Reforming EU Pension Systems: Equity and Sustainability in Conflict

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Abstract

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1 Introduction

The economic life cycle is characterized by periods of dependency in young and old ages when consumption exceeds income earned. While the state and to a great extent also parents finance consumption demands of young people (including education, health and living expenses), consumption in old age is shaped by specific retirement schemes.

In pay-as-you-go (PAYG) pension systems, the currently active population in the labor force finances the benefits of current retirees. As a result, these systems are exposed to demographic risk arising from an increasing share of older individuals relative to the working-age population. Pension systems can be further classified into defined benefit (DB) and defined contribution (DC) schemes. In DB systems, demographic and economic risks are largely borne by the pension system, whereas in DC systems these risks are mainly borne by individuals. Beyond these broad institutional distinctions, pension systems differ along several parametric dimensions across specific implementations of retirement schemes. These include, among others, the statutory retirement age, incentives to continue working, the pension accrual period, and minimum pension benefits.

Common to all pension systems is the fact that they are coming under increasing financial pressure caused by demographic change (an increase in the proportion of retired to active people, i.e. population ageing, in case of a PAYG system). According to European Comission, DG ECFIN (2024), gross public pension expenditures in countries such as Austria, Germany, Italy, and Poland are projected to change between 2022 and 2045 by 0.5–0.9 percentage points relative of GDP, or equivalently by 0.75–1.36 percentage points of total labor income. The financial pressure on pension systems is reinforced by multiple crises including the financial crisis, health shocks (Covid), political instability (wars) that have depressed economic growth and spurred public debt.

Faced with these challenges, the topic of how to reform old age security is high on the agenda in most European countries. It has been studied already for several decades, as population and individual ageing have long been projected and the resilience of pension systems to economic and political change has also been extensively researched.

In recent years, several studies (Jones and Li, 2023; Börsch-Supan et al., 2023; Díaz-Saavedra, 2023; Sánchez-Romero et al., 2024) have also shown that pension reforms may reinforce existing inequalities or even cause new inequalities across and within generations. Not only are groups of different socioeconomic status (SES) affected differently by pension reforms but pension reforms may induce different behavioral reactions across the life course depending on the SES one belongs to.

Our paper contributes to this literature in several dimensions. First, we study current pension systems and possible reforms in four European countries (Austria, Germany, Italy and Poland) that differ in their pension set up (with Austria and Germany running a PAYG-DB system and Italy and Poland a NDC system) as well as the pension replacement rate (with higher pension replacement rates in Austria and Italy compared to those in Germany and Poland). We offer a common framework how to model these different pension systems and reforms. Studying four different pension systems allows us to not only compare how vulnerable various pension systems are to projected demographic change, but also how various pension reforms may yield different results depending on the pension system in place. Second, we take into account that aging is heterogeneous across individuals and show that pensions systems that treat all individuals equally can generate unintended re-distributions and may, as a result, augment existing and cause new inequalities. We build up a CGE model that allows for heterogeneous life histories with respect to economic and demographic life course events including education, labor force participation, fertility, health and mortality. We assume realistic non stable population dynamics allowing for two genders and varying household size over the life cycle of individuals. To account for idiosyncratic shocks at the individual level, we assume health and employment shocks depend on individual characteristics. Together with innate heterogeneity in the schooling effort and learning ability, these shocks generate heterogeneous life-course trajectories. We assume an open economy with an aggregate production function in capital and effective labor and a government that balances all pension benefits and other social benefits each time period by collecting pension and other social contributions through taxes on labor income. Third, we use microsimulations together with Bayesian melding to calibrate our model to the four countries (i.e., Austria, Germany, Italy, and Poland). Fourth, we evaluate current pension systems and four pension reforms (minimum pension benefits (MinPB), progressive pension benefits (PPB), delayed retirement (DR), sustainability factor (SF)) in each of the four countries across several dimensions. We consider macroeconomic indicators (such as annual growth rates of national income, labor income, capital income, private and public consumption, all measured per capita) as well as fiscal and social benefit outcomes (retirement age, contribution rate, pension-to-income ratio, retirees per worker) together with distributional outcomes (measured by the internal rate of return and the gender pension gap, both differentiated by SES). We close by a welfare comparison across gender and SES group measured by the consumption equivalent variation.

At the macroeconomic level, we find that the average annual growth rate of national income per capita over the period 2020-2070 is higher in countries with a NDC system as compared to a PAYG-DB system caused by the higher capital income in NDC systems. National savings per capita are projected to be negative for Austria and stay rather constant for the other countries. Introducing MinPB reduces the growth rate of national income for all countries and at most for those countries with a low replacement rate (Germany and Poland) or countries with a high unemployment rate (Italy). Making benefits more progressive (PPB) increases the growth rate of national income per capita in countries with a high replacement rate (Austria and Italy) since higher-income households will increase their savings. The largest positive effects on economic growth are generated by delaying the retirement age (DR). Introducing a SF also increases economic growth.

In terms of fiscal and social benefit outcomes, we find that only in case of a DR pension reform, the retirement age increases and the number of retirees per worker decreases. The pension-to-income ratio is rather stable for Austria and Germany and decreases for countries with a NDC system due to increasing life expectancy. While the drop is rather modest in Italy, it is very pronounced in Poland, indicating that an increasing share of retirees in Poland may face higher risk of poverty in the future. Contribution rates are projected to increase in Austria and modestly in Germany and also in the short run for Italy and Poland. Introducing a MinPB reform increases the pension to income ratio and contribution rate in countries with low replacement rates (Germany and Poland) and high unemployment (Italy). More progressive pension structures (PPB), however, lower the-pension-to-income ratio and contribution rates, as high income earners experience reductions in pension benefits. Introducing a delay in retirement (DR) increases the pension-to-income ratio only in NDC systems, while it reduces contribution rates in PAYG-DB and NDC systems. Introducing a sustainability factor (SF) reduces the pension-to-income ratio and increases the contribution rate.

We measure distributional outcomes of the pension reforms by the internal rate of return (IRR) and the gender pension gap (GPG), which refers to the difference in the average pension between men and women as a percentage of men's average pension. For both indices we compare for each country the baseline pension with the four reforms on the index across the lowest and highest income quantile (i.e. by lowest and higest SES) and across gender.

Increasing the MinPB raises the IRR of the lowest SES group, especially for females, while the IRR decreases for the highest SES group for both genders. The change in the IRR also depends on the replacement rate of the pension system and is almost negligible in Austria and Italy for men (due to high replacement rates) and positive for men in the lowest SES group in Germany and Poland also for men (due to low replacement rates). Introducing PPB we find an increase in the IRR for low and a decrease for high SES groups. Within each group the gains are more pronounced for women compared to men and the opposite holds for losses, which are more pronounced for men compared to women. Delaying the retirement age (DR) decreases the IRR in Austria across all groups. In an NDC system, as in Poland, the IRR increases for men and women in the highest SES group, while it negatively affects women in the lowest SES group, thereby increasing inequality. Introducing a sustainability factor (SF), the IRR in Austria and Germany decreases with the exception of women in Austria in the lowest SES group.

Gender Pension Gaps (GPG) are quite high in Italy and Poland with 60% in 2020 compared to 40% in Austria and Germany.[1] The GPG is higher among higher SES groups in Austria and Poland. Overall, the GPG narrows over time in countries running a NDC pension system (Italy and Poland), since a higher share of individuals qualify for minimum pension benefits due to the decline in the pension replacement rate. Overall, pension reforms that reduce inequality (by increasing the IRR for lower SES groups) also decrease the GPG. For reforms targeting financial sustainability, the effect on GPG depends on the features of the pension system and the level of minium pension benefits. Pension reforms that increase the MinPB decrease the GPG particularly for women with low SES. Similarly PPB reforms narrow the GPG. However, the reductions are bigger for higher SES groups compared to lower SES groups. A delay in retirement (DR) has almost no effect for both SES groups. Introducing a sustainability factor has no effect in Germany but decreases the GPG in Austria since a higher share of females becomes eligible for minimum pension benefits in Austria.

We measure welfare effects across SES groups by the consumption equivalent variation. Increasing minimum pension benefits (MinPB) raises pension benefits for both genders in the lowest SES group except for Italian men who do not quantify for MinPB. Individuals in the highest SES group experience welfare losses. Also for the PPB reform we obtain welfare gains for low SES groups and welfare losses for high SES groups. Delaying the retirement age (DR) has different welfare implications depending on the pension system in place. In a PAYG-DB system the DR pension reform implies welfare losses while it increases welfare in NDC systems. In contrast, the introduction of a sustainability factor (SF) leaves almost all individuals worse of in terms of welfare except Austrian females in the lowest SES group who benefit from lower contributions but still qualify for minimum pension benefits.

Our results clearly indicate that sustainability and equity of pension systems and pension reforms may not move in parallel. Among the four pension reforms we consider, the ones that foster economic growth and sustainability (delayed retirement and introduction

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[1] For this calculation, we consider all women and men regardless of the number of years contributed to the pension system.

of a sustainability factor) are often those that exaggerate inequality among SES groups. Even within pension systems (PAYG-DB and alternatively NDC) differences in pension parameters like the replacement rate or minium pension benefits may induce different results for the same pension reform within a pension system and across different SES groups. As argued in Börsch-Supan et al. (2023) in the end it is the social planner and the voters that determine the optimal mix between different reforms. Our paper offers the input to such decisions by showing the results of pension reforms within different settings of pension systems and across different dimensions, including various macroeconomic outcomes and distributional measures. The weight on these different indicators will determine the final outcome of pension systems on equity and sustainability.

The paper is structured as follows. In the next section we position our paper into the literature emphasizing existing literature on which our work builds upon and pointing towards research gaps we aim to close with our approach. In section 3 we introduce the building blocks of our model. We show how aggregate population dynamics can be derived and particularly hint towards realistic modeling of fertility, mortality and health transitions. We continue defining the income process over the life cycle allowing for human capital to augment productivity according to the Ben-Porath mechanism. Households are assumed to decide on consumption, education and retirement but are faced with health, unemployment and mortality shocks. Assuming that households have preferences over consumption and time in retirement, we introduce the value function of the household together with the dynamics of household financial wealth and pension benefits. To allow for a common framework across alternative pension systems, we calculate pension benefits based on a pension point system that can then be parameterized to represent the PAYG-DB system in Austria and Germany as well as the NDC system in Italy and Poland. To close our model framework, we assume a standard Cobb Douglas production function in capital and labor and state the government role in balancing the pension system together with running the social insurance and government expenditures. Based on Huggett and Ventura (1999) we state the general equilibrium of our model. In section 4 we summarize which data and procedures we apply to parametrize and calibrate our model to the four countries. By relying on publicly available data we aim to provide a framework for our model set up that can be replicated for other countries as well. Innovative is our combination to combine microsimulations for parametrization with Bayesian melding to calibrate our model to various birth cohorts in the four countries. A key aspect of the paper is to study which pension reforms help to foster sustainability and equity of pension systems. We introduce four specific reforms in section 5. We start by introducing higher minimum pension benefits or alternatively progressive pension benefits, with both of these reforms targeted to enhance equality across different socioeconomic groups in old age. Two reforms that are rather targeted to increase sustainability of pensions are delayed retirement or introducing a sustainability factor. In section 6 we evaluate the pension reforms across the four countries considering different dimensions. We start by summarizing macroeconomic outcomes and fiscal and social benefit outcomes and continue with distributional and welfare outcomes.

2 Relevant Literature

We synthesize the literature along key modeling and institutional dimensions that are central to evaluating both the distributional and sustainability effects of pension reforms.

To maintain a coherent analytical framework and ensure comparability across studies, our review focuses on contributions that employ overlapping generations (OLG) models with heterogeneous agents and realistic demography, which are particularly well suited to analyzing life-cycle behavior, intergenerational redistribution, and long-run fiscal dynamics.

Institutional and individual factors shape both the long-run sustainability of pension systems and their redistributive properties. At the institutional level, pension system design—such as defined-benefit versus defined-contribution schemes, replacement rate progressivity, minimum pension provisions, and retirement age rules play a central role in determining redistribution and fiscal outcomes. Several papers investigate the trade-offs between defined-benefit and defined-contribution pension systems in terms of sustainability and inequality (Tyrowicz et al., 2018; Sánchez-Romero et al., 2020; Díaz-Saavedra et al., 2023; Börsch-Supan et al., 2023, among others). Overall, this literature shows that defined-benefit systems provide stronger insurance and redistribution, whereas defined-contribution systems improve labor supply incentives and fiscal sustainability but tend to increase inequality.

To reduce inequality, the degree of progressivity embedded in the pension system is a key determinant of its redistributive properties. Heterogeneous-agent OLG models illustrate how pension design influences welfare and redistribution across earnings groups and cohorts (Huggett and Ventura, 1999; Fehr and Habermann, 2008; Fehr et al., 2013). Huggett and Ventura (1999), for example, analyze the welfare effects of introducing a two-tier pension system in the United States—combining a basic redistributive tier with an earnings-related second tier—relative to an existing progressive benefit formula in which replacement rates are tilted toward lower-income workers. They find that such a reform is politically unpopular, as the pre-reform system already provides substantial insurance against unemployment risk for medium-ability workers. For the German pension system, which is almost a purely earnings-related pension scheme, Fehr and Habermann (2008) and Fehr et al. (2013) show, respectively, that introducing progressivity can enhance efficiency and be welfare improving. In this case, the additional insurance against wage and disability risk, together with liquidity relief provided by a more progressive system, outweighs the associated labor supply distortions. Overall, these results highlight that similar pension reforms can have markedly different welfare consequences depending on the initial institutional environment.

Another policy to cope with pension inequality is the minimum pension benefits, which has also been studied by Buyse et al. (2017) and Tyrowicz et al. (2018). This literature finds that higher minimum pensions mitigate old-age poverty among low-ability individuals and can partially offset the increase in consumption inequality associated with a shift toward defined-contribution systems (Tyrowicz et al., 2018). However, such policies typically reduce labor supply, output, and aggregate welfare, reflecting the trade-off between redistribution and efficiency (Buyse et al., 2017). A related strand of the OLG literature examines the distributional consequences of increasing the statutory retirement age. These studies consistently find that while higher retirement ages improve fiscal sustainability, because they raise aggregate labor supply—mostly along the extensive margin—and increase capital accumulation (Imrohoroğlu and Kitao, 2012). However, they tend to increase inequality, as low-skilled, unhealthy, and short-lived individuals are less able to adjust labor supply and benefit less from longer working lives (Fehr and Uhde, 2013; Jones and Li, 2023; Börsch-Supan et al., 2023; Sánchez-Romero et al., 2024).

The present paper complements these strands of the literature at the institutional level along two dimensions. First, while existing OLG studies typically analyze individual pension reforms in isolation—such as changes in progressivity, minimum pensions, or retirement ages—our framework, similar to Börsch-Supan et al. (2023), allows for a joint assessment of multiple reform dimensions within a unified model. This enables us to study how replacement rates, pension system type (defined-benefit versus defined-contribution), and retirement age rules interact in shaping both inequality and sustainability. Second, most of the existing literature focuses on single-country settings. In contrast, our paper conducts a systematic cross-country comparison of four EU countries—Austria, Germany, Italy, and Poland—within a common OLG framework. By holding the model structure fixed and varying only institutional parameters, we isolate the role of pension system design in driving cross-country differences in redistributive and fiscal outcomes.

At the individual level, health and mortality risks, labor market trajectories, fertility choices, and caregiving responsibilities generate substantial heterogeneity within and between cohorts, which can affect sustainability and pension redistribution. Indeed, recent research shows that ignoring heterogeneity in mortality and health can substantially bias conclusions about equity and actuarial fairness. OLG models incorporating longevity and health gradients find that pension systems that appear neutral on average may be regressive once differences in life expectancy by income and education are accounted for (e.g., Bagchi, 2019; Laun et al., 2019; Jones and Li, 2023; Sánchez-Romero et al., 2020; Díaz-Saavedra, 2023; Sánchez-Romero et al., 2024).

Family structure and gender roles are central to the distributional effects of pension systems. OLG models that explicitly incorporate households and intra-family insurance demonstrate that reforms can have significant different welfare implications once spousal earnings, derived pension rights, and survivor benefits are taken into account (Fehr et al., 2017; Nishiyama, 2019; Kindermann and Püschel, 2024). Differences in labor market attachment, part-time work, and career interruptions imply that pension systems redistribute not only across income levels but also across life courses (Kindermann and Püschel, 2024). This literature provides strong motivation for analyzing inequality in pension outcomes through a life-cycle perspective taking into consideration different family structures, since labor supply vary by gender, income, and family size.

While this literature establishes the importance of families and gender, many models rely on simplified or static household structures. In contrast, this paper allows household size to evolve over the life cycle of the household head and introduces a one-time fertility shock determining the total number of children conditional on the educational choice. This feature is particularly relevant for assessing inequality and old-age poverty risks, as childbearing decisions and caregiving responsibilities interact with labor supply and benefit entitlements in gender-specific ways.

Table 1 below provides a structured comparison of the institutional and individual factors across OLG pension reform studies. Each column summarizes the main dimensions along which the cited papers differ. In particular, the country context considered; whether demographic change is modeled through a non-stable population; the equilibrium concept (steady-state versus fully dynamic settings); the pension system and reform margins analyzed (e.g., DB versus NDC designs, progressivity, minimum benefits, and PAYG versus funded arrangements); and the extent of heterogeneity and risk incorporated (earnings and life-expectancy heterogeneity, as well as productivity, employment, and health/disability shocks). The table also records key behavioral margins—such as endogenous labor supply, retirement, and human-capital choices.

Table 1: Institutional and individual factors across OLG pension reform studies

Paper	**Country scope**	**Non-stable population**	**Equilibrium**	**Pension system / reform margin**	**Minimum income**	**Gender**	**Household structure**	**Earnings heterogeneity**	**Labor productivity shocks**	**Employment shocks**	**Health / disability shocks**	**Life expectancy heterogeneity**	**Endog. labor supply**	**Endog. human capital**
Bagchi (2019)	US	No	Steady-state	Alternative levels of progressivity	No	No	Single-agent	Yes	Yes	No	No	Yes	Hours worked	No
Börsch-Supan et al. (2023)	EU3 (mixed btw. France, Germany, and Italy)	Yes	Dynamic	Parametric PAYG pension reforms (DB baseline)	No	Yes	Single-agent	Yes	No	No	No	Yes	Hours worked and retirement	No
Buyse et al. (2017)	Belgium	Yes	Dynamic	Minimum pension + benefit–earnings link; PAYG vs funded	Yes	No	Single-agent	Yes	No	No	No	No	Hours worked and retirement	Yes
Díaz-Saavedra (2023)	Spain	No	–	Parametric pension reforms under heterogeneous longevity	Yes	No	Single-agents	Yes	Yes	Yes	No	Yes	Hours worked and retirement	No
Díaz-Saavedra et al. (2023)	Spain	Yes	Dynamic	Worker's backpack vs PAYG pensions	No	No	Single-agents	Yes	Yes	Yes	No	No	Hours worked, labor search, and retirement	No
Jones and Li (2023)	US	No	Steady-state	Changes in payroll taxes, tax rates, benefit formula, and pension corridor	Yes	No	Single-agent	Yes	Yes	Yes	Yes	Yes	Hours worked and retirement	No
Fehr and Habermann (2008)	Germany	Yes	Dynamic	Progressive pension arrangements (risk sharing)	No	No	Single-agent	Yes	Yes	No	No	No	Hours worked	No
Fehr and Uhde (2013)	Germany	No	Steady-state	Optimal design: flat pension + means-testing	Yes	No	Single-agent	Yes	Yes	No	No	No	Hours worked	No
Fehr et al. (2017)	Germany	No	Steady-state	Family insurance + privatization/abolition of PAYG	No	Yes	Singles + couples; children	Yes	Yes	No	No	No	Hours worked	Yes
Fehr et al. (2013)	Germany	No	Dynamic	Pension progressivity (flat vs earnings-related)	Yes	No	Single-agent	Yes	Yes	No	Yes	Yes	Hours worked and retirement	No
Huggett and Ventura (1999)	US	No	Steady-state	Two-tier reform; distributional effects	Yes	No	Single-agent	Yes	Yes	No	No	No	Hours worked	No
Imrohoroğlu and Kitao (2012)	US	No	Partial	Claiming incentives; NRA/benefit/tax reforms	Yes	No	Single-agent	Yes	Yes	Yes	Yes	Yes	Hours worked and retirement	Yes
Kindermann and Püschel (2024)	Germany	No	Steady-state	Women's incentives; taxes/transfers and pensions	No	Yes	Couples + children	Yes	Yes	Yes	No	No	Hours worked, labor participation (not retirement)	No
Laun et al. (2019)	Norway	No	–	Retirement reform with health / longevity risk	Yes	No	Single-agent	Yes	Yes	Yes	Yes	Yes	Hours worked and retirement	No
Nishiyama (2019)	US	No	Steady-state	Spousal/survivor benefits and joint labor supply	No	Yes	Singles + couples; children	Yes	Yes	No	No	No	Hours worked	No
Sánchez-Romero et al. (2020)	US	Yes	Dynamic	Compare DB vs DC/NDC under SES longevity	No	No	Single-agent	Yes	No	No	No	Yes	Hours worked and retirement	Yes
Sánchez-Romero et al. (2024)	Austria	Yes	Dynamic	Reform packages with hetero life expectancy	Yes	No	Singles + children	Yes	No	No	No	Yes	Hours worked and retirement	Yes
Tyrowicz et al. (2018)	Poland	Yes	Dynamic	System comparisons (DB/DC/NDC) and inequality	Yes	No	Single-agent	Yes	No	No	No	No	Hours worked	No
This paper	Austria, Germany, Italy, Poland	Yes	Dynamic	DB vs NDC; parametric reforms	Yes	Yes	Singles + children	Yes	No	Yes	Yes	Yes	Retirement	Yes

3 Model

3.1 Demographics

Population initial characteristics The model is populated by overlapping generations or birth cohorts. Time is discrete, a model period t represents one year. Our unit of analysis is households. Households consist of an adult individual (household head) and a number of dependent children. Individuals enter the model at age $j = 0$, face mortality risk, and may live up to a maximum of $J_\Omega = 98$ years. Each birth cohort is comprised of a number of heterogeneous individuals that initially differ according to their gender $g \in \mathbb{G} = \{f, m\}$, where f denotes females and m males, and by a set $\theta \in \Theta$ of permanent unobservable characteristics: a learning ability level (ξ_h) and a schooling effort level (ξ_e); i.e. $\theta = (\xi_h, \xi_e) \in \Theta$, where Θ is the set of all possible combinations of unobservable characteristics. The learning ability level reflects an individual's capacity to acquire new skills, which positively influences her/his labor income. Schooling effort represents the nonpecuniary costs of education (Oreopoulos, 2007; Sánchez-Romero and Prskawetz, 2020). The combination of the two endowments θ and the prevailing economic and demographic circumstances to be faced by each individual determine the level of education $e \in \mathbb{E} = \{1, 2\}$, where 1 corresponds to less than post-secondary education (ISCED 0-3) and 2 to post-secondary or higher education (ISCED 4-8). The choice of the educational attainment is further explained in Section 3.4.

Fertility Women give birth to children over their reproductive life according to cohort– and education–specific fertility rates. Children leave their parents home at age $J_0 = 18$ and set up their own household. As a result, the total number of household members changes over the life cycle of the household head depending on her fertility profile. Upon completion of education, every woman is assigned a fertility profile $\hat{n}(t, j, e, n)$. The fertility profile, that a woman will face in each period t and age j, is drawn at random from a set of realizations that depend on the mothers educational attainment e and the total number of children—or completed fertility—$n \in \mathbb{F} = \{0, 1, 2, 3+\}$. The quantity $\hat{n}(t, j, e, n)$ gives the average number of children living in the household in period t at age j (household head), for the combination (e, n) of education level and completed fertility. The probability of completed fertility depends on the birth cohort—i.e., $t - j$—and the educational level of the household head $\pi^c(n|t - j, e)$. In total, for each birth cohort, this gives 4×2 different fertility profiles within the population. Appendix A.2 shows how these profiles are computed for each birth cohort using age- and education-specific fertility rates from Eurostat.

Health and survival Individuals face health and mortality risks. Health risk is modeled as a two-state Markov chain. Let $h \in \mathbb{H} = \{1, 2\}$ denote the health state: where $h = 1$ is good health and $h = 2$ is bad health. Health transition probabilities $\pi^h(h'|t, j, g, e, h)$ from health state h to $h' \in \mathbb{H}$ depend on period, age, gender, and education. In order to define the bad health state, we use the Global Activity Limitation Index (GALI), which is a standard measure for daily activity limitations (Jagger et al., 2010). See the calculation of the health transition probabilities, which are consistent with Eurostat data, in Appendix A.3.

Let $\pi^S(t, j, g, e, h)$ be the probability of surviving in period t from age j to age $j + 1$ for individuals of gender g, education e, in health stage h and $S(t, j, g, e, h)$ be the unconditional probability of survival in period t up to age j for individuals of gender g, education e, in health state h. Health affects survival. Individuals with poor health face in period t at any age j a lower probability of surviving to the next age than those with good health; i.e. $\pi^S(t,j,g,e,1) > \pi^S(t,j,g,e,2)$. The dynamics of the unconditional survival probability of individuals of gender g and education e is given by

$$S(t+1,j+1,g,e,h') = \sum\nolimits_{h\in\{1,2\}} S(t,j,g,e,h)\pi^S(t,j,g,e,h)\pi^h(h'|t,j,g,e,h) \tag{1}$$

where the last term accounts for the probability to move from health state h to h'.

Unemployment Workers are also assumed to face unemployment shocks along their working lives. We assume two employment states $u \in \mathbb{U} = \{1,2\}$: Employed ($u=1$) and non-employed ($u=2$). Non-employed is comprised of individuals that are unemployed or out-of-the labor force. We use a two-state Markov chain to model labor states, where the transition probabilities $\pi^u(u'|g,e,n,u)$ from state u to state u' depend on gender g, education e, and the number of children—below age 6—in the household n. The employment state determines whether an individual receives labor income or other social transfers. Appendix A.4 shows how these profiles are computed using data from Eurostat and ILO.

Population Dynamics Given that our populations are open to migration flows—emigration and immigration—and are comprised of heterogeneous individuals that differ in period t at each age j according to their gender g, set of permanent and unobservable characteristics θ, education e, completed fertility n, health status h, and unemployment status u, in this section we explain how we build up the demography of our heterogeneous individuals to be consistent with real population data. Let $\mathbf{s}_{tj} = (t,j,g,\theta,e,n,h,u)$ denote the state of individuals in period t of age j. The distribution in period t of age j individuals across the states $\mathbf{s}_{tj} \in \mathbb{S} = \mathbb{G}\times\Theta\times\mathbb{E}\times\mathbb{F}\times\mathbb{H}\times\mathbb{U}$ is represented by the density function Γ^N_{tj}. The dynamics of the population $\mathbf{N}$ between period t and $t+1$ is given by the following population balance equation

$$\mathbf{N}_{t+1} = \sum\nolimits_{j=0}^{J_\Omega}\left(\mathbf{M}_{t+1,j} + \mathbf{N}_{tj}\int_{\mathbb{S}}\frac{S(\mathbf{s}_{tj})}{\mathbf{S}_{tj}}\left(\pi^S(\mathbf{s}_{tj}) + f(\mathbf{s}_{tj})\right)\,\mathrm{d}\Gamma^N_{tj}(\mathbf{s}_{tj})\right), \tag{2}$$

where $\mathbf{M}_{t+1,j}$ denotes the total net migrants in period $t+1$ of age j—i.e, the difference between the total number of immigrants and emigrants, $\mathbf{N}_{tj}$ is the total population in period t of age j, $S(\mathbf{s}_{tj})$ is the probability of survival in period t up to age j of the population in state $\mathbf{s}_{tj}$—with $\mathbf{S}_{tj} = \int_{\mathbb{S}} S(\mathbf{s}_{tj})\,\mathrm{d}\Gamma^N_{tj}(\mathbf{s}_{tj})$ being the average probability of survival of the population in period t up to age j, $\pi^S(\mathbf{s}_{tj})$ is the probability of surviving to the next age of the population in state $\mathbf{s}_{tj}$, and $f(\mathbf{s}_{tj})$ represents the age-specific fertility rate of the population in state $\mathbf{s}_{tj}$. The first term inside the parentheses implies that net migrants enter the population at the end of the period. The ratio following the integral accounts for heterogeneity in survival probabilities across individuals; that is, individuals face different likelihood of survival at each age. Ignoring these survival differences leads to an underestimation of the pension system's cost, as individuals with higher survival probabilities tend, on average, to receive higher pension benefits.

3.2 Earnings

Individuals are assumed to have three primary sources of income over two main periods. Before retirement, employed individuals earn income proportional to their productivity, while unemployed individuals receive a fraction of their productivity. After retirement, the main source of income is pension benefits. The labor productivity of an individual in period t, age j, and gender g is assumed to be a function of individual unobservable characteristics θ, education e, completed fertility n, and health status h; i.e. $y^{prod}(t, j, g, \theta, e, n, h)$. We assume that every additional year of education beyond age 14 increases the stock of human capital and hence labor productivity. The stock of human capital accumulates according to a simple Ben-Porath (1967) technology.[2] As a result, the proportional (log) change in productivity from the educational choice $e \in \mathbb{E} = \{1, 2\}$, which we denote by $\rho_e(\mathbf{s}_{tj})$, is

$$\rho_e(\mathbf{s}_{tj}) := \frac{\mathrm{d} \log y^{prod}(\mathbf{s}_{tj})}{\mathrm{d}e} = \frac{\xi_h \, 4}{1 + (1 - \gamma_h)\xi_h \, 4e},$$

where $\gamma_h \in (0, 1)$ is the returns-to-scale to the additional years in education and ξ_h is the learning ability level of the individual. We denote by J_e the age at which an individual finishes her education and enters the workforce (which depends on the education level e).

Employed individuals contribute to the pension system (τ_t^s) and other social insurance schemes (τ_t^u), with both rates varying over time t. In contrast, unemployed individuals receive social transfers equal to a fixed fraction ϕ_U of their potential labor income, defined as $w_t \, y^{prod}$, where w_t is the market wage rate in period t. Retired individuals earn pension benefits b. Let ζ indicate the retirement status, where $\zeta = 0$ means individuals are not retired, and $\zeta = 1$ means they are retired.

The taxable income of an individual with $\mathbf{s}_{tj}$ characteristics is

$$y^{tax}(\mathbf{s}_{tj}, \zeta) = \begin{cases} \mathbf{1}_{\{j \geq J_e\}} \left((1 - \tau_t^s - \tau_t^u)\mathbf{1}_{\{u=1\}} + \phi_u \mathbf{1}_{\{u=2\}} \right) \, w_t \, y^{prod}(\mathbf{s}_{tj}) & \text{if } \zeta = 0, \\ b & \text{if } \zeta = 1. \end{cases}$$

Before receiving their net income, individuals also pay a proportional income tax on their taxable income $T(y^{tax})$. In addition, depending on gender, they either pay $\tau_t^g < 0$ or receive $\tau_t^g > 0$ net gender transfers to partly finance children's consumption. Assuming that children's costs are borne by women, they receive a transfer ($\tau_t^f > 0$) and men give transfers ($\tau_t^m < 0$). Because most children settle their own household before their parents retire, we restrict net gender transfers to the working period. Combining all the sources of income over the life span, the disposable (non-financial) income of an individual in state $\mathbf{s}_{tj}$ is given by

$$\omega(\mathbf{s}_{tj}, \zeta) = (1 + (1 - \zeta)\tau_t^g) \, y^{tax}(\mathbf{s}_{tj}, \zeta) - T(y^{tax}(\mathbf{s}_{tj}, \zeta)), \tag{3}$$

where $T(y^{tax}(\mathbf{s}_{tj}))$ is the total labor income tax paid.

3.3 Preferences

Households receive utility from consumption (c), which is divided between household members according to an equivalence scale $\eta(t, j, g, e, n) = \sqrt{1 + \hat{n}(t, j, e, n) \cdot \mathbf{1}_{\{g=f\}}}$ that

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[2] We assume that human capital (H) accumulates according to the law of motion $\partial H / \partial j = \xi_h H^{\gamma_h}$.

depends on the number of children present in the household. Given that children's cost are assumed to be borne by women, note that $\hat{n}(t,j,e,n)$ only applies to female headed households. Upon retirement ($\zeta = 1$, otherwise $\zeta = 0$), individuals are assumed to gain an extra utility from being retired. This additional utility is inversely related to the remaining life expectancy $\mathrm{LE}(t,j,g,e)$ in period t at age j associated to individuals of gender g and educational attainment e (Sánchez-Romero et al., 2020). For simplicity, we assume preferences are separable, logarithmic in consumption, and, similar to Braun et al. (2009), multiplied by the number of household members.[3] The period utility U at time t of an individual of age j, gender g, education e, and completed fertility n, given (c,ζ) is expressed as follows:

$$U(c,\zeta,t,j,g,e,n) = \eta(t,j,g,e,n)\,\log\left(\frac{c}{\eta(t,j,g,e,n)}\right) + \zeta\,\alpha_1^g\,\mathrm{LE}(t,j,g,e)^{-\alpha_2}. \tag{4}$$

where $\alpha_1, \alpha_2 > 0$ reflects that the utility from being retired is an decreasing function with respect to the remaining life. This implies that the marginal cost of not being retired increases with age.

3.4 Household problem

Households make decisions about consumption (c), education (e) and retirement (ζ) in order to maximize lifetime utility, subject to a budget constrained and pension rules. Upon retirement, individuals start receiving pension benefits as income. Health, unemployment and mortality risk are uninsurable, and individuals have rational expectations about the probabilities of these risks.

Household value function Conditional on their education decision e, household heads are characterized in each period t and age j by their gender g, a set of permanent, unobservable characteristics θ, completed fertility level n, their health status h, an unemployment status u. Let $\mathbf{s}_{tj} \in \mathbb{S}$ characterize the individual. At the beginning of each period t and age j, individuals know their current state variables $\mathbf{x}_{tj} = (\mathbf{s}_{tj}, a, b, \zeta) \in \mathbb{S} \times \mathbb{R}_+^2 \times \{0,1\}$, where $a \geq 0$ represents their financial wealth, and $b \geq 0$ denotes the amount of pension benefits they would receive if they were retired, and ζ indicates retirement status. $\zeta = 0$ means individuals are not retired, and $\zeta = 1$ means they are retired. Once they reach the minimum retirement age, they decide whether to retire. The retirement decision is assumed to be irreversible. An individual's value function is given as

$$V(\mathbf{s}_{tj}, a, b, \zeta) = \max_{c,\zeta'} \left\{ U(c,\zeta,\mathbf{s}_{tj}) + \beta\,\mathbb{E}\left[\pi^S(\mathbf{s}_{t+1,j+1}) V(\mathbf{s}_{t+1,j+1}, a', b', \zeta') \middle| \mathbf{s}_{tj}\right] \right\} \tag{5a}$$

subject to

$$a' = (1 + r(1-\tau^k))\,a + \omega(\mathbf{s}_{tj},\zeta) - (1+\tau^c)c, \tag{5b}$$

$$b' = D^i(\mathbf{s}_{tj}, b, \zeta, w_t\, y^{prod}(\mathbf{s}_{tj})), \tag{5c}$$

and the boundary condition that the financial wealth, a, at the maximum age, $J_\Omega = 98$ years, should be non-negative. The components of the dynamic equation for financial

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[3] This formulation implies that adding household members increases total household consumption spending.

wealth a are as follows: Household heads hold financial wealth a, receive (net of capital income tax) interests on their savings, receive a disposable income of $\omega(\mathbf{s}_{tj}, \zeta)$, which depends on the retirement status, and pay for the total household consumption $(1+\tau^c)c$.

Pension benefits accumulate throughout an individual's working life according to the pension rule $D^i(\,)$ for the pension system $i \in \{\text{PAYG-DB}, \text{NDC}\}$, which is a function of period, age, current pension benefits, retirement status, and gross labor income. The pension rule $D^i(\,)$ associated to each pension system i—i.e., pay-as-you-go defined-benefit (PAYG-DB) or notional defined-contribution (NDC)—will be described in more detail in Section 3.5.

Solving the household problem (5) we obtain the following set of policy functions $(\mathbf{c}^*(\mathbf{x}_{tj}),\ \boldsymbol{\zeta}^*(\mathbf{x}_{tj}),\ \mathbf{a}^*(\mathbf{x}_{tj}),\ \mathbf{b}^*(\mathbf{x}_{tj}),\ \mathbf{s}^*(\mathbf{x}_{tj}))$ that corresponds to consumption, retirement status, financial wealth, pension benefits, and saving—i.e. $\mathbf{s}^*(\mathbf{x}_{tj}) = \mathbf{a}^*(\mathbf{x}_{t+1,j+1}) - \mathbf{a}^*(\mathbf{x}_{tj})$, respectively, for individuals in state $\mathbf{x}_{tj}$, which includes all demographic and economic states.

Education Decision At age J_0, individuals decide whether to remain without higher education and enter the labor force, or attain higher education. Attaining higher education takes four years, during which individuals do not receive labor income but social benefits. Further they face a non-monetary cost of schooling captured through the parameter ξ_e which is part of the initial characteristics θ. Individuals receive their draw of fertility level n after the education decision, and they are aware that the choice of education influences their fertility outcome. Therefore they form two expectation values by weighting life-time utility over all possible fertility outcomes n conditioned on lower education $(e = 0)$ and higher education $(e = 1)$. The optimal expected utility of an individual in period t at age J_0 with education e is

$$\hat{V}(t, J_0, g, \theta, e) = \sum_{n=0}^{N} V^*(\mathbf{s}_{t,J_0}(e, n), 0, 0, 0)\, \pi^c(n|t - J_0,\ e), \tag{6}$$

where $V^*(\mathbf{s}_{t,J_0}(e, n), 0, 0, 0)$ denotes the optimal expected utility in period t at age J_0 for an individual in state $\mathbf{s}_{t,J_0}(e, n)$ conditional on education e and fertility level n, and $\pi^c(n|t - J_0, e)$ is the conditional probability to have completed fertility n for a woman born in period $t - J_0$ given education level e. Then, following Heckman et al. (1998) individuals choose their education by comparing the two outcomes taking into account their personal non-monetary costs of attaining higher education ξ_e:

$$e^*(\mathbf{s}_{tj}) = \arg \max_{e\in\{0,1\}} \left\{ \hat{V}(t, J_0, g, \theta, e) - e\,\xi_e \right\}, \tag{7}$$

where $e^*(\mathbf{s}_{tj})$ denotes the optimal level of education for an individual in state $\mathbf{s}_{tj}$.

3.5 Pension System

To calculate the pension benefits $\mathbf{b}^*(\mathbf{s}_{tj})$ that an individual receives in each country and state $\mathbf{s}_{t,j}$, we use the pension point system as in Sánchez-Romero et al. (2020) and Sánchez-Romero et al. (2024). As stated in the household problem section, pension benefits can be described by the dynamic equation (8). We chose this general representation in order to model both notional defined-contribution (NDC) and pay-as-you-go defined-benefit (PAYG-DB) systems within the same framework. This will allow us to replicate the PAYG-DB systems of Austrian and German and the NDC systems of Italian and Polish pension systems by applying different parametrization of the same pension benefit formula. In particular, the pension rule $D^i(\mathbf{s}_{tj}, \mathbf{b}^*(\mathbf{s}_{tj}), \boldsymbol{\zeta}^*(\mathbf{s}_{tj}), w_t\, y^{prod}(\mathbf{s}_{tj}))$ is equal to

$$\begin{cases} \left(\mathbf{b}^*(\mathbf{s}_{tj})(1+\widehat{r}_t) + \mathbf{1}_{\{u=1\}}\, w_t\, y^{prod}(\mathbf{s}_{tj})\, A^i_{tj}\, \lambda^i_{tj}\right) (A^i_{t+1,j+1}/A^i_{tj}) & \text{if } \zeta^*(\mathbf{s}_{tj}) = 0, \\ \max(\mathbf{b}^*(\mathbf{s}_{tj})(1+\widetilde{r}_t), b^{\min}_t) & \text{if } \zeta^*(\mathbf{s}_{tj}) = 1. \end{cases} \tag{8}$$

In general terms, before retirement (i.e., $\zeta^*(\mathbf{s}_{tj}) = 0$) individuals pension benefits increase due to three factors. First, benefits are capitalized at the pension system's rate of return $\widehat{r}_t$. Second, when employed, benefits grow by a fraction $A^i_{tj}\, \lambda^i_{tj}$—or accrual rate generosity—of the labor income earned $w_t\, y^{prod}(\mathbf{s}_{tj})$. This fraction depends on the term A^i_{tj}, that denotes a system-specific adjustment parameter. In the notional defined-contribution scheme (NDC), it represents the annuity conversion factor that translates accumulated pension wealth into periodic retirement payments

$$A^{\text{NDC}}_{tj} = \begin{cases} (\text{LE}_{t-j+\underline{J_{tj}},\underline{J_{tj}}})^{-1} & \text{for } j < \underline{J_{tj}}, \\ (\max\{\text{LE}_{tj}, \text{LE}_{t-j+\overline{J_{tj}},\overline{J_{tj}}}\})^{-1} & \text{for } j \geq \underline{J_{tj}}, \end{cases} \tag{9}$$

where LE_{tj} denotes the life expectancy in period t at age j of the total population. In the pay-as-you-go defined-benefit schemes (PAYG-DB), it captures the adjustment of pension benefits due to early or late retirement relative to the normal (or statutory) retirement age J^N_{tj}

$$A^{\text{PAYG-DB}}_{tj} = \begin{cases} 1 - pen \cdot (J^N_{tj} - max\{\underline{J_{tj}}, j\}) & \text{for } j < J^N_{tj}, \\ 1 + rew \cdot (min\{\overline{J_{tj}}, j\} - J^N_{tj}) & \text{for } j \geq J^N_{tj}, \end{cases} \tag{10}$$

where pen is the annual penalty rate for retiring before J^N_{tj}, rew is the annual reward rate for retiring after J^N_{tj}, and $\{\underline{J_{tj}}, \overline{J_{tj}}\}$ are the minimum and maximum retirement age, respectively. Also, it depends on the term λ^i_{tj}. The symbol λ^i_{tj} measures the generosity of the pension system. In the notional defined-contribution scheme (NDC), it corresponds to the social contribution rate τ^s, while in the pay-as-you-go defined-benefit scheme (PAYG-DB) it reflects the product of the pension replacement rate and the accrual rate

$$\lambda^i_{tj} = \begin{cases} \tau^s & \text{if } i = \text{NDC}, \\ \varphi / wy_{tj} & \text{if } i = \text{PAYG-DB}, \end{cases} \tag{11}$$

where φ is the pension replacement rate and wy_{tj} denotes the total number of working years that individuals in period t and age j need to qualify for full pension benefits. In both cases, λ^i_{tj} determines the ratio of pension benefits to labor income. Third, the pension benefits increase due to the adjustment of the replacement rate formula with each additional year of work, represented by $A^i_{t+1,j+1}/A^i_{tj}$. Upon retirement (i.e., $\zeta^*(\mathbf{s}_{tj}) = 1$), individuals receive the accumulated pension benefits, which can increase with age at a rate $\widetilde{r}$.[4] If this amount falls below the statutory minimum pension set in period t, $b^{\min}_t$, they are instead entitled to the minimum benefit level. All parametric components for both pension systems are reported in Section D in the Appendix.

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[4] In Germany, pension benefits continue to increase after retirement at a rate of $\widetilde{r} = \widehat{r}$, while in Austria pension benefits remain constant; i.e. $\widetilde{r} = 0$.

3.6 Government

The government maintains a pension system, a social insurance, and a general budget for government expenditure. All three budgets need to be balanced each period. To finance all pension claims B_t and all other social benefits U_t, the government collects pension contributions $\tau_t^s\, w_t\, L_t$ and other social contributions $\tau_t^u\, w_t\, L_t$. The government budget for pensions and other social benefits is

$$(\tau_t^s + \tau_t^u)\, w_t\, L_t = U_t + B_t, \tag{12}$$

where in the NDC system, the pension contribution rate is assumed to remain constant over time (i.e. $\tau_t^s = \tau^s$, $\forall t$), while in the PAYG-DB system, the contribution rate adjusts over time to finance total pension claims (i.e. $\tau_t^s\, w_t\, L_t = B_t$). For the NDC system, this implies that τ_t^u must adjust whenever total contributions do not match total pensions claimed.

To finance government consumption G_t, the government collects taxes on income, consumption, capital gains, and all accidental bequest. Thus, the general budget of the government satisfies in each period t: $G_t = T_t + \tau^c\, C_t + \tau^k\, r\, W_t + Bequest_t$, where T_t is the total income tax, C_t is the total consumption, W_t is the total financial wealth of households, $Bequest_t$ is the total accidental bequest, and the tuple (τ^k, τ^c) is the capital income tax rate and the consumption tax rate, respectively.

3.7 Production

We consider a representative firm that produces in each period t a final good by combining capital K_t and effective labor L_t. Output can be allocated either to consumption or investment. The production technology exhibits constant returns to scale and is given by

$$Y(K_t, L_t) = (K_t)^{\alpha_Y}\,(Z_t L_t)^{1-\alpha_Y}, \tag{13}$$

where Y denotes aggregate output, α_Y is the capital share, Z_t is labor-augmenting technology that evolves according to the law motion $Z_{t+1} = (1 + g_Z)Z_t$, and g_Z is the rate of growth of the labor-augmenting technology. The aggregate capital stock follows the law of motion $K_{t+1} = K_t(1 - \delta_K) + I_t$, where δ_K is the depreciation rate of capital and I_t is aggregate gross investment.

The representative firm maximizes net cash flow by renting capital and hiring labor from households in competitive markets at rental rate r and wage rate w_t. Optimal choices of capital and labor inputs are characterized by the first-order conditions:

$$r + \delta_K = \alpha_Y\, Y(K_t, L_t)/K_t, \tag{14}$$

$$w_t = (1 - \alpha_Y)\, Y(K_t, L_t)/L_t. \tag{15}$$

3.8 Equilibrium

We follow the equilibrium definition from Huggett and Ventura (1999), while extending it for time dependency.

Household density Within every period t, agents are heterogeneous with respect to age j and their state $\mathbf{x}$. The density of households in period t of age j across the states $\mathbf{x}$ is represented by a probability measure $\Gamma_{tj}(\cdot)$ on the probability space $(\Omega, \mathcal{F}, \Gamma_{tj})$. The probability space of the model is defined by setting $\Omega = \mathbb{S} \times \mathbb{R}^2 \times \{0, 1\}$. The corresponding sigma algebra is denoted by $\mathcal{F}$. Formally, the number $\Gamma_{tj}(B)$ is the share of all age j individuals in period t whose individual state $\mathbf{x}$ is contained in B.

Household law of motion The solution of the household problem gives rise to a household law of motion, which we will denote by $P_{tj}(\mathbf{x}, B)$ in analogy to Huggett and Ventura (1999). This means that $P_{tj}(\mathbf{x}, B)$ denotes the probability that an age j household who is in state $\mathbf{x}$ at time t transitions to a state $\tilde{x} \in B$ at age $j+1$ and time $t+1$.

General equilibrium We follow the equilibrium definition from Huggett and Ventura (1999) and adapt it to a small open economy with foreign capital and labor. In contrast to Huggett and Ventura (1999), the equilibrium quantities also have a time dependency, since exogenous inputs like the demographic characteristics of the model depend on time. The definition of an equilibrium in our model is given by:

Definition 3.1. *A time dependent equilibrium is a tuple* $(\mathbf{c}^*(\mathbf{s}_{tj}),\, \mathbf{a}^*(\mathbf{s}_{tj}),\, \mathbf{s}^*(\mathbf{s}_{tj}),\, \mathbf{e}^*(\mathbf{s}_{tj}),\, \boldsymbol{\zeta}^*(\mathbf{s}_{tj}),\, r,\, w_t,\, K_t,\, L_t,\, U_t,\, B_t,\, T_t,\, Bequest_t)$ *such that*

1. $(\mathbf{c}^*(\mathbf{s}_{tj}),\, \mathbf{a}^*(\mathbf{s}_{tj}),\, \mathbf{e}^*(\mathbf{s}_{tj}),\, \boldsymbol{\zeta}^*(\mathbf{s}_{tj}))$ *solve the household problem from section 3.4.*

2. *Distributions are consistent with household behavior:*

$$\Gamma_{j+1,t+1}(B) = \int_\Omega P_{tj}(\mathbf{x}, B)\, \mathrm{d}\Gamma_{tj}(\mathbf{x})$$

3. *Firms maximize their net present value of the future stream of profits.*

4. *The interest rate r clears the capital market:*

$$W_t = \sum_{j=J_0}^{J_\Omega - 1} \mathbf{N}_{tj} \int_\Omega \mathbf{a}^*(\mathbf{x}_{tj})\, \mathrm{d}\Gamma_{tj}(\mathbf{x}_{tj}), \tag{16}$$

$$K_t = W_t + F_t, \tag{17}$$

where W_t is the aggregate financial wealth of households and F_t is the net-foreign capital.

5. *Wages w_t satisfy*

$$w_t = \partial_L Y(K_t, L_t) \tag{18}$$

6. *Labor market clears:*

$$L_t = \sum_{j=J_0}^{J_\Omega - 1} \mathbf{N}_{tj} \int_\Omega \frac{S(\mathbf{x}_{tj})}{\mathbf{S}_{tj}} \pi^S(\mathbf{x}_{tj})\, (1 - \boldsymbol{\zeta}^*(\mathbf{x}_{tj}))\, y^{prod}(\mathbf{x}_{tj})\, \mathbf{1}_{\{u=1\}}\, \mathrm{d}\Gamma_{tj}(\mathbf{x}_{tj}). \tag{19}$$

7. *Final goods market clears:*

$$Y(K_t, L_t) - r_t\, F_t - \delta_K\, K_t = C_t + G_t + S_t, \tag{20}$$

where

$$C_t = \sum_{j=J_0}^{J_\Omega - 1} \mathbf{N}_{tj} \int_\Omega \frac{S(\mathbf{x}_{tj})}{\mathbf{S}_{tj}} \pi^S(\mathbf{x}_{tj})\, \mathbf{c}^*(\mathbf{x}_{tj})\, \mathrm{d}\Gamma_{tj}(\mathbf{x}_{tj}) \tag{21}$$

$$S_t = \sum_{j=J_0}^{J_\Omega - 1} \mathbf{N}_{tj} \int_\Omega \frac{S(\mathbf{x}_{tj})}{\mathbf{S}_{tj}} \pi^S(\mathbf{x}_{tj})\, \mathbf{s}^*(\mathbf{x}_{tj})\, \mathrm{d}\Gamma_{tj}(\mathbf{x}_{tj}) \tag{22}$$

are aggregate consumption and saving, respectively.

8. *Pension budget, unemployment insurance budget and general government budget constraints are satisfied:*

   (a) $(\tau^s_t + \tau^u_t)\, w_t\, L_t = B_t + U_t$

   (b) $G_t = T_t + \tau^c\, C_t + \tau^k\, r_t\, W_t + Bequest_t$

   where

$$U_t = \sum_{j=J_0}^{J_\Omega - 1} \mathbf{N}_{tj} \int_\Omega \frac{S(\mathbf{x}_{tj})}{\mathbf{S}_{tj}} \pi^S(\mathbf{x}_{tj})\, (1 - \boldsymbol{\zeta}^*(\mathbf{x}_{tj}))\, \phi_U\, w_t\, y^{prod}(\mathbf{x}_{tj})\, \mathbf{1}_{\{u=2\}}\, \mathrm{d}\Gamma_{tj}(\mathbf{x}_{tj}), \tag{23}$$

$$B_t = \sum_{j=J_0}^{J_\Omega - 1} \mathbf{N}_{tj} \int_\Omega \frac{S(\mathbf{x}_{tj})}{\mathbf{S}_{tj}} \pi^S(\mathbf{x}_{tj})\, \boldsymbol{\zeta}^*(\mathbf{x}_{tj})\, \mathbf{b}^*(\mathbf{x}_{tj})\, \mathrm{d}\Gamma_{tj}(\mathbf{x}_{tj}), \tag{24}$$

$$T_t = \sum_{j=J_0}^{J_\Omega - 1} \mathbf{N}_{tj} \int_\Omega \frac{S(\mathbf{x}_{tj})}{\mathbf{S}_{tj}} \pi^S(\mathbf{x}_{tj})\, T(y^{tax}(\mathbf{x}_{tj}))\, \mathrm{d}\Gamma_{tj}(\mathbf{x}_{tj}), \tag{25}$$

   are aggregate received unemployment benefits, pension claims and labor income tax, respectively, and

$$Bequest_t = (1 + r_t) \sum_{j=J_0}^{J_\Omega - 1} \mathbf{N}_{tj} \int_\Omega \frac{S(\mathbf{x}_{tj})}{\mathbf{S}_{tj}} (1 - \pi^S(\mathbf{x}_{tj}))\, \mathbf{a}^*(\mathbf{x}_{tj})\, \mathrm{d}\Gamma_{tj}(\mathbf{x}_{tj}), \tag{26}$$

   denotes the total accidental bequest.

9. *Total gender transfers received by one gender equals total gender transfers given by the other gender*

$$0 = \sum_{j=J_0}^{J_\Omega - 1} \mathbf{N}_{tj} \int_\Omega \frac{S(\mathbf{x}_{tj})}{\mathbf{S}_{tj}} \pi^S(\mathbf{x}_{tj})\, (1 - \boldsymbol{\zeta}^*(\mathbf{x}_{tj}))\, \tau^g_t\, y^{tax}(\mathbf{x}_{tj})\, \mathrm{d}\Gamma_{tj}(\mathbf{x}_{tj}), \tag{27}$$

   with $\tau^g_t \neq 0$ *for any* $g \in \{f, m\}$.

4 Data, Parametrization and Calibration

Due to the complexity and rich heterogeneity of the economic model, we use a three stage procedure to set its parameters. In the first stage (data sources and parametrization), we combine (mostly publicly available) data from multiple sources, including data on demographics, labor markets and earnings. We use this data in combination with parameters from the existing literature to set all parameters that can be identified exogenously. In the second step (microsimulations) we run a microsimulation model, which is a reduced form of the full economic model, in order to generate additional inputs for the final calibration. In the third step (structural calibration) we structurally calibrate the remaining parameters of the model by combining moment matching and Bayesian melding. The reason for using our three stage procedure has multiple reasons. Only the last step requires us to run the full economic model, which is by far the most computationally costly step. Besides computational aspects, using microsimulations enables us to make the most out or the limited publicly available data, and its outputs further serve us as a verification device for the full economic model.

4.1 Data Sources and Parametrization

Data Sources To infer the parameters of our model, we combine multiple data sources. Thereby we aim to rely as much as possible on publicly available data. Demographic data and projections for Austria, Germany, Italy, and Poland, by birth cohort, number of children, gender, and skill group, are taken from Eurostat (EUROPOP2023) and the Wittgenstein Centre Human Capital Data Explorer. Data on employment transitions by gender and year from Eurostat is combined with data on prime-age labour force participation rates by sex, household type and presence of children from ILOSTAT and historical labor force participation data from SHARE (wave 5, 6, 7, 8 and 9)[5]. Further we combine information on earnings advantages by skill level from the OECD report: Education at a Glance 2023 and labor income profiles from the AGENTA database (Istenič et al., 2016) to generate labor income profiles by gender and skill level for all four countries.[6]

Health and mortality Publicly available data frequently provide information on prevalence rates of disability that can be used as a proxi for bad health ($h = 2$). The prevalence rate of disability is the proportion of individuals with disability in a given population. We will use the Global Activity Limitation Index (GALI), which is a standard measure for daily activity limitations (Jagger et al., 2010). We denote by $P_{tj}(g, e)$ the prevalence rate of disability of an individual of gender g born in year t, with education e, at age j. Using the notation from Section 3, $P_{tj}(g, e)$ is equal to $\mathbf{N}_{tj}(g, e, h = 2)/\mathbf{N}_{tj}(g, e)$, i.e. the number of disabled individuals divided by the total number of individuals (within the respective group). Unfortunately, the prevalence rate of disability alone does not allow to uniquely calculate the transition probabilities between health states and the corresponding mortality risks. In order to proceed, we combine two well established assumptions: First, we assume that the mortality hazard rate of individuals with bad health is ν times larger than the mortality hazard rate of individuals in good health, i.e. $-\log \pi^S(t, j, g, e, h = 2) = -\nu \log \pi^S(t, j, g, e, h = 1)$. We set the value of ν at 1.5 following Forman-Hoffman et al. (2015). Using this relationship we derive conditional survival probabilities for both health states. Second, we associate the transition probability from being in good health to being in bad health, $\pi^h(h = 2|t, j, g, e, h = 1)$, with the frailty index pioneered by Rockwood and Mitnitski (2007). The frailty index reflects the likelihood that frailty, or some disability, is present at each age and therefore it is

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[5] Datasets: (SHARE-ERIC, 2024a,b,c,d,e). References: Börsch-Supan et al. (2013), Bergmann et al. (2019a). Methodological Documentation: Malter and Börsch-Supan (2015), Malter and Börsch-Supan (2017), Bergmann et al. (2019b), Bergmann and Börsch-Supan (2021), Bergmann et al. (2024).

[6] See the AGENTA data explorer.

equivalent to the probability of becoming disabled. Our analysis relies on the estimated values of the frailty index by gender, education, and age for European countries from Table 3 in Jenkins et al. (2023). Finally, we determine the probability of moving from a state of poor health to a state of good health $\pi^h(h = 1|t, j, g, e, h = 2)$ by using a dynamic equation for the prevalence rate. Details on the whole derivation are in Appendix A.3.

Employment transitions Eurostat provides public data on job finding rates ($\pi^u(u = 1|g, u = 2)$) and job separation rates ($\pi^u(u = 2|g, u = 1)$) for the age group 15-74, broken down by gender.[7] However, information on these probabilities by education level is not available. To estimate these rates by skill level and gender for selected EU countries, we assume that job finding rates are similar across skill groups, which together with available data from Eurostat on employment rates by education and gender, allows us to uniquely determine the separation rate for each skill group and gender. Details can be found in Appendix A.4.

Children frequently penalize the working careers of mother (Kleven et al., 2023; **?**). To account in our model for the negative impact of having children on women's employment rates, we assume that the separation rate of women exponentially increases with the number of children living in the household according to a logistic distribution. Both, the precise formula and the estimated parametric components of the logistic distribution can be found in Appendix A.4.

Pensions To compare the pension systems across countries, we first follow Auerbach (2025) and impute the total cost of the pension system to workers (see the derivation in Section D.1). Therefore, our pension contribution rate includes the pension contribution rate paid by employers, employees, and the government. The distribution of the total cost across these institutional agent can be seen in European Commission, Directorate-General for Economic and Financial Affairs (2024). Second, we replicate both defined-benefit and defined-contribution pension systems within a common framework using the pension point system (Sánchez-Romero et al., 2020).

	Symbol	PAYG-DB		NDC	
		Austria	Germany	Italy	Poland
Pension contributions rate	τ^s	‡0.2954	‡0.1702	0.2665	0.1778
Accrual generosity at age 65	$A\,\lambda$	0.0158	0.0098	†0.0128	†0.0098
Minimum pension benefits	$b^{\min}/\bar{y}$	0.3040	0.1280	0.1980	0.2490

Table 2: Main parametric components of the pension systems in Austria, Germany, Italy, and Poland. † Based on life expectancy values at age 65 in year 2023. ‡ Note that pension contribution rates will vary over time in PAYG-DB systems.

As shown in equation (8) in Section 3.5, our pension point system is defined by four key parameters: the pension capitalization factor $(1 + \hat{r})$, the accrual rate $(A\,\lambda)$, the retirement age adjustment factor (A), and the minimum pension benefit $(b^{\min})$. The capitalization factor in each of the four countries is the growth rate of the total wage bill of the economy, approximated by the sum of the growth rate of the total population

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[7] See employment transitions probability by gender and year at Eurostat.

aged 18-65 and the growth rate of the labor-augmenting technology.[8] For comparability with European Commission et al. (2020), we assume that g_Z is constant over time at 1.5 percent per year. This capitalization factor ensures that the pension system maintains the purchasing power of new retirees by linking their pension benefits to current wage levels.

The accrual rate in NDC systems depends on both, the social contribution rate and life expectancy at retirement. Consequently, the accrual rate varies as life expectancy changes. In PAYG-DB systems, by contrast, the accrual rate remains constant as long as the statutory retirement age does not change. Table 2 reports the social contribution rate and the accrual rate at age 65 for the 1957 birth cohort under the NDC and PAYG-DB systems across the four countries analyzed. Multiplying the accrual rate by the number of years contributed gives the pension replacement level. Figure 1 shows the evolution across birth cohorts of the pension replacement level for a worker contributing from age 20 until the statutory retirement age in Austria, Germany, Italy, and Poland. Austria exhibits the highest generosity, with replacement levels close to 71 percent, followed by Italy around 60 percent, Germany 44 percent, and Poland starting at 44 percent for the 1960 birth cohort and declining to 30 percent for the 2020 birth cohort.

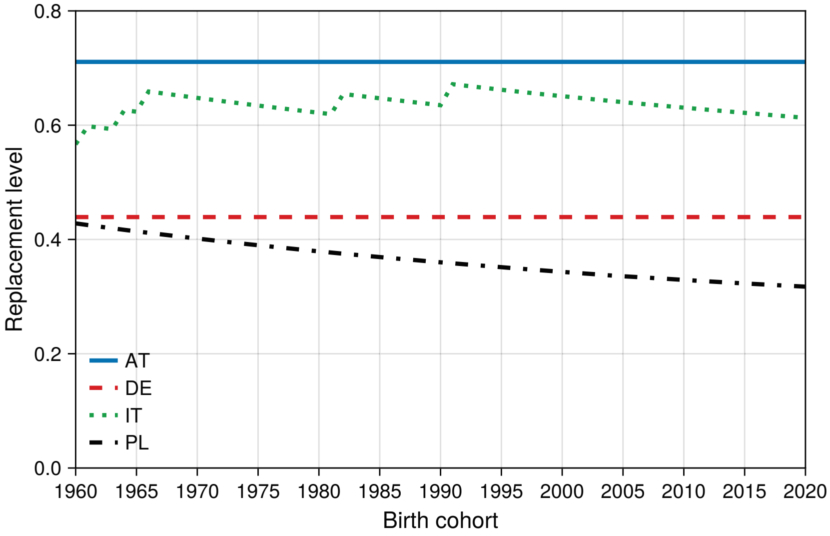

Figure 1: Average pension replacement level after contributing from age 20 to the statutory retirement age in Austria (solid blue line), Germany (dashed red line), Italy (dotted green line), and Poland (dash-dot black line). Source: Own calculations multiplying the accrual rate by the number of years from age 20 until the statutory retirement age for each birth cohort.

The term A captures the changes in the pension replacement level associated with working one additional year. This term reflects the penalties and rewards of retiring between the minimum retirement age ($\underline{J}$) and the statutory retirement age (J^N) or later than the statutory retirement age. For cohorts born in or before 1957, the statutory

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[8] In Italy, past contributions are capitalized using the growth rate of the gross domestic product rather than the growth rate of the total wage bill. However, since we assumed a constant labor share and constant returns to scale in the production of the final good, the growth rate of the total wage bill is the same as the growth rate of the gross domestic product (GDP).

retirement age for men is 65 in all countries, while for women it is 60 in Austria, Italy, and Poland, and 65 in Germany. The statutory retirement age will progressively increase in Austria for women until age 65, and in Germany and Italy for both men and women until 70, while it remains unchanged in Poland. The statutory retirement age by birth cohort across the four countries are reported in Appendix, Table D.2. Moreover, individuals may retire earlier: up to two years before the statutory retirement age in Germany, and three years earlier in Austria and Italy. 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 (pen) 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 pension replacement (rew) of 4.2 percent in Austria and of 6 percent in Germany.

To compute the minimum pension benefit ($b^{\min}$) we use the minimum old-age income floor for a single pensioner in Austria, the basic income in old-age in Germany, the social allowance in Italy, and the statutory minimum old-age pension in Poland. All values are calculated relative to the average productivity of a worker. For more details about the minimum pension benefit estimation see Appendix, Table D.3.

Other parameters Explanations on other parametrized components of the model, and a summary table of the parametrization (including parameters from the microsimulations section) can be found in Appendix A.1.

4.2 Microsimulations

Before solving the full economic model, we combine the data and parametrization from above to implement a simplified microsimulation model. The microsimulation model is the same as the model presented in Section 3, except for the part of economic decision making and fertility: Education decisions, income profiles and retirement behavior are taken exogenously as in the data (see previous paragraph) and consumption and savings are not modeled. Further we simulate fertility using fertility matrices, as explained in Appendix A.2. We use Monte Carlo simulations to generate a large number of profiles $\hat{x}_{itj}$ where i is the index of the simulation, t is period and j is age. The resulting profiles $\hat{x}_{itj} = (\hat{g}_{it}, \hat{e}_{it}, \hat{y}_{itj}, \hat{u}_{itj}, \hat{h}_{itj}, \hat{n}_{itj}, \hat{b}_{itj}, \hat{\zeta}_{itj}, \hat{m}_{itj})$ are by gender g_{it} and education e_{it}, and contain profiles for labor income $\hat{y}_{itj}$, employment state $\hat{u}_{itj}$, health state $\hat{h}_{itj}$, fertility $\hat{n}_{itj}$, pension benefits $\hat{b}_{itj}$, retirement state $\hat{\zeta}_{itj}$ and mortality $\hat{m}_{itj} \in \{0, 1\}$ (where 1 stands for alive and 0 for deceased). Besides using the microsimulations to parametrize the model, it also serves as a verification device of our full model. Along the modeling process, we repeatedly compare the outputs of the full model with the microsimulation profiles. This helps us to stay consistent with model inputs and identify potential errors within the solution algorithm of the economic model.

Fertility profiles We use the simulated profiles to calculate average fertility profiles by education and completed fertility. This works as follows: The microsimulation model delivers N fertility age-profiles ($\hat{n}_{itj}$) for every period t. We sort the profiles by completed fertility $\bar{n}_{it} \in \{0, 1, 2, 3+\}$ and period. Finally, we calculate the average fertility profile within every category of completed fertility and period. This results in four age-fertility profiles for every model period, which are the fertility profiles we use for the economic model. More details on this procedure are provided in Appendix A.2.

Labor income profiles To estimate the parameters of the labor income profiles, we divide the per capita labor income—estimated using OECD and AGENTA data—by the simulated employment rates, both disaggregated by gender and skill level (see Appendix A.5 for more details). Then, we regress the simulated log labor income profiles from age 22 to 55 by gender and skill groups simultaneously using the following equation:

$$log(\hat{y}_{itj}) = \beta_0 + \beta_1 j + \beta_2 j^2 + Skill_{\hat{e}_{it}} + u_{ij} \tag{28}$$

where the term $Skill_{\hat{e}_{it}}$ captures the earnings advantage of those who are high-skilled, and u is the error term. Table A.5 in the appendix summarizes the estimated coefficients of the regression (28) for women and men for the four European countries. The estimated coefficients will be used in the full economic model. In particular, the wage rate per hour worked of an individual of gender g born in year t with a skill level e at age j will be given by the following equation

$$y^{prod}(\mathbf{s}_{tj}) = \exp\left\{\beta_0 + \beta_1 j + \beta_2 j^2 + g_Z \cdot t + \rho_e(\mathbf{s}_{tj})\, e + \delta_B log(S(\mathbf{s}_{tj}))\right\} \tag{29}$$

where $\mathbf{s}_{tj}$ is the vector of individual states as defined in the previous section, $\rho_e(\mathbf{s}_{tj})$ represents the proportional (log) change in productivity from the educational choice $e \in \{1, 2\}$ (see section 3), which depends on the learning ability θ and the number of years of education. Thus, parameter θ will be calibrated to replicate the skill premium $Skill$ from Table A.5. The parameters (β_1, β_2), reflecting the influence of age on productivity, are taken directly from Table A.5. The parameter g_Z reflects the annual growth of the labor-augmenting technology, which we set at 1.5 percent. The last term accounts for the faster decline in productivity for less healthy individuals (Weil, 2007; Bloom et al., 2024), where $S(\mathbf{s}_{tj})$ is the probability of surviving from birth to age j, which will depend on the health history of each individual. Following Bloom et al. (2024) we set δ_B at 0.848. Details on how the labor income is constructed within the microsimulations can be found in Appendix A.5.

4.3 Calibration

Following the steps outlined in Section 4.1, nine free household related parameters remain per country (see Table B.1). Further, gender transfer rates, unemployment contribution rates, and remaining free parameters of the pension system have to be found such that the corresponding equilibrium equations from Section 3 are satisfied. Our calibration approach is divided into two main stages: Within the first stage, we estimate retirement preferences, learning ability and effort of schooling parameters for a representative cohort (1960 cohort), using a balanced-growth-path (BGP) framework. Our assumption is that these individual characteristics do not vary between cohorts. We target mean retirement ages for both genders, as well as multiple statistics on income and education. Appendix B provides details on the target statistics we use. In the second stage, we readjust transfer and contribution rates, as well as the components of the pension system to make them cohort dependent, and solve the full dynamic equilibrium of the model. In total we calibrate two kinds of model parameters:

Retirement preferences The gendered retirement related preference parameters α_1^g from (4) are estimated by minimizing the distance between the model and data mean retirement age for both genders (see Table B.1), using the representative cohort, and individually for every country. We observe that the model sufficiently replicates differences in mean retirement age by educational group, which is an untargeted statistic.

Learning ability and schooling effort We use Bayesian Melding to jointly estimate the parameters for the distribution of learning ability and schooling effort. In total these are seven parameters $(\mu_h^w, \mu_h^m, \sigma_h, \mu_e^w, \mu_e^m, \sigma_e^w, \sigma_e^m)$ which represent gendered mean and non-gendered variance for learning ability, and gendered mean and variance for schooling effort. These parameters are estimated such that the educational shares for both gender, skill premia on income for both genders, and gender-pay-gaps for both educational groups are matched. We use the representative cohort within this step, and estimate the parameters for each country individually. We then readjust the parameters $(\mu_{e,t}^w, \mu_{e,t}^m)$ and make them cohort dependent, such that the evolution of educational shares over time is well captured. Details on the Bayesian melding algorithm as well as the estimation results are in Appendix B.

5 Pension Reforms

We implement four alternative pension reforms aimed either at reducing inequality—by increasing the *minimum pension benefit* (MinPB) or by introducing *progressive pension benefits* (PPB)—or at enhancing the sustainability of the pension system—*by delaying the statutory retirement age* (DR) or by introducing a *sustainability factor* (SF). Pension reforms aimed at reducing inequality (MinPB and PPB) are implemented in all countries. The DR reform is simulated only for Austria and Poland, as it is already part of the baseline in Germany and Italy. The SF reform is introduced only in Austria, since it is already implemented in the baseline in the other three countries.

Higher minimum pension benefits (MinPB): To reduce inequality in pension income, we increase the minimum pension benefit relative to the average labor income (denoted by $\bar{y}$) from 0.304 in Austria, 0.128 in Germany, 0.198 in Italy, and 0.249 in Poland to fifty percent. This reform is assumed to apply to all retirees starting in 2025, benefiting all retirees for which their working salaries were below the average labor income salary. See the estimation of the minimum pension benefits relative to the productivity of the average worker in the Appendix, Section D.3.

Progressive pension benefits (PPB): Following recent proposals aimed at addressing increasing inequality in life expectancy (Breyer and Hupfeld, 2009; Ayuso et al., 2016, 2017; Holzmann et al., 2019; Sánchez-Romero et al., 2020, 2024), we assume that the generosity of the pension system—measured by the pension replacement rate—is inversely related to the pension rights accumulated. Specifically, pension benefits are adjusted relative to the average pension rights of all retirees. We assume that if an individual's pension points are 1 percent lower (respectively, higher) than the average, their replacement rate increases (respectively, decreases) by 0.22 percentage points.

$$\mathbf{b}^*(\mathbf{s}_{tj}) = b \cdot \exp\left\{-0.22\,\xi_t\left(\frac{b}{\bar{\mathbf{b}}_t} - 1\right)\right\},$$

where b is the pension benefit that a retiree would have received under the baseline pension system—i.e., flat pension replacement rate— and $\overline{\mathbf{b}}_t$ is the average pension benefit in period t. The PPB reform is phased in gradually over twenty years in a linear manner, with ξ_t denoting the degree of implementation. Before 2025, we assume ξ_t equals 0; between 2025 and 2045, ξ_t is equal to $\frac{t-2025}{20}$; and from 2045 onward the reform is fully implemented, $\xi_t = 1$.

Delayed retirement (DR): In this reform, we adjust the statutory retirement age from the currently set normal retirement age by birth cohort to age 70 in the pension systems of Austria and Poland. The objective of this policy differs across the two countries, reflecting the distinct nature of their pension systems. In Austria, which operates a PAYG-DB system, the aim is to limit the growing cost of pensions borne by workers. In Poland, which runs a NDC system, the goal is to prevent pension benefits from becoming too low. This reform is gradually implemented in Austria starting with the 1975 birth cohort (phase-in) and finishing with the 1983 birth cohort (phase-out). In Poland, which exhibits the same expected old-age dependency ratio as in Italy in 2065, we assume that the increase in normal retirement ages follows the same time path as already implemented in Italy in the baseline scenario. For consistency with the pension design, in PAYG-DB systems the working years (wy) are increased consistently with the statutory retirement age. See the statutory retirement ages in the Appendix, Table D.2.

Sustainability factor (SF): We implement this policy in countries running a PAYG-DB system. This policy is not applied in Italy and Poland, as the contribution rate in defined-contribution systems is, by design, fixed. This pension reform has two main objectives. First, to prevent the cost of the pension system from rising in line with the old-age dependency ratio. Second, to ensure that the average pension benefit does not exceed the average labor income (net of social contributions). To limit the growing pension burden on workers, we impose a maximum pension contribution rate of 35 percent in Austria and of 24 percent in Germany. Once this cap is reached, all pension benefits will be adjusted downward to ensure that total benefits paid match total contributions collected. See Section E.3 for an analysis of the evolution of the pension replacement level in Austria and Germany under alternative formulations of the sustainability factor.

6 Results

In this section, we summarize the main economic effects of the pension reforms introduced in Section 5 for Austria, Germany, Italy, and Poland. We assess these effects by analyzing key macroeconomic indicators such as per-capita national income growth, per-capita consumption growth, the evolution of the retirement age, the evolution of the pension-to-income ratio, and the social contribution rate, as well as the inter- and intra-generational distributional consequences and the impact of each reform across different socioeconomic groups and genders. The section concludes with a welfare analysis both within and across birth cohorts.

6.1 Macroeconomic outcomes

Table 3 reports average annual per-capita growth rates over the period 2020–2070 for national income (column I) and total consumption (column IV), together with their components—labor and capital income (columns II–III) and private and public consumption (columns V–VI). Here, capital income refers to the returns generated from households' accumulated wealth, which can be invested in domestic capital or oversees.

The first row for each country reports the baseline results, while the subsequent rows show absolute deviations for each pension reform from each country's baseline. In the baseline, per-capita national income grows in percentage points by 1.59 in Austria, 1.56 in Germany, 1.89 in Italy, and 1.84 in Poland. The corresponding growth rates (in percent) for per-capita total consumption are 1.71, 1.55, 1.84, and 1.82, respectively. Per-capita national income growth is higher in countries with NDC systems (Italy and Poland) than in those with PAYG-DB systems (Austria and Germany) because average per-capita capital-income growth over 2020–2070 is greater in NDC countries. It reflects the declining generosity of NDC pensions compared to PAYG-DB schemes, which increases the need for private savings, given the link between life expectancy and retirement benefits. Specifically, per-capita capital income growth reaches 2.74 percent in Poland and 1.97 percent in Italy, while it is only 1.76 percent in Austria and 1.66 percent in Germany.

By multiplying the per-capita income growth rate by the growth rate of the per-capita population over the period 2020–2070 in each country (0.22 for Austria, 0.0 for Germany, −0.29 for Italy, and −0.37 for Poland), we obtain the aggregate national income growth rate. The simulation results indicate that Austria exhibits the highest average annual national income growth rate (1.81), followed by Italy (1.60), Germany (1.56), and Poland (1.47) over the period 2020-2070. For more information about the evolution of the demographics in each country see Appendix A.7.

Another interesting result from Table 3 is the evolution of national savings per-capita, which can be approximated by the difference between the growth rates of national income per-capita and total consumption per-capita; see (20). Using the baseline figures, this gap equals -0.12 percentage points in Austria (1.59 minus 1.71), 0.01 in Germany (1.56 minus 1.55), 0.05 in Italy (1.89 minus 1.84), and approximately 0.02 in Poland (1.84 minus 1.82). Thus, households' wealth is expected to decrease in Austria and it will slightly increase in Germany, Italy, and Poland over the period 2020-2070.

Pension reforms modify these growth rates in line with the findings in Sánchez-Romero et al. (2024). Introducing minimum pension benefits (MinPB) lowers both per-capita national income and per-capita total consumption in every country. The effects are modest in Austria (−0.04 and −0.02 percentage points), Germany (−0.10 and −0.06), and Italy (−0.09 and −0.04), and stronger in Poland (−0.13 and −0.11). Therefore, the negative impact of the MinPB reform on per-capita national income growth is stronger in countries with lower pension replacement levels, that are either due to the pension formula or to higher unemployment rates.

Making benefits more progressive (PPB) increases per-capita national income in countries with higher pension replacement levels (0.08 in Austria and 0.11 in Italy) and yields modest or no gains in countries with lower pension replacement levels (0.03 in Germany and 0.0 in Poland). This outcome is consistent with increases in capital income per-capita under PPB, reflecting higher savings among higher-income households, who typically have greater propensities to save. In addition, the positive gap between per-capita national income and per-capita consumption indicates that the PPB reform raises household wealth

	Per capita national income I	Per capita labor income II	Per capita capital income III	Per capita total cons. IV	Per capita private cons. V	Per capita public cons. VI
Austria (Baseline)	1.59	1.54	1.76	1.71	1.76	1.61
Absolute difference with respect to baseline						
Minimum pension benefits (MinPB)	−0.04	0.00	−0.19	−0.02	−0.01	−0.03
Progressive pension benefits (PPB)	0.08	−0.03	0.31	0.00	0.00	0.00
Delayed retirement (DR)	0.30	0.23	0.50	0.16	0.11	0.28
Sustainability factor (SF)	0.14	0.00	0.49	0.01	0.00	0.05
Germany (Baseline)	1.56	1.51	1.66	1.55	1.60	1.48
Absolute difference with respect to baseline						
Minimum pension benefits (MinPB)	−0.10	−0.01	−0.29	−0.06	−0.03	−0.12
Progressive pension benefits (PPB)	0.03	−0.01	0.13	0.01	0.01	−0.01
Sustainability factor (SF)	0.06	0.00	0.20	0.02	0.01	0.05
Italy (Baseline)	1.89	1.86	1.97	1.84	1.82	1.90
Absolute difference with respect to baseline						
Minimum pension benefits (MinPB)	−0.09	0.02	−0.45	−0.04	−0.02	−0.10
Progressive pension benefits (PPB)	0.11	0.01	0.33	0.09	0.10	0.06
Poland (Baseline)	1.84	1.51	2.74	1.82	1.86	1.73
Absolute difference with respect to baseline						
Minimum pension benefits (MinPB)	−0.13	−0.04	−0.25	−0.11	−0.09	−0.19
Progressive pension benefits (PPB)	0.00	−0.01	−0.02	−0.01	−0.01	−0.01
Delayed retirement (DR)	0.19	0.24	0.20	0.18	0.14	0.26

Table 3: Macroeconomic impact of pension reforms over the period 2020–2070 (Average annual growth rates, in %)

relative to the baseline in all countries.

Delaying retirement (DR) generates the largest positive effects on economic growth. In Austria, it increases per-capita national income by 0.30 and per-capita total consumption by 0.16, driven by higher labor income (0.23) and capital income (0.50). In Poland, the corresponding gains amount to 0.19 and 0.18.

Introducing a sustainability factor (SF) in Austria produces a similar, though smaller, effect as delaying the statutory retirement age (DR). National income rises by 0.14, entirely supported by a higher capital income (0.49), and total consumption by 0.01. In Germany, the impact of this pension reform on per-capita national income growth is also positive (0.06), but smaller than in Austria because the corresponding increase in capital income Per capita is smaller (0.20). Given that the demographic characteristics in the two countries are very similar, this difference is explained by the smaller absolute change in the social contribution rate in Germany, which in turn reflects its lower pension replacement rate compared to Austria.

6.2 Fiscal and social benefits outcomes

Figure 2 presents simulation results on the impact of various pension reform scenarios—baseline, raising the minimum pension benefit (MinPB), progressive pension benefits (PPB), delayed retirement (DR), and the sustainability factor (SF)—on the retirement age (first row), retirees per worker (second row), pension-to-income ratio (third row), and contribution rate (fourth row) across Austria, Germany, Italy, and Poland. We chose the last three indicators because under the assumption that all pension claims are financed by current workers, the following relationship is satisfied

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

That is, the relative cost of the pension system per worker—i.e., contribution rate—depends on the total number of retirees per worker and the ratio between the average pension benefit and the average labor income.

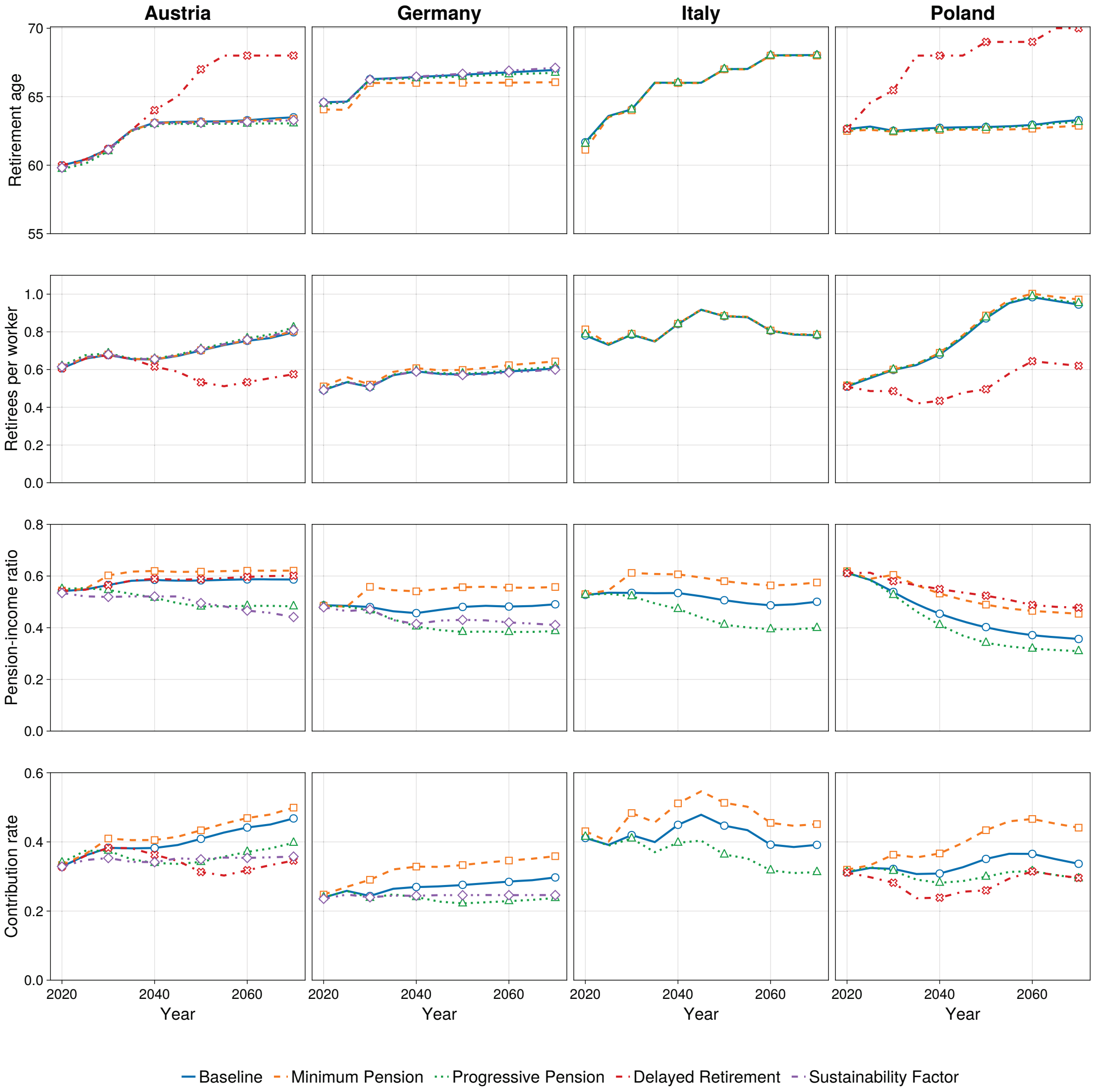

Figure 2: Retirement age, retirees per worker, average pension-to-average income ratio, and contribution rate from 2020 to 2070 in Austria, Germany, Italy, and Poland. *Source*: Authors' simulations. *Notes*: The pension-income ratio and the contribution rate are calculated using the total labor cost of a worker rather than the gross labor income. Pension reforms: Higher minimum pension benefit (MinPB), Progressive pension benefits (PPB), Delayed retirement (DR), and Sustainability factor (SF).

Examining the first two rows of Figure 2, we observe that only the delayed retirement

(DR) policy increases the average retirement age and reduces the retirees-to-workers ratio relative to the baseline scenario (blue solid lines). All other pension reforms yield a similar evolution of the average retirement age and the retirees-to-workers ratio as in the baseline scenario.

Several important findings emerge when analyzing the pension-to-income ratio (third row) in the baseline simulation. First, the pension-to-income ratio exhibits distinct dynamics across the four European countries, with values ranging between 40 and 60 percent of the total labor cost of a worker. In Austria and Germany, the pension-to-income ratio remains relatively stable or increases slightly over the period 2020–2070. In Austria, this increase is driven by the gradual rise in the effective retirement age, which reduces the penalty associated with early retirement. Italy and Poland—both operating notional defined contribution (NDC) systems—are projected to experience a decline in pension-to-income ratios, primarily due to rising life expectancy. In Italy, the decline is modest, partly offset by increases in the retirement age (see first row). In Poland, however, since the average retirement age remains largely unchanged, the pension-to-income ratio falls sharply from about sixty percent to below forty percent of the total labor cost of a worker. This indicates that an increasing share of Polish retirees may face a higher risk of poverty, despite being covered by a public pension system.

Contribution rate projections also differ by country. Austria and Germany are expected to face steadily rising contribution rates unless further reforms are implemented, though Germany appears more stable due to reforms already in place that delay retirement ages beyond 65.[9] In Italy and Poland, temporary imbalances between contributions and accumulated pension rights will cause contribution rates to rise in the short run, adding fiscal pressure.

The impacts of the reforms differ across pension systems. For instance, increasing the minimum pension benefit (MinPB, orange dashed lines) raises incomes among low-income retirees and consequently increases pension-to-income ratios and contribution rates, particularly in countries with high unemployment or low replacement rates. In Poland, where the pension-to-income ratio declines more rapidly, the contribution rate could increase from just above thirty percent to nearly fifty percent, assuming workers adjust only through changes in their retirement age.

By contrast, adopting a more progressive pension structure (PPB, dotted green lines) lowers the overall pension-to-income ratio, as higher-income earners—who are the most costly for the system due to their longer life expectancy—experience reductions in pension benefits, which in turn leads to lower contribution rates.

Policies that delay retirement (DR, dash-dotted red lines) have strong effects in Austria and Poland. Germany and Italy already incorporate such measures in their baseline systems. In defined-benefit (DB) systems, delayed retirement does not affect the pension-to-income ratio, as the pension formula is not adjusted by life expectancy. In contrast, in defined-contribution (DC) systems, delayed retirement increases pension-to-income ratios because the replacement rate is inversely related to life expectancy at retirement. Across both system types, however, postponing retirement reduces contribution rates, thereby alleviating fiscal pressures.

The introduction of sustainability factors (SF, purple dash-dotted lines), designed to stabilize social contribution rates over time, is projected to reduce the average pension-

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[9] The results are shown under the assumption of constant productivity growth. In practice, negative shocks could generate imbalances in the system. Thus, even in Germany, it is important to implement, or maintain, financial buffers to absorb potential adverse aggregate shocks.

to-income ratio from fifty-four percent and forty-eight percent in Austria and Germany, respectively, in 2020 to around forty-five percent and forty percent by 2070.[10] In Germany, the reduction is smaller than expected due to the continued increase in the statutory retirement age (see Table D.2 in Appendix D.2). However, because the burden of the pension adjustment is shared between workers by 75 percent and by retirees by 25 percent (α_{SF}), the contribution rate is expected to continue rising from 2030 onward.

6.3 Distributional outcomes

To study the distributional outcomes of the pension reforms, we use two indices: The internal rate of return (IRR) and the gender pension gap (GPG). The IRR is the implicit rate of return that contributors receive on their contributions, given the expected benefits they will receive from the system during retirement. GPG refers to the difference in average pension income between men and women, and is expressed as a percentage of men's average pension.

Intra-generational inequality To evaluate how current pension systems and alternative reform scenarios redistribute resources within birth cohorts, we compute the internal rate of return (IRR) from contributing to the pension system. The IRR is calculated by incorporating all relevant financial flows required to finance pension claims, rather than considering only the social contribution rate. The IRR is an important index, since it informs about the generosity of the system and is not affected by the level of contributions paid. The formula used for calculating the IRR of a cohort born in period t at age J_0 is

$$\sum_{j=J_0}^{J_\Omega-1} e^{-\int_{J_0}^{j}\mathbf{IRR}\,\mathrm{d}s}\, S(\mathbf{x}_{j,t+j-J_0}) \left[\mathbf{b}^*(\mathbf{x}_{j,t+j-J_0}) - \frac{B_{t+j-J_0}}{L_{t+j-J_0}}\,\mathbf{1}_{\{u=1\}}\, y^{prod}(\mathbf{x}_{j,t+j-J_0})\right] = 0.$$

Figure 3 illustrates the impact of various pension reform scenarios—raising the minimum pension benefit (MinPB), progressive pension benefits (PPB), delayed retirement (DR), and the sustainability factor (SF)—on the internal rate of return (IRR) across Austria, Germany, Italy, and Poland by gender and two socioeconomic levels (bottom vs. top). To clearly show the impact of implementing a reform, the vertical axis depicts the difference in the IRR between the pension reform and the baseline. Socioeconomic groups were selected to represent the two extreme socioeconomic groups within each gender. The lowest socioeconomic group represents agents in the lowest income quintile who have less than tertiary education, while the highest socioeconomic group represents those in the highest income quintile, who attained tertiary education.

Analyzing pension reforms we can see that raising the minimum pension benefit (yellow dashed line) increases the internal rate of return (IRR) of the lowest socioeconomic status (SES) group—particularly women—as their contributory pension benefits fall below the new minimum threshold. Conversely, it reduces the IRR for both genders in the highest SES group, as they have to pay higher pension contributions (see the pension contribution rate in Figure 2). The magnitude of the effects of this policy on the IRR also depends on the replacement rate level. In Germany and Poland, this reform has a positive impact on men in the lowest SES group because these pension systems have

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[10] Note that notional defined-contribution (NDC) systems are inherently structured to maintain stable contribution rates.

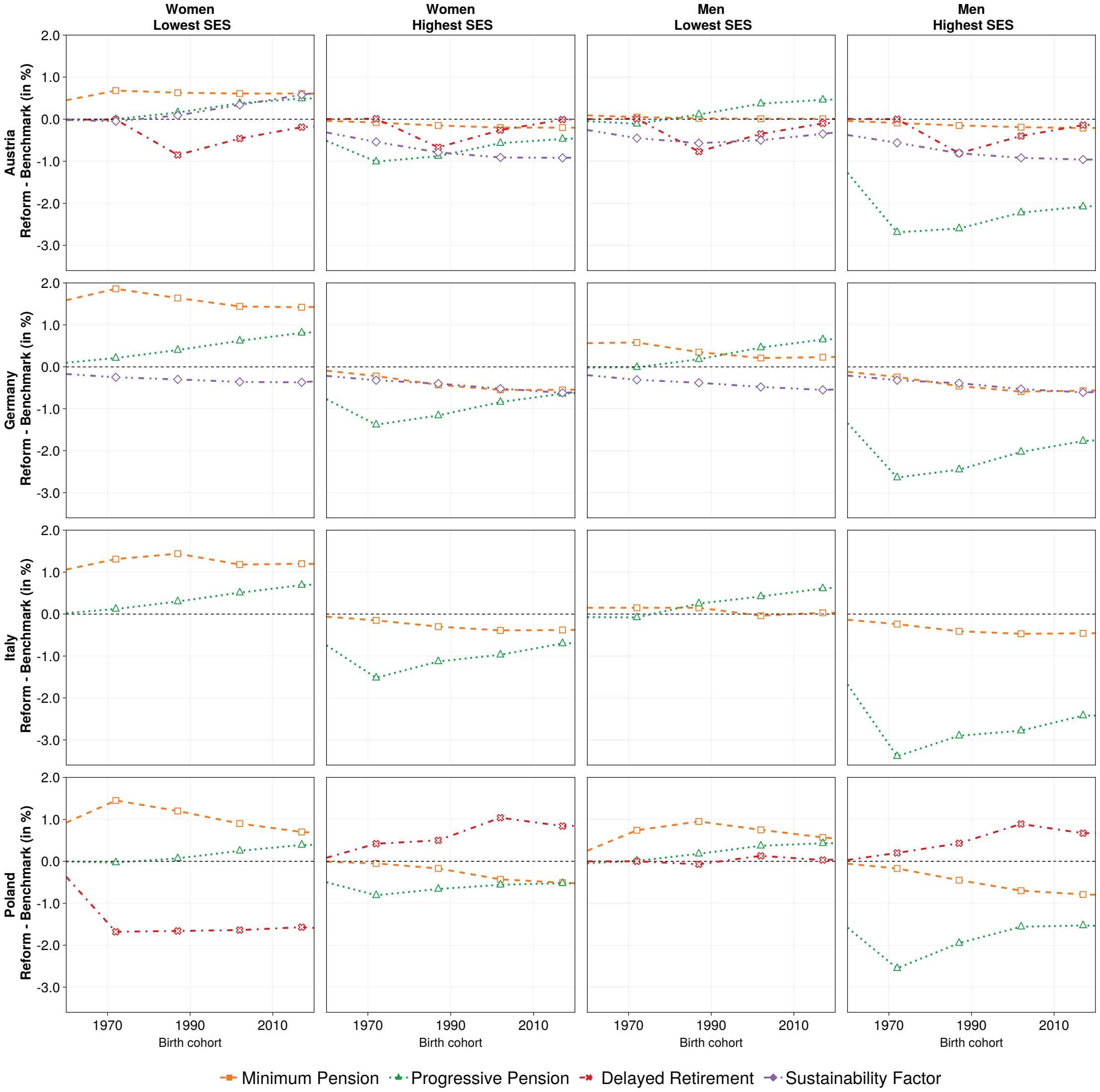

Figure 3: Difference in the internal rate of return (IRR) between the pension reform and the baseline by country, birth cohort, and socioeconomic group (lowest and highest). *Source*: Authors' simulations. *Notes*: Pension reforms: Higher minimum pension benefit (MinPB), Progressive pension benefits (PPB), Delayed retirement (DR), and Sustainability factor (SF). The lowest SES group represents individuals in the bottom income quintile among those with less than tertiary education, while the highest SES group includes individuals in the top income quintile among those with tertiary education.

relatively low replacement rates. In contrast, its effect is negligible in Austria and Italy, where pension benefits are often already higher than the new minimum threshold.

Implementing a progressive pension benefit structure (dotted green line) increases the IRR for individuals in the lowest SES groups and reduces it for those in the highest SES groups. The gains are more pronounced for women than for men, whereas the losses are greater for men than for women. The magnitude of these effects is driven by the income adjustment introduced through this policy.

In Austria, delaying the retirement age (dashed-dot red line) decreases the IRR across all groups. In Poland, however, this policy benefits men and women in the highest SES group, as they face lower pension contributions and, by postponing retirement, experience an increase in their pension replacement rate. For women in the lowest SES group, the reform has a negative impact because additional years of work do not translate into higher pension benefits; they continue to receive only the minimum pension. In both countries, the decline in the IRR is more pronounced for women in the lowest SES group, thereby exacerbating inequality.

Introducing a sustainability factor in Austria reduces the IRR for all groups, as it entails a reduction in pension benefits, except for women in the lowest SES group, who continue to receive the minimum pension benefit and pay lower contributions after this reform. It is important to recall that the minimum pension benefit level in Austria—which is approximately thirty percent of the total labor cost of a worker—is the highest among the four countries analyzed. In Germany, the impact of introducing the sustainability factor is slightly negative for all SES groups, as the reduction in pension contributions is not large enough to offset the reduction in pension benefits and the minimum pension benefits level is lowest among all four countries.

Gender pension gap (GPG) by educational attainment Figure 4 shows the evolution of the GPG from 2020 to 2070 across Austria, Germany, Italy, and Poland, distinguishing between low- and high-educated groups under the baseline and four different pension reform scenarios. To calculate the gender pension gap we consider all women and men regardless of the number of years contributed to the pension system.[11]

Before analyzing the figure, it is important to note that conditional employment rates by gender, education, and number of children are fixed over time (see Section 3.1). This assumption is consistent with the results of Blundell et al. (2025), who show that the wage penalty remains strongly associated with motherhood, even among women who postpone childbearing. Consequently, changes in education-specific employment rates across cohorts are driven in our model by changes in fertility patterns. According to Eurostat (2023), the total fertility rate (TFR) from 2020 to 2100 will rise from 1.435 to 1.636 in Austria, from 1.531 to 1.675 in Germany, from 1.244 to 1.557 in Italy, and from 1.395 to 1.665 in Poland. As a result, women's employment rates by education are expected to worsen due to the projected increasing childbearing.

Our baseline simulation results yield three main findings. First, in 2020 the GPG is around sixty percent in Italy and Poland, compared to about forty percent in Austria and Germany. In both Austria and Poland, highly educated women show a higher pension gap than low educated women. These values are larger than the gender wage gap, particularly for women with low education, which points to the greater employment disadvantages linked to childbearing (see Table 4 below). Second, the GPG gradually narrows over time in countries running NDC systems (Italy and Poland), as an increasing share of individuals qualify for the minimum pension benefit. Third, higher female educational attainment does not substantially reduce the gap. This is because conditional gender pension gaps are quite similar across education groups (see Table A.6 in Appendix A.5), reflecting the fact that the gender wage gap is larger among highly educated individuals than among those with less than tertiary education.

Our simulation results indicate that pension reforms aimed at reducing inequality

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[11] Because most reports restrict the calculation of the gender pension gap to individuals eligible for contributory pension benefits, their estimates are systematically smaller than the gaps generated by our simulations.

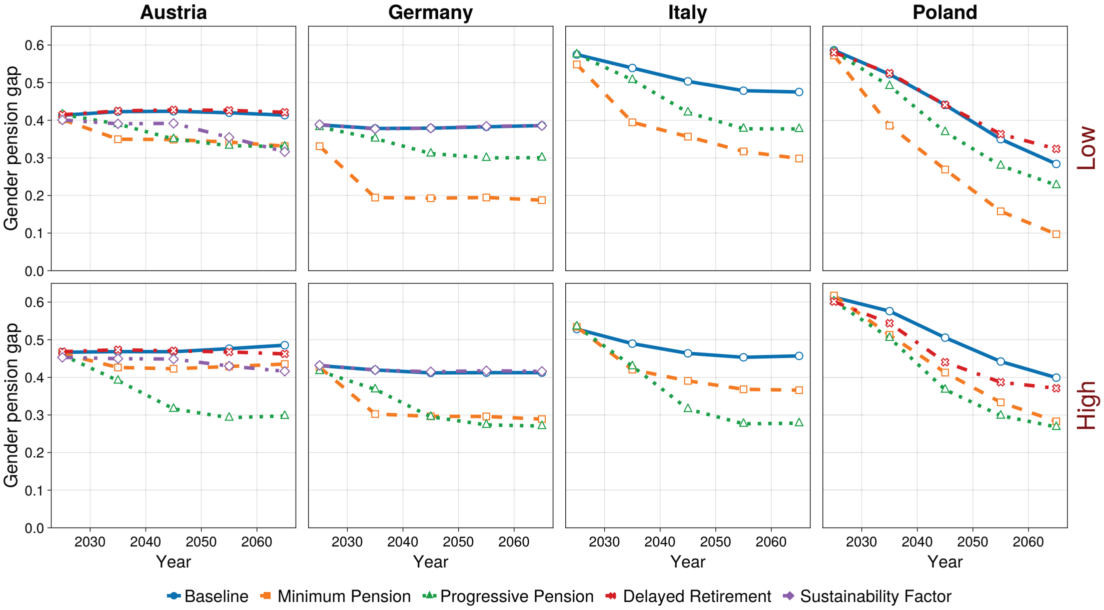

Figure 4: Gender pension gap by educational attainment (low vs. high) from 2020 to 2070 in Austria, Germany, Italy, and Poland. *Source*: Authors' simulations. *Notes*: Pension reforms: Higher minimum pension benefit (MinPB), Progressive pension benefits (PPB), Delayed retirement (DR), and Sustainability factor (SF).

	Austria	Germany	Italy	Poland
Low education	0.176	0.242	0.126	0.189
High education	0.337	0.409	0.375	0.454

Table 4: Conditional gender wage gap by education level and country. Source: See data from Table A.4.

also tend to decrease the gender pension gap (GPG). By contrast, for reforms targeting financial sustainability, the effect on the GPG depends on features of the pension system and the level of the minimum pension benefit. More specifically, increasing the minimum pension benefit (MinPB)—represented by the squared yellow dashed lines—substantially lowers the GPG, particularly for women with low education. Following this reform, the gap declines to roughly 30 percent in Austria and Italy, falls below 20 percent in Germany, and approaches 10 percent in Poland. The magnitude of the reduction reflects that a larger share of women qualify for the minimum pension benefit in countries with lower pension replacement rates and more unstable labor markets. For highly educated women, the reduction in the GPG is more limited because their lifetime earnings are higher. In this group, the gap decreases only slightly in Austria, falls below 30 percent in Germany and Poland, and drops below 40 percent in Italy.

Implementing a progressive pension benefit formula (PPB)—triangle green dotted lines—also narrows the GPG. However, unlike the MinPB reform, the PPB leads to a larger reduction in the GPG among highly educated individuals than among those with lower levels of education. In addition, the magnitude of the reduction is greater in countries with higher pension replacement rates, such as Austria and Italy, because the absolute decline in the pension replacement rate is more substantial when the average pension replacement level is higher.

Delaying retirement age (DR)—crossed red lines—has almost no effect on the gender pension gap for both low- and high-educated women in Austria. However, in Poland it reduces the gap for high-educated women compared to the baseline, as this policy assumes that the statutory retirement ages across gender converge.

Finally, our simulation results show that introducing a sustainability factor (SF)—represented by the diamond purple lines—reduces the GPG in Austria but not in Germany. This difference arises because, in Austria, the higher minimum pension benefit level leads to a larger share of women qualifying for the minimum benefit after the reform, whereas in Germany the corresponding effect is much smaller.

6.4 Welfare

To complete the analysis, we assess the welfare consequences of each pension reform. To do so, we compute welfare gains at birth—measured as consumption equivalent variation (CEV)—under the implementation of our four different pension reforms. The CEV measures the percentage change in the baseline consumption path that makes the expected lifetime utility in the status quo equal to the expected lifetime utility in the pension reform (Nishiyama and Smetters, 2014). A negative value implies a welfare loss, whereas a positive value means welfare gains. Figure 5 shows how different pension reforms (SF, DR, MinPB, PPB) affect welfare across birth cohorts in four countries (Austria, Germany, Italy, Poland), split by gender and two extreme learning ability groups (lowest learning ability quintile vs. highest learning ability quintile).

Our simulation results indicate that an increase in the minimum pension benefit (MinPB) reduces disposable labor income, encourages earlier retirement, and raises pension benefits for individuals in the lowest ability group (see orange dashed lines). The welfare effect is positive for those who benefit from higher pension entitlements, namely women in the lowest ability quintile in all four countries and men in the lowest ability quintile in Austria, Germany, and Poland. In contrast, in Italy, men in the lowest ability quintile retire earlier, which negatively affects their pension benefits, as they do not qualify for the minimum pension benefit. Individuals in the highest ability quintile experience welfare losses, as their disposable income declines and their pension benefits may decrease if they choose to retire earlier.

Implementing a progressive pension benefit formula (PPB) generates welfare gains for both men and women in the lowest socioeconomic status (SES) groups, while it results in welfare losses for individuals in the highest SES groups. These welfare losses and gains are associated with corresponding reductions and increases in the pension replacement rate.

The welfare effect of delaying the retirement age (DR) depends on the pension system in place. In pay-as-you-go defined-benefit (PAYG-DB) systems, the number of contribution years required to qualify for the full pension replacement rate increases in line with the statutory retirement age. As a result, this policy does not raise pension benefits and instead generates welfare losses in Austria (see the red dashed lines in Figure 5). Only future cohorts benefit from this policy, owing to continued increases in life expectancy and lower pension contribution rates (see the red dashed line in the top-right panel). In contrast, in notional defined-contribution (NDC) systems, such as Poland's, pension benefits are closely linked to expected remaining lifetime at retirement. Consequently, an increase in the retirement age leads to higher pension benefits and welfare gains. How-

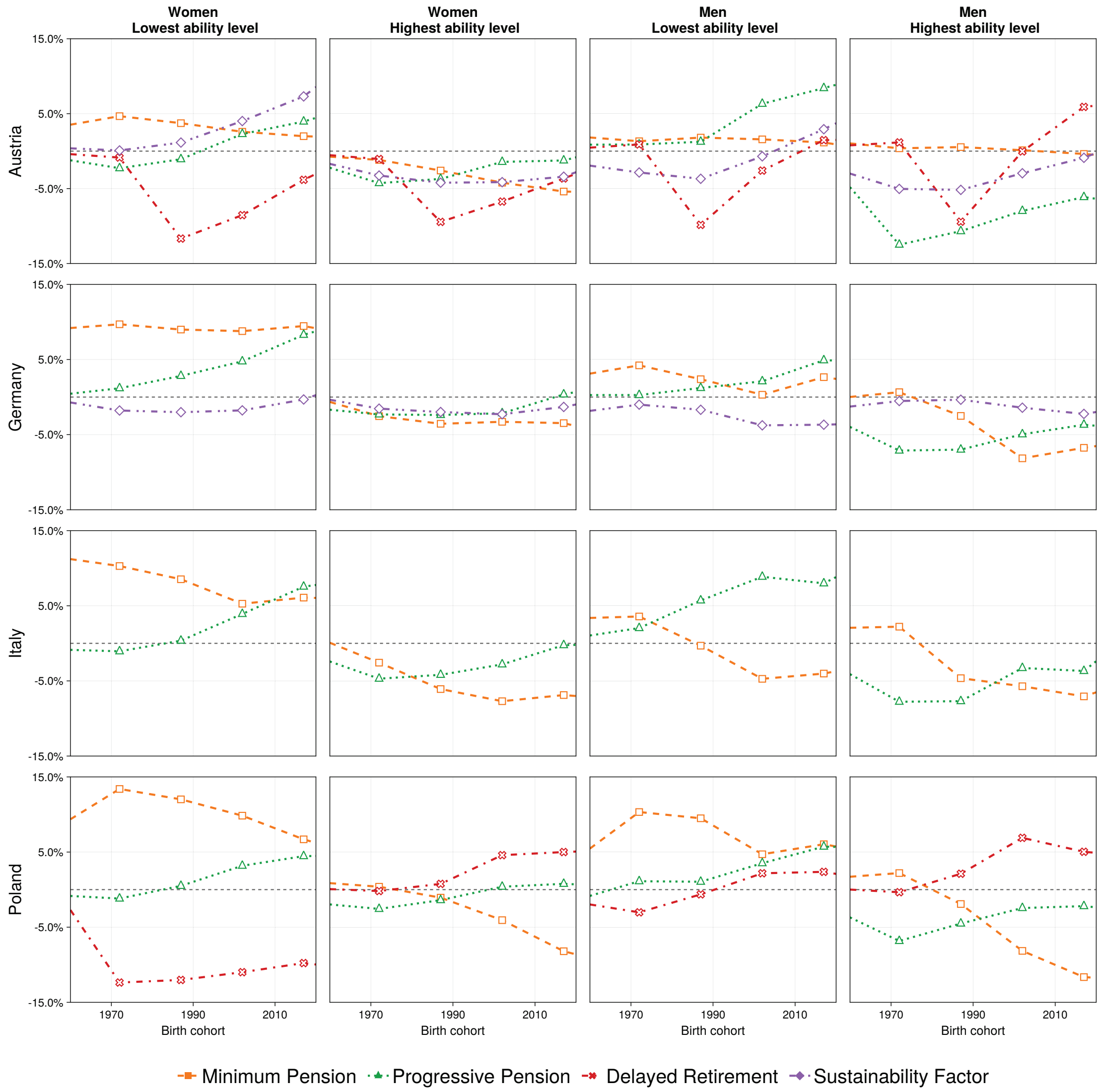

Figure 5: Welfare effects (measured as consumption equivalent variation, CEV) of pension reforms by country, birth cohort, gender, and learning ability level (bottom and top quintile groups). *Source*: Authors' simulations. *Notes*: Pension reforms: Higher minimum pension benefit (MinPB), Progressive pension benefits (PPB), Delayed retirement (DR), and Sustainability factor (SF). The lowest SES group represents individuals in the bottom income quintile among those with less than tertiary education, while the highest SES group includes individuals in the top income quintile among those with tertiary education.

ever, for individuals who continue to qualify for the minimum pension benefit even after delaying retirement, this policy may still result in welfare losses. See men and women in the lowest ability level.

Finally, the introduction of a sustainability factor (SF) leaves almost all individuals worse off, as they experience a continuous decline in pension benefits that is not fully offset by the reduction in contribution rates. The main exception concerns Austrian women in the lowest ability group. This group benefits from lower contribution rates, due to the declining cost of the pension system relative to the baseline, while their minimum pension benefit remains unchanged.

7 Conclusion

In this paper we have offered a unified framework to study the sustainability and equity of different pension systems. Our model allows for heterogeneous, optimizing households that react to the pension set up. Households are defined by innate abilities that will determine their educational choice and hence also influence on their labor income, fertility, retirement decisions, health and mortality. Households are also exposed to various shocks during their life course (unemployment, health, and mortality) that are assumed to depend on their economic and demographic characteristics. We allow for varying household size and two genders and assume realistic demographic parameters. Our calibration process is complex, as it combines microsimulation with Bayesian melding.

We choose to investigate four European countries (Austria, Germany, Italy, and Poland) that differ in their pension system and replacement rates. For each country, we implement up to four pension reforms that are evaluated at various dimensions characterizing macroeconomic and equity indicators. Figure 6 summarizes our findings.

Among the four pension reforms, we find that increasing the minimum pension benefits (MinPB) negatively affects most macro-economic indicators, such as national income and consumption, and increases the contribution rates. It however positively affects the pension to income ratio. Moreover, increasing the MinPB has positive effects on equity, as it reduces the inequality across SES groups. It increase the IRR for low SES groups and decreases the IRR for high SES groups. The gender pension gap (GPG) is reduced for both SES groups.

Introducing progressive pension benefits (PPB) has rather positive effects on the sustainability and equity indicators. This reform increases national income and consumption, and reduces the contribution rate. Only the pension-to-income ratio declines. PPB raises the IRR for low SES groups and lowers it for high SES groups, thereby fostering equity. In addition, the gender pension gap (GPG) is reduced for both SES groups.

Delaying the retirement age mainly fosters the sustainability of the pension system, but it increases inequality between SES groups. Introducing a sustainability factor has similar results by mainly fostering sustainability but making equity worse.

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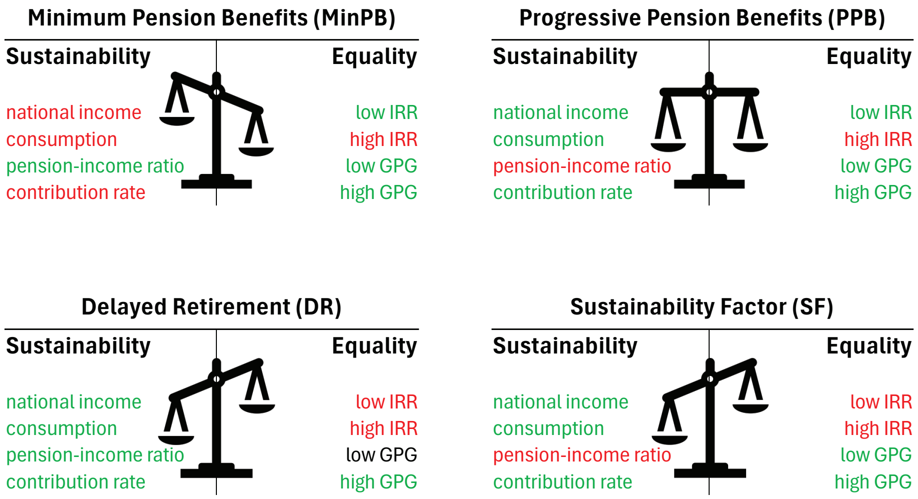

Figure 6: The tradeoff between sustainability and equality across pension reforms. Red expressions stand for negative and green expressions for positive effects on the respective indicators.

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A Parametrization, Data and Microsimulations

A.1 Parametrization

Table A.1 summarizes the main parameter values of the model, which have not been calibrated.

Variable Name	Symbol	Austria	Germany	Italy	Poland	Description
Demographics						
Maximum possible age	J_Ω	98	98	98	98	
Minimum possible retirement age	$\underline{J}$	55	55	55	55	
Maximum possible retirement age	$\overline{J}$	71	71	71	71	
Preferences						
Subjective discount factor	β	0.99	0.99	0.99	0.99	Factor reflecting time preference
Risk aversion	γ	1	1	1	1	Braun et al. (2009)
Retirement preference elasticity	α_2	-2.0	-2.0	-2.0	-2.0	
Prices						
Productivity growth rate	g_Z	0.0150	0.0150	0.0150	0.0150	Annual labor-augmenting technological growth rate
Capitalization factor of pension wealth	$\hat{R}$	$1+n+g$	$1+n+g$	$1+n+g$	$1+n+g$	
Capitalization factor of wealth	$\tilde{R}$	1.0350	1.0350	1.0350	1.0350	
Unemployment replacement rate	ϕ_U	0.33	0.33	0.33	0.33	
Human capital						
Returns to education	γ_h	0.66	0.66	0.66	0.66	Cervellati and Sunde (2013)
Age-specific productivity						
Women: Scale	β_0	-1.25631	-1.85290	-2.61778	-2.22996	See Section A.5
Women: Age	β_1	0.03936	0.07269	0.13031	0.11080	
Women: Age^2	β_2	-0.00044	-0.00088	-0.00161	-0.00153	
Men: Scale	β_0	-1.74785	-4.13022	-1.70587	-1.88069	
Men: Age	β_1	0.08668	0.19812	0.08796	0.10413	
Men: Age^2	β_2	-0.00094	-0.00222	-0.00090	-0.00135	
Unemployment probabilities						
Women: Elasticity	β^π	-0.6243	-0.7749	-0.3314	-0.4693	See Section A.4
Women: Scale low-skilled	α^π_{low}	56.53	75.28	19.04	45.78	
Women: Scale high-skilled	α^π_{high}	91.10	130.38	61.42	178.01	
Men: Elasticity	β^π	0.0	0.0	0.0	0.0	
Men: Scale low-skilled	α^π_{low}	28.07	31.26	29.12	39.00	
Men: Scale high-skilled	α^π_{high}	62.29	85.96	48.02	139.85	
Taxes						
Value added tax	τ^c	0.200	0.190	0.220	0.230	
Capital income tax	τ^k	0.275	0.264	0.260	0.190	
Labor income tax	$T(y)$					
minimum taxable income (relative to the mean income)	$y^{\min}$	0.33	0.33	0.33	0.33	See Section A.6
maximum tax	$\overline{\tau}$	0.3840	0.5722	0.5188	0.3147	
degree of progressivity	a	12.1240	15.0000	2.5911	15.3170	

Table A.1: Non-calibrated model parameters

Following Hurd and McGarry (2002), we assume a subjective discount factor of 0.99, reflecting an annual discounting of future consumption by 1 percent, excluding mortality risks. We use a consumption utility function with constant relative risk aversion equal to one, resulting in log-utility, multiplied by the number of household members—measured in equivalent scale—similar to Braun et al. (2009). We fix the retirement elasticity parameter at $\alpha_2 = 2$ for all countries. We found that this value performs well at replicating differences in retirement ages between education groups and genders, for all four different countries (see Section B).

A.2 Fertility Profiles

To construct future age-specific fertility rates for low- and high-skilled individuals, we use data from the Wittgenstein Centre Human Capital Explorer on age-specific fertility rates, age-specific survival ratios by education, the population size by education, total fertility rates, and total fertility rates by education. However, this database does not provide information on fertility by parity, or the number of times a woman has given birth to a child, which is necessary for understanding the economic challenges faced by individuals of different family sizes. To construct these fertility profiles by parity, we assume that the fertility rate of women born in year t with educational level e at age j is a realization of a temporal Poisson process whose mean is the observed cohort-education-age-specific fertility rate f_{tej}. Under this assumption, we can construct the age-specific fertility transition matrix of women born in year t with education e at age j as follows

$$\mathbf{F}_{tej} = \begin{bmatrix} e^{-f_{tej}} & 0 & \dots & 0 \\ f_{tej}e^{-f_{tej}} & e^{-f_{tej}} & \dots & 0 \\ \frac{(f_{tej})^2}{2!}e^{-f_{tej}} & f_{ejt}e^{-f_{tej}} & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 1-\sum_{i=0}^{\bar{n}-1}\frac{(f_{tej})^i}{i!}e^{-f_{tej}} & 1-\sum_{i=0}^{\bar{n}-2}\frac{(f_{tej})^i}{i!}e^{-f_{tej}} & \dots & 1 \end{bmatrix}, \tag{30}$$

where $\bar{n}$ denotes the maximum number of children. Note that for the cell $\mathbf{F}_{tej}[u, v]$, the $v-$th column corresponds to the state of having $v-1$ children, while the $u-$th row represents having $u-v$ additional children. Therefore, the cell $\mathbf{F}_{tej}[1, 1]$ gives the probability of not having a child, conditional of not having any children. Similarly, $\mathbf{F}_{tej}[2, 1]$ is the probability of having a first child conditional of not having any children, and $\mathbf{F}_{tej}[3, 2]$ is the probability of having one additional child, conditional on already having one child.

A.3 Health transition probabilities

For the sake of clearer notation, we omit in the following equations dependencies on gender g and education e. To obtain the transition probabilities from the prevalence rates of disability, we first assume that the mortality hazard rate of individuals with bad health is ν times larger than the mortality hazard rate of individuals in good health, i.e. $-\log\pi^S(t, j, h = 2) = -\nu\log\pi^S(t, j, h = 1)$. We set the value of ν at 1.5 following Forman-Hoffman et al. (2015). Using this, since the overall mortality hazard rate is the weighted sum of the mortality hazard rates in each health state times the probability of being in each state, i.e.

$$\log\pi^S(t, j) = P_{tj}\cdot\log\pi^S(t, j, h = 2) + (1 - P_{tj})\cdot\log\pi^S(t, j, h = 1),$$

we can express the survival probabilities in each health state in terms of the population wide conditional survival probability

$$\pi^S(t, j, h = 1) = \left(\pi^S(t, j)\right)^{1/(1+P_{tj}(\nu-1))} \tag{31}$$

$$\pi^S(t, j, h = 2) = \left(\pi^S(t, j)\right)^{\nu/(1+P_{tj}(\nu-1))}. \tag{32}$$

For $\nu > 1$, equations (31) and (32) imply that the difference between the population-wide conditional survival probability ($\pi^S(t,j)$) and the conditional survival probability in good health ($\pi^S(t,j,h=1)$) becomes larger, the greater is the observed prevalence rate of disability. Hence, since the prevalence rate usually increases with age, most of the observable differences in life expectancy between individuals in good health and in bad health will become apparent at old age.

We determine the probability of moving from a state of poor health to a state of good health by using a dynamic equation for the prevalence rate, along with equations (31) and (32), and the frailty index: Given the definition of the prevalence rate, we can write the dynamic equation of the prevalence rate using the transition probabilities for health as follows:

$$\begin{aligned}\frac{P_{tj+1}}{P_{tj}} &= \frac{\mathbf{N}_{tj+1}(h=2)}{\mathbf{N}_{tj}(h=2)}\frac{\mathbf{N}_{tj}}{\mathbf{N}_{tj+1}} \\ &= \pi^h(h=2|t,j,h=1)\frac{\pi^S(t,j,h=1)}{\pi^S(t,j)}\frac{\mathbf{N}_{tj}(h=1)}{\mathbf{N}_{tj}(h=2)} \\ &+ (1-\pi^h(h=1|t,j,h=2))\frac{\pi^S(t,j,h=2)}{\pi^S(t,j)}\frac{\mathbf{N}_{tj}(h=2)}{\mathbf{N}_{tj}(h=2)},\end{aligned}$$

where we use that stocks in the next period can be expressed as stocks in the current period times transition rates and survival. Multiplying both sides of the equation by P_{tj} gives

$$\begin{aligned}P_{tj+1} &= \pi^h(h=2|t,j,h=1)\frac{\pi^S(t,j,h=1)}{\pi^S(t,j)}(1-P_{tj}) \\ &+ (1-\pi^h(h=1|t,j,h=2))\frac{\pi^S(t,j,h=2)}{\pi^S(t,j)}P_{tj}.\end{aligned}$$

Rearranging terms yields

$$\begin{aligned}\pi^h(h=1|t,j,h=2) &= 1 + \frac{1-P_{tj}}{P_{tj}}\pi^h(h=2|t,j,h=1)\frac{\pi^S(t,j,h=1)}{\pi^S(t,j,h=2)} \\ &- \frac{P_{tj+1}}{P_{tj}}\frac{\pi^S(t,j)}{\pi^S(t,j,h=2)}.\end{aligned}$$

A.4 Unemployment transition probabilities

We compute the unemployment transition probabilities by number of children and educational attainment in two steps. First, we calculate the probabilities for each gender and education level $e \in \{l,h\}$ using the steady-state employment equilibrium condition of a search-matching model (Mortensen and Pissarides, 1994):

$$Emp_e^g = \frac{\pi^u(u=1|g,e,u=2)}{\pi^u(u=2|g,e,u=1)+\pi^u(u=1|g,e,u=2)} \tag{33}$$

$$\pi^u(u=2|g,e,u=1) = \frac{1-Emp_h^g}{Emp_h^g}\pi^u(u=1|g,e,u=2), \tag{34}$$

where Emp_e^g is the employment rate of individuals aged 25–64 of gender g and skill level e. Table A.2 summarizes the labor market characteristics for the selected EU countries that will be used in the model.

	Employment rate, *Emp*		Job finding rate, $\pi^u(u = 1 \mid u = 2)$	Separation rate, $\pi^u(u = 2 \mid u = 1)$		
Skill level	Low	High	Avg.	Avg.	Low	High
Austria						
Women	0.812	0.877	0.196	0.039	0.045	0.028
Men	0.863	0.932	0.217	0.028	0.035	0.016
Germany						
Women	0.795	0.874	0.175	0.038	0.045	0.025
Men	0.867	0.946	0.202	0.024	0.031	0.012
Italy						
Women	0.572	0.808	0.109	0.057	0.081	0.026
Men	0.817	0.879	0.148	0.029	0.033	0.020
Poland						
Women	0.730	0.921	0.130	0.032	0.048	0.011
Men	0.878	0.962	0.180	0.018	0.025	0.007

Table A.2: Average labor market statistics by gender and skill group. Source: Employment rates by gender and educational attainment are obtained from Eurostat—Employment by educational attainment level `lfsi_educ_a` (annual data, 2022). Low-skilled workers include individuals with less than tertiary education (ISCED levels 0–4), whereas high-skilled workers hold tertiary qualifications (ISCED 5–8). Job-finding rates are computed as the average for the period 2011–2023 using Eurostat's `lfsi_long_a` dataset. Job-separation rates by gender and skill level are derived using (34). The overall (average) job-separation rate by gender is calculated as the weighted mean of separation rates, with population weights by gender and skill level taken from Eurostat—Labour market transitions (annual data, 2022).

Second, we assume that having children imposes labor income penalties on women—but not on men—through two channels. First, the presence of a newborn temporarily increases the risk of job separation rate, defined as the number of workers leaving their jobs compared to the total number of workers, by forty percent (Kleven et al., 2024). Second, we assume the separation rate of women with skill level e, at age j, and n children younger than age 6 living in the household in country i follows a logistic distribution

$$\operatorname{logit}(\pi_i^u(u = 2 \mid g, e, n_6, u = 1)) = \log \alpha_{e,i}^{\pi} + n_6\, \beta_i^{\pi}, \tag{35}$$

where n_6 is the number of children below age 6 living in the household and β_π is our variable of interest. Then, using the estimated value of β_π and combining (35), with the number of children below age 6 obtained from the microsimulation for the 1960 birth cohort, and with the job separation rate by skill level in Table A.2, we derive $\alpha_{\pi,e}$. To calculate β_π, we collected annual data on prime-age labor force participation rate by sex, household type, and presence of children for the period 2012–2022 from ILOSTAT. [12] The estimated parametric components of the logistic distribution, done using year fixed-effects, are shown in Table A.3, where β^π captures the impact of the number of children on the separation rate and α_e^π is a scale factor that matches the separation rate by skill level displayed in Table A.2.

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[12] See the International Labour Organization (ILO) database at https://ilostat.ilo.org/data/.

	Women			Men		
	β^{π}	α_e^{π}		β^{π}	α_e^{π}	
Skill level		Low	High		Low	High
Austria	-0.6243	56.53	91.10	0.0	28.07	62.29
Germany	-0.7749	75.28	130.38	0.0	31.26	85.96
Italy	-0.3314	19.04	61.42	0.0	29.12	48.02
Poland	-0.4693	45.78	178.01	0.0	39.00	139.85

Table A.3: Parametric components of the separation rate function. Source: Own calculation using job separation rates by skill level from Table A.2 and job separation rates by number of children below age 6 from ILO. Low-skilled workers include individuals with less than tertiary education (ISCED levels 0–4), whereas high-skilled workers hold tertiary qualifications (ISCED 5–8).

A.5 Labor income profiles

In order to construct income profiles for the microsimulation model, we begin by collecting information on earnings advantages by skill level from the OECD report Education at a Glance 2023. To construct Table A.4 below, we use the information on educational attainment by age group and gender contained in Table X3.A1.3 and on actual earnings of full-time full-year workers by age group, educational attainment, and gender in Table X3.A4.5.

	Total		Women		Men	
Skill level	Low	High	Low	High	Low	High
Austria	83.1	125.7	73.2	105.1	87.8	138.7
Germany	80.8	135.2	69.2	103.2	86.2	151.4
Italy	88.4	134.7	75.4	111.5	94.0	158.3
Poland	81.2	129.1	71.4	113.4	88.1	153.9

Table A.4: Relative earnings of workers compared to the average worker by gender, skill level, and country (Ref: Average worker aged 25–64=100). Source: OECD report: Education at a Glance 2023.

Table A.4 presents the relative earnings advantage with respect to the average worker associated with being in either the low-skilled or high-skilled group by gender across selected European countries. In the next step, we use the information from Table A.4 to re-scale the normalized total labor income profiles from the AGENTA database (Istenič et al., 2016) to generate labor income profiles by gender and skill level for selected European countries. The re-scaled labor income profiles represents an average for both employed and non-employed individuals by gender and skill level. However, we only need the labor income of employed workers. To get this, we divide the profiles by the fraction of people employed at each age using the generated employment profiles $\hat{u}_{itj}$ from the microsimulations.

Table A.5 presents the estimated coefficients of regression (28) for men and women across four European countries. Since women's labor income profiles in 2010 depend on the number of children under the age of six, we focus on the 1977 birth cohort. This cohort is obtained by subtracting from 2010 the sum of the mean age at childbearing—approximately 30 years—and the average age of young children, about 3 years. The age range 30–55 is selected because age 30 is insignificantly influenced by the labor market entry age in the model, while age 55 is the earliest age at which individuals are allowed to retire in the model.

	Austria		**Germany**		**Italy**		**Poland**	
	Women	Men	Women	Men	Women	Men	Women	Men
β_0	-1.78413	-1.37598	-1.06980	-3.00035	-0.78203	-0.58228	-1.02987	-1.73039
	(0.210)	(0.103)	(0.193)	(0.081)	(0.138)	(0.087)	(0.078)	(0.077)
β_1	0.06374	0.07074	0.03501	0.14610	0.04548	0.03569	0.05472	0.09801
	(0.010)	(0.005)	(0.009)	(0.004)	(0.007)	(0.004)	(0.004)	(0.004)
β_2	-0.00072	-0.00077	-0.00045	-0.00164	-0.00065	-0.00031	-0.00089	-0.00129
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$Skill$	0.54133	0.53399	0.51108	0.59527	0.67890	0.62001	0.74642	0.62839
	(0.011)	(0.006)	(0.011)	(0.005)	(0.008)	(0.005)	(0.004)	(0.004)
N	52	52	52	52	52	52	52	52
R^2	0.978	0.995	0.979	0.997	0.994	0.997	0.999	0.998

Table A.5: Estimated coefficients of the log labor income of employed workers profile, $\log(\hat{y}_{itj})$, for individuals aged 30–55 in the 1977 birth cohort, by gender, across four European countries. *Notes*: Labor income profiles of employed workers are standardized relative the average labor income of employed workers between ages 30 and 49.

Table A.6 reports the gender-wage ratio and skill-premiums at age 40 in Austria, Germany, Italy, and Poland that results from the estimated coefficients reported in Table A.5.

	Austria			**Germany**		
	low	high	Skill premium	low	high	Skill premium
Women	0.674	1.159	1.720	0.682	1.138	1.669
Men	1.232	2.102	1.706	1.233	2.234	1.812
Gender wage ratio	0.547	0.551		0.553	0.509	
	Italy			**Poland**		
	low	high	Skill premium	low	high	Skill premium
Women	1.004	1.980	1.972	0.678	1.422	2.097
Men	1.411	2.622	1.858	1.225	2.282	1.863
Gender wage ratio	0.712	0.755		0.553	0.623	

Table A.6: Gender wage ratios by skill level and skill premiums by gender at age 40 for Austria, Germany, Italy, and Poland. Skill premium is computed as the ratio between high and low. Gender wage gap is computed as the ratio between low and high. *Source:* Own calculations. *Notes:* Low-skilled workers include individuals with less than tertiary education (ISCED levels 0–4), whereas high-skilled workers hold tertiary qualifications (ISCED 5–8).

A.6 Taxes

We include three main taxes: value added tax (indirect tax), capital income tax, and personal income tax. Both the value added tax rate (τ^c) and capital income tax rate (τ^k) are assumed to be constant. The value added tax for Austria, Germany, Italy, and Poland is taken from European Commission VAT rates. Capital income taxes for the four countries are taken from Tax Foundation Europe. Personal income tax is assumed to be progressive and, for tractability, that the marginal tax rate is bounded and monotonically increasing

$$\tau(y^{\text{tax}}/\bar{y}) = \begin{cases} 0 & \text{for } y^{\text{tax}} \leq y^{\text{min}}, \\ \tau^{\max}\left(1 - e^{-a\, y^{\text{tax}}/\bar{y}}\right) & \text{for } y^{\text{tax}} > y^{\text{min}}. \end{cases}$$

where $\tau^{\max}$ is the maximum marginal income tax, $y^{\min}/\bar{y}$ is the minimum taxable income relative to the average labor income y, and a reflect the degree of progressivity. The total and average personal income tax paid by an individual with a personal income tax of y^{tax} are, respectively, given by

$$\frac{T(y^{\text{tax}})}{y^{\text{tax}}} = \int_0^{y^{\text{tax}}} \frac{\tau(y/\bar{y})}{y^{\text{tax}}}\, \mathrm{d}y = \tau^{\max}\left(1 - \frac{y^{\min}}{y^{\text{tax}}}\right)\left(1 - \frac{e^{-a\, y^{\min}/\bar{y}} - e^{-a\, y^{\text{tax}}/\bar{y}}}{a(y^{\text{tax}} - y^{\min})/\bar{y}}\right).$$

We set the minimum taxable income at 0.33 of the average labor income, which coincides with the rate of other social benefits, ϕ_U, and is therefore exempt from personal income taxation. To calibrate the parameters $(a, \tau^{\max})$ for each country, we use data on the average tax wedge for single individuals earning 67, 100, and 167 percent of the average wage over the period 2015–2024 in Austria, Germany, Italy, and Poland, as reported in OECD (2024). From these values, we subtract the social contribution rates to isolate the personal income tax component and divide by one minus the social contribution rate.[13] The resulting parameter values are presented in Table A.1, while the functional form of the average personal income tax rate is displayed in Figure A.1.

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[13] Data on average personal income tax rates in country i in year t has been calculated as

$$\text{avg. personal income tax rate}_{it} = (\text{tax wedge}_{it} - \tau^s)/(1 - \tau^s),$$

where τ^s is the social contribution rate reported in Table D.1.

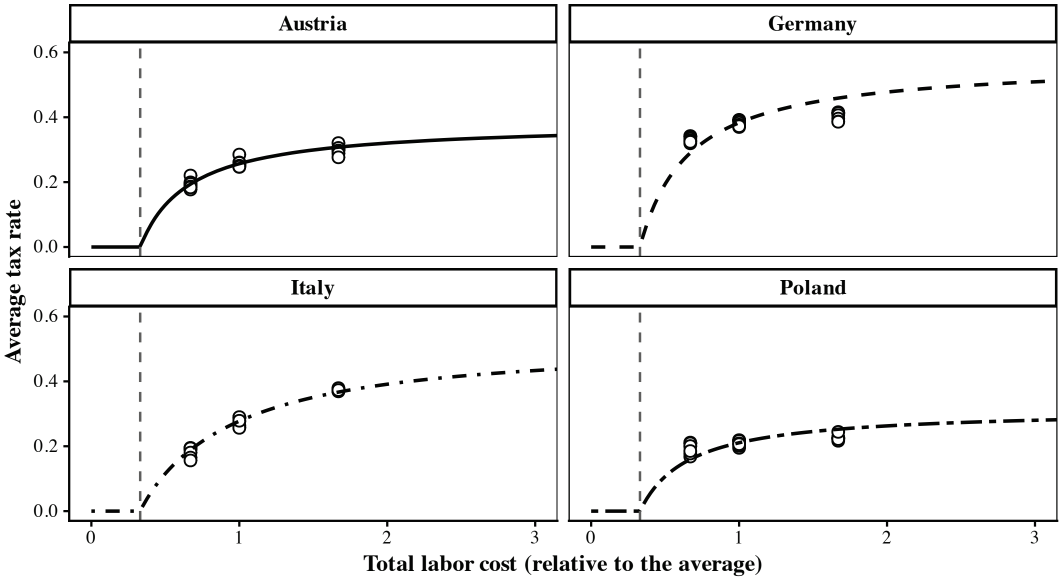

Figure A.1: Average personal income tax rate functions. *Source*: Own calculations. *Notes*: Data (black circles) taken from OECD (2024). For consistency with the model setup, all average tax rate values have been re-scaled relative to the total labor cost of a worker.

A.7 Demographics

Tables A.7 and A.8 in this section report the evolution of the main demographic indicators for the period 2020-70 in Austria, Germany, Italy, and Poland.

Period	**2020-30**	**2030-40**	**2040-50**	**2050-60**	**2060-70**
Austria					
Population (thousands)	9 121	9 500	9 733	9 838	9 880
Population growth rate (%)	0.47	0.27	0.16	0.05	0.04
Old-age dependency ratio (%)	32.0	39.5	43.8	47.1	50.8
Employment rate among the pop. aged 18 to 65 (%)	73.2	75.2	77.7	77.9	78.5
Germany					
Population (thousands)	83 641	83 870	83 714	83 298	83 128
Population growth rate (%)	0.10	-0.02	-0.03	-0.04	0.01
Old-age dependency ratio (%)	39.0	47.5	48.4	49.6	51.7
Employment rate among the pop. aged 18 to 65 (%)	82.6	84.0	60.5	62.2	61.8
Italy					
Population (thousands)	59 039	58 216	56 947	54 961	52 684
Population growth rate (%)	-0.15	-0.16	-0.26	-0.36	-0.36
Old-age dependency ratio (%)	42.0	52.5	63.8	65.7	64.0
Employment rate among the pop. aged 18 to 65 (%)	49.0	46.5	46.3	48.6	51.0
Poland					
Population (thousands)	37 547	36 123	34 779	33 551	32 184
Population growth rate (%)	-0.24	-0.39	-0.31	-0.34	-0.41
Old-age dependency ratio (%)	33.7	38.5	46.3	59.7	64.0
Employment rate among the pop. aged 18 to 65 (%)	57.6	56.1	56.3	52.9	55.1

Table A.7: Expected evolution of main demographic variables along the period 2020-2070. Note: The old age dependency ratio is defined in this table as the number of people 65 or older relative to the number of people between ages 18 and 64.

Period	**2020-30**	**2030-40**	**2040-50**	**2050-60**	**2060-70**
Austria					
Women – Life expectancy at age 65 (years)	19.9	21.3	22.3	23.2	24.1
Men – Life expectancy at age 65 (years)	17.0	18.3	19.3	20.3	21.2
Women – Healthy life expectancy at age 65 (years)	10.6	11.1	11.4	11.7	11.9
Men – Healthy life expectancy at age 65 (years)	10.7	11.2	11.7	12.1	12.4
Women – Share of high-skilled adults (%)	29.7	35.6	41.5	47.4	53.4
Men – Share of high-skilled adults (%)	31.9	35.3	38.8	42.7	46.8
Germany					
Women – Life expectancy at age 65 (years)	19.8	20.9	22.0	23.0	23.9
Men – Life expectancy at age 65 (years)	16.8	17.9	19.0	20.0	20.9
Women – Healthy life expectancy at age 65 (years)	12.8	13.3	13.7	14.1	14.4
Men – Healthy life expectancy at age 65 (years)	11.8	12.3	12.8	13.2	13.7
Women – Share of high-skilled adults (%)	36.3	42.8	49.1	55.2	61.0
Men – Share of high-skilled adults (%)	40.2	43.0	46.1	49.6	53.2
Italy					
Women – Life expectancy at age 65 (years)	20.8	22.2	23.1	23.9	24.7
Men – Life expectancy at age 65 (years)	17.9	19.2	20.1	20.9	21.7
Women – Healthy life expectancy at age 65 (years)	11.8	12.2	12.5	12.7	13.0
Men – Healthy life expectancy at age 65 (years)	11.7	12.2	12.6	13.0	13.4
Women – Share of high-skilled adults (%)	22.7	28.3	33.9	40.1	47.0
Men – Share of high-skilled adults (%)	18.9	22.4	26.0	29.9	34.5
Poland					
Women – Life expectancy at age 65 (years)	18.4	20.1	21.3	22.5	23.5
Men – Life expectancy at age 65 (years)	14.4	16.2	17.6	18.8	20.0
Women – Healthy life expectancy at age 65 (years)	10.7	11.3	11.8	12.1	12.5
Men – Healthy life expectancy at age 65 (years)	9.9	10.7	11.3	11.9	12.4
Women – Share of high-skilled adults (%)	38.4	44.5	50.5	56.5	61.8
Men – Share of high-skilled adults (%)	28.4	32.7	37.0	41.1	44.8

Table A.8: Expected evolution of main demographic variables along the period 2020-2070. Note: The old age dependency ratio is defined in this table as the number of people 65 or older relative to the number of people between ages 18 and 64.

B Calibration

B.1 Target statistics

To fit the retirement-related parameters, we target the mean retirement age for men and women. The mean retirement age is calculated based on historical labor force participation data from SHARE wave 5, 6, 7, 8 and 9. (Datasets: (SHARE-ERIC, 2024a,b,c,d,e)), averaging the ages at which individuals exit the workforce across multiple years. The difference in mean retirement age between low- and high-skilled individuals is then an internal model outcome, which we do not explicitly match to the data. The model's ability to produce a difference in mean retirement age by skill group that aligns with the data validates its capacity to capture important mechanisms underlying retirement decisions. The parameters shaping the distribution of characteristics are calibrated to best match educational outcomes and income disparities within and across genders. Specifically, we use the share of high-skilled individuals by gender, the gender pay gap for both skill groups, and the skill premium on income by gender as target statistics. In total, this yields eight target means (see Table B.1).

B.2 Calibration process

Our calibration procedure is iterative. We begin by using a representative cohort framework (1960 birth cohort) in combination with a balanced growth path assumption (BGP). We employ a multistep procedure for each country that combines moment matching and Bayesian melding, implemented through the basic IMIS algorithm (Raftery and Bao, 2010). This iterative process continues until the contribution and gender transfer rates converge, and the target statistics are sufficiently matched. The calibration procedure exhibits monotonic and well-behaved convergence, typically requiring relatively few iterations. Additionally, the adjusted parameter values demonstrate consistency, showing no drastic variation when contributions and transfer rates are updated. This robustness provides practical validation for our calibration strategy. Calibrating a single country requires approximately 24 hours when parallelized on a high-performance Windows machine with 16 cores running at 3.40 GHz. Algorithm 1 gives an outline of our calibration procedure.

When we later use the calibrated parameters to solve for the full dynamic equilibrium with multiple cohorts, we translate the schooling effort distributions depending on the cohort, such that the evolution of the educational shares over time is well captured. This implies that within the full dynamic model, the parameters $(\mu^w_{t,e}, \mu^m_{t,e})$ become cohort dependent.

Algorithm 1: Algorithm for Calibration Routine

```
Input: Household problem for $N$ individuals with characteristics $(\xi_h, \xi_e)$ distributed within a predefined grid
Output: Distribution of characteristics $(\{\mu^g_h, , \sigma_h, \mu^g_e, \sigma^g_e\}_{g\in\{f,m\}})$, retirement preferences $(\{\alpha^g_2\}_{g\in\{f,m\}})$, social contribution rates and gender transfer rates $\boldsymbol{\tau} \equiv \left(\tau^S, \tau^U, \tau^{Hf}, \tau^{Hm}\right)$
Initialize the set of contribution rates and gender transfer rates $\boldsymbol{\tau} = (0, 0, 0, 0)$
for $i \leftarrow 1$ to $n$ do
    Find the set $(\{\alpha^g_2\}_{g\in\{f,m\}})$ of retirement preferences that match the retirement-age moments for each gender
    Solve the household problem {See Algorithm 1} for the $N$ individuals in the predefined grid using the new $(\{\alpha^g_2\}_{g\in\{f,m\}})$ and $\boldsymbol{\tau}$ {This section stores all the new model profiles}
    Find the set $(\{\mu^g_h, \sigma_h, \mu^g_e, \sigma^g_e\}_{g\in\{f,m\}})$ that governs the population distribution of characteristics by calling the Bayesian algorithm {See Algorithm 3 Bayesian melding with IMIS Algorithm}
    Aggregate household profiles using the new population distribution of characteristics
    Calculate the new set of contribution rates and gender transfer rates $\boldsymbol{\tau}$
    Calculate the difference in total consumption between genders $L[i]$
    if $L[i] < min$ then
        Stop
    end if
end for
return Distribution of characteristics $(\{\mu^g_h, \sigma_h, \mu^g_e, \sigma^g_e\}_{g\in\{f,m\}})$, retirement preferences $(\{\alpha^g_2\}_{g\in\{f,m\}})$, social contribution rates and gender transfer rates $\boldsymbol{\tau}$, and life-cycle profiles for the $N$ households
```

B.3 Bayesian melding

We calibrate the distributions of individual characteristics using a Bayesian melding procedure implemented through the basic IMIS algorithm (Raftery and Bao, 2010). The Bayesian melding provides a robust inferential framework for both deterministic and stochastic models, accounting for the inputs and outputs of the model. A key feature of this method is its ability to simultaneously calibrate the set of inputs (in this case, unobservable characteristics) avoiding the Borel paradox (Poole and Raftery, 2000; Raftery and Bao, 2010). This paradox occurs when the choice of the parameterization strategy influences the outcome. Finally, we adjust the contribution rates and gender transfer rates. These steps are iterated until the equilibrium outcomes reach convergence. In the first step, we repeatedly solve the household problem within a numerical optimization framework to minimize the distance between the mean retirement ages produced by the model and those observed in the data. This step requires approximately one hour of computation.

In preparation for the second step, we solve the household problem on a predefined grid of 200 points along the learning ability dimension. The resulting profiles are stored and used within the Bayesian melding algorithm, where each of the 200 points is individually weighted to best approximate the distribution of characteristics. This process is repeated in every iteration of the IMIS algorithm. This preparatory step ensures computational feasibility and robustness for the Bayesian melding procedure. An alternative strategy, which would involve sampling a fixed number of draws from the distribution of learning ability, would require significantly more samples to achieve comparable accuracy and robustness. By leveraging the grid approach, we efficiently maintain high precision with fewer computational resources. This step remains the most computationally demanding part of the calibration procedure, requiring approximately four hours per iteration.

The Bayesian melding component itself requires relatively little computation time. This part of the algorithm is detailed in Algorithm 2. As a result, we obtain the set of parameters related to learning ability (ξ_h) and schooling effort (ξ_e) with the highest likelihood of the targeted moments.

Figure B.1 presents a stylized population distribution of the two key characteristics: learning ability (ξ_h) and schooling effort (ξ_e). The figure depicts for each learning ability level (see the vertical dashed lines) how these two characteristics jointly influence the proportion of individuals classified as low-skilled (white area) or high-skilled (gray shaded area) across the population.

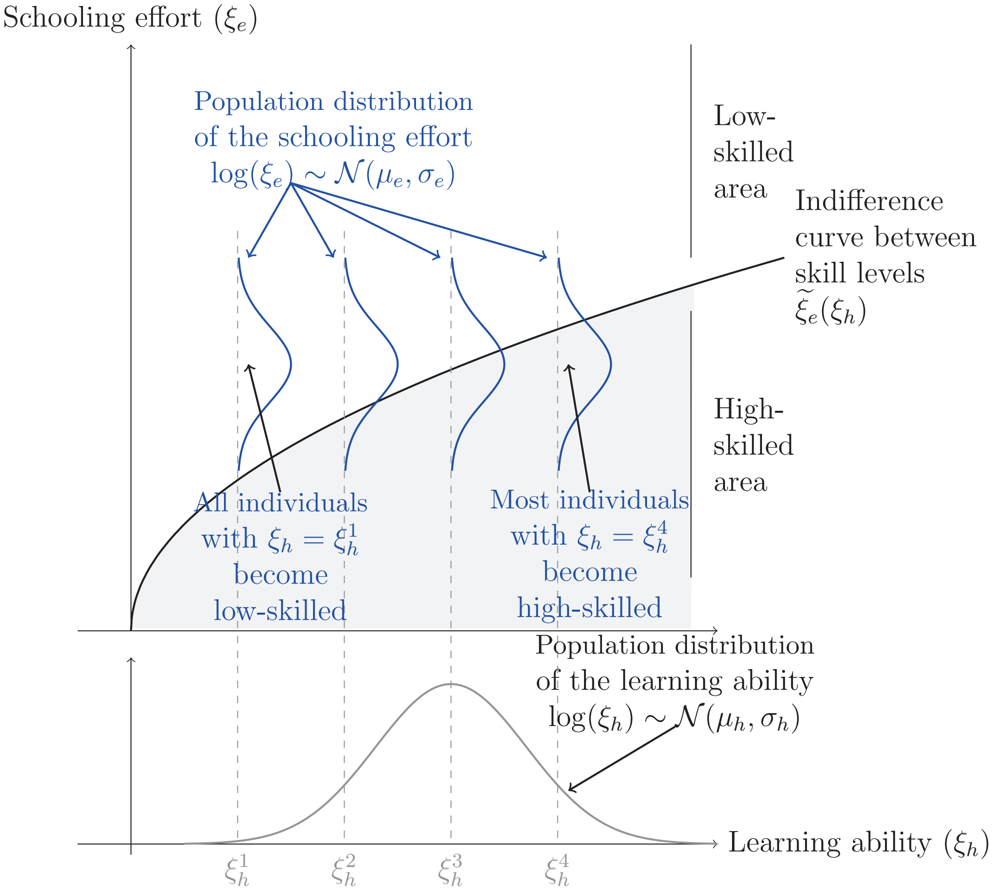

Figure B.1: Stylized representation of the distribution of the learning ability level and effort of schooling ($\theta = (\xi_h, \xi_e)$) across the population.

Algorithm 2: Bayesian melding with Incremental Mixture Importance Sampling (IMIS) Algorithm (Raftery and Bao, 2010)

```
Require: Joint prior distribution $p(\Theta)$, model $F$, and data likelihood $\mathcal{L}(\cdot|\text{data})$
Ensure: Approximation of posterior distribution for inputs and outputs
1: Initial Stage:
    1. Draw $N_0 = 7\,000$ independent and identically distributed (i.i.d.) samples $\{\theta_1, \ldots, \theta_{N_0}\}$ from the joint prior $p(\Theta)$.
    2. For each $\theta_i$, compute the model outputs $\phi_i$.
    3. Calculate the likelihood for each output $\mathcal{L}(\phi_i|\text{data}) \quad \text{for } i = 1, \ldots, N_0$.
    4. Construct importance weights: $\omega(\theta_i) \propto \frac{q(\phi_i)\mathcal{L}(\phi_i|\text{data})}{\sum_{i=1}^{N_0} q(\phi_i)\mathcal{L}(\phi_i|\text{data})} \quad \text{for } i = 1, \ldots, N_0$.
2: Importance Sampling Stage: For $k = 1, 2, \ldots$
    1. Identify the current maximum weight input:
       $\theta^{(k)} = \arg\max_{\theta \in \{\theta_1, \ldots, \theta_{N_{k-1}}\}} \big(w(\theta_1), \ldots, w(\theta_{N_{k-1}})\big)$.
    2. Estimate $\Sigma^{(k)}$ as the weighted covariance of the $B = 700$ inputs with the smallest Mahalanobis distances to $\theta^{(k)}$. The Mahalanobis distance is:
       $d(\theta, \theta^{(k)}) = \sqrt{(\theta - \theta^{(k)})' Q (\theta - \theta^{(k)})}$, where $Q$ is the covariance matrix of the prior distribution, and the weights are $\big(w(\hat{\theta}_1) + \frac{1}{N_k}, \ldots, w(\hat{\theta}_B) + \frac{1}{N_k}\big)$.
    3. Sample $B$ new inputs $(\theta_{N_{k-1}+1}, \ldots, \theta_{N_{k-1}+B})$ from the multivariate Gaussian distribution: $H_k : \mathcal{N}(\theta^{(k)}, \Sigma^{(k)})$.
    4. Calculate likelihoods for the new inputs and combine them with the existing ones. Compute the updated importance weights:
       $w(\theta_i) = c \cdot q_2(\phi_i)\mathcal{L}(\phi_i) \times \frac{p(\theta_i)}{q^{(k)}(\theta_i)}$, where $q^{(k)}(\theta_i) = \frac{N_0}{N_k} p(\theta_i) + \frac{B}{N_k} \sum_{s=1}^{k} H_s(\theta_i)$,
       $H_s(\theta_i)$ is the probability of $\theta_i$ in $\mathcal{N}(\theta^{(s)}, \Sigma^{(s)})$, and $c$ ensures $\sum_{i=1}^{N_k} w(\theta_i) = 1$.
       Here $N_k = N_0 + kB$.
3: Resample Stage: Once the expected fraction of unique points in the resample, $\sum_{i=1}^{N_k} \big(1 - (1 - w(\theta_i))^J\big)$, is at least 0.632 out of $3\,000$ random draws, resample $J = 200$ inputs with replacement from $\{\theta_1, \ldots, \theta_{N_k}\}$ using weights $\{w(\theta_1), \ldots, w(\theta_{N_k})\}$ to approximate the posterior distribution.
```

B.4 Calibration outcome and model fit

Table B.1 presents the calibrated parameters and the model's fit to the moments targeted for each of the four countries: Austria, Germany, Italy, and Poland. For each country, the table is structured into two sections. The first section displays the calibrated parameters (α_1^w, α_1^m) that govern the retirement decision for each gender. In particular, we aim at matching the mean retirement age of women and men. The second section includes the parameters $(\mu_h^w, \mu_h^m, \sigma_h, \mu_e^w, \sigma_e^w, \mu_e^m, \sigma_e^m)$ that influence the distribution of educational attainment and income for each gender. The parameter values reported in this section correspond to those with the highest likelihood of the targeted moments. To complement these values, figure **??** (Missing! To be included) depicts the marginal posterior distribution of each parameter alongside their correlations. The targeted mean values in this section are: the gender-pay gap of women and men, the skill premium for women and men, and the share of women and men who are high-skilled. In both sections, the left-hand side lists the values of the calibrated parameters, while the right-hand side shows the model's alignment with the targeted moments.

				Target Statistics				
Parameter	Estimate	95% Cr.I.	Description	Model		Data		Description
				low	high	low	high	
Austria								
			Utility from retirement					
α_1^w	1327.9			59.9		59.9		Total mean retirement age (women)
α_2^w	−2.0			59.7	60.7	59.5	61.3	Mean retirement age (women)
α_1^m	660.9			62.2		62.2		Mean retirement age (men)
α_2^m	−2.0			62.1	62.5	61.7	63.5	Skill gap retirement age (men)
			Educational distribution and Wages					
μ_h^w	0.226		Mean learning ability (women)					
μ_h^m	0.255		Mean learning ability (men)					
σ_h	0.047		SD learning ability	0.55	0.55	0.55	0.55	Gender wage ratio (women/men)
μ_e^w	48.30		Mean schooling effort (women)	1.72		1.72		Skill premium (women)
σ_e^w	36.71		SD schooling effort (women)	1.71		1.71		Skill premium (men)
μ_e^m	21.50		Mean schooling effort (men)	0.21		0.22		Share of high-skilled (women)
σ_e^m	23.23		SD schooling effort (men)	0.26		0.27		Share of high-skilled (men)
Germany								
			Utility from retirement					
α_1^w	609.9			64.1		64.2		Total mean retirement age (women)
α_2^w	−2.0			63.1	66.0	64.0	64.4	Mean retirement age (women)
α_1^m	168.4			64.5		64.5		Total mean retirement age (men)
α_2^m	−2.0			64.0	65.4	64.2	65.0	Mean retirement age (men)
			Educational distribution and wages					
μ_h^w	0.326							
μ_h^m	0.189							
σ_h	0.061			0.55	0.50	0.55	0.50	Gender wage ratio (women/men)
μ_e^w	33.271			1.66		1.66		Skill premium (women)
σ_e^w	47.76			1.81		1.81		Skill premium (men)
μ_e^m	7.534			0.32		0.32		Share of high-skilled (women)
σ_e^m	11.609			0.36		0.36		Share of high-skilled (men)
Italy								
			Utility from retirement					
α_1^w	678.6			63.0		63.0		Total mean retirement age (women)
α_2^w	−2.0			63.3	63.6	62.6	65.1	Mean retirement age (women)
α_1^m	630.0			64.24		64.23		Total mean retirement age (men)
α_2^m	−2.0			64.3	64.8	64.0	65.7	Mean retirement age (men)
			Educational distribution and wages					
μ_h^w	0.367							
μ_h^m	0.416							
σ_h	0.071			0.70	0.75	0.71	0.76	Gender wage ratio (women/men)
μ_e^w	48.10			1.97		1.97		Skill premium (women)
σ_e^w	32.12			1.85		1.86		Skill premium (men)
μ_e^m	39.15			0.15		0.15		Share of high-skilled (women)
σ_e^m	27.83			0.13		0.14		Share of high-skilled (men)
Poland								
			Utility from retirement					
α_1^w	772.135			60.8		60.8		Total mean retirement age (women)
α_2^w	−2.0			60.7	61.5	60.4	62.0	Mean retirement age (women)
α_1^m	440.29			64.3		64.2		Total mean retirement age (men)
α_2^m	−2.0			64.4	65.1	63.8	66.6	Mean retirement age (men)
			Educational distribution and wages					
μ_h^w	0.307							
μ_h^m	0.192							
σ_h	0.207			0.56	0.63	0.55	0.62	Gender wage ratio (women/men)
μ_e^w	37.496			2.10		2.10		Skill premium (women)
σ_e^w	31.985			1.87		1.86		Skill premium (men)
μ_e^m	45.405			0.26		0.26		Share of high-skilled (women)
σ_e^m	37.897			0.17		0.16		Share of high-skilled (men)

Table B.1: Calibrated parameters and model fitting for the representative cohort.

C Numerical Solution of Household Problem and Dynamic Equilibrium

After estimating individual parameters using a representative cohort approach, we solve the full dynamic equilibrium of the model. This means repeatedly solving the household problem (see Algorithm 3) for all cohorts, and adjusting transfer and contribution rates, as well as other components, depending on the pension system in place. We iterate until the equilibrium conditions from Definition 3.1 are satisfied with sufficient precision. In Algorithm 4 we describe the iteration procedure schematically. The full replication code with all details of the implementation is available at ADD REPLICATION LINK.

Algorithm 3: Algorithm for Solving the Household Problem

```
Input: Global parameters and individual specific characteristics
Output: Mean profiles for specific type of individual (expected utility,
  consumption, wealth, labor income, received unemployment transfers, claimed
  pension benefits, and labor supply)
for $j \leftarrow J_{max}$ to 1 do
    Solve life-cycle problem backwards in time using value function iteration, store
    individual policy functions
end for
for $j \leftarrow 1$ to $J_{max}$ do
    Calculate distribution across state space forward in time
end for
Use policy functions and distribution to calculate mean profiles by skill level
return mean profiles for expected utility, consumption, wealth, labor income,
  received unemployment transfers, claimed pension benefits, and labor supply (at the
  extensive margin)
```

Algorithm 4: Algorithm for Solving the Dynamic Equilibrium

```
Input: Estimated Parameters and initial values for transfer and contribution rates
  $(\tau_t^{s,0}, \tau_t^{u,0}, \tau_t^{g,0})$.
Output: 1) Mean life-cycle profiles for every type of individuals (cohort, gender,
  education, fertility, learning ability, schooling effort) for all control and state
  variables in the model. 2) Equilibrium values for transfer and contribution rates
  $(\tau_t^{s,*}, \tau_t^{u,*}, \tau_t^{g,*})$.
while $error > eps$ do
    Solve household problem for every cohort, gender, education, fertility, learning
    ability and schooling effort
    Calculate LHS and RHS of the equilibrium equations 3.1 for every year $t$, and
    update $(\tau_t^{s,*}, \tau_t^{u,*}, \tau_t^{g,*})$ using the error and the previous value
end while
return Dynamic Equilibrium transfer and contribution rates $(\tau_t^{s,*}, \tau_t^{u,*}, \tau_t^{g,*})$, and
  ean life-cycle profiles for every type of individual.
```

D Pension Systems

D.1 Translation of the total pension cost to workers

A balanced pension budget in period t in which total pension benefits (B_t) are financed by the government, employers, and employees is given by:

$$(1-\phi_t)B_t = (\tau_t^{s,\text{employers}} + \tau_t^{s,\text{employees}})w_t\, L_t^{gross}, \tag{36}$$

where ϕ_t is the fraction of the total pension paid by the government in period t, $\tau_t^{s,\text{employers}}$ is the pension contribution rate levied on employers in period t, $\tau_t^{s,\text{employees}}$ is the pension contribution rate levied on workers in period t, and $w_t L_t^{gross}$ is the total gross labor income earned by employees

$$w_t L_t^{gross} = \sum_{j=J_0}^{J_\Omega-1} \mathbf{N}_{tj} \int_\Omega \frac{S(\mathbf{x}_{tj})}{\mathbf{S}_{tj}} \pi^S(\mathbf{x}_{tj})\,(1-\boldsymbol{\zeta}^*(\mathbf{x}_{tj}))\, w_t\, y^{gross}(\mathbf{x}_{tj})\, \mathbf{1}_{\{u=1\}}\, \mathrm{d}\Gamma_{tj}(\mathbf{x}_{tj}) \tag{37}$$

with w_t being the wage rate per unit of effective worker, and $w_t\, y^{gross}(\mathbf{s}_{tj})$ is the gross labor income received by a worker with characteristics $\mathbf{s}_{tj}$. Let assume the total labor cost of a worker in period t is equal to the total productivity of the worker

$$w_t\, y^{prod}(\mathbf{s}_{tj}) = (1+\tau_t^{s,\text{employer}})\, w_t\, y^{gross}(\mathbf{s}_{tj}).$$

Substituting the previous equation in (37) and using (19), we can express L_t^{gross} as a function of L_t

$$w_t\, L_t^{gross} = \frac{w_t\, L_t}{1+\tau^{s,\text{employer}}}. \tag{38}$$

Next, substituting (38) in (36), the total pensions claimed in period t is

$$B_t = \frac{1}{1-\phi_t} \frac{\tau_t^{s,\text{employers}} + \tau_t^{s,\text{employees}}}{1+\tau^{s,\text{employer}}} w_t\, L_t. \tag{39}$$

Therefore, if we assume that the total pension cost is paid by workers, the pension contribution rate applied by over the total productivity of workers (τ_t^s) is given by

$$\tau_t^s = \frac{1}{1-\phi_t} \frac{\tau_t^{s,\text{employers}} + \tau_t^{s,\text{employees}}}{1+\tau^{s,\text{employer}}}.$$

In addition to the pension contribution rate, the pension replacement rate must also be adjusted, since it is defined as a fraction of total gross labor income rather than in terms of a worker's total productivity. Accordingly, our pension replacement rate (φ) is calculated as the fraction of total gross labor income divided by one plus the employer's social contribution rate. Table D.1 summarizes the adjustments to the main parametric components of the pension systems in Austria, Germany, Italy, and Poland. The final row of Table D.1 illustrates the overall generosity of each system. Using Austria as the reference, a retiree with 45 years of contributions who retires at age 65 would receive 81 (=0.0128/0.0158) percent of the Austrian pension replacement rate in Italy, and 62 (=0.0098/0.0158) percent in Germany and Poland. In terms of contributions, an Italian worker would pay 90 (=0.2665/0.2954) percent of the Austrian level, a German

	Symbol	PAYG-DB		NDC	
		Austria	Germany	Italy	Poland
Pension contributions rate	τ^s	‡0.2954	‡0.1702	0.2665	0.1778
Employer	$\tau^{s,\text{employer}}$	0.1255	0.0930	0.2381	0.0976
Employee	$\tau^{s,\text{employee}}$	0.1025	0.0930	0.0919	0.0976
Government	ϕ	0.3000	-	-	-
Pension replacement rate	φ	0.7108	0.4392	-	-
Working years	wy	45	45	-	-
Life expectancy at age 65†	$\text{LE}_{2023,65}$	19.9	19.5	20.9	18.2
Accrual generosity at age 65	$A\,\lambda$	0.0158	0.0098	0.0128	0.0098

Table D.1: Main parametric components of the pension systems in Austria, Germany, Italy, and Poland. † Based on life expectancy values at age 65 in year 2023. ‡ Note that pension contribution rates will vary over time in PAYG-DB systems.

worker would pay 58(=0.1702/0.2954) percent, and a Polish worker 60(=0.1778/0.2954) percent.

Since the accrual generosity of NDC systems is adjusted by life expectancy at the retirement age, Eurostat population projections indicate that the accrual rate generosity for the 2002 birth cohort in Italy and Poland will be 1.02 percent and 0.71 percent, respectively. This translates into an average decline in pension benefits—holding the rate of return of the pension system constant—of 14 percent in Italy and 22 percent in Poland.

D.2 Pension corridor: Retirement ages

Table D.2 shows the normal retirement ages (J^N) by birth cohort and gender under the baseline simulation and in the pension reform of the delay retirement age across Austria, Germany, Italy, and Poland. In addition, individuals may retire earlier: up to two years before the normal retirement age in Germany, three years earlier in Austria and Italy. In Poland, under the general pension regime, individuals can retire only from the normal retirement age on (OECD, 2023).

Country	**Baseline**			**Delay retirement (DR)**		
	Birth cohort	**Women**	**Men**	**Birth cohort**	**Women**	**Men**
Austria	$\text{cohort} < 1965$	60	65	$\text{cohort} < 1965$	60	65
	$1965 \leq \text{cohort} < 1967$	61	65	$1965 \leq \text{cohort} < 1967$	61	65
	$1967 \leq \text{cohort} < 1969$	62	65	$1967 \leq \text{cohort} < 1969$	62	65
	$1969 \leq \text{cohort} < 1971$	63	65	$1969 \leq \text{cohort} < 1971$	63	65
	$1971 \leq \text{cohort} < 1973$	64	65	$1971 \leq \text{cohort} < 1973$	64	65
	$\text{cohort} \geq 1973$	65	65	$1973 \leq \text{cohort} < 1975$	65	65
				$1975 \leq \text{cohort} < 1977$	66	66
				$1977 \leq \text{cohort} < 1979$	67	67
				$1979 \leq \text{cohort} < 1981$	68	68
				$1981 \leq \text{cohort} < 1983$	69	69
				$\text{cohort} \geq 1983$	70	70
Germany	$\text{cohort} < 1959$	65	65			
	$1959 \leq \text{cohort} < 1961$	66	66			
	$1961 \leq \text{cohort} < 1964$	67	67			
	$1964 \leq \text{cohort} < 1966$	68	68			
	$1966 \leq \text{cohort} < 1968$	69	69			
	$\text{cohort} \geq 1968$	70	70			
Italy	$\text{cohort} < 1958$	60	65			
	$1958 \leq \text{cohort} < 1959$	61	65			
	$1959 \leq \text{cohort} < 1960$	62	65			
	$1960 \leq \text{cohort} < 1961$	63	66			
	$1961 \leq \text{cohort} < 1962$	64	66			
	$1962 \leq \text{cohort} < 1963$	65	66			
	$1963 \leq \text{cohort} < 1964$	66	67			
	$1964 \leq \text{cohort} < 1965$	67	67			
	$1965 \leq \text{cohort} < 1981$	68	68			
	$1981 \leq \text{cohort} < 1990$	69	69			
	$\text{cohort} \geq 1990$	70	70			
Poland	all cohorts	60	65	$\text{cohort} < 1958$	60	65
				$1958 \leq \text{cohort} < 1959$	61	65
				$1959 \leq \text{cohort} < 1960$	62	65
				$1960 \leq \text{cohort} < 1961$	63	66
				$1961 \leq \text{cohort} < 1962$	64	66
				$1962 \leq \text{cohort} < 1963$	65	66
				$1963 \leq \text{cohort} < 1964$	66	67
				$1964 \leq \text{cohort} < 1965$	67	67
				$1965 \leq \text{cohort} < 1981$	68	68
				$1981 \leq \text{cohort} < 1990$	69	69
				$\text{cohort} \geq 1990$	70	70

Table D.2: Statutory or normal retirement age by birth cohort, gender, and country in the baseline and under the delay retirement (DR) pension reform.

D.3 Minimum pension benefits

We define the minimum old-age income floor as the legally guaranteed amount available to a single pensioner. In Austria, this is the *Ausgleichszulage* "Richtsatz", which is paid 14 times per year (Bundesministerium für Soziales, Gesundheit, Pflege und Konsumentenschutz, 2025; Republik Österreich, 2025). For Germany, we use the cash standard rate for *Grundsicherung im Alter* (*Regelbedarfsstufe 1*), excluding case-specific housing and heating support (Bundesministerium für Arbeit und Soziales, 2025a,b). For Italy, we use the *Assegno sociale*, paid 13 times per year; 2025 levels are set by INPS and Circular 23/2025 (Istituto Nazionale della Previdenza Sociale (INPS), 2025; INPS, 2025). For Poland, we use the statutory minimum old-age pension (*najniższa emerytura*) effective 1 March 2025 (Zakład Ubezpieczeń Społecznych (ZUS), 2025; Prezes Zakładu Ubezpieczeń Społecznych, 2025) that provides an annual minimum benefit of PLN 22 546.92 (received in 12 payments), which is close 27.3 percent of the average annual wage. We annualize each by multiplying the monthly amount by the standard number of payments (Austria: 14; Germany: 12; Italy: 13; Poland: 12) and divide by OECD "Average annual wages" 2023, in national currency (OECD, 2025). The resulting benefit-to-income ratios are reported in Table D.3.

Country	Minimum benefit used	Annual min. benefit	Avg. annual wage (OECD)	Ratio	Adj. Ratio
Austria (EUR)	Ausgleichszulagenrichtsatz, single (14 payments)	€ 17 835.86	€ 53 242.00	0.335	0.304
Germany (EUR)	Grundsicherung im Alter, Regelbedarfsstufe 1 (12 payments)	€ 6 756.00	€ 48 301.00	0.140	0.128
Italy (EUR)	Assegno sociale (13 payments)	€ 7 002.97	€ 32 450.00	0.216	0.198
Poland (PLN)	Minimum contributory pension (12 payments)	PLN 22 546.92	PLN 82 488.00	0.273	0.249

Table D.3: Minimum old-age income floors (latest available). *Notes:* Annual minimum benefits are computed as the legally guaranteed monthly floor times the standard number of pension payments per year in each country (Austria: 14; Germany: 12; Italy: 13; Poland: 12). Ratios use the latest complete OECD "Average annual wages" (AV_AN_WAGE) in national currency (current prices), year 2023.

E Additional figures

E.1 Internal rate of return

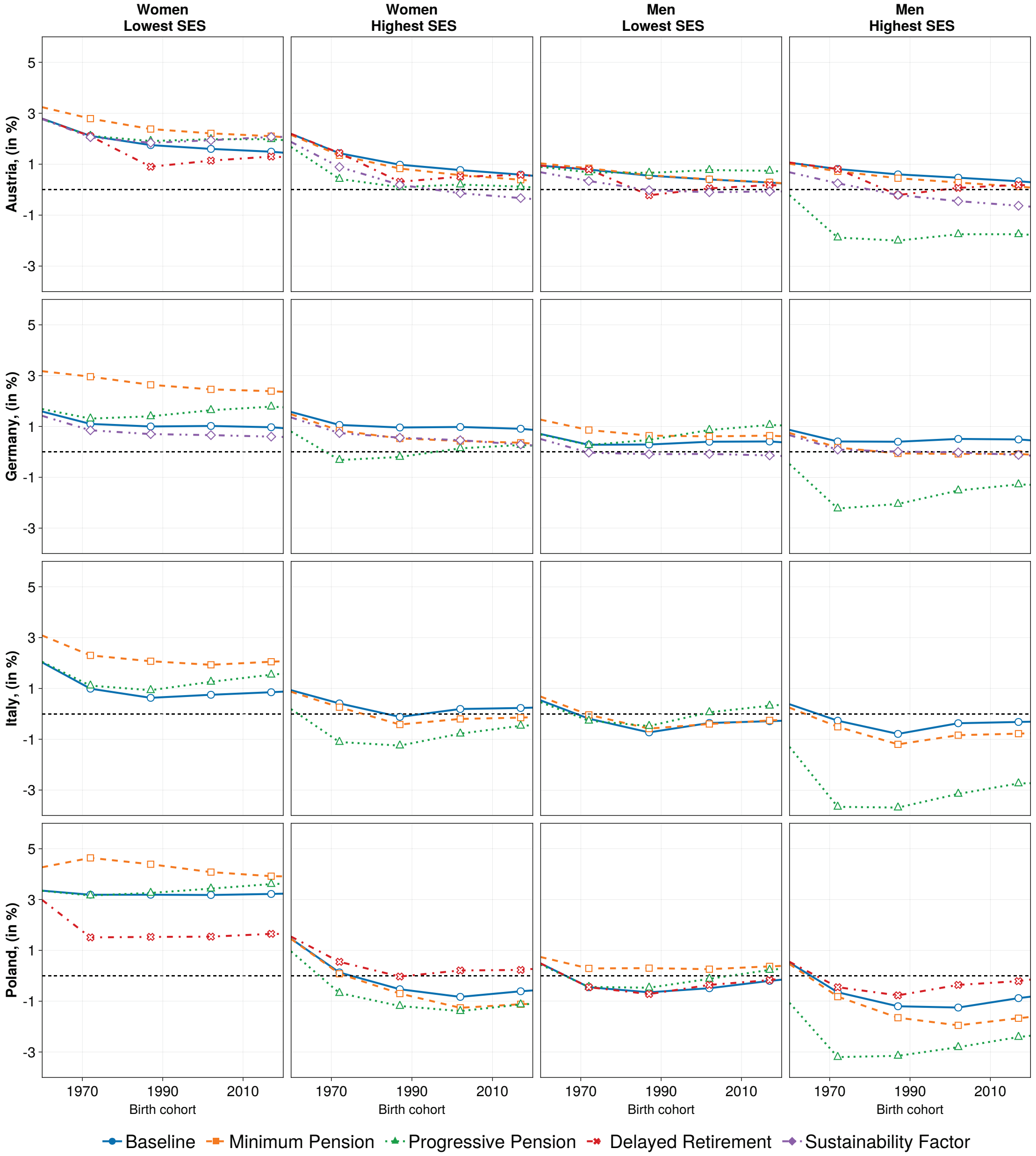

Figure E.1: Internal rate of return (IRR) for the baseline and each pension reform by country, birth cohort, and socioeconomic group (lowest and highest). *Source*: Authors' simulations. *Notes*: Pension reforms: Higher minim um pension benefit (MinPB), Progressive pension benefits (PPB), Delayed retirement (DR), and Sustainability factor (SF). The lowest SES group represents individuals in the bottom income quintile among those with less than tertiary education, while the highest SES group includes individuals in the top income quintile among those with tertiary education.

E.2 Educational choice

Figure E.2 presents the share of individuals in each birth cohort who attain post-secondary education, disaggregated by gender and country. The figure is organized into two blocks. The left block shows the evolution of educational attainment across cohorts in the baseline simulation. The panels in the right block display the deviation from this baseline after the implementation of the pension reform. As shown on the right-hand side, pension reforms aimed at reducing inequality slightly diminish the returns to schooling. Reforms aimed at improving financial sustainability may either increase the returns to schooling (delayed retirement) or reduce the returns to schooling (sustainability factor). The obtained impact of pension reforms on educational attainment is fully consistent with Sánchez-Romero et al. (2024).

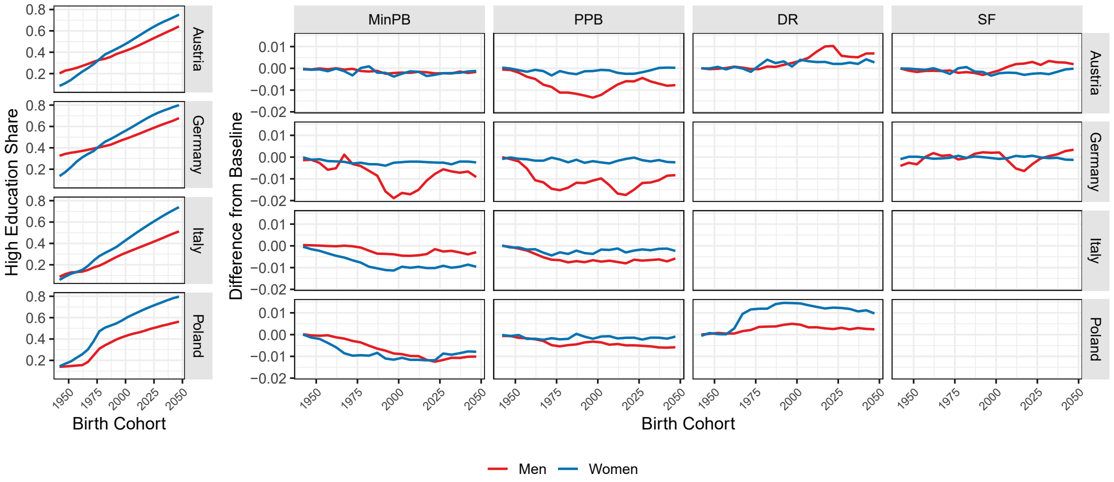

Figure E.2: Share of people in tertiary education by birth cohort, gender, and country under the baseline and pension reforms. *Source*: Authors' simulations. *Notes*: The model has been set so as to replicate in the baseline simulation the share of people in post-secondary by gender and birth cohort in each country from Wittgenstein Centre for Demography and Global Human Capital (2018).

E.3 Pension replacements under different sustainability factors

Figure E.3 shows the evolution of the pension replacement level in Austria and Germany from 2020 to 2070. The figure displays four lines. The solid blue lines show the pension replacement rate under a scenario in which the sustainability factor keeps the pension contribution rate fixed at its 2020 level in each country. The dashed black lines represent the pension replacement rate when the sustainability factor is linked to the evolution of the retiree-to-worker ratio (RW), which corresponds to the sustainability factor currently in place in Germany. Under our model setup, pension benefits should be adjusted according to the following formula

$$\mathbf{b}^*(\mathbf{x}_{tj}) = b \cdot \exp\left\{-\alpha_{\mathrm{SF}} \sum_{s=t_0}^{t} \log\left(\frac{\mathrm{RW}_t}{\mathrm{RW}_{t-1}}\right)\right\} \text{ for } t \geq t_0, \tag{40}$$

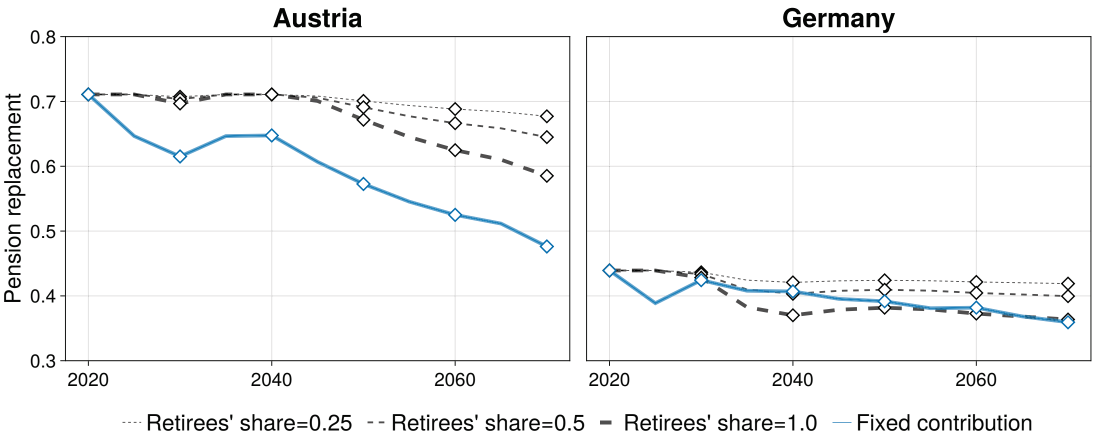

Figure E.3: Pension replacement level from 2020 to 2070 in Austria and Germany under four different sustainability pension reforms.

where α_{SF} reflects how the burden of the pension adjustment is shared between workers and retirees (Börsch-Supan and Wilke, 2006). A value of $\alpha_{\text{SF}} = 1$ implies that retirees bear the full adjustment, while a value of $\alpha_{\text{SF}} = 0$ implies workers bear all the cost. The term t_0 is the first year in which the sustainability factor is applied, which we set to 2025. The width of each black dashed line represents pension replacement level when retirees bear 25, 50, 100 percent of the adjustment cost.

The difference between thick dashed black line and the blue solid line in Austria is explained by the fact that the average pension points of retirees increase faster than the average labor income of workers. Moreover, our simulation results suggest that the German sustainability factor—based on the evolution of the number of retirees per worker—will not be triggered until 2030.