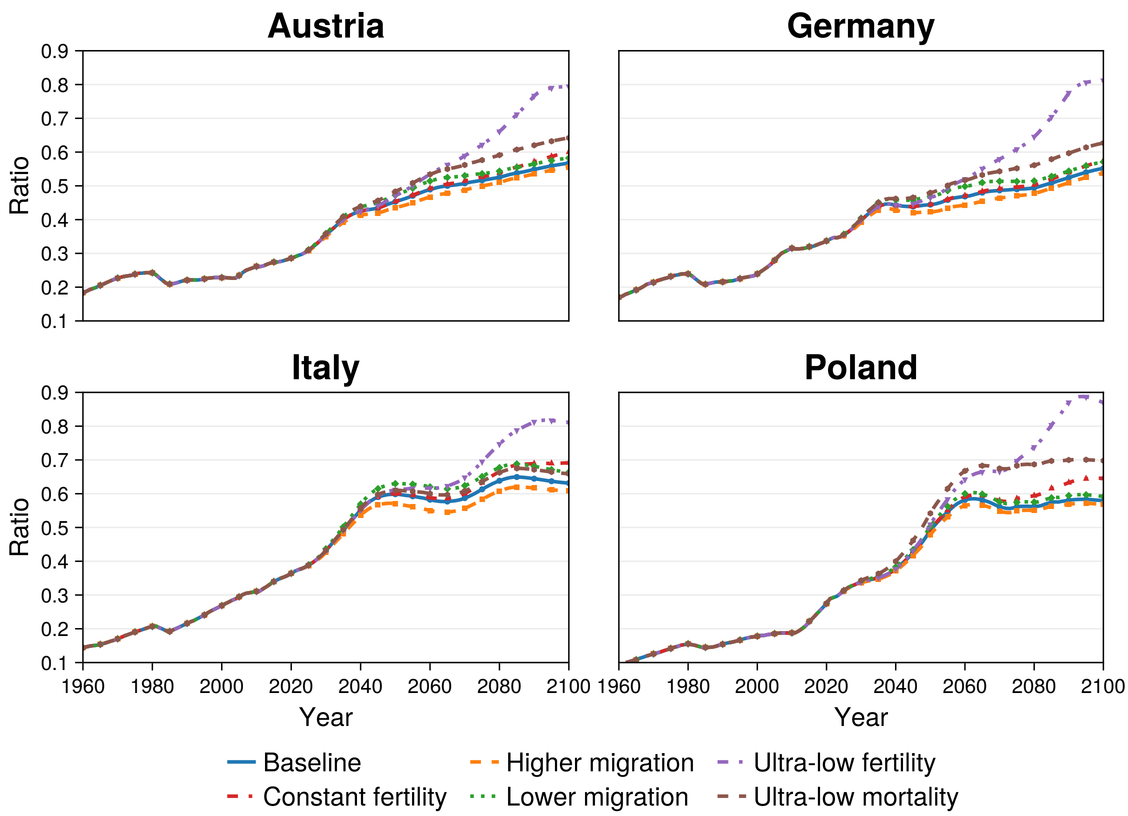

Figure 4: Evolution of the old-age dependency ratio across six alternative demographic scenarios in Austria, Germany, Italy, and Poland for the period 1960–2100. *Source*: Eurostat and authors' simulations. *Notes*: Baseline (solid-blue line), *constant fertility* (dashed-dot red line), *higher migration* (dashed-orange line), *lower migration* (doted green line), *ultra-low fertility* (dashed-purple line), and *ultra-low mortality* (dashed brown line).

Under the *baseline*, the OADR in 2020 ranges between 0.25 and 0.35—i.e., roughly three to four potential workers per retiree—and increases to close to 0.6 by the end of the century—about 1.5 potential workers per retiree. The baseline trajectory also indicates a faster increase over the next 15 years in Austria, Germany, and Italy, reflecting the retirement of the baby-boom cohorts and subsequent baby-bust dynamics (see Figure 1).

[3]Due to computational constraints, the model imposes an upper age limit of 98 years. As a result, survival at very advanced ages is truncated, which leads to a slight underestimation of total population size relative to projections that allow for survival beyond age 98. This limitation affects on ultra-low mortality simulation results.

For Poland, the increase is more pronounced over 2040–2060, consistent with a later timing of the baby-boom and baby-bust process. Across scenarios, the OADR declines only under *higher migration* and rises in all other cases, with particularly large increases under *ultra-low mortality* and *ultra-low fertility*. *Ultra-low mortality* raises the OADR rapidly, with the resulting gap relative to the *baseline* remaining broadly stable through the end of the century. By contrast, the effect of *ultra-low fertility* materializes mainly after 2060, when the smaller cohorts born in the 2030s enter the working-age population.

While the OADR is widely used to discuss the sustainability of current pension systems, it has several important limitations. Most importantly, it is not a one-to-one mapping of pensioners to contributors: it does not account for delayed labor-market entry due to education, unemployment, inactivity, early retirement, or changes in labor productivity and earnings. In addition, the OADR abstracts from policy and behavioral responses—such as reforms affecting eligibility and effective retirement ages—and it does not incorporate the benefit formula or the contribution base. The next sections incorporate these elements into the economic analysis.

5 Educational expansion and pension system cost

In this section, we quantify how changes in educational attainment affect the contribution rate required to finance the pay-as-you-go pension system. In the short run, educational expansion can reduce the required contribution rate because a larger share of high-skilled workers—who earn higher labor income—contributes to financing pension benefits that are still paid largely to cohorts with lower educational attainment. Over the longer run, as these high-skilled workers retire, average pension claims increase, which tends to raise pension expenditures.

To formalize this mechanism, consider the pension system's budget-balance condition, where we assume that debt is zero,

$$\tau_t^S = \frac{b_t}{y_t} \times \mathrm{OADR}_t, \tag{1}$$

where τ_t^S is the social contribution rate in year t, b_t is the ratio between total pension claims in year t and the total population aged 65 and older, y_t is the ratio between the total labor income in year t and the total population between ages 15 and 64, and OADR_t is the old-age dependency ratio in year t. See the evolution of the OADR in Figure 4 above. To make the role of educational composition explicit, we can rewrite the budget-balance condition as

$$\tau_t^S = \frac{b^\ell}{y^\ell} \times \frac{1 + \phi^{\text{retirees}} \cdot \omega_t^{\text{retirees}}}{1 + \phi^{\text{workers}} \cdot \omega_t^{\text{workers}}} \times \mathrm{OADR}_t, \tag{2}$$

where y^ℓ is the average labor income of low-skilled individuals between ages 15 and 64, b^ℓ is average pension of low-skilled individuals older than 65 years, $\phi^i > 0$ is the relative income advantage of high-skilled compared to low-skilled individuals in group $i \in \{workers, retirees\}$, and $\omega^i \in [0, 1]$ is the share of high-skilled individuals in group i. The first term on the right-hand side of (2) is the pension-to-income ratio for low-skilled individuals. The second term is a skill-composition adjustment factor. It reflects the relative income advantage of high-skilled retirees to the relative income advantage of high-skilled workers. For expositional convenience, we refer to this adjustment as the **relative retiree skill premium**.

Intuitively, educational expansion reduces pension-system cost when the skill premium is larger during the working life than in retirement ($\phi^{\text{workers}} > \phi^{\text{retirees}}$), and it increases pension-system cost when the opposite holds ($\phi^{\text{retirees}} > \phi^{\text{workers}}$). During the transition to a new educational steady state, however, the dynamics are asymmetric: $\omega_t^{\text{workers}}$ increases earlier than $\omega_t^{\text{retirees}}$, because educational expansion first affects cohorts entering the labor force. As a result, the denominator in (2) rises before the numerator, which temporarily reduces τ_t^S. As the high-skilled cohorts age into retirement, $\omega_t^{\text{retirees}}$ increases, pushing τ_t^S upward until the new equilibrium is reached.

Figure 5 shows the projected evolution of the share of high-skilled individuals born between 1943 and 2043 in Austria, Germany, Italy, and Poland. Educational attainment is calibrated in our model to match the cohort- and gender-specific shares of individuals with post-secondary education reported in Wittgenstein Centre for Demography and Global Human Capital (2018). The figure indicates that, for earlier cohorts, men's educational attainment exceeded women's. In recent cohorts—and throughout the projection horizon—women exhibit higher rates of post-secondary education than men, and the gender gap is projected to widen.

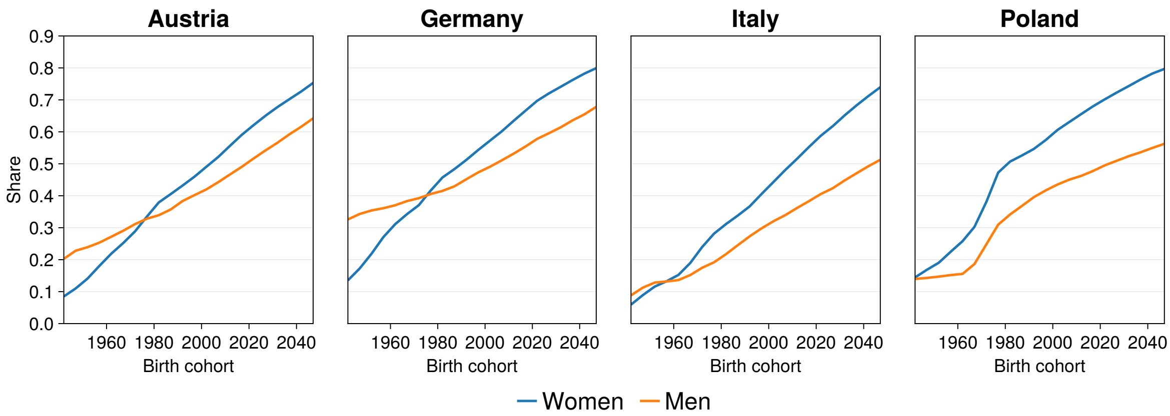

Figure 5: Share of people with post-secondary education by birth cohort, gender, and country. *Source*: Author's simulations. *Note*: Our model has been set so as to replicate in the baseline simulation the share of people in post-secondary education by gender and birth cohort in each country from Wittgenstein Centre for Demography and Global Human Capital (2018). Results under alternative demographic scenarios are quantitatively very close to those obtained under the baseline scenario. For clarity of presentation, we therefore report only the baseline trajectory for each country.

To see the impact of the educational expansion depicted in the previous figure on pension-system cost, Figure 6 illustrates the evolution of the relative retiree skill premium between 1960 and 2100 in Austria, Germany, Italy, and Poland under the *baseline*. The figure indicates that educational expansion reduces the contribution rate τ_t^S in all four countries. This result stems from the fact that the skill premium among retirees is smaller than the skill premium among workers, reflecting progressive elements of the pension system—such as minimum pension benefits—that compress at the population level pension incomes relative to labor incomes.

In our simulations, the worker skill premium is (in percent) approximately 53 in

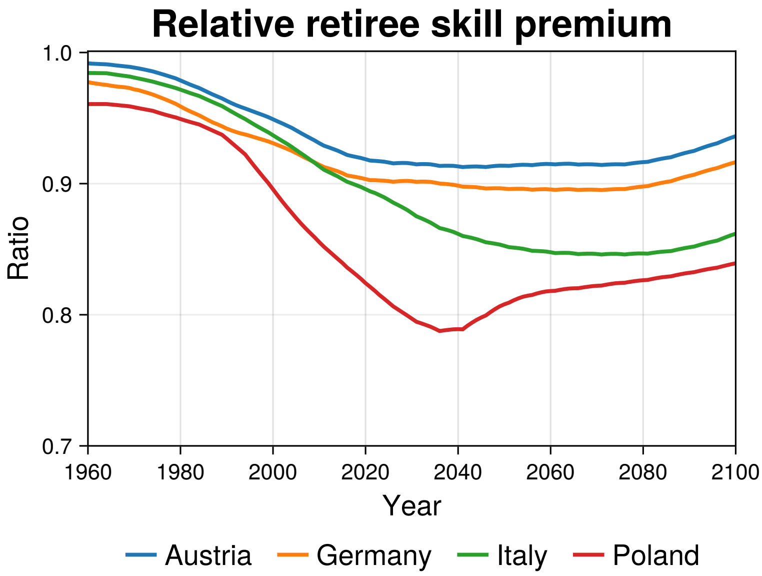

Figure 6: Relative retiree skill premium in Austria, Germany, Italy, and Poland for the period 1960–2100. *Source*: Eurostat and authors' simulations. *Notes*: Results under alternative demographic scenarios are quantitatively very close to those obtained under the baseline scenario. For clarity of presentation, we therefore report only the baseline trajectory for each country.

Austria, 59 in Germany, 76 in Italy, and 94 in Poland, whereas the retiree skill premium is (in percent) about 50, 49, 54, and 62, respectively. As a consequence, the increasing share of high-skill individuals reduces the required contribution rate by roughly 10 percentage points in Austria and Germany between 2020 and 2080. The effect is larger in Italy—close to 15 percentage points—partly because educational expansion started later but progressed more rapidly than in Austria and Germany and partly due to the higher difference between the skill premium during the working years and at retirement. In Poland, the reduction is even larger (around 20 percentage points), consistent with the rapid expansion of post-secondary education for cohorts born around 1970 and the higher skill premium gaps between workers and retirees.

Another important result follows from the fact that the educational expansion has progressed faster among women than among men (see Figure 5). For this reason, the decline in pension-system cost up to 2020 is mainly driven by the entry of increasingly high-skilled women into the labor market. Finally, we do not observe a significant change in the influence of education on pension-system cost across the different demographic scenarios, except in Poland for the ultra-low fertility and ultra-low mortality that further reduce the pension cost.

6 The impact of population ageing on the labor market and economic growth

In the next sections, we examine how population ageing affects labor supply, retirement, economic growth, and, ultimately, the sustainability and redistributive properties of the pension system (see Section 7). The future cost of the pension system is determined by the joint evolution over time of two key components—the number of retirees per worker and the pension-labor income ratio—which together determine the contribution rate to the pension system:

$$\text{Retirees per worker} \times \text{Pension-labor income ratio} = \text{Contribution rate}.$$

To project the share of retirees-per-worker, the following subsections analyze the evolution of total employment and the total number of retirees. To assess the macroeconomic implications of these demographic trends, we analyze economic growth, which in turn affects the pension to labor income ratio and study it from a national accounting perspective and the perspective of the demographic dividend. The first perspective focuses on the generation and uses of income, whereas the second emphasizes the role of changes in the age structure.

6.1 Total employment

The total population of Austria, Germany, Italy, and Poland is projected to either remain rather stable or decline over the coming decades (see Table 2). At the same time, the projected increase in the old-age dependency ratio (OADR) in all four countries (see Figure 4) implies a rising share of retirees and hence a contraction of the population aged 15 to 64.

Figure 7 illustrates the projected evolution of total employment in Austria, Germany, Italy, and Poland by gender over the period 2020–2100 under the baseline scenario and five alternative demographic scenarios. For expositional clarity, total employment in 2025 is used as the reference point. In all scenarios, employment projections are generated using a microsimulation model, combined with the economic model, that incorporates heterogeneity in employment rates by education, gender, and the presence of children under age six in each country.

Under the baseline scenario, Austria exhibits a distinct pattern relative to the other three countries. Between 2025 and 2060, the total number of employed women is projected to exceed its 2025 level, while male employment is expected to remain rather stable or to decline slightly over the same period. By contrast, Germany, Italy, and Poland are projected to experience a decline in total employment, with larger reductions among women than among men. Between 2025 and 2060, the decline is moderate in Germany and Italy—on the order of 10 percent—but substantially stronger in Poland, where employment is projected to fall by nearly 25 percent. From 2060 onward, total employment continues to decline in all four countries under the baseline scenario. By 2100, employment is projected to be around 30 percent lower in Austria and Italy, 40 percent lower in Germany, and 60 percent lower in Poland than its 2025 level.

The alternative demographic scenarios highlight the sensitivity of employment trajectories to migration, fertility, and mortality assumptions. When the migration rate is assumed to be 33 percent lower than in the baseline, total employment by 2100 declines

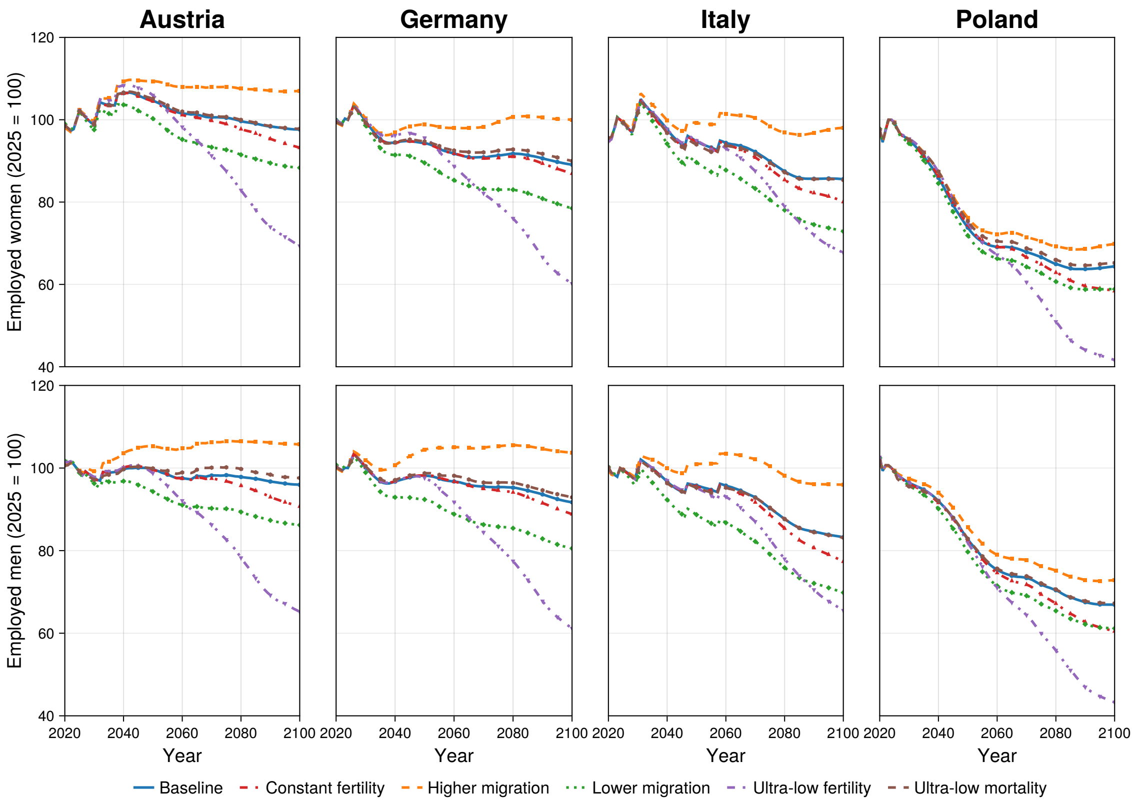

Figure 7: Total number of employed individuals (Ref: 2025=100) by gender in Austria, Germany, Italy, and Poland. *Source*: Authors' calculations. *Notes*: Baseline (solid-blue line), constant fertility (dashed-dot red line), *higher migration* (dashed orange line), *lower migration* (doted green line), *ultra-low fertility* (dashed-purple line), and *ultra-low mortality* (dashed brown line).

by almost 10 additional percentage points in Austria, Germany, and Italy, and by around 5 percentage points in Poland. The impact of reduced migration becomes visible with a delay of approximately five years. Conversely, assuming a migration rate 33 percent higher than in the baseline yields the opposite effect: total employment increases in Austria and Germany, declines only slightly in Italy, and significantly mitigates the projected employment losses in Poland.

Holding fertility constant at its 2022 level leads to a modest reduction in total employment—around 5 percentage points below the baseline by 2100—although this effect materializes only after 2060. Two additional scenarios, ultra-low mortality and ultra-low fertility, produce more interesting outcomes. Under ultra-low mortality, total employment increases slightly, driven by two mechanisms. First, lower mortality among older individuals raises employment at older ages. Second, longer life expectancy increases the returns to education, leading to a higher share of highly educated workers, higher employment rates, and delayed retirement. These effects outweigh the negative impact of later labor market entry associated with longer educational trajectories.

In the *ultra-low fertility* scenario, employment effects vary over time. In the short run, women in the first ultra-low fertility cohorts exhibit higher employment rates, reflecting reduced childrearing responsibilities. However, after 2050, total employment falls below the baseline as smaller cohorts progressively enter the labor market.

6.2 Total number of retirees

With population ageing, the total number of retirees is expected to increase across all four countries. This trend is driven by two main factors. First, the large baby-boom cohorts are progressively reaching retirement age. Second, life expectancy has increased substantially in all four countries between 1960 and 2020 and is projected to continue rising after the temporary pandemic-related mortality shock, leading to longer durations spent in retirement.

Figure 8 illustrates the projected evolution of the total number of retired individuals by gender in Austria, Germany, Italy, and Poland over the period 2020–2100, expressed as an index with 2025 set to 100. Across all countries, the baseline scenario points to a substantial increase in the number of retirees, reflecting the continued trend of population ageing. The increase is generally more pronounced among men than among women, especially in Poland, as lower initial male longevity implies a stronger relative response to mortality improvements (see the evolution of the expected age at death for 65 years old in Figure 2).

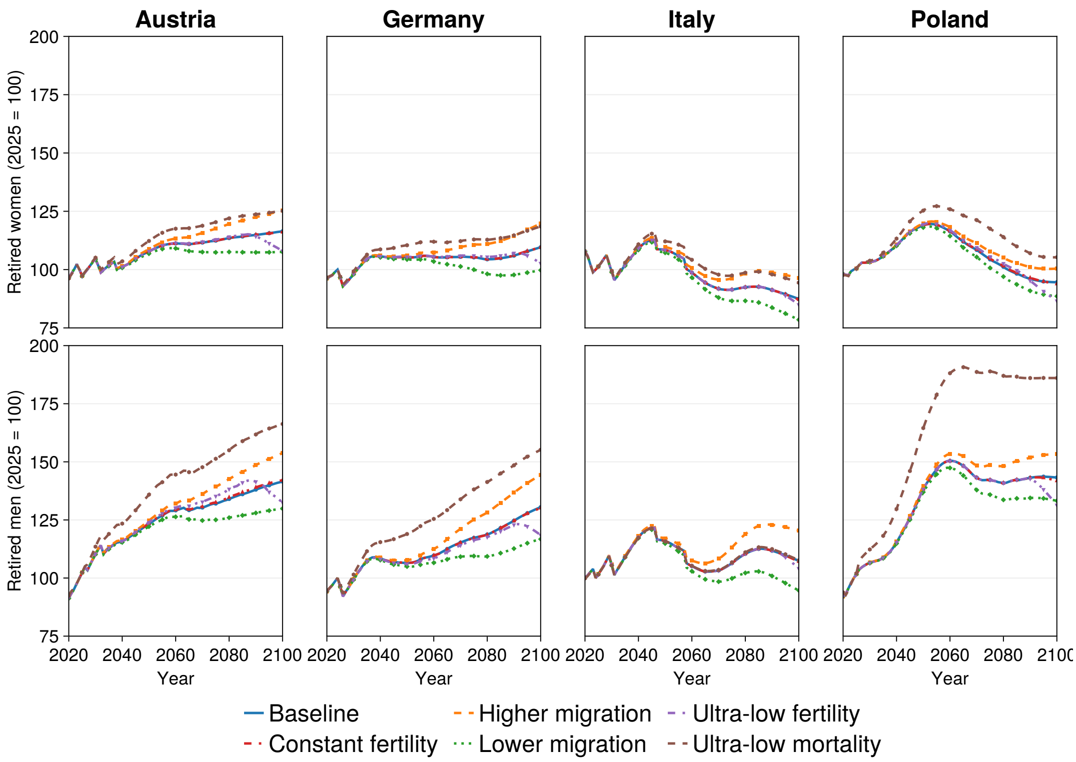

Figure 8: Total number of retired individuals (Ref: 2025=100) by gender in Austria, Germany, Italy, and Poland. *Source*: Authors' calculations. *Notes*: Baseline (solid-blue line), *constant fertility* (dashed-dot red line), high migration (dashed orange line), low migration (doted green line), ultra-low fertility (dashed-purple line), and ultra-low mortality (dashed brown line).

Migration assumptions play an important role in shaping the projected evolution of the number of retirees. *Higher migration* increases the future growth in the number of retirees, whereas *lower migration* reduces the increase in the number of retirees. Fertility assumptions have more delayed effects: *constant fertility* and *ultra-low fertility* scenarios begin to diverge from the baseline only after 2090, once smaller cohorts reach retirement age.

The *ultra-low mortality* scenario has the strongest impact on the number of retirees in all four countries. By substantially extending longevity at older ages, it leads to a sharp increase in the retired population, especially among men, and most markedly in Poland. Overall, the figure showcases that the evolution of the number of retirees is mainly driven by mortality improvements, while migration and fertility mainly influence the timing and magnitude of the growth in the number of retirees, with important implications for pension system sustainability.

6.3 Economic growth

Decomposing GDP per capita growth. Table 3 summarizes the macroeconomic implications of the different demographic scenarios by reporting average annual growth rates over the period 2020–2070 for aggregate (see first two columns) and per capita variables. In all scenarios we have assumed that labor-augmenting technology grows exogenously by 1.5 percent per year. Under the baseline scenario, all four countries experience positive growth in total national income despite stagnant or declining population dynamics, implying sustained increases in per capita income. The contrast is particularly pronounced in Italy and Poland, where negative population growth coexists with relatively strong per capita income growth, reflecting capital deepening and compositional effects in the labor force. However, without productivity growth, Poland and Germany will stagnate. An additional pattern emerging from Table 3 is that per capita national income grows faster in countries operating notional defined contribution (NDC) pension systems, such as Italy and Poland, than in countries relying on defined benefit (DB) systems, such as Austria and Germany. This difference is primarily driven by a more pronounced increase in capital income in the NDC countries, reflecting stronger capital accumulation incentives and higher capital–labor ratios. This shows an important resilient aspect of the four economies to extreme demographic changes.

Alternative demographic scenarios mainly affect economic growth through their impact on population size, labor supply, and capital accumulation. *Higher migration* uniformly raises total national income growth by expanding the population and the workforce, while *lower migration* has the opposite effect. Per capita values, however, are much less sensitive to migration assumptions, as changes in aggregate income are largely offset by changes in the population size. Similarly, holding fertility constant reduces population growth but has only modest effects on per capita income. Thus, small changes in migration or fertility shows its limited role for changes in living standards over the period analyzed.

The *ultra-low fertility* and *ultra-low mortality* scenarios generate more pronounced effects on per capita variables. In all four countries, *ultra-low fertility* is associated with lower population growth but substantially higher growth in capital income and per capita output, driven by increased savings capacity and higher employment rates. Ultra-low mortality also raises per capita income growth, though to a lesser extent compared to ultra low fertility, reflecting longer working lives, delayed retirement, and stronger incentives for human capital accumulation (Sánchez-Romero et al., 2016). Overall, the results indicate that while demographic change constrains aggregate growth through population dynamics, its effects on per capita economic performance are mitigated—and in some cases reversed—by behavioral and compositional adjustments in labor supply, education,

Simulation	Total National Income	Total Population	Per capita National Income	Per capita Labor Income	Per capita Capital Income	Per capita Cons.	Per capita Private Cons.	Per capita Public Cons.
Austria (Baseline)	1.72	0.14	1.58	1.55	1.68	1.72	1.77	1.59
Absolute difference with respect to baseline								
Constant fertility	0.00	−0.03	0.03	0.02	0.05	0.02	0.03	0.03
Higher migration	0.14	0.13	0.01	0.02	−0.01	0.00	−0.01	0.03
Lower migration	−0.16	−0.13	−0.03	0.00	0.00	0.00	0.01	−0.02
Ultra-low fertility	−0.09	−0.29	0.20	0.10	0.51	0.15	0.16	0.16
Ultra-low mortality	0.10	0.07	0.03	−0.05	0.30	0.04	0.05	0.03
Germany (Baseline)	1.58	0.02	1.56	1.51	1.67	1.55	1.60	1.47
Absolute difference with respect to baseline								
Constant fertility	0.00	−0.02	0.02	0.01	0.05	0.02	0.02	0.03
Higher migration	0.17	0.16	0.01	0.02	−0.02	0.00	−0.01	0.02
Lower migration	−0.18	−0.16	−0.02	−0.04	0.04	0.00	0.02	−0.01
Ultra-low fertility	−0.06	−0.33	0.27	0.14	0.53	0.21	0.21	0.22
Ultra-low mortality	0.13	0.08	0.05	−0.04	0.23	0.03	0.06	−0.01
Italy (Baseline)	1.68	−0.23	1.91	1.88	2.00	1.86	1.83	1.92
Absolute difference with respect to baseline								
Constant fertility	0.00	−0.06	0.06	0.04	0.11	0.04	0.04	0.05
Higher migration	0.17	0.16	0.01	0.03	−0.06	0.00	−0.01	0.02
Lower migration	−0.19	−0.18	−0.01	−0.04	0.08	0.01	0.02	−0.02
Ultra-low fertility	−0.01	−0.19	0.18	0.10	0.38	0.14	0.13	0.14
Ultra-low mortality	0.05	0.02	0.03	−0.04	0.13	0.01	0.02	−0.01
Poland (Baseline)	1.50	−0.34	1.84	1.52	2.74	1.81	1.85	1.73
Absolute difference with respect to baseline								
Constant fertility	−0.01	−0.07	0.06	0.04	0.09	0.05	0.04	0.05
Higher migration	0.10	0.09	0.01	0.02	0.00	0.01	0.00	0.01
Lower migration	−0.11	−0.09	−0.02	−0.03	−0.01	−0.01	−0.01	−0.02
Ultra-low fertility	−0.12	−0.31	0.19	0.11	0.40	0.18	0.18	0.18
Ultra-low mortality	0.19	0.14	0.05	−0.11	0.31	0.02	0.04	−0.04

Table 3: Macroeconomic effects across demographic simulation scenarios over the period 2020-70 (annual average growth, in percent). *Source*: Authors' simulations. *Notes*: All simulations assume an annual growth rate of 1.5 percent for labor-augmenting technological progress (Z_{gr}).

and capital accumulation, showing a strong resilience effect.

Demographic dividend. Mortality, fertility, migration, retirement behavior, education, and saving decisions can all have offsetting effects not only on per capita income, as shown in the previous paragraph, but also on the living standards (i.e., per capita consumption). The demographic dividend perspective provides a more coherent link between demographic projections and macroeconomic outcomes, and therefore it is a better framework for studying the economic consequences of ageing. Following (Sánchez-Romero and Prskawetz, 2024), we examine the demographic dividend by decomposing per capita consumption growth as follows

$$\left(\frac{C}{N}\right)_{\text{gr}} = \left(\frac{C}{Y}\right)_{\text{gr}} + \underbrace{\frac{\alpha}{1-\alpha}\left(\frac{K}{Y}\right)_{\text{gr}} + Z_{\text{gr}} + \left(\frac{L}{W}\right)_{\text{gr}}}_{(Y/W)_{\text{gr}}} + \left(\frac{W}{N}\right)_{\text{gr}}, \tag{3}$$

where the first term denotes the growth rate of the average propensity to consume out of total output; the second term corresponds to the growth rate of the capital–output ratio, which is assumed to be zero because the four economies are modeled as small open economies. The third term captures the growth rate of exogenous (labor-augmenting) technological progress, the fourth term reflects the growth rate of human capital per worker, and the final term represents the growth rate of the support ratio.

Table 4 decomposes the average per capita consumption growth of Austria, Germany, Italy, and Poland for the period 2020-70 into its main demographic dividend components (see Eq. (3)) under the baseline and alternative demographic scenarios, following the standard accounting framework in the demographic dividend literature (Kelley and Schmidt, 1995; Bloom and Williamson, 1997, 1998; Kelley and Schmidt, 2005; Prskawetz et al., 2007; Sánchez-Romero, 2013; Sánchez-Romero et al., 2018). Per capita consumption growth can be expressed as the sum of the growth rate of the average propensity to consume, a productivity component—capturing changes in output per worker—and a translation component—reflecting changes in the ratio of workers to total population. The latter captures the classic first demographic dividend, while productivity-related channels are closely related to the second demographic dividend through capital deepening and human capital accumulation.

Under the baseline demographic scenario, all four countries exhibit positive per capita consumption growth despite adverse population ageing trends. This outcome is primarily driven by the productivity component ($(Y/W)_{\text{gr}}$), while the translation component ($(W/N)_{\text{gr}}$) is generally negative, except for Italy, reflecting declining support ratios as the population ages. The contrast is particularly stark in Poland, where a large negative translation component ($(W/N)_{\text{gr}} = -0.35$) is more than offset by productivity gains ($(L/W)_{\text{gr}} = 0.37$), illustrating how economic adjustments can mitigate the mechanical effects of ageing on living standards.[4]

Alternative demographic scenarios mainly operate through the translation component. *Higher migration* systematically improves the support ratio (W/N), yielding a positive translation effect that raises per capita output, whereas *lower migration* has the opposite effect. However, the positive (resp. negative) effect on per capita output is offset by a lower (resp. higher) propensity to consume, yielding almost no effect on per capita

[4]In future work, we plan to explore the sensitivity of our results to alternative assumptions regarding exogenous productivity growth by considering both lower and higher growth rates of Z.

Simulation	Per capita consumption	Propensity to consume	Productivity component				Translation component		
	C/N	C/Y	Total	K/Y	Z†	L/W	Total	W	N
Austria (Baseline)	1.71	0.16	1.70	0.00	1.50	0.20	−0.14	−0.01	−0.13
Absolute difference with respect to baseline									
Constant fertility	0.03	0.00	0.00	0.00	0.00	0.00	0.01	−0.02	0.03
Higher migration	0.00	−0.03	0.00	0.00	0.00	0.00	0.02	0.15	−0.13
Lower migration	0.00	0.03	0.00	0.00	0.00	0.00	−0.04	−0.17	0.13
Ultra-low fertility	0.16	0.06	0.03	0.00	0.00	0.03	0.06	−0.23	0.29
Ultra-low mortality	0.04	0.09	0.00	0.00	0.00	0.00	−0.05	0.02	−0.07
Germany (Baseline)	1.55	0.04	1.68	0.00	1.50	0.18	−0.16	−0.14	−0.02
Absolute difference with respect to baseline									
Constant fertility	0.02	0.00	0.00	0.00	0.00	0.00	0.02	−0.01	0.03
Higher migration	0.00	−0.03	0.00	0.00	0.00	0.00	0.02	0.18	−0.16
Lower migration	0.01	0.03	−0.01	0.00	0.00	−0.01	−0.04	−0.20	0.16
Ultra-low fertility	0.22	0.07	0.02	0.00	0.00	0.02	0.12	−0.23	0.35
Ultra-low mortality	0.04	0.07	0.01	0.00	0.00	0.01	−0.04	0.03	−0.07
Italy (Baseline)	1.85	−0.02	1.76	0.00	1.50	0.26	0.11	−0.12	0.23
Absolute difference with respect to baseline									
Constant fertility	0.05	0.01	0.01	0.00	0.00	0.01	0.04	−0.02	0.06
Higher migration	0.00	−0.03	0.01	0.00	0.00	0.01	0.04	0.20	−0.16
Lower migration	0.01	0.05	0.00	0.00	0.00	0.00	−0.03	−0.22	0.19
Ultra-low fertility	0.14	0.04	0.02	0.00	0.00	0.02	0.09	−0.11	0.20
Ultra-low mortality	0.01	0.04	0.00	0.00	0.00	0.00	−0.03	−0.01	−0.02
Poland (Baseline)	1.80	0.28	1.87	0.00	1.50	0.37	−0.35	−0.70	0.35
Absolute difference with respect to baseline									
Constant fertility	0.05	0.01	0.01	0.00	0.00	0.01	0.04	−0.03	0.07
Higher migration	0.01	−0.01	0.00	0.00	0.00	0.00	0.02	0.12	−0.10
Lower migration	−0.01	0.02	−0.01	0.00	0.00	−0.01	−0.02	−0.11	0.09
Ultra-low fertility	0.18	0.07	0.03	0.00	0.00	0.03	0.08	−0.24	0.32
Ultra-low mortality	0.02	0.14	0.02	0.00	0.00	0.02	−0.12	0.03	−0.15

Table 4: Demographic dividend analysis under six alternative demographic scenarios in Austria, Germany, Italy, and Poland for the period 2020–70 (annual average growth, in percent). *Source*: Authors' simulations. *Notes*: †All simulations assume an annual growth rate of 1.5 percent for labor-augmenting technological progress (Z_{gr}).

consumption. Fertility changes have comparatively modest effects over the period 2020-70, consistent with the delayed impact of cohort size on the working-age population emphasized in the demographic dividend literature.

Ultra-low fertility and *ultra-low mortality* scenarios highlight the interaction between the first and second demographic dividends. *Ultra-low fertility* improves per capita consumption growth despite worsening support ratios, as smaller cohorts raise capital intensity and productivity. *Ultra-low mortality*, by contrast, tends to deteriorate the translation component through population ageing, but this effect is partially offset by productivity gains associated with longer working lives and stronger incentives for human capital accumulation.

Overall, the results confirm a central insight of the demographic dividend literature: while population ageing weakens the first demographic dividend by reducing support ratios, its adverse effects on living standards are not mechanical. Behavioral responses, capital deepening, and productivity gains play a crucial role in sustaining per capita consumption growth, underscoring the importance of labor market institutions, education, and pension system design in ageing societies.

7 Resilience of current pension systems to demographic changes

To assess the impact of population ageing on pension costs, we include in our model all individuals regardless of the number of years they have contributed to the system (i.e., irrespective of their eligibility for contributory pensions). This assumption increases measured pension costs, but not total social support expenditures, since individuals without sufficient contribution histories typically receive non-contributory benefits.

7.1 Pension costs

Figure 9 summarizes the joint dynamics of the two key determinants of the pension contribution rate—retirees per worker and the pension–income ratio—over the period 2020–2100. Across all four countries, the baseline scenario points to a pronounced increase in retirees per worker, reflecting population ageing driven by declining fertility and rising longevity. These forces shape the evolution of both the total number of retirees (see Figure 8) and total employment (see Figure 7). The increase is particularly strong in Poland, where the retirees-per-worker ratio rises sharply from around 50 percent to approximately 100 percent after 2060, while Austria and Germany exhibit a more gradual but persistent upward trend. Austria displays a higher retirees-per-worker ratio than Germany, reflecting its lower average retirement age (see Figure 12 in the Appendix B). Italy shows a comparatively flatter profile, reflecting earlier ageing dynamics in which both employment and retirement evolve more smoothly over time.

The evolution of the pension–income ratio partially offsets these demographic pressures in Italy and Poland. In these two countries, pensions are negatively adjusted to increases in life expectancy at retirement under notional defined contribution (NDC) pension systems, leading to a declining pension–income ratio that mitigates the impact of rising dependency ratios. In contrast, in Austria and Germany—both operating defined benefit (DB) pension systems—the pension–income ratio increases over time, amplifying the effect of ageing on the contribution-rate. This effect is stronger in Austria, where the statutory retirement age remains unchanged at 65 for both men and women for future cohorts (see Table 5 in the Appendix A).

Combining these two components, the contribution rate increases in all countries under the baseline scenario. Austria and Germany face steady increases driven mainly by demographic pressures, while contribution rates in Italy and Poland remain relatively stable due to offsetting movements in the pension–income ratio. Overall, the figure illustrates that pension system costs are jointly determined by demographic structure and economic adjustments, reinforcing the importance of institutional adaptation in coping with ongoing demographic change.

The alternative demographic scenarios shown in Figure 9 underscore the sensitivity of pension financing outcomes to migration, fertility, and mortality assumptions. *Higher migration* (respectively, *lower migration*) systematically reduces (respectively, increases) the number of retirees per worker in all four countries. At the same time, *higher migration* (respectively, *lower migration*) rejuvenates (respectively, accelerates the ageing of) the labor force (see Table 1), thereby reducing (respectively, increasing) average labor income. As a result, changes in the pension–income ratio largely offset changes in retirees per worker, leaving the contribution rate almost unchanged.

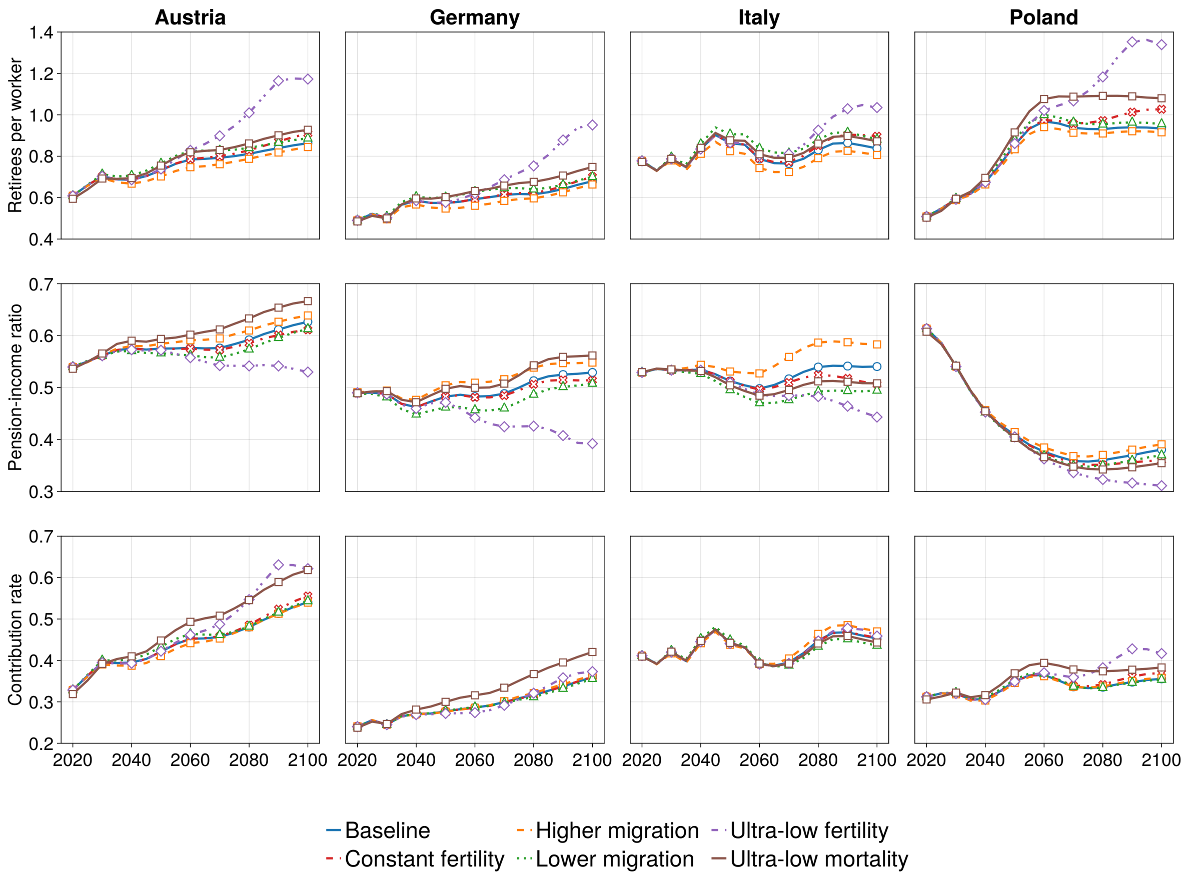

Figure 9: Retirees per worker, average pension-to-average income ratio, and contribution rate from 2020 to 2100 in Austria, Germany, Italy, and Poland. *Source*: Authors' simulations. *Notes*: The pension-income ratio and the contribution rate are calculated using the total labor cost of a worker rather than the gross labor income.

Fertility and mortality scenarios mainly affect pension system costs through longer-term channels. *Ultra-low fertility* leads to a marked increase in the contribution rate toward the end of the projection horizon, driven by a sharp rise in retirees per worker that is only partially offset in the initial decades by productivity gains, as reflected in lower pension–income ratios. In contrast, *ultra-low mortality* substantially increases the number of retirees by expanding the retired population and extending benefit durations, particularly in Poland. In countries operating notional defined contribution (NDC) systems, these effects are partly mitigated by behavioral responses—such as increased investment in human capital—and declining pension replacement rates. However, longevity improvements pose a fundamental challenge for defined benefit systems, where replacement rates remain unchanged and pension–income ratios therefore increase. As a result, *ultra-low mortality* leads to a rapid rise in contribution rates in Austria and Germany.

Overall, these alternative scenarios indicate that notional defined contribution (NDC) systems, as implemented in Italy and Poland, are more resilient to demographic change than defined benefit (DB) systems in Austria and Germany. In the latter, future pension system costs are highly dependent on demographic developments and institutional design, reinforcing the need for policies that jointly address labor supply, retirement behavior, and benefit adjustment mechanisms.

7.2 Intergenerational distribution

Using the information displayed in Figure 9, we can further analyze how the pension system redistributes across generations by comparing the average pension benefit relative to the average labor income (net of pension contributions). Focusing on net rather than gross labor income provides a more informative measure of intergenerational distribution, as it explicitly accounts for the contribution burden borne by the working-age population and therefore better reflects the effective income position of retirees relative to the working-age population.

Figure 10 shows the projected evolution of the average pension benefit relative to average labor income net of social contributions in Austria, Germany, Italy, and Poland over the period 2020–2100 under the baseline and alternative demographic scenarios. The horizontal reference line at unity indicates whether the average pension benefit received by retirees exceeds the average net labor income of workers.

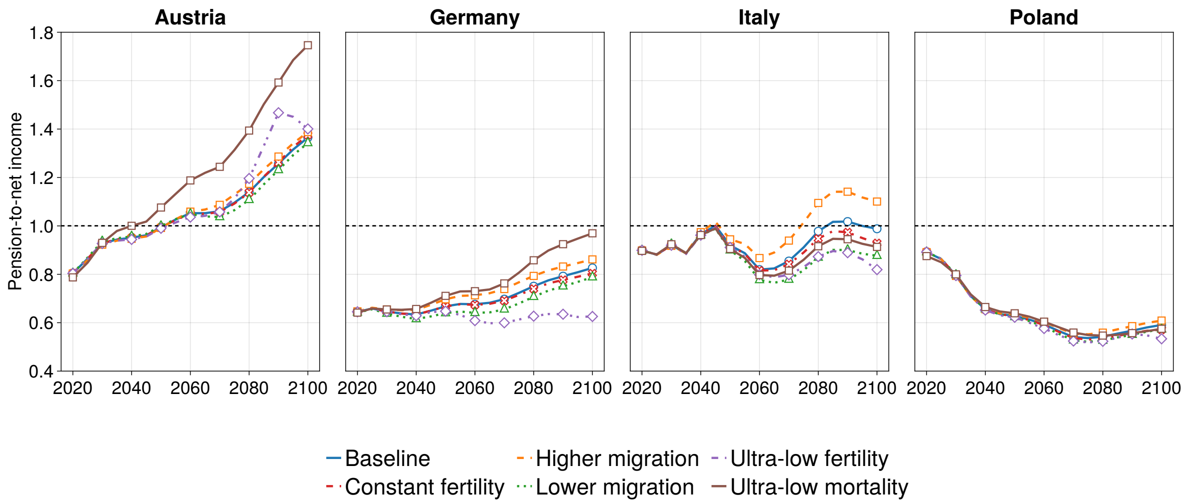

Figure 10: Pension-to-net(of social contributions)-income ratio in Austria, Germany, Italy, and Poland from 2020 to 2100 under the baseline and five alternative demographic scenarios. *Source*: Authors' simulations. *Notes*: All simulations for Germany are done without the implementation of the sustainability factor.

Under the *baseline* scenario, the simulations indicate a pronounced increase in the pension-to-net-income ratio in Austria, which rises well above unity to around 1.4 by the end of the projection horizon. In the absence of pension reforms, this implies that from around 2050 onward average pension benefits exceed the net labor income of workers, who simultaneously finance dependent children. This pattern reflects the combined effect of population ageing and rising social pension contribution rates. Germany exhibits a more moderate but still upward trajectory, with the ratio remaining below unity while increasing from a value slightly above 60 percent in 2020 to eighty percent by 2100. It should be noted that the projections for Germany abstract from the implementation of the sustainability factor. By contrast, Italy and Poland display declining or broadly stable pension-to-net-income ratios under the baseline scenario, consistent with the automatic adjustment mechanisms embedded in their notional defined contribution systems, which link pension benefits to life expectancy at retirement. In Italy, the ratio remains broadly stable due to the continuous increase in the statutory retirement age, whereas the decline observed in Poland reflects fixed statutory retirement ages.

The alternative demographic scenarios reinforce these cross-country differences in pension system responses. *Higher migration* has only limited effects on the pension-to-net-income ratio, as changes in labor income and pension benefits largely offset each other. Fertility assumptions mainly affect the ratio in the long run. *Ultra-low fertility* leads to higher pension-to-net-income ratios in Austria, but not in Germany due to delayed retirement age adjustments, while effects remain muted in countries operating notional defined contribution systems. Moreover, under *ultra-low fertility*, the average age of workers increases, leading to higher average labor income. As a result, although the average worker continues to earn a net income above the average pension, younger workers may still experience lower labor incomes relative to pensioners. In contrast, the *ultra-low mortality* scenario has a strong impact in Austria and Germany, sharply increasing the pension-to-net-income ratio as longer benefit durations are not fully offset by benefit adjustments. In Italy and Poland, the same longevity improvements result in much smaller changes, as declining replacement rates dampen the effect of increased life expectancy.

7.3 Intragenerational distribution

To study the redistributive properties of pension systems under different demographic scenarios, we use the internal rate of return (IRR) on pension contributions. The IRR is defined as the annual rate at which the present value of all pension contributions paid during working life equals the present value of all pension benefits received during retirement. A higher (respectively, lower) IRR implies that, relative to contributions, an individual receives more (respectively, less) generous pension benefits.

Figure 11 illustrates how alternative demographic scenarios affect the internal rate of return from contributing to the public pension system across birth cohorts born between 1960 and 2020, disaggregated by gender and socioeconomic status (lowest and highest SES) in Austria, Germany, Italy, and Poland. To capture intragenerational distributional effects, we further disaggregated the results by gender and SES, as these groups differ systematically in employment histories, earnings profiles, health status, and longevity, all of which directly shape lifetime contributions, benefit receipt, and hence their IRR from contributing to the pension system. The two socioeconomic groups were selected to capture the extremes of the socioeconomic distribution within each gender. The lowest-SES group comprises agents in the lowest income quintile with less than tertiary education, while the highest-SES group consists of individuals in the highest income quintile, who have attained tertiary education. The vertical axis reports the absolute difference in the IRR of each demographic scenario relative to the baseline scenario, thereby isolating the impact of demographic changes on individual pension returns.

Across all four countries, demographic changes generate sizeable differences in IRRs across birth cohorts, genders, and socioeconomic groups. In particular, our simulation results indicate that higher (respectively, lower) migration generally has a positive (respectively, negative) effect on IRRs for all groups and cohorts considered, as higher (respectively, lower) immigration initially reduces (respectively, increases) the number of retirees per worker and, consequently, pension costs.

Fertility and mortality scenarios, by contrast, have more pronounced and uneven effects across individuals. *Ultra-low fertility* tends to reduce the IRR for younger cohorts, particularly among higher-SES individuals, who face a higher retirees-per-worker ratio and do not qualify for the minimum pension benefit. This pattern is less pronounced among women in the lowest SES group, as they are more likely to qualify for minimum

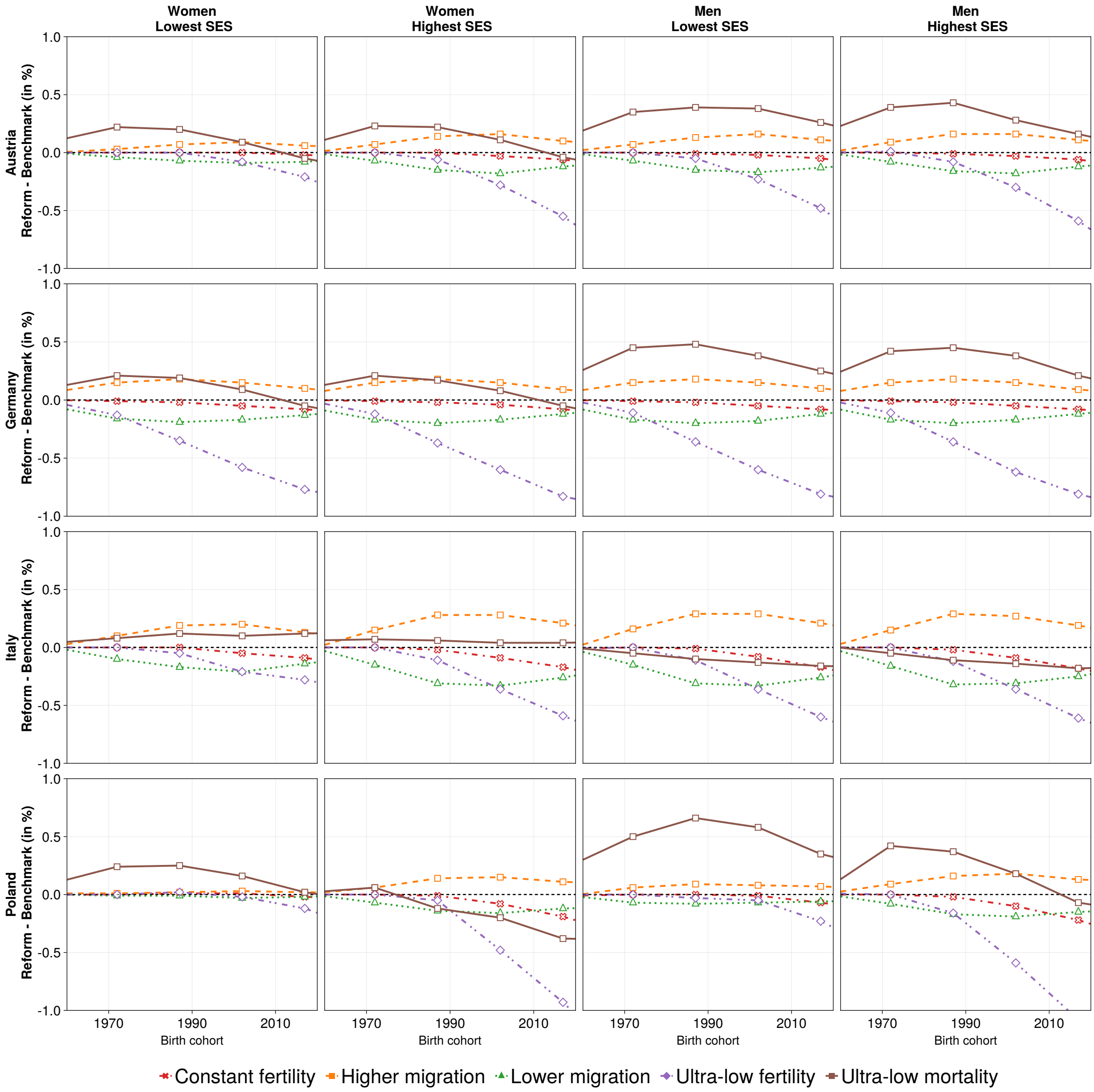

Figure 11: Difference in the internal rate of return (IRR) between alternative demographic scenarios and the baseline by country, birth cohort, gender and socioeconomic group (lowest and highest). *Source*: Authors' simulations.

pension benefits.

Ultra-low mortality has the opposite effect of *ultra-low fertility*, increasing IRRs, especially for men in Austria, Germany, and Poland. Longer life expectancy raises the duration of benefit receipt. However, in the long run it also requires higher contribution rates, leading to lower IRRs. Gender differences arise because women already benefit from higher baseline longevity, so additional mortality improvements translate into smaller marginal IRR gains relative to men. In Italy, where the modeling strategy does not generate further increases in male life expectancy (see Figure 2), *ultra-low mortality* reduces the IRR for this group, as they only face higher contribution rates. In Poland, which operates a notional defined contribution system with a declining pension replacement rate (see the middle panel on the right-hand side in Figure 9), low-SES individuals benefit more than high-SES individuals, as their pension benefits are less strongly adjusted downward due to eligibility for minimum pensions.

Overall, the figure highlights that demographic change has important intragenerational distributional consequences within pension systems. Fertility and mortality developments interact with pension system design, gender-specific labor market trajectories—particularly through the presence of minimum pensions—and socioeconomic status.

8 Conclusion

Current trends in population aging are projected to put pressure on our welfare state system that was designed for a demographic situation that was very different to today's population structure. In this paper, we apply a general equilibrium model of overlapping generations to project future costs of the pension system, taking into account that pension systems may intensify existing inequalities within the population. We therefore assume heterogeneous households who decide on their education, consumption, savings and retirement along their life cycle. Households are heterogeneous with respect to innate characteristics like learning ability and schooling effort, which implies heterogeneous life cycle decisions. Moreover, households experience idiosyncratic shocks of fertility, unemployment, health and mortality depending on their socioeconomic status (SES). We calibrate our model for four European countries: Austria, Germany, Italy and Poland.

We have chosen those four countries—which differ in their pension system and the pension replacement level—in order to investigate the resilience of pension systems with respect to the structure and parametric characteristics of these systems. In addition, we assume various demographic scenarios that differ in terms of future fertility, mortality and migration. Through these different demographic scenarios across four countries, we capture the marginal impact of demographic risk faced by each pension system.

Pension systems and their resulting costs are closely connected to the country's economic situation and particularly to its evolution of the productivity of the labor force, which in turn is determined by the evolution of the educational attainment. To account for this important effect, our model assumes the continued increase in educational attainment in all four countries (Austria, Germany, Italy and Poland), which is more pronounced among women compared to men, following the projections from Wittgenstein Centre for Demography and Global Human Capital (2018). Thus, our results show that the educational expansion of the last decades, especially of women, has significantly reduced the pension costs.

The number of employed individuals is projected to decrease up to 2100 in the baseline demographic scenario for all countries and genders, with Poland experiencing the strongest decline. Our results clearly show the risk associated with different demographic scenarios in different pension systems. While higher migration attenuates the decline of the labor force in Austria, Germany and Italy, the assumed evolution of the net migration in Poland cannot stop the decline of its labor force.

The importance to consider not only heterogeneity but also behavioral changes becomes visible when simulating ultra-low fertility and ultra-low mortality. While the former leads to a decline in the labor force for all countries in the long run, the labor force initially increases because less children imply higher labor force participation rates for females. In terms of ultra-low mortality, we observe for Austria, Germany and Italy a slight increase in employment compared to the baseline demographic scenario, as lower mortality induces higher educational investment and later retirement ages. These results clearly indicate that the resilience of the labor force to various demographic scenarios will depend on the behavioral reactions these scenarios induce.

At the economic level, the different demographic scenarios reduce economic growth but keep per capita economic performance rather unchanged. Behavioral and compositional adjustments in labor supply, education, and capital accumulation are again dampening the demographic effects. However, the different demographic scenarios have a rather pronounced effect on pension costs and pension equity. Overall, our results support the argument that NDC systems are much better prepared to demographic risk (as represented by the different demographic scenarios) compared to DB systems. However, there is one caveat, NDC systems need to also adjust the retirement age to increasing survival, since these systems would otherwise foster poverty in old age when survival increases.

Another important result of our model is to show that the increase in the ratio of pension to net income is much more pronounced in DB systems for the risk of ultra-low mortality compared to ultra-low fertility. While ultra-low mortality has an immediate effect on the number of retirees in the short run, ultra-low fertility affects the labor force with a delay of two to three decades, initially increasing labor supply through higher female employment rates. Moreover, in the long run, the number of retirees will also decrease.

We could also show that the intra-generational distribution caused by pension systems (as measured by the internal rate of return, IRR, of the pension system by SES and gender) is sensitive to the demographic scenarios. Higher migration has a positive effect on the IRR relative to *lower migration*, as the associated expansion of the labor supply temporarily reduces contribution rates. In addition, while ultra-low mortality increases the IRR, ultra-low fertility leads to a decrease of the IRR. These effects differ across gender and SES. Higher-SES groups and men are generally more exposed to adverse demographic shocks, as their pension benefits are closely tied to their lifetime contributions. Instead, minimum pensions provide partial insurance for women and low-SES groups, reducing their exposure to demographic risks.

Finally, although our results clearly show in the long-run how different demographic scenarios will affect inter- and intra-generational redistribution. In the short run, however, our results also indicate that these costs are rather independent from the demographic scenarios we assume. In particular, the increase in pension costs—measured by the pension contribution rate—is most pronounced in Austria, where contributions rise approximately six percentage point from 2020 to 2035, while for Germany the increase is about three percentage point for the same period. In contrast, contribution rates in Italy and Poland are quite stable between 2020 and 2035, as long as productivity growth remains constant and positive. These findings suggest that pressures on pension system resilience are not only a long-term concern driven by future demographic risks, but that current demographic conditions already pose a challenge to the fiscal sustainability of defined benefit pension systems.

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A Pension system

Pension benefits can be described using the following dynamic equation:

$$\text{Pen. benefits}_{j+1} = \begin{cases} \widehat{R}_j^w \cdot \text{Pen. benefits}_j \cdot \phi_{j+1} + \text{Labor income}_j \cdot \varphi_{j+1} & \text{for } j < J, \\ \widehat{R}_j^r \cdot \text{Pen. benefits}_j & \text{for } j \geq \max(\underline{J}, J), \end{cases} \tag{4}$$

where $\widehat{R}_j^i$ for $i \in \{w, r\}$ is the capitalization factor of the pension system at age j during the working period ($i = w$) or during retirement period ($i = r$). The capitalization factor at age j used in each of the four countries is the growth rate of the total wage bill of the economy when the individual is of age j.[5] The term ϕ_{j+1} captures the changes in the pension replacement rate formula at age j from working one additional year. This term accounts for the penalties and rewards from retiring between the minimum retirement age ($\underline{J}$) and the normal retirement age (J^N) or later than the normal retirement age. In Italy and Poland, which run a defined-contribution system, the adjustment is based on the life expectancy at the retirement age. In Austria and Germany, every additional year before the normal retirement age is penalized with a reduction in the pension replacement rate of 5.1 percent in Austria and of 3.6 percent in Germany. In contrast, retiring after the normal retirement age is rewarded with an increase in the replacement rate of 4.2 percent in Austria and of 6 percent in Germany. The term φ_{j+1} is the age-specific accrual rate for the social contributions paid at age j. In the case of defined-benefit pension systems, the accrual rate can be approximated by the pension replacement rate divided by the

[5] Note that by assuming a constant labor share, the growth rate of the total wage bill is the same as the growth rate of the gross domestic product (GDP).

expected number of years of contributions when retiring at the normal (or statutory) retirement age. In the case of defined contribution pension systems, the accrual rate is the pension contribution rate divided by the remaining life expectancy at retirement.

We have imputed the total cost of the pension system to workers. Therefore, our pension contribution rate includes the pension contribution rate paid by the employer ($\tau_{S,t}^{\text{employer}}$), the employee ($\tau_{S,t}^{\text{employee}}$), and the government. The proportion of the total cost borne by each institutional agent can be see in European Commission, Directorate-General for Economic and Financial Affairs (2024). The following conversions are necessary for comparison to actual numbers:[6]

$$\tau_{S,t} = \frac{\tau_{S,t}^{\text{employer}} + \tau_{S,t}^{\text{employee}}}{1 + \tau_{S,t}^{\text{employer}}} \frac{1}{1 - \%\text{ Financed by government}}, \tag{5}$$

where the first fraction represents the pension contribution rate assuming it is fully financed by the employee, while the second fraction reflects the additional contribution rate required to cover the portion financed by the government. In addition, for the defined-benefit systems—Austria and Germany—the pension replacement rates are also divided by $1+\tau_{S.t}^{\text{employer}}$ to account for the fact that pension replacement rates are expressed as a fraction of labor income (after deducting the social contributions paid by the employer), rather than as a share of the total labor cost. These conversions allow us to compare pension systems across countries.

In addition, each country imposes different pension corridors that differ by their early ($\underline{J}$), normal (J_N), and late ($\overline{J}$) retirement ages. In general, early retirement ages are three years earlier than the normal retirement age. Table 5 summarizes the normal retirement ages for each country, cohort and gender as implemented in the model.

[6] Let the total labor cost of an average worker in year t be $y_t = (1 + \tau_{S,t}^{\text{employers}})w_t$, where $\tau_{S,t}^{\text{employers}}$ is the pension contribution rate paid by the employer in year t and w_t is the average labor income of workers in year t. A balanced pension budget in which total pension benefits are financed by the government, the employer, and employees is given by:

$$(1 - \phi_t)b_t P_t = (\tau_{S,t}^{\text{employers}} + \tau_{S,t}^{\text{employees}})w_t W_t,$$

where ϕ_t is the fraction of the total pension paid by the government in year t, b_t is the average pension benefit in year t, P_t is the total number of pensioners, $\tau_{S,t}^{\text{employees}}$ is the pension contribution rate paid by the workers in year t, and W_t is the total number of workers in year t. Substituting for the average wage rate (w_t) the the total labor cost (y_t) divided by $(1 + \tau_{S,t}^{\text{employers}})$ and dividing both sides of the equation by $1 - \phi_t$ gives

$$b_t P_t = \tau_{S,t} y_t W_t,$$

where $\tau_{S,t} = \frac{\tau_{S,t}^{\text{employers}} + \tau_{S,t}^{\text{employees}}}{1+\tau_{S,t}^{\text{employers}}} \frac{1}{1-\phi_t}$ is the pension contribution rate applied over the total labor cost.

Country	Birth Cohort	Normal Retirement Age (J^N)	
		Women	Men
Austria	cohort < 1965	60	65
	1965 ≤ cohort < 1967	61	65
	1967 ≤ cohort < 1969	62	65
	1969 ≤ cohort < 1971	63	65
	1971 ≤ cohort < 1973	64	65
	cohort ≥ 1973	65	65
Germany	cohort < 1959	65	65
	1959 ≤ cohort < 1961	66	66
	1961 ≤ cohort < 1964	67	67
	1964 ≤ cohort < 1966	68	68
	1966 ≤ cohort < 1968	69	69
	cohort ≥ 1968	70	70
Italy	cohort < 1958	60	65
	1958 ≤ cohort < 1959	61	65
	1959 ≤ cohort < 1960	62	65
	1960 ≤ cohort < 1961	63	66
	1961 ≤ cohort < 1962	64	66
	1962 ≤ cohort < 1963	65	66
	1963 ≤ cohort < 1964	66	67
	1964 ≤ cohort < 1965	67	67
	1965 ≤ cohort < 1981	68	68
	1981 ≤ cohort < 1990	69	69
	cohort ≥ 1990	70	70
Poland	all cohorts	60	65

Table 5: Normal retirement age implemented in the model by cohort, gender, and country

B Retirement ages

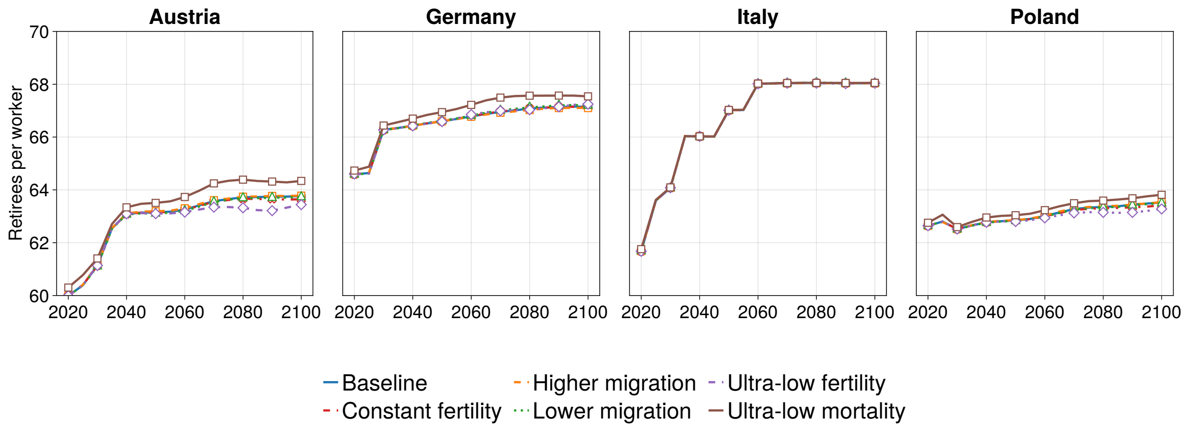

Figure 12: Evolution of the retirement age in Austria, Germany, Italy, and Poland between 2020 and 2100. *Source*: Authors' simulations.

C Migration scenarios

Table 6: Net-migration assumptions under baseline and migration scenarios (persons)

Country	Scenario	Year 2022	2025	2035	2045	2055	2065	2075	2085	2095
Austria	Baseline	103 673	23 515	39 489	37 196	36 949	34 904	34 364	33 721	32 591
	Higher migration	103 673	38 868	50 625	47 280	45 831	43 287	41 752	40 297	38 629
	Lower migration	103 673	8 148	28 482	27 354	28 044	26 647	26 959	27 115	26 517
Germany	Baseline	1 631 271	354 990	280 121	266 385	272 088	247 506	232 148	231 942	215 986
	Higher migration	1 631 271	509 925	397 452	373 776	366 287	335 209	313 692	301 826	279 635
	Lower migration	1 631 271	200 048	165 122	162 855	177 626	159 787	153 394	161 498	151 765
Italy	Baseline	348 481	230 833	278 064	250 262	236 389	238 510	237 440	217 324	212 022
	Higher migration	348 481	312 716	360 036	330 936	316 542	318 144	315 110	292 146	283 845
	Lower migration	348 481	149 030	196 114	169 601	156 615	158 873	159 781	142 790	140 213
Poland	Baseline	1 000 859	-70 950	24 856	56 058	60 736	60 369	82 198	90 660	95 050
	Higher migration	1 000 859	-44 945	53 251	83 578	87 828	87 035	107 932	115 662	120 825
	Lower migration	1 000 859	-96 958	-3 525	28 567	33 661	33 728	56 498	65 684	70 206

Notes: Values are annual net migration for the total population. Source: Eurostat (ESTAT), *Assumptions for net migration by age, sex and type of projection* (dataset `proj_23nanmig`); extracted 14 January 2026; dataset last updated 24 May 2023.