Population Aging, Public Finances, and Alternatives for Retirement Reform*

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Abstract

We study retirement reforms that ensure sustainable public finances in the face of population aging. We build a structural life-cycle model with a pension scheme that includes a public pay-as-you-go pillar and a mandatory fully-funded pillar. The two pillars interact through a means-testing mechanism. The higher the fully-funded benefit, the lower the public pay-as-you-go benefit. The interaction allows us to assess a reform in which increases in fully-funded contributions and benefits reduce public pension benefits through means testing. We compare this reform to three alternatives: Increasing the retirement age, cutting public benefits, and increasing taxes to finance growing public pension expenditures. We estimate the model to Danish micro data and find that expanding fully-funded pensions to indirectly lower public pensions yields the highest welfare. Among the remaining reforms, we show that directly lowering public benefits outperforms hiking taxes and increasing the retirement age.

JEL: E24, J11, J22, J26

KEYWORDS: Pension reform, life-cycle models, inequality, longevity

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1 Introduction

In most advanced economies, public pension schemes are coming under fiscal pressure due to population aging. As expected lifetime increases and fertility decreases, the old-age dependency rate grows. This trend makes it increasingly difficult for governments to guarantee adequate old-age benefits while maintaining sustainable public finances. Countries have addressed the issue by increasing the statutory retirement age, lowering benefits, or increasing contributions to accommodate increasing pension expenditures. Moreover, many advanced economies are moving from systems with dominant public pay-as-you-go (PAYG) schemes toward more balanced multi-pillar systems, including mandatory fully-funded (FF) pensions. This shift can also help alleviate fiscal pressure, provided the two pension pillars interact through means testing. That is if income from FF pensions reduces public PAYG benefits. In this context, OECD (2021) reports that 34 out of 38 OECD countries provide some means-tested pension benefits. On average, means-tested benefits constitute 16% of gross average earnings. While economists have studied the rise of FF pensions extensively, the interaction with the PAYG scheme through means testing has been widely overlooked.

In this paper, we assess pension reforms that restore fiscal sustainability in the face of demographic change. Our main contribution is to consider a reform that increases FF contributions to lower PAYG benefits through means testing. We compare this reform to an increase in the statutory retirement age, a direct cut of PAYG benefits, and a tax hike to finance growing public pension expenditures. To this end, we develop a structural life-cycle model with a public PAYG pillar, a mandatory FF pillar, and a third pillar consisting of voluntary retirement savings. While the PAYG scheme pays out defined benefits financed by general taxes, the FF scheme mandates working agents to save on individual accounts annuitized at retirement. Whereas the return in the PAYG scheme comes from population and wage growth, the FF scheme earns the market return. The two pension schemes are the only institutions that provide annuities. Thus, we implicitly assume that markets for voluntary savings are incomplete. This assumption is in line with the literature on the so-called annuity puzzle, i.e., the observation that non-mandated saving in annuities is low. For a summary, see Benartzi et al. (2011). The two pension schemes interact, as PAYG benefits are means tested on FF benefits and returns on voluntary savings. We are particularly interested in measuring the socioeconomic effects of reforms. Therefore, our model incorporates exogenous agent heterogeneity in income profiles, preferences, and mortality risk, varying with education.

We estimate the structural model on high-quality Danish micro data to pin down preference parameters. The estimation procedure targets moments of labor and savings of different education groups. Subsequently, we use the estimated model to analyze reforms that restore fiscal balance amid population aging.

We find that increasing the mandatory contributions to the FF scheme is best for welfare. Welfare gains arise as the FF scheme provides fair annuities and, thus, better longevity risk insurance than voluntary saving. Moreover, the expansion of the FF scheme diminishes the relative importance of the return-dominated PAYG scheme. Extra welfare gains materialize as agents become wealthier, allowing them to enjoy more leisure. In isolation, mandated FF savings lead to more agents being borrowing constrained early in life. However, this effect is mitigated considerably by FF contributions being tax deductible. In contrast, adjusting the tax rate to finance public pension expenditure is the most detrimental to welfare, as it maintains a PAYG scheme with low returns and makes the young more borrowing constrained.

The paper contributes two different strands of literature. First, it contributes to a literature that uses life-cycle models to assess the effect of pension schemes and social security on labor supply and retirement (see, e.g. Groneck and Schneider (2022); Groneck and Wallenius (2021); Salvati (2021); Laun and Wallenius (2016); Jacobs and Piyapromdee (2016); Gustman and Steinmeier (2015); Haan and Prowse (2014); Lainter and Silverman (2012); Imrohoroglu and Kitao (2012); French and Jones (2011); Iskhakov (2010); Bound et al. (2010); van der Klaauw and Wolpin (2008); French (2005); Rust and Phelan (1997); Gustman and Steinmeier (1986)). Within this literature, there a few papers studying the implications of means testing in social security (see Tran and Woodland (2014); Kudrna and Woodland (2011); Sefton et al. (2008); Kudrna et al. (2019)). Kudrna et al. (2022) illustrate how means testing public pensions with income on voluntary savings serves as an automatic stabilizer when longevity increases. Despite thematic similarities, our paper differs in several important respects. Most importantly, our means-testing mechanism includes benefits from mandatory FF pensions. Moreover, we conduct policy analysis under a criterion of fiscal sustainability. Finally, we have a strong empirical focus using structural estimation on Danish micro data.

The second strand of literature studies the welfare effects of restoring fiscal sustainability in public pension schemes facing demographic pressure (see, e.g. Attanasio et al. (2007); De Nardi et al. (1999)). Within this strand, the papers closest to ours are Haan and Prowse (2014) and Laun et al. (2019). Haan and Prowse (2014) use German data to estimate a life-cycle model including an earnings-related public pension system. In the model, retired agents dissave an amount equal to the annuity value of accumulated savings. Thus, the post-retirement consumption plan is entirely exogenous, precluding endogenous responses to changes in life expectancy and pension reform. Laun et al. (2019) build a life-cycle model to study policies that restore fiscal sustainability in public pensions using Norway as their laboratory. Their model includes heterogeneous agents who face health, mortality, and income risk and choose consumption and discrete labor supply. Particularly, they consider increasing the early retirement age, increasing income taxes, lowering old-age retirement benefits, and lowering disability benefits. While these papers focus on PAYG, we add a FF scheme and allow the two schemes to interact through means testing. As an additional contribution to this literature, we carefully model accidental bequest rather than assuming an absorbing confiscatory tax when conducting policy analysis. This generalization avoids the often-overlooked issue of giving an unfair advantage to PAYG and FF schemes that redistribute from the dead to the living.

The paper proceeds as follows. First, 2 describes Denmark's institutional setup, and the data that we use to estimate the model. Section 3 develops, solves, and simulates a structural life-cycle model. Section 4 outlines the structural estimation strategy. Next, for estimated parameters, Section 5 analyses the conventional and the alternative reforms to restore fiscal sustainability. Finally, Section 6 concludes by summarizing and discussing key findings.

2 Institutional Background and Data

Before going into the model, the estimation, and the policy analysis, we first take a closer look at the institutional setup in Denmark and the high-quality register data we have at our disposal.

2.1 The Danish Pension System

The pension system in Denmark has three pillars. The first pillar is a public PAYG scheme (Folkepension) with defined benefits. The benefit consists of a base amount that is the same for everyone and a supplement that is means tested on old-age income. Specifically, the supplement depends negatively on pension benefits from the second and third pillars and other capital income. Figure 1 depicts a stylized version of the means-testing schedule in Denmark.[1] The plot includes the base amount and the two most significant components of the total supplement.[2] Although the supplement is somewhat targeted, a large majority of retirees receive a positive amount on top of the base amount.[3] Unlike US social security, the public scheme is financed entirely through general taxes. Thus, tracking individual contributions to the public pension scheme is

[1] For evidence on the degree of means testing in other countries, see Figure 9 in Appendix C.

[2] These two components are known as Folkepensionstillæg and Ældrecheck. While both are income tested and depend on civil status, the latter is also depends on a wealth test. We disregard a few minor benefits for housing, heating, and health.

[3] For example, according to ATP (2019), 75% of individuals in cohort 1942 received more than the base amount at age 66. At age 75, the corresponding number is 87%.

not possible.

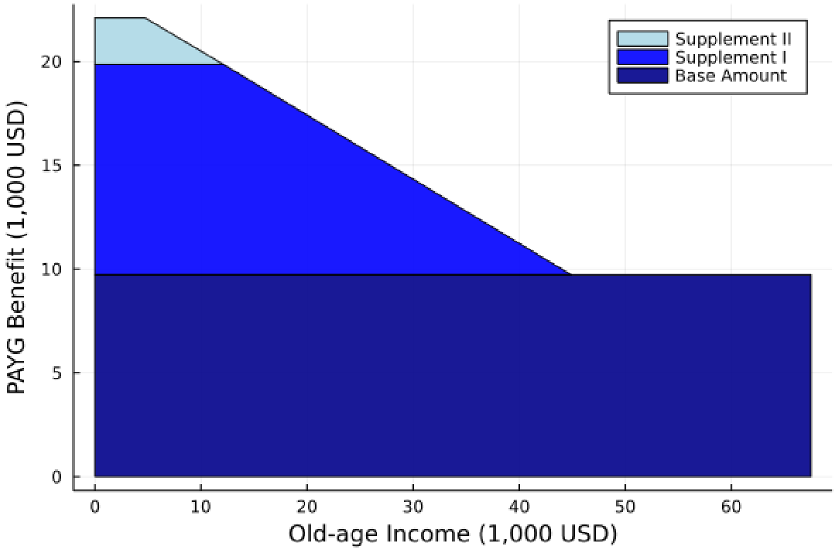

Figure 1: Means Testing. Stylized example based on 2015 rates for a retiree who lives alone and has no significant liquid wealth. Old-age income includes all income other than the public PAYG benefit.

In the second pillar, individuals pay into mandatory defined-contribution FF pensions. Contributions to this scheme are entirely tax deductible. Meanwhile, returns on FF pension wealth are subject to a special capital-income tax. In retirement, the pension fund pays out an annuity benefit based on accumulated pension wealth in the individual account. Benefits from the FF scheme are taxed as labor income. Pension funds in the second pillar are largely occupation specific. Thus, each fund typically has a relatively homogeneous member base with similar incomes and expected lifetimes. However, there are typically systematic differences in incomes and lifetimes across funds. Accordingly, the fair annuity formula differs, such that funds with short-lived members have higher annuity factors. Furthermore, pension funds have different contribution rates. Typically, the contribution rates increase with the life expectancy of members of the fund. This partly reflects differences in annuity returns. Moreover, later labor market entry requires higher contribution rates to achieve a given compensation rate. Finally, there is a relatively small third pillar. The third pillar allows individuals to save in private pension arrangements. These arrangements are similar to the second pillar, but participation is voluntary. In this paper, we explicitly consider the first and second pillars while taking the third pillar to be a part of liquid voluntary savings.

Traditionally, the public system dominated the occupational system. However, a 1987 collective agreement between the social partners and the government (Fælleserklæringen) later stipulated a gradual increase in contribution rates. Following the implementation of the agreement a few years later, the importance of the occupational scheme increased substantially over the years. This shift was further amplified by public pensions being means tested on income from occupational pensions. Shortly after, in 1993, the government introduced a relative increase in supplementary benefits. Thus, the strength of the in-built means-testing mechanism increased even further. Inspired by this, we explore the case for using means testing combined with increasing occupational pensions to reduce public pension expenditure.

2.2 Data

We use Danish register data to calibrate and estimate the model. Register data contains detailed information on every individual living in Denmark in a given year. It covers a vast set of variables linked through an anonymized personal identification number. Moreover, it is possible to link individuals to their spouses and parents to their children. These linkages make register data ideal for conducting both cross-section and panel-data studies with many covariates and a long time horizon for a vast number of individuals. In this paper, we use the population register, BEF, to identify individual characteristics such as age, gender, marital status, etc.. Occasionally, we need to keep track of people entering or exiting the data due to either death or migration. To this end, we use the date-of-death register, DOD, and the migration register, VNDS. To estimate lifecycle earning profiles, we use data on personal income, taxes, and transfers from the income register, IND. We rely on the education register, UDDA, to subdivide individuals into education groups. We use the socioeconomic classification register, AKM, to determine when and how an individual leaves the labor market. To determine individual wealth, we use the pension wealth register, PENSFORM, and the net wealth register, FORMGELD. Except for the latter, data is available from 1980 to 2020. Apart from micro data, we use information from the Danish ministry of finance on actual policy rates for the pension system and a selection of tax rates.

3 The Life-cycle Model

To study pension reform in a framework with behavioral responses, we build a life-cycle model where individuals choose consumption and labor supply while facing idiosyncratic income and mortality risk. The state vector at time t includes two continuous state variables: cash-on-hand, m_t, and FF pension savings, w_t - as well as endogenous retirement status, d_t, and education type, e. As education type is constant, we suppress notation by indicating education-specific terms with superscript e.

Because we are interested in the welfare effects of policy across socioeconomic groups, we introduce ex-ante heterogeneity by allowing mortality rates, life-cycle income profiles, and preferences for labor to vary by education. For an agent with education e, ψ_t^e denotes the probability of surviving from period t to $t+1$. Likewise, x_t^e denotes the education-specific life-cycle productivity profile. Moreover, education types differ in their disutility for labor, δ^e. Finally, education types face different mandatory contributions to FF pensions, ϕ_t^e. Both survival rates, productivity profiles, and contribution rates are estimated using administrative data, as shown in Section 4.1. Preference parameters are estimated structurally in Section 4.2.

Consumption, c_t, is a continuous choice, albeit subject to a standard borrowing constraint. In contrast, the labor decision, l_t is discrete. Agents can either work full time or retire. Retirement is an absorbing state. Hence, once retired, the individual remains retired. If the individual elects to retire before the statutory retirement age, she faces a decision, s_t, over whether to claim the pre-old-age social security benefit, q_0, at a utility cost, χ. After reaching the statutory retirement age, the pre-old-age benefit ceases, and the disutility of claiming disappears. To formalize, individual decisions, d_t, take a finite set, $\mathcal{D} = [1, 2, 3]$, which represents the following combinations of l_t and s_t

$$[(l_t = 1, s_t = 0), (l_t = 0, s_t = 0), (l_t = 0, s_t = 1)].$$

To emulate the Danish pension system, we model a public PAYG pension scheme and a mandatory FF pension scheme and let the two schemes interact through means testing. To be precise, public pension benefits decrease in income from FF pensions. The following sections provide nuance to each component of the model.

3.1 The Pension System

We model an old-age pension system, including a public and a mandatory occupational scheme. For tractability, we perceive voluntary pension contracts in the third pillar as part of voluntary savings. The same goes for any other assets that could serve as a vessel in saving for retirement, e.g., housing. Although our focus is old-age pensions, we include a simple social security benefit to give agents a margin of adjustment when facing a contractionary pension reform.

Public Pension System

To model Danish public pensions in a simple way, we consider two benefits; a universal base amount, p_b, and a single supplement, $p_s(y_t^o)$. The supplement is reduced linearly at a constant penalty rate, π, with all old-age income, y_t^o, including all pension, labor, and net capital income. Assuming that the individual has reached the statutory retirement age, T_r, the public pension benefit formula is given by

$$p_t = p_b + p_s\left(y_t^o\right)$$
$$p_s\left(y_t^o\right) = \max\left\{0, p_s - \pi y_t^o\right\}.$$

Given proper calibration, this specification closely tracks the actual means-testing schedule of the three largest components of public pensions. The actual benefit formula includes a deductible that we do not model. Rather, we modify the maximum supplement and apply the penalty to all old-age income. We deem this a reasonable price to pay for model parsimony. As means testing depends on capital income, the individual must consider the impact on future public pensions when making consumption-saving decisions. For details, see Section 3.2. Abstracting from differences in mortality, the PAYG scheme redistributes from rich to poor. The redistribution channel is important for welfare in and of itself, but also as ex-post intragenerational redistribution works as ex-ante insurance of individual income risk. As the model contains no aggregate risk, we abstract from the inter-generational risk-sharing channel.

Although it is technically possible to postpone public pensions, we assume that the take-up rate is 100%. This assumption also applies to individuals who continue to work past the statutory retirement age. This simplification is rather innocuous, as very few people are eligible to postpone public pensions, and only a fraction of them elect to do so.[4] In practice, this simplification is equivalent to limiting the scope for tax planning for a small subset of the population.

Pre-old-age Social Security

To have a channel for backlash to retirement reform, we allow agents to go on social security benefits before the statutory retirement age. For simplicity, the social security benefit is a flat rate, q_0. We assume that everyone is eligible to go on benefits at any time. However, apart from the direct loss of labor income, agents that claim benefits suffer a utility loss, χ. This parameter could represent either social stigma or disutility from mandatory participation in active labor market programs. Henceforth, we refer to this as the stigma parameter. Because of the stigma, some individuals may leave the labor market without claiming the benefit. That is, agents can self-retire, living solely off their voluntary savings and FF pensions.

[4] According to ATP (2018), only 3.3% of 65-74 year-olds were postponing public pensions in 2016. As it is only possible to postpone for ten years, no one postpones at higher ages.

Fully-Funded Pensions

Individuals enter a fully-funded pension scheme with no initial pension wealth, $w_0 = 0$. In every period thereafter, they accumulate pension wealth on individual accounts by contributing at a rate, ϕ_t, on all before-tax labor income. The law of motion for pension wealth in the account of an individual worker is defined by

$$w_{t+1} = R^e_{t+1} w_t + \phi_t y_{t+1} l_t,$$

Here, $R^e_t = \frac{R}{\psi^e_t}$ is a fair, education-specific annuity return with $R = 1 + (1 - \tau_a)\,\mathtt{r}$ denoting the gross after-tax return and $\mathtt{r}$ denoting the real market return. Intuitively, R^e_t decreases with the education-specific survival rate, ψ^e_t. The split of annuity returns into education groups is rather natural, as Danish pension funds are predominantly occupation specific.

Individuals become eligible for FF pension benefits at age T_p. Following standard principles, the earliest payout age is 60. Suppose a worker stops working at some age, $r \geq T_p$. In every period thereafter, the individual has no labor income but instead receives an actuarially fair annuity based on wealth at retirement

$$f(w_r) = \frac{w_r}{\sum_{\tau=r}^{T} \frac{R^e_r}{\prod_{j=r}^{\tau} R^e_j}}.$$

The individual continues to receive this amount every year until its eventual death. However, as pension wealth is a state variable, it is still helpful to keep track of remaining pension wealth after retirement, although FF pension benefits do not change. The law of motion for the pension wealth of a retiree is

$$w_{t+1} = R^e_{t+1} w_t - f(w_r).$$

Hence, w_t is pension wealth in period t net of current benefits. In Appendix A, we use the law of motion to show that annuitizing the FF pension wealth at retirement is equivalent to re-annuitizing remaining pension wealth in every following period. Hence, we re-annuitize the pension wealth of a retiree in every period rather than changing state variables after retirement. The equivalence property allows us to express the future pension benefit as a function of current pension wealth

$$f_{t+1}(w_t) = \frac{w_t}{\sum_{\tau=t+1}^{T} \frac{1}{\prod_{j=t+1}^{\tau} R_j}}.$$

This is useful not only in solving but also in simulating the model.

3.2 Individual Decision Problem

As always, agents make decisions to maximize expected utility. In this case, expected utility at any age, t, of an individual with education level e is given by

$$U_t = \mathbb{E}_t \left[\sum_{\tau=t}^{T} \beta^{\tau-t} \prod_{s=t-1}^{\tau-1} \psi_s^e \cdot u\left(c_\tau, l_\tau, s_\tau\right) \right],$$

where β is the subjective discount factor and ψ_s^e is the education-specific conditional survival rate at age s. Moreover, $u\left(\cdot\right)$ is the instantaneous utility function over current consumption, labor, and pre-old age social security claiming status

$$u\left(c_t, l_t, s_t\right) = \frac{c_t^{1-\rho}}{1-\rho} - \delta^e l_t - \chi \cdot s_t + \underline{u}.$$

That is, instantaneous utility over consumption is a standard CRRA with the inverse elasticity of intertemporal substitution, ρ. In the special case where $\rho = 1$, utility takes a logarithmic specification. The disutility from discrete labor supply is linear but differs over education groups. To ensure that utility is positive, we add a constant, $\underline{u}$, to the instantaneous utility function. The constant does not change the optimality conditions but ensures that we have a reasonable point of departure for studying welfare implications of pension system reform.[5] Next, we rewrite the individual decision problem in recursive form. As retirement is an absorbing state, we split the recursive form of the utility maximization problem into two - the worker's problem and the retiree's problem, starting with the former.

The Worker's Problem

The value function of a worker of education type e with current state variables of cash-on-hand, m_t, and pension wealth, w_t, is given by:

$$V_t^e\left(m_t, w_t\right) = \max_{d_t \in \mathcal{D}} \left\{ v_t^e\left(m_t, w_t, d_t\right) + \lambda \epsilon\left(d_t\right) \right\}$$

where $v_t^e\left(m_t, w_t, d_t\right)$ is a choice-specific value function over consumption for a given choice, d_t. The value function is education-specific, as both preferences for labor, potential income, and survival probabilities differ over education groups. Discrete labor choice generally introduces kinks in the value function and jumps in the policy func-

[5] Without ensuring positivity of instantaneous utility, welfare decreases when longevity increases, which would obfuscate the interpretation of our results when doing policy analysis. To pin down this parameter, we fit the model to empirical estimates for the value of statistical life in Denmark as discussed in Section 5.3.

tion, propagating backward in time. Because of these kinks, there are multiple solutions to the Euler equation. Consequently, we use the Discrete-Choice Endogenous Grid Method (DC-EGM), Iskhakov et al. (2017). This an extension of the Endogenous Grid Method, see Carroll (2006), to a setting with a discrete labor choice. Although the solution method can handle non-convexities and multiple solutions to the Euler equation, we also consider a type-1 extreme-value taste shock, $\epsilon(d_t)$, with scale parameter, λ.[6] As shown in McFadden (1973), the taste shock acts as a logit smoother of value functions by making labor choices probabilistic. For our purposes, the taste shock represents unobserved factors of individual choice and permits a smoother transition into retirement, providing a better model fit. The choice-specific value function for a worker, $d_t = 1$, can be written in the following recursive form

$$
\begin{aligned}
v_t^e(m_t, w_t, 1) &= \max_{a_t \geq 0} \left\{ u(c_t, 1, 0) + \beta \cdot \psi_t^e \cdot \mathbb{E}_t \left[V_{t+1}^e(m_{t+1}, w_{t+1}) \right] \right\} \\
&st. \\
m_t &= a_t + (1 + \tau_c) c_t \\
m_{t+1} &= (1 - \tau_y(\cdot)) \left[(1 - \phi_{t+1}) y_{t+1} + \mathbb{I}_{t+1}^p p_{t+1}\left(y_{t+1}^o\right) \right] + b_{t+1}^e + Ra_t \\
y_{t+1}^o &= (1 - \phi_{t+1}) y_{t+1} + (R - 1) a_t \\
w_{t+1} &= R_{t+1}^e w_t + \phi_{t+1} y_{t+1} \\
y_{t+1} &= exp\left(x_{t+1}^e + z_{t+1}\right) \\
z_{t+1} &\sim \mathcal{N}\left(\mu, \sigma^2\right).
\end{aligned}
$$

Here, y_{t+1} is an income shock that has two components; A deterministic component, x_{t+1}^e, that captures the productivity pattern over the life cycle, and a stochastic component, z_{t+1}, following a log-normal distribution. We pin down the parameters of the log-normal shock distribution by a panel wage regression in Section 4.1. Meanwhile, b_{t+1}^e denotes income in the form of accidental bequest. While accidental bequest is exogenous in the structural estimation, we endogenize the bequest distribution in the policy analysis. For more on the transmission of bequest, see Section 5.2. Furthermore, $\mathbb{I}$ denotes indicator functions for eligibility of different benefits, while $\tau_y(\cdot)$ is s progressive income tax function and τ_c is a proportional consumption tax rate. It is straightforward to derive the first-order condition for optimal consumption

$$
c_t^{-\rho} = \beta \cdot \psi_t^e \cdot \mathbb{E}_t \left[\left(R + (1 - \tau_y(\cdot)) \, \mathbb{I}_{t+1}^p \frac{\partial p_{t+1}\left(y_{t+1}^o\right)}{\partial a_t} \right) c_{t+1}^{-\rho} \right].
$$

[6] See Adda et al. (2017) and Groneck and Schneider (2022) for other examples of life-cycle models solved using DC-EGM with taste shocks.

For a young worker who is ineligible for public pensions ($t < T_r$), this reduces to the standard case. The eligible worker ($t \geq T_r$), however, faces a crowding-out effect from voluntary savings onto public pension benefits. As the first-order condition shows, evaluating expectations over future choices and values is essential. Thus, we briefly introduce some concepts that are helpful in this endeavor. Note first that income and taste shocks are uncorrelated. Therefore, we can rewrite the continuation value of the worker as

$$\mathbb{E}_t \left[V_{t+1}^e \left(m_{t+1}, w_{t+1} \right) \right] = \int EV_{t+1}^{\epsilon} \left[v_{t+1}^e \left(m_{t+1}, w_{t+1}, d_{t+1} \right) \right] dy,$$

where EV_{t+1}^{ϵ} is the expectation over the future taste shock for given future states of income. The integral over y then accounts for expectations over the income shock. In evaluating expectations over the income shock, we discretize the log-normal distribution using Gauss-Hermite Quadrature with $S = 5$ points. For the taste shock, we use the well-known log-sum formula for independent, extreme-value distributed random variables

$$EV_{t+1}^{\epsilon} = \lambda \cdot log \left(\sum_{d_{t+1} \in \mathcal{D}} exp \left(\frac{v_{t+1}^e \left(m_{t+1}, w_{t+1}, d_{t+1} \right)}{\lambda} \right) \right).$$

We apply similar techniques to compute expectations over the policy function when evaluating the Euler equation.

The Retiree's Problem

A retiree has stopped working, $d_t > 1$, and faces no more income risk or taste shocks to preferences for labor. Consequently, the decision problem of a retiree simplifies somewhat. The recursive formulation of the utility maximization problem for a retiree of education type e with claiming status s_t is given by

$$\begin{aligned}
v_t^e \left(m_t, w_t, d_t > 1 \right) = \max_{a_t \geq 0} & \left\{ u \left(c_t, 0, s_t \right) + \beta \cdot \psi_t^e \cdot v_{t+1}^e \left(m_{t+1}, w_{t+1}, d_t > 1 \right) \right\} \\
st. & \\
m_t &= a_t + \left(1 + \tau_c \right) c_t \\
m_{t+1} &= R a_t + \left(1 - \tau_y \left(\cdot \right) \right) \left(\mathbb{I}_{t+1}^f f_{t+1} \left(w_t \right) + \mathbb{I}_{t+1}^p p_{t+1} \left(y_{t+1}^o \right) + \mathbb{I}_{t+1}^d q_0 \right) \\
y_{t+1}^o &= \left(R - 1 \right) a_t + \mathbb{I}_{t+1}^f f_{t+1} \left(w_t \right) \\
w_{t+1} &= R_{t+1}^e w_t - \mathbb{I}_{t+1}^f f_{t+1} \left(w_t \right).
\end{aligned}$$

As the retiree faces no more income and taste shocks, one can solve the problem by the standard Endogenous Grid Method (EGM), see Carroll (2006). However, as the means-testing schedule of public pensions is not globally differentiable, we amend the standard procedure with an upper-envelope program that handles potential multiplicity of equilibria.

4 Estimation

We follow a two-stage estimation strategy. In the first stage, we calibrate and estimate a selection of exogenous model parameters as shown in Section 4.1. In the second stage, we use the Simulated Method of Moments (SMM) to estimate all preference parameters as described in Section 4.2.

4.1 Estimation Outside the Model

This section covers the calibration of parameters determined outside the model. For a quick overview, see Table 1. First, we calibrate the timing of the model. Here, we set the starting age to 25 and the maximum age to 95. Individuals start to receive bequest at 55 and stop receiving bequest at 65. To match the institutional setup for the relevant cohorts, we set the statutory retirement age to 65. Meanwhile, the earliest access age for funded benefits is 60. Public benefits and the means testing schedule are calibrated to match actual rates. Finally, we assume a real net return of 3%. This return is well in line with the related literature. Second, we use econometric methods to estimate education-specific mortality rates, life-cycle productivity profiles, and mandated FF contribution rates. Unless otherwise stated, we use data for cohorts 1949-1953. We focus on these cohorts, as they start to become eligible for retirement in 2015, such that we have data for many years before the statutory retirement age and for some years after. Also, these cohorts were unaffected by a significant reform in 2011. In addition, we use 2015 data to estimate an income tax polynomial.

Table 1: Calibration of Exogenous Parameters

Parameter	Description	Value	Origin
Timing			
T	Maximum age of life	95	
T_{birth}	Age at birth	25	
T_r	Eligibility age for public pensions	65	Actual retirement age
T_p	Earliest access to funded benefit	50	Danish legislation
T_l	Earliest age of receiving bequest	55	
T_u	Latest age of receiving bequest	65	
Demographics			
ψ^j	Survival prob. betw. age j and $j+1$	See Figure 2	DST Data, Lee-Li model
labor productivity			
$\{x_e\}$	Earnings potential	See Figure 3	DST Data, Wage regression
$\{\sigma_e\}$	Variance of productivity shock	$\{0.516, 0.501, 0.562\}$	DST Data, Wage regression
$Prob_{parents\|children}$	Education transmission matrix	See Table 3	DST Data, Markov matrix
Taxes and Social Security			
$\tau_y(\cdot)$	Income tax function	See Figure 4	DST Data 2015, Polynomial fit
τ_c	Value added/consumption tax	0.25	Danish tax code
τ_a	Capital income tax	0.27	Danish tax code
τ_b	Inheritance Tax	0.15	Danish tax code
q_0	Pre-retirement benefit	18,900 USD	DST Data 2015
$p(\cdot)$	Retirement benefit function	See Figure 1	Current Legislation
p_0	Base amount of old-age benefits	9,715 USD	Legislation 2015
p_1	Supplement of old-age benefits	12,384 USD	Legislation 2015
π	Means-testing penalty rate	0.309	Legislation 2015
Prices			
R	Gross interest rate after taxes	1.03	

Notes: The table contains all parameters calibrated and estimated outside the model.

Education Types

As we model exogenous agent heterogeneity by educational attainment, we first need to define the allocation of individuals to education groups. The allocation mechanism works as follows. First, we rank individuals of a cohort and gender according to their highest degree at age 32 or the earliest age that education data is available from the registers. Within each degree, we further rank individuals according to their age at graduation. The lower the age at graduation, the higher the education rank. We use this ranking mechanism to split each cohort into three equally sized education groups - Low, Middle, and High - for each gender. As a final step, we aggregate over genders to produce three equally sized education groups with a balanced gender composition.

Mortality

To produce coherent forecasts for sub-population mortality for all education groups, we use a standard Li and Lee (2005) model, which builds on the well-known Carter and Lee (1992) model. For details on the model, we refer to Appendix B. We apply the model to 41 years of Danish register data for ages 50 to 95. We consider equally-sized groups based on education rank to avoid well-known issues with drift when using education level as the allocation mechanism. In this way, we produce group-specific survival rates as depicted in Figure 2. As expected, survival rates increase monotonically across education groups at all ages. The estimated survival rates are consistent with expected lifetimes of 80.8, 82.8, and 84.7 years for people of Low, Middle, and, High education. The differences in longevity are not only important for individual decisions. They also limit the scope for redistribution through the public pension system. This could have important consequences for the welfare response to different policies in the policy analysis.

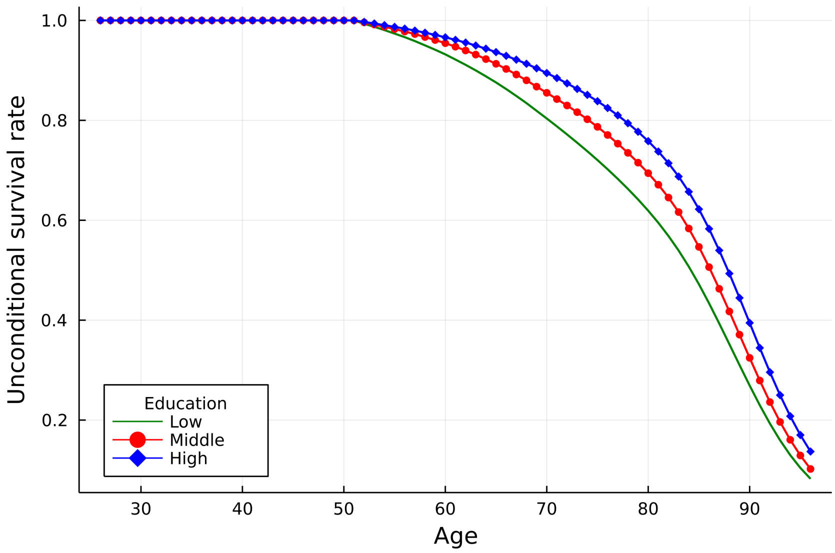

Figure 2: Education-specific Conditional Survival Rates

Life-cycle Productivity

To estimate the life-cycle productivity pattern, we use Danish register data on income and run a panel regression with a fifth-order age polynomial as well as individual and year-fixed effects on income. Like in Cocco et al. (2005), our income measure includes labor income plus social benefits, including social security. The regression equation is given by

$$
\begin{aligned}
Y_t^i &= x_t^e + \mathbb{I}_t + u^i + \epsilon_t^i \\
x_t^e &= \alpha_1 a_t + \ldots + \alpha_n a_t^n,
\end{aligned}
$$

where Y_t^i is full-time equivalent labor income in logs, x_t^e is a fifth-order age polynomial, $\mathbb{I}_t$ are year fixed effects, u^i denotes individual fixed effects, and ϵ_t^i is a transitory idiosyncratic income shock. We use the standard errors from this regression to pin down the standard deviation of the income shock, σ_e, and set $\mu_e = 0$.

In the regression, we use income data for cohorts 1949-1953 for both men and women aged 25 to 63. After age 63, potential earnings remain unchanged. This procedure produces the life-cycle productivity pattern depicted in Figure 3. The resulting earnings patterns differ in several respects. Most importantly, better-educated individuals have higher lifetime incomes. However, at very young ages, people with lower education tend to be more productive than their better-educated peers. This crossing-over of earnings profiles is also found by Cocco et al. (2005). This property is likely associated with differences in education and tenure. The associated standard deviations of the income shocks of the three education groups are $\sigma_1 = 0.516, \sigma_2 = 0.501, \sigma_3 = 0.562$.

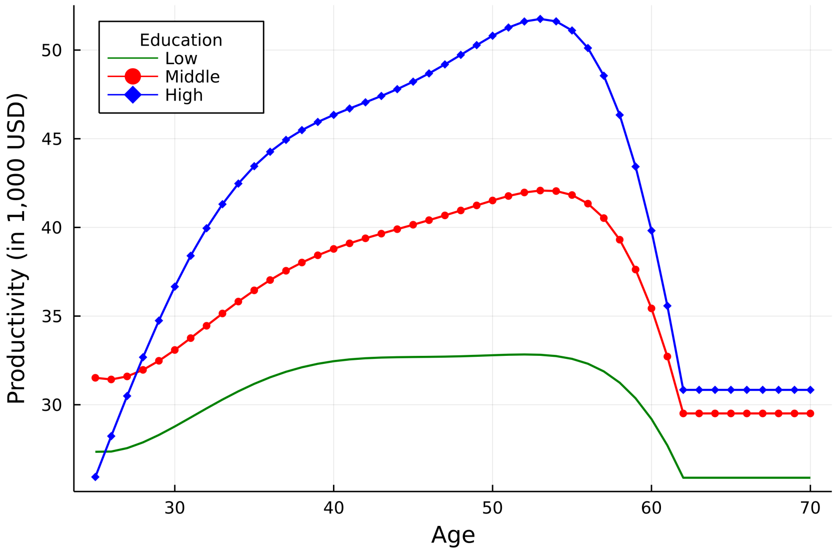

Figure 3: Education-specific Average Earnings

Taxes

Much like the pension system, the Danish tax system is rather complex. To keep things simple, we implement a stylized version of the tax system. The stylized system consists of income taxes, a value-added tax, a capital tax, and an inheritance tax. In accordance with the actual tax code, consumption is taxed at $\tau_c = 25\%$. Meanwhile, capital is taxed at $\tau_a = 27\%$, and bequest at $\tau_b = 15\%$. Income taxes, $\tau_y(\cdot)$, are calculated by a polynomial tax function over taxable income. Here, taxable income includes labor income (after contributions to FF pensions) and benefits from FF and public pensions. To elicit the tax polynomial, we fit a second-order polynomial on average tax rates within income bins of $1,350$ USD ($10,000$ DKK) for all individuals with income below $135,000$ USD (1 million DKK), using 2015 register data. In that way, we abstract from specific tax rates and deductibles to capture overall progressivity in a simple way. For reference, see Laun et al. (2019). The results are depicted in Figure 4. Unsurprisingly, the tax function is progressive. To avoid decreasing tax rates at very high income levels, we let the tax rate be constant above the polynomial mode. In the model, we apply the tax function to all income except for returns on voluntary savings.

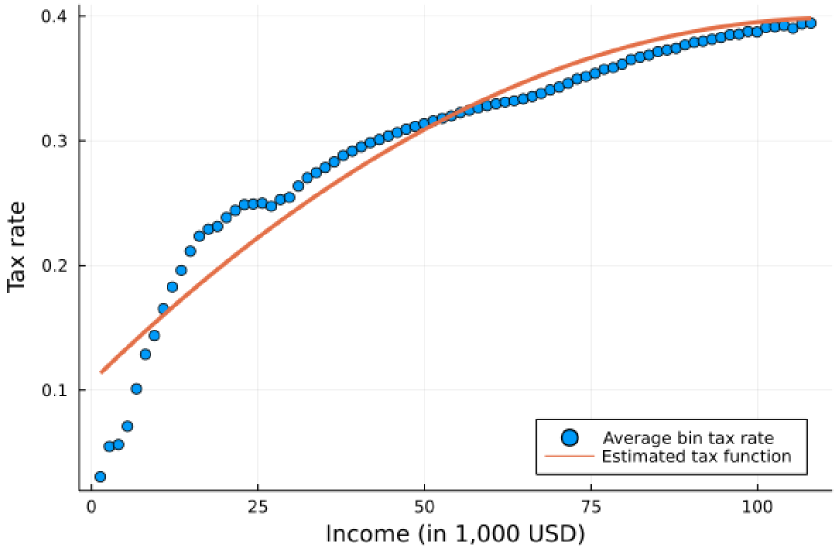

Figure 4: Tax Function

Funded Pension Contribution Rates

In Denmark, pension contribution rates are negotiated between unions and employer associations and are, therefore, largely occupation specific. As contributions to some extent reflect longevity differences, academics and white-collar workers traditionally have higher contribution rates than blue-collar workers. For a detailed overview of union-specific contribution rates, see Finansministeriet (2017). In the model, we base education-specific contribution rates on union-specific rates. Figure 5 depicts the resulting contribution rates. Notably, contribution rates increased significantly for all groups between 1991 and 2009 and have remained constant since. Recalling the section on the institutional setup in Denmark, this increase resulted from a political agreement from 1987. The agreement was highly politicised and took several years to step into effect. Thus, it is reasonable to assume that individuals could foresee future contribution rates with some accuracy. Therefore, we assume perfect foresight with respect to contributions.

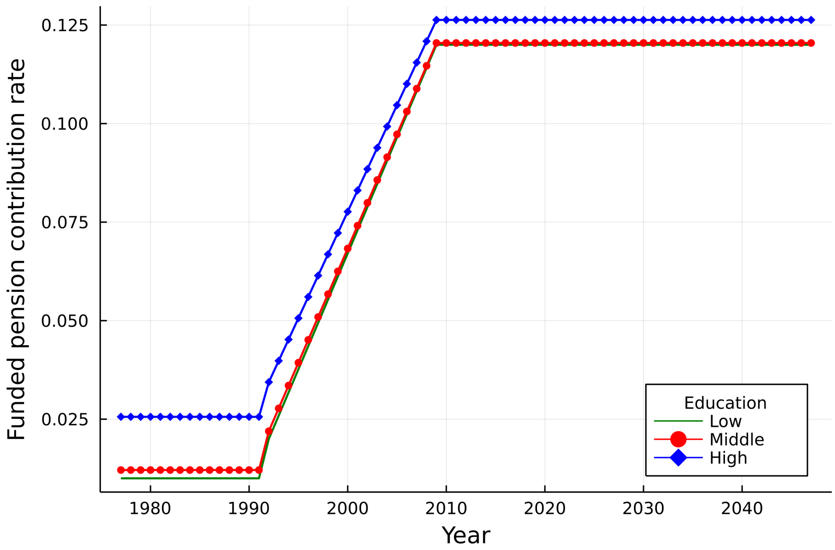

Figure 5: Funded Pension Contribution Rates

4.2 Estimating Structural Parameters

We pin down all preference parameters by way of structural estimation. That is, we match a series of simulated model moments to corresponding data moments by varying a vector of parameters. The first type of moment that we target pertains to the labor supply of cohorts 1949 to 1953. We specifically target education-specific labor force participation at ages 58, 62, and 65. Second, we target levels of voluntary savings at age 55. In doing so, we again use register data to identify voluntary savings for each education group.

We estimate the inter-temporal substitution parameter, ρ, the subjective discount factor, β, the education-specific disutility of labor, δ^e, the social stigma, χ, and the scale parameter for the taste-shock, λ. In estimating the model, we rely on the simulated method of moments (SMM); A version of the generalized method of moments used when analytical model moments are unavailable. The SMM estimator is the argument that minimizes a weighted sum of distances between moments in the model and moments in the data

$$\hat{\theta} = \underset{\theta}{\operatorname{argmin}}\, e\left(\tilde{x}, x|\theta\right)' W e\left(\tilde{x}, x|\theta\right).$$

Here, $e\left(\tilde{x}, x|\theta\right) = \frac{m(\tilde{x}|\theta)-m(x)}{m(x)}$ is a vector of percentage deviations for $K = 12$ moment conditions, and W is a weighting matrix. We use a two-step procedure. First, we set $W = I$ and solve for $\hat{\theta}$. In the second stage, we use bootstrapping to update the weighting matrix. More precisely, we sample $S = 100$ instances of the economy to estimate the variance of the sample errors and set the diagonal elements of the weighting matrix equal to the inverse of these estimates. Given the updated weights, we solve again for

$\hat{\theta}$ [7] The resulting solution is characterized by the parameters listed in Table 2. [8]

Table 2: Structurally Estimated Parameters

Parameter	Description	Value
β	Subjective discount factor	0.9739
ρ	Inverse elasticity of substitution	2.3522
χ	Stigma	0.5853
$\{\delta^e\}$	Disutility from work	[0.494, 0.4237, 0.3129]
λ	Taste shock scaling parameter	0.7551

Notes: To validate the solution, we run the algorithm again for a different set of starting values.

Having estimated the model, we are now ready to examine the outcomes of the estimated models. To this end, Appendix C contains figures illustrating the life-cycle behavior of different variables. Note that these are conditional on survival. The plots show that labor income increases at early ages only to flatten and decrease as individuals become less productive or retire. There is a clear tendency for the propensity to retire early and to claim the early retirement benefit to decline with education. As people grow older, they transition into retirement. In retirement, the public benefit is larger than the FF benefit for all education groups. However, the difference declines in education. For all education groups, the consumption profile is relatively flat. The associated profiles for savings and wealth display a distinct rise and fall but hit their apex at different ages. To be precise, agents start to save down in liquid wealth early on, before the illiquid FF pension wealth has reached its apex. As expected, better-educated individuals tend to consume the most and to have the highest net worth.

4.3 Targeted Moments

In this section, we evaluate the model fit for targeted variables. First, Figure 6 compares labor supply in the model to labor supply in the data for each education group at all ages. Note here that we target levels at ages 58, 62, and 65. To compute labor supply in the data, we introduce a sample selection criterion to include only individuals who are not on sickness benefits at the age of 40. After that, we use socioeconomic classification provided by statistics Denmark to determine whether an individual is working

7 For the optimization routine, we call a numerical solver from the Optim.jl package in Julia. To increase the likelihood of finding a global solution, we run the two-step SMM for different vectors of starting values.

8 To increase the likelihood of finding the global minimum, we explored several bounded and unbounded routines and different starting values.

or not. We use the same criterion to gauge total wealth. The model over-predicts labor supply by five to ten percentage points at early ages, but the errors decline somewhat as individuals start to retire. The problems of matching the data at early ages likely have to do with conceptual differences between classifications of labor market participation in the model versus the data. For instance, we do not explicitly model people who are on disability benefits all of their life. Although the fit is not perfect, we are satisfied with errors of this size.

5 Policy Analysis

Having pinned down all the model parameters, we evaluate the economic and social impact of various reforms in the face of fiscal pressure deriving from increases in longevity and falling fertility. The reforms that we consider are: increasing taxes, increasing the retirement age, lowering public benefits directly, and increasing mandatory contributions to fully-funded pensions to lower public benefits indirectly. In Appendix D, we consider a couple of additional policies. All policy evaluations rely on comparisons across steady states. First, we consider a baseline steady state in which agents have the survival rates of the 1952 cohort. Next, we increase longevity to that of cohort 1962. This corresponds to an increase in remaining life expectancy by 2 years at the age of 40. Meanwhile, the fertility rate, n, adjusts to match expected changes in the Danish old-age dependency ratio between 2015 and 2035.[9,10] We then verify that the demographic change puts pressure on public finances as it increases old-age pension expenditure more than it increases tax revenue. Based on this observation, we then consider the economic impact of each of the reforms intended to ensure fiscal sustainability. Throughout, we take fiscal sustainability to imply that residual government consumption per capita is unchanged from the baseline. However, we first pause to describe the feedback effects introduced by the government ensuring fiscal sustainability and by overlapping generations passing on bequest.[11] Moreover, we outline the definition of a pecuniary welfare measure.

[9] According to the OECD, the Danish old-age dependency ratio was 33.0 in 2015 and is expected to increase to 40.5 in 2035. Given estimated mortality, this implies a drop in the fertility rate from $n = 0.008$ to $n = 0.004$.

[10] Compared to the estimated model, we keep most parameters constant. However, instead of increasing pension contributions over the life cycle, we keep them constant at post-reform levels, i.e. after 2009. Furthermore, we adjust the age-specific earnings potential, x_t^e, for real wage growth.

[11] We use the term *feedback effects* rather than *general-equilibrium effects* to avoid confusion about the exogeneity of factor prices.

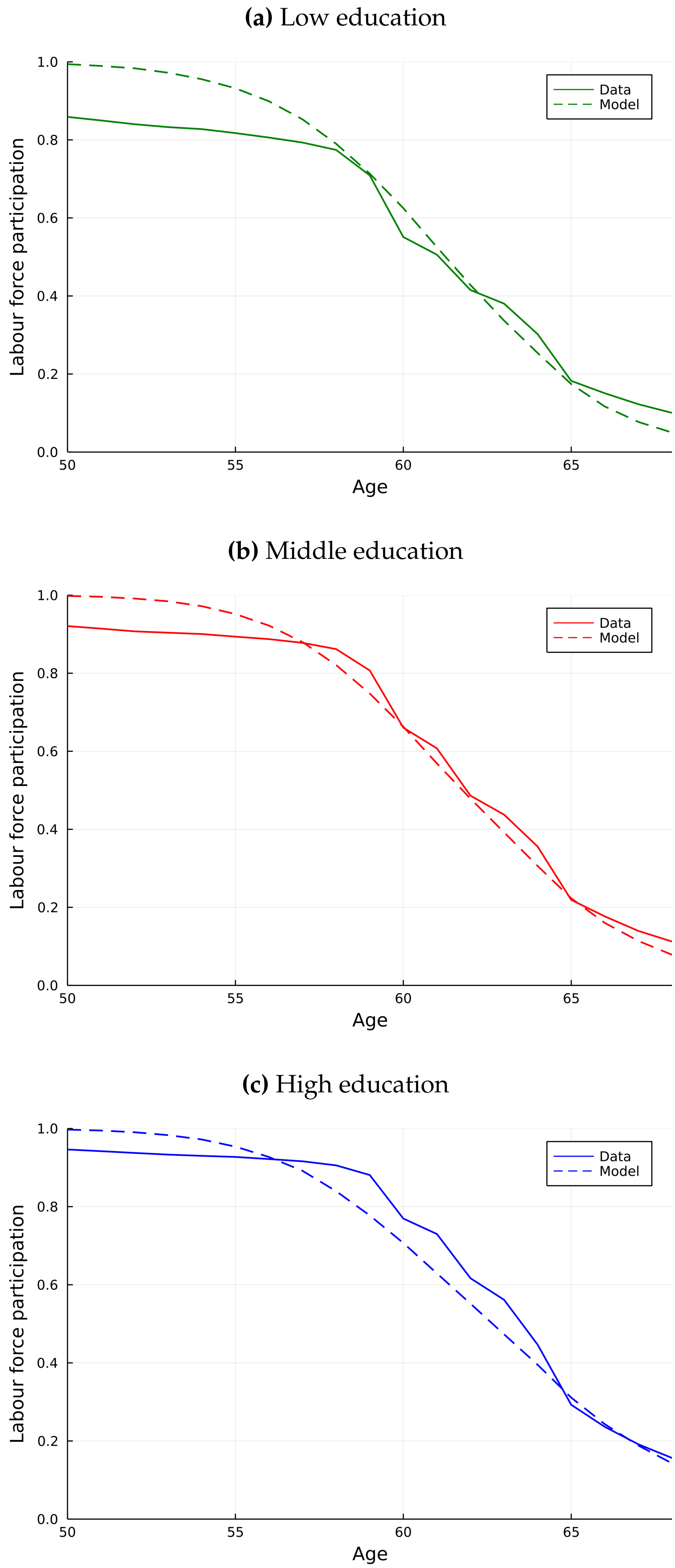

Figure 6: Labour Force Participation

5.1 The Government Budget

The government finances government consumption through income taxes on wages and pensions, consumption taxes, capital income taxes, and inheritance taxes. Apart from social security benefits, the proceeds finance residual government consumption (e.g. healthcare, education, infrastructure, etc.). To evaluate fiscal pressure, we require residual government consumption per capita, $\mathcal{G}$, to be constant. Thus, following a change in survival and fertility, one or more policy parameters must adjust to keep this measure constant. Denoting by $\mathcal{T}^e_{y,\tau}$ average type-specific income taxes, by $\mathcal{T}^e_{c,\tau}$ consumption taxes, by $\mathcal{T}^e_{a,\tau}$ all capital income taxes, by $\mathcal{T}^e_{b,\tau}$ all inheritance taxes, and by P^e_τ public pension and pre-old age social security expenditures, fiscal sustainability is ensured by the following condition

$$\mathcal{G} = \frac{\sum_{\tau=1}^{T} \sum_e \left(\mathcal{T}^e_{y,\tau} + \mathcal{T}^e_{c,\tau} + \mathcal{T}^e_{a,\tau} + \mathcal{T}^e_{b,\tau} - P^e_\tau \right) \frac{\Psi^e_\tau}{(1+n)^\tau}}{\sum_{\tau=1}^{T} \sum_e \frac{\Psi^e_\tau}{(1+n)^\tau}}.$$

Here, n denotes a constant population growth rate that we incorporate to match the slowdown of fertility. Whatever policy instrument we consider, any reform generally affects all the revenue and expenditure terms on the right-hand side - some directly and others indirectly. The requirement of fiscal sustainability introduces feedback effects in the policy analysis. On the one hand, pension policy affects both choices and the budget. In turn, choices affect the budget and vice versa. Hence, we let taxes and choices converge to their steady-state levels following each reform.

5.2 Bequest

Within the related quantitative literature on pension system reform, most papers do not explicitly account for the redistribution of unclaimed savings of the dead. In most cases, we take this to mean that unclaimed savings are simply disregarded. We argue that disregarding bequest has limiting implications for policy analysis, as it mechanically tips the scales in favor of pension schemes that internalize the biological return. To avoid such limitations, we model an internally consistent level of education-specific bequest. We assume that children receive bequest from age T_l to T_u. If parents with education type e' have probability $prob\left(e|e'\right)$ of having a child with education type e, the bequest given to children of this type reads

$$b_{t+1}^{e}=\frac{R\left(1-\tau_{b}\right)\sum_{\tau=1}^{T}\sum_{e} prob\left(e|e'\right)\dfrac{\mathbb{E}\left(a_{\tau}^{e'}\right)\left(1-\psi_{\tau}^{e'}\right)\Psi_{\tau-1}^{e'}}{\left(1+n\right)^{\tau}}}{\sum_{\tau=T_{l}}^{T_{u}}\dfrac{\Psi_{\tau}^{e}}{\left(1+n\right)^{\tau}}}.$$

Thus, an individual of a specific education rank inherits the mean unclaimed savings of its probabilistic ancestors. Note that τ_b is an inheritance tax, which we calibrate according to Danish tax code. We use administrative data to link parents to their children and to produce education transition probabilities. We then compute a Markov matrix containing switching probabilities. To be consistent with the split by equally sized groups of education rank, we impose the additional restriction that the switching matrix is doubly stochastic. Table 3 contains the resulting transition probabilities for the 1950 cohort of parents and their children.

Table 3: Education Transition Matrix

	Parent rank		
Child rank	1	2	3
1	0.431352	0.345354	0.223294
2	0.324353	0.372327	0.303320
3	0.244295	0.282319	0.473386

Notes: Parents are born in 1950 and children are born between 1965 and 1990. Education ranks are constructed at age 30. The Markov matrix is doubly stochastic, implying that both rows and columns sum to one. Thus, transition probabilities are consistent with the definition by tertiles.

Much like the sustainability criterion for public finances, the preservation of resources through accidental bequest introduces feedback effects between individual choices and the aggregate level of bequest. To overcome this, we again require all individual choices and aggregate variables to converge for every policy. In practice, we implement a convergence loop around the solution and simulation algorithms.

5.3 Welfare Measurement

When evaluating the welfare effect of public policy, one could potentially consider welfare for each education group at every age. However, we focus on welfare behind the veil of ignorance, i.e., before individuals learn their education type. This welfare measure amounts to average welfare over the groups when entering the economy. However, as we want to describe the socioeconomic aspects of pension reform, we also compute welfare after individuals learn their type but before observing any income shocks. Furthermore, as it is often difficult to interpret welfare changes in utility terms, we compute the compensating variation (CV) for each policy relative to the reform that delivers the least welfare on average. Intuitively, the CV is the amount an individual would require as compensation to support the worst policy. Recalling Section 3.2, we add a positive constant, $\underline{u}$, to the instantaneous utility function. The constant does not affect individual decisions but merely ensures a positive value of life when doing welfare analysis. We calibrate this parameter to match empirical and legal estimates of the value of statistical life (VSL) in Denmark of 4,185,000 USD (31 million DKK), (see **?**).[12]

5.4 Evaluating Fiscal Pressure

As a benchmark, we first examine the effect of demographic change on individual decisions, social welfare, and the public budget by allowing residual government consumption to go down in the new steady state. We refer to this as the unfinanced steady state. For this and all subsequent policy experiments, we list the responses in voluntary savings, total savings (i.e. voluntary savings plus pension wealth), labor supply, and welfare in Tables 5 through 8. Note that we report the results from all policy experiments relative to the outcomes of the tax reform.

Intuitively, an increase in longevity puts upward pressure on voluntary savings for given retirement decisions. At the same time, a longer life also leaves room for an extended work life. An additional year of working increases lifetime labor income, which tends to increase voluntary saving. However, it also means fewer years of retirement, lowering the desire to save. Going from the old to the new equilibrium, the response in both voluntary savings and labor is positive for all education groups. Naturally, the increase in labor is further associated with an increase in FF pension wealth. Combined with the voluntary saving surge, this increases total savings.

The increase in the old-age dependency ratio increases pension expenditure in the government budget. At the same time, the overall increase in labor income tends to increase the tax base and, thereby, helps to ease the fiscal burden. Moreover, the demographic change affects the consumption tax, the capital tax, the inheritance tax, and

[12] VSL represents the amount that agents are willing to pay for a reduction in mortality risk. One can easily derive this measure by total differentiation of the value function

$$VSL_t(m_t) = \frac{\frac{\partial V_t(m_t, w_t)}{\partial \psi_t}}{\frac{\partial V_t(m_t, w_t)}{\partial m_t}}.$$

public expenditures on pensions and social security. In Table 12, we break down how the demographic change affects each budget component. The combined result is a decrease in residual government consumption by 5.0%, indicating that demographic change threatens fiscal sustainability. For welfare, Table 8 contains the CV measure associated with each policy for every education group. As expected, given that utility and the value of life are positive, the welfare effect of an increase in longevity is also positive.

Table 4: Required Policy Change

	Baseline SS	New SS	Change
Tax increase, τ_0	10.65%	12.04%	1.39 p.p.
Retirement age increase, T_r	65	69	4 years
Decreasing the benefit, p	24,768 USD	19,747 USD	-10.6%
Increasing FF contri., ϕ	[0.12, 0.12045, 0.1263]	[0.136, 0.137, 0.143]	13.6%

Notes: The increase in the retirement age also comes with a lower tax rate, τ_0, of 10.36% .

5.5 Increasing the Tax Rate

As the first policy instrument, we adjust income taxes to finance the extra expenditure on public old-age pensions and pre-old-age social security. Specifically, we increase the baseline of the tax function to balance the budget. We find that the proportional part of the tax function has to increase by 1.39 percentage points to 12.04% to balance the budget.

Coming from the unfinanced steady state, increasing the tax rate lowers lifetime income, implying a negative income effect on voluntary savings for all education groups. Especially early in life, the increase in taxes forces more agents into the borrowing-constrained corner. In the estimated model, average voluntary savings decrease by 0.59%. For labor supply, a higher tax rate implies a positive income effect, as individuals become poorer and, hence, can afford less leisure. On the other hand, a negative substitution effect exists as the relative price of leisure decreases. In the estimated model, the substitution effect dominates, such that people retire later than in the unfinanced steady state. Average labor increases by approximately 0.87% percentage points. This combined results in a slight decrease in total wealth for all education groups. The change in labor supply feeds back to the public budget through a smaller tax base and an associated uptick in expenditures on pre-old-age benefits.

In terms of redistribution, the tax reform lowers disposable income for everyone, but more so for high-income individuals. That is, increasing the tax rate preserves redistribution to some extent. Furthermore, a tax hike decreases after-tax pension benefits for everyone. As before-tax benefits do not change, there are only second-order effects on the insurance value of pensions. The response in welfare is negative. In fact, increasing the tax rate yields lower welfare for all education groups than any of the policies under consideration. In the following, we use the tax reform as an anchor to compare outcomes across reforms. Consequently, we standardize the CV measure of welfare is 0 USD for the tax reform. Despite the adverse welfare effects of the reform, welfare is still higher than before the demographic change. This is a reminder that a longer life is not necessarily a threat to social welfare, despite the fiscal challenges it may pose.

5.6 Increasing the Retirement Age

In a second policy experiment, we adjust the retirement age in one-year increments until the budget is in surplus. Subsequently, we balance the budget by lowering the tax rate. In doing so, we find that an increase in the retirement age by 4 years combined with a slight reduction in taxes is enough to restore residual government consumption. The government needs an increase of this order because agents no longer eligible for old-age benefits respond by going on early-retirement benefits. Laun et al. (2019) find similar results.[13]

From a life-cycle perspective, a higher retirement age puts upward pressure on savings. That is, all else constant, individuals must shift part of their income to later ages to compensate for missing public pensions. Simultaneously, the loss of lifetime income implies a negative income effect on savings, as the individual has a smaller budget to save from. However, the total response in savings also depends on the labor effect of the reform. If individuals work more, income increases, exerting a positive income effect on savings and a negative substitution effect, shifting income forward in time. In addition, the labor response influences public finances through a feedback effect on the tax base. If individuals elect not to work, the feedback effect on public finances further depends on whether or not they claim the pre-old-age benefit as a backlash to reform. Compared to the baseline tax reform, increasing the retirement age reform leads to higher voluntary savings within all education groups. Regarding labor, the retirement age reform provides participation rates similar to the tax reform. As a result, total wealth is greater for all education groups than under the tax reform.

In terms of welfare, increasing the retirement age lowers the net present value of public pension benefits for everyone. However, those with low education or bad income shocks lose the most. Nonetheless, the retirement age reform leads to better welfare outcomes for all education groups vis a vis increasing the tax rate. To see this,

[13] The required increase in retirement age would likely be smaller if we accounted for improvements in earnings ability associated with improvements in health and longevity.

the average CV measure is 3,715 USD. Intuitively, this is the minimum compensation the average individual would require to accept the tax reform over the retirement age reform. The education-specific CV is lowest for the lowest education group and highest for the middle group. For most reforms, there is a tendency for the low-education group to have the lowest CV. This group works less, pays less in taxes, and relies more on public benefits. Thus, they require a smaller compensation to accept a tax reform that keeps public benefits intact.

5.7 Decreasing Benefits

In the third experiment, we balance the budget by proportionally adjusting the base amount, p_0, and the supplement, p_1. We find that benefits have to decrease by 10.6% to ensure sustainability.

Lowering benefits affects voluntary savings in two ways. First, there is a negative income effect on savings. At the same time, consumption-smoothing motives imply that an individual must save more to maintain old-age consumption. Thus, the overall sign and size of the response depend on competing effects. The reform also affects labor supply through two channels. First, the individual could try to offset the loss of pension income by staying longer in the labor market. Second, a lower supplement shifts more people to a part of the benefit schedule where the penalty rate is zero. Hence, the marginal penalty for labor income and pension wealth is smaller, improving labor incentives. In the estimated model, the benefit reform leads to higher voluntary savings than the tax reform. However, voluntary saving is not nearly as high as for the retirement age reform. Average labor supply is comparable to the tax and retirement age reforms. However, the sign and size of the difference between reforms vary over education groups. Total wealth is higher for all groups compared to the tax reform. However, average wealth is lower than under the retirement age reform.

Lowering the base benefit lowers the expected present value of public pension benefits for everyone. However, lump-sum decreases matter more for poor individuals in welfare terms. Thus, there are adverse effects on average welfare by limiting redistribution between education groups and, by extension, decreasing income insurance coverage. Lowering the supplement limits redistribution and insurance even further by taking resources from those who rely most on the supplement. However, welfare improves for all education groups compared to the reforms considered thus far. The average individual requires compensation to the tune of 4,658 USD to accept the tax reform over the benefit reform. The positive welfare implications go through several channels. First, it directly reduces turnover in the return-dominated public pension scheme. Furthermore, the insurance loss is likely negligible as public pensions are already high, and we do not model any permanent or persistent income shocks.

5.8 Increasing Contributions to FF Pensions

As another means to achieve fiscal sustainability, we increase FF pension contributions to lower public pension expenditure via means testing. In this experiment, the contribution rates must increase by 13.6% to ensure sustainability. Thus, education-specific contributions increase to [0.136, 0.137, 0.143].

Increasing contribution rates defers part of one's income to later in life. Thus, the increase in forced savings crowds out voluntary savings. As voluntary savings decrease, more people are likely to become borrowing constrained early in life. However, the fact that FF pension contributions are tax deductible mitigates the effect of being constrained. For labor, there is an income effect that depends on the effect on total savings. If agents become richer, they can retire earlier and vice versa. Furthermore, labor incentives worsen with higher contribution rates, as extra FF pension income leads to means testing of public pension benefits later in life. In the estimated model, the contribution rate reform implies the lowest voluntary savings and labor supply of any of the reforms under consideration. Total wealth increases because forced savings crowd out voluntary saving less than one-to-one.

The contribution rate reform has the highest average welfare of all the reforms considered for all education groups. To put things into perspective, the average CV measure is 6,890 USD. Part of the welfare effect comes from enjoying more leisure. Moreover, saving in annuities via the FF scheme provides better longevity insurance than voluntary savings and pays a higher return than PAYG. Finally, the higher total wealth under this reform leads to high consumption levels for middle-aged and old agents.

Table 5: Aggregate Voluntary Savings

	Education			
	Low	Middle	High	Average
Baseline SS	0.9405	0.9117	0.8974	0.9131
New SS, unfinanced	1.044	1.0428	1.0371	1.0407
Fiscally sustainable policies				
Tax increase, τ_0	1.0	1.0	1.0	1.0
Retirement age increase, T_r	1.1622	1.147	1.1168	1.1382
Decreasing the benefit, p	1.0755	1.0951	1.0932	1.0892
Increasing FF contri., ϕ	0.9619	0.9405	0.9251	0.9396

Notes: Savings are measured relative to the new tax-financed steady state.

Table 6: Aggregate Total Savings

	Education			
	Low	Middle	High	Average
Baseline SS	0.9202	0.9153	0.9145	0.9163
New SS, unfinanced	1.0069	1.0062	1.0051	1.0059
Fiscally sustainable policies				
Tax increase, τ_0	1.0	1.0	1.0	1.0
Retirement age increase, T_r	1.0424	1.036	1.0249	1.0331
Decreasing the benefit, p	1.0194	1.0255	1.0271	1.0246
Increasing FF contri., ϕ	1.0859	1.0787	1.0735	1.0784

Notes: Savings are measured relative to the new tax-financed steady state.

Table 7: Aggregate Labor Supply

	Education			
	Low	Middle	High	Average
Baseline SS	0.9563	0.9569	0.9594	0.9576
New SS, unfinanced	0.9907	0.9908	0.9927	0.9914
Fiscally sustainable policies				
Tax increase, τ_0	1.0	1.0	1.0	1.0
Retirement age increase, T_r	1.0056	0.9996	0.9937	0.9995
Decreasing the benefit, p	0.9994	1.0011	1.004	1.0016
Increasing FF contri., ϕ	0.9889	0.9881	0.9888	0.9886

Notes: Labor is measured as total labor supply relative to the new tax-financed steady state.

Table 8: Welfare

	Education			
	Low	Middle	High	Average
Baseline SS	-25,753	-35,643	-23,734	-28,116
New SS, unfinanced	9,279	11,206	6,641	8,894
Fiscally sustainable policies				
Tax increase, τ_0	0	0	0	0
Retirement age increase, T_r	2,612	4,887	4,006	3,715
Decreasing the benefit, p	4,595	5,740	3,922	4,658
Increasing FF contri., ϕ	7,206	9,252	4,799	6,890

Notes: Welfare is measured as the compensating variation, CV, relative to the new tax-financed steady state. CV is measured in 1,000 USD.

6 Conclusion

Throughout this paper, we study a set of pension system reforms intended to restore fiscal sustainability in the face of demographic pressure. We document how each reform affects individual decisions and welfare through policy analysis. For the policy analysis, we build a structural life-cycle model with heterogeneous agents and several sources of idiosyncratic risk. The institutional setup of the model includes a public pay-as-you-go scheme and a mandatory fully-funded pension scheme that interact through means testing. To estimate the model, we use Danish micro data. While we estimate a series of model parameters outside the model using econometric methods, we pin down all preference parameters through structural estimation, targeting moments of labor supply and wealth at different ages and education levels.

Using the estimated model, we find that different reforms affect individual incentives and welfare differently. Most notably, increasing contributions to mandatory fully-funded pensions gives the highest average welfare. On the other hand, accommodating fiscal pressure by increasing taxes yields the lowest welfare. Out of the remaining policies, increasing the retirement age is slightly better for welfare than increasing taxes, whereas cutting benefits or increasing means testing provides decent welfare outcomes. The apparent efficacy of policies that directly or indirectly lower public pensions rather than accommodating fiscal pressure likely has to do with the public pension scheme being return dominated. Moreover, given the limited role of redistribution and income insurance in the model, the public pension system is likely too big in the first place. This is especially true when also considering how differences in longevity tend to limit redistribution between education groups even further. Nonetheless, the indirect approach yields better welfare outcomes than directly cutting benefits.

The insights of this paper should be of interest to all countries that wish to reform the pension system in response to population aging. In this context, our results on expanding the fully-funded scheme to to lower public pension expenditure indirectly deserve special attention for three reasons. First, the mechanism is novel in the literature on population aging and public finances. Second, almost all advanced economies already have some means testing in public pensions. Finally, our results suggest that the transition to a fully-funded scheme seems to be very effective for welfare compared to other reforms.

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A Reannuitizing Pension Wealth

At the beginning of a retirement period, the individual has $\tilde{w}_t$ pension wealth in its account. After accounting for the current benefit f_t, the individual account holds w_t pension wealth. Writing pension wealth forward, we have:

$$\begin{aligned} w_{t+1} &= \tilde{w}_{t+1} - f_{t+1}\left(\tilde{w}_{t+1}\right) \\ \tilde{w}_{t+1} &= R_{t+1} w_t \end{aligned}$$

Tomorrow's pension benefit comes about by annuitizing $\tilde{w}_{t+1}$. Using the motion equation for beginning-of-period pension wealth allows us to express the future pension benefit in terms of current pension wealth net of benefits:

$$f_{t+1}\left(\tilde{w}_{t+1}\right) = \frac{w_t}{\sum_{\tau=t+1}^{T} \frac{1}{\prod_{j=t+1}^{\tau} R_j}}$$

According to standard annuity principles, the benefit is constant. Hence, we can carry the benefit computed at retirement as a state variable. However, for computational ease, we use that annuitizing at retirement is equivalent to reannuitizing remaining pension wealth in every period. To see this, we annuitize remaining pension wealth one period ahead using $\tilde{w}_{t+2} = R_{t+2} w_{t+1}$:

$$f_{t+2}\left(\tilde{w}_{t+2}\right) = \frac{w_{t+1}}{\sum_{\tau=t+2}^{T} \frac{1}{\prod_{j=t+2}^{\tau} R_j}}$$

where:

$$w_{t+1} = w_t \left(R_{t+1} - \frac{1}{\sum_{\tau=t+1}^{T} \frac{1}{\prod_{j=t+1}^{\tau} R_j}} \right)$$

such that f_{t+2} equals f_{t+1}:

$$f_{t+2}\left(\tilde{w}_{t+2}\right) = \frac{w_t}{\sum_{\tau=t+1}^{T} \frac{1}{\prod_{j=t+1}^{\tau} R_j}}$$

B Forecasting Mortality Rates

We produce coherent forecasts for sub-population mortality for all education groups using a standard Li and Lee (2005) model, which builds on the well-known Carter and Lee (1992) model. The Lee-Li model reads:

$$\log\left(m_{t,a}^{g}\right) = \alpha_a^g + B_a K_t + \beta_a^g \kappa_t^g + \epsilon_{t,a}^g \tag{1}$$

where α_a^g denotes a time-stationary pattern over the life cycle for group g. Moreover, B_a is an age-dependent slope parameter, which is multiplied by a time-dependent process K_t. Together, they are the Lee-Carter estimates for the general population. Finally, β_a^g and κ_t^g allow for subgroup slopes to deviate from the general population. For forecasting purposes, K_t follows a random walk with drift,

$$K_t = c_1 + K_{t-1} + e_t, \tag{2}$$

Here, $e_t \overset{iid}{\sim} \mathcal{N}\left(0, \sigma_e^2\right)$. Furthermore, κ_t^g follows a trend-stationary AR(1) with a constant,

$$\kappa_t^g = c_2 + \gamma^g \kappa_{t-1}^g + v_t, \tag{3}$$

where $v_t \overset{iid}{\sim} \mathcal{N}\left(0, \sigma_v^2\right)$. Stationarity rules out random divergence in subgroup mortality, while the presence of a constant allows some group differences to persist in the long run. In line with Li and Lee (2005), we assume that the error terms are independent. To estimate the model in practice, we first produce general-population Lee-Carter estimates and subsequently compute the group-specific Lee-Li estimates, using singular value decomposition alongside a standard bias correction. To produce group-specific forecasts, we forecast the unit root processes for the common term and the auto-regressive process for individual subgroups. Figures 8 and 7 depict estimated and forecasted mortality rates and the life expectancy at age 40 for each education group.

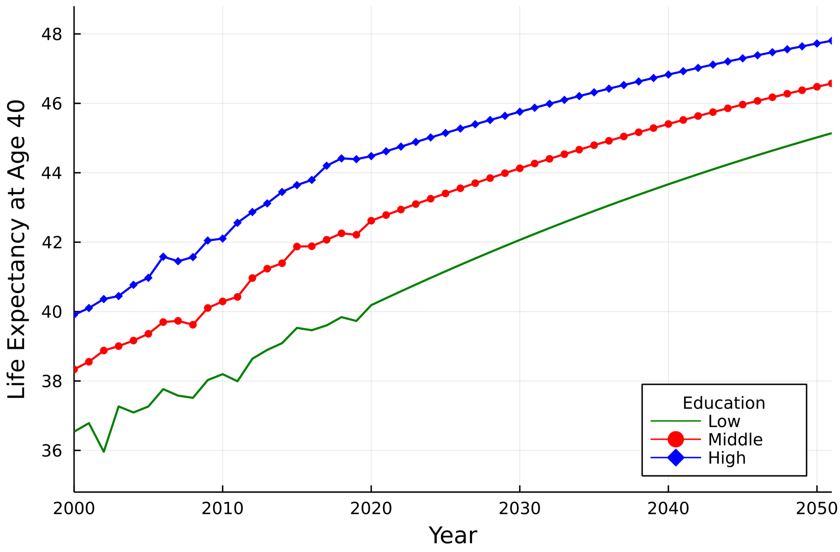


Figure 7: Life Expectancy at Age 40

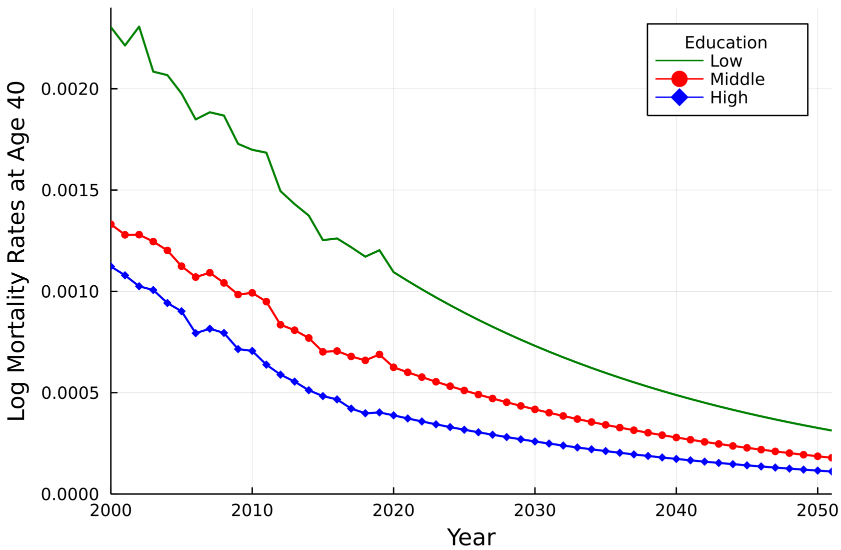


Figure 8: Log-mortality Rates at Age 40

C Additional figures

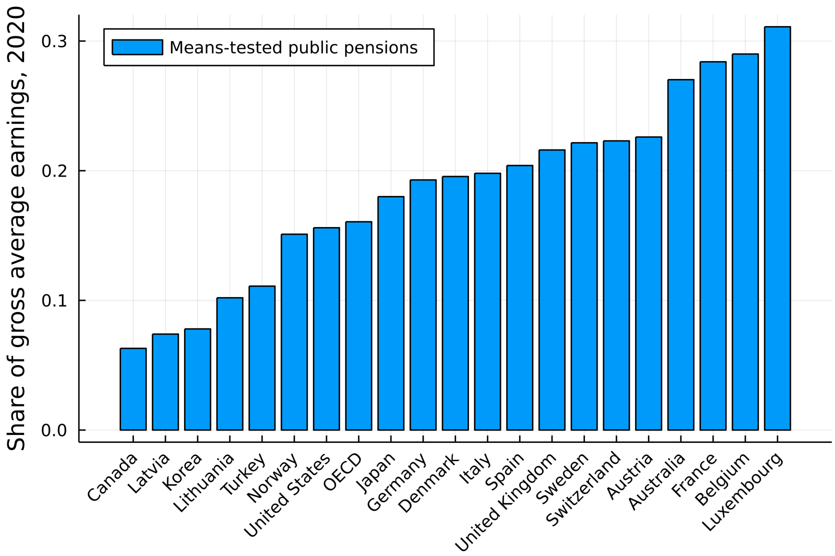


Figure 9: Means-tested Pensions in OECD countries. Source: OECD (2021)

Figure 10: After-tax Income, Low Education

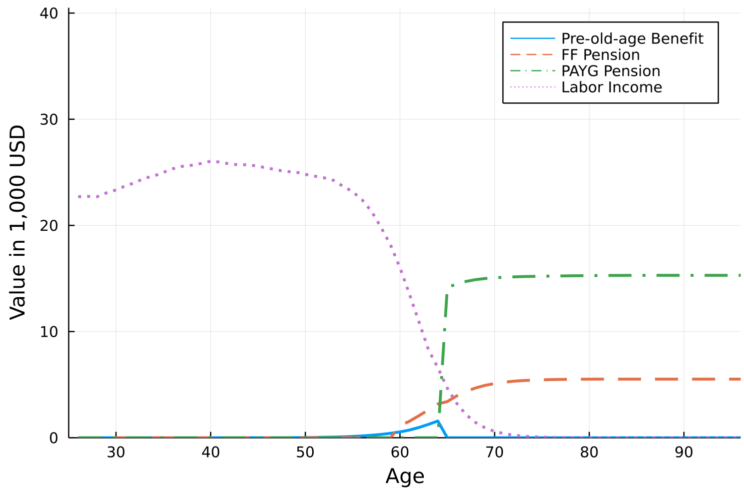


Figure 11: After-tax Income, Middle Education

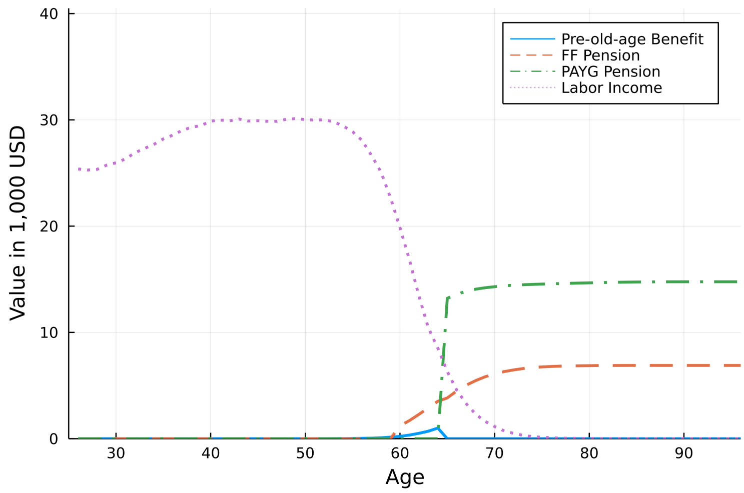


Figure 12: After-tax Income, High Education

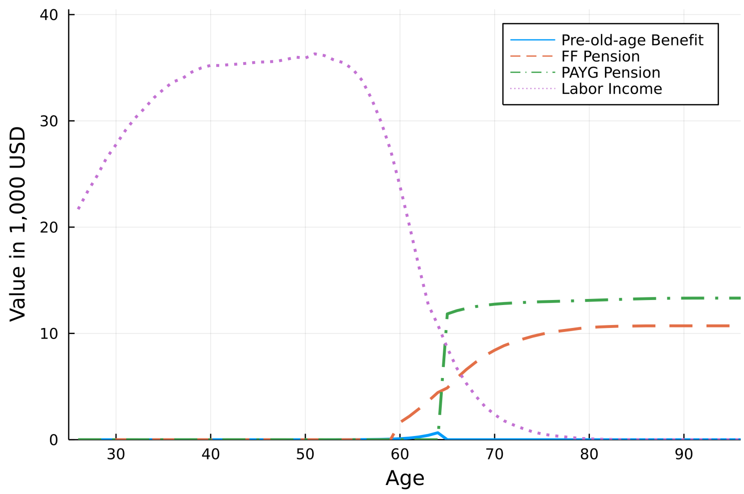


Figure 13: Consumption and Saving, Low Education

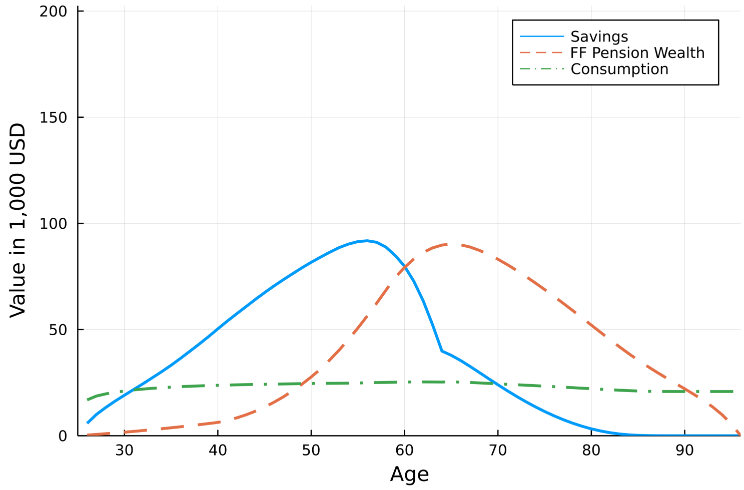


Figure 14: Consumption and Saving, Middle Education

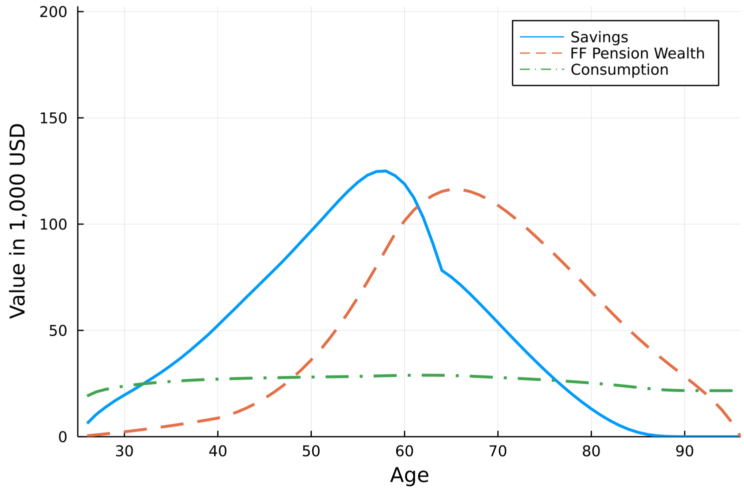
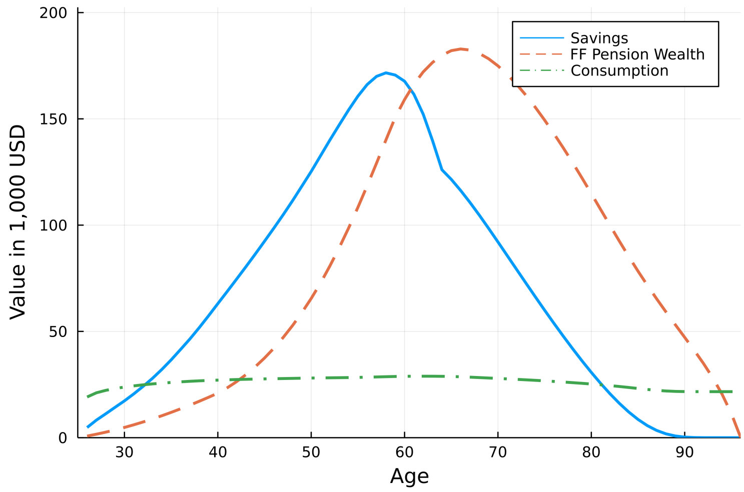


Figure 15: Consumption and Saving, High Education



D Additional Policy Experiments

In addition to the reforms considered in the main paper, this section conducts a few extra policy experiments.

D.1 Decreasing the Base Benefit

In the first additional experiment, we balance the budget by adjusting the base amount of public pensions, p_0, alone. We find that the base benefit must decrease by 24.8% to keep residual government consumption unchanged. Lowering the base amount exerts a negative income effect on savings. At the same time, lower survival-contingent benefits mean that the individual needs to save more to maintain old-age consumption. Thus, the sign and size depend on competing effects. A similar line of reasoning applies to labor. In the estimated model, lower benefits lead to larger savings compared to the baseline tax policy, but lower than when decreasing the retirement age. Average labor supply, on the other hand, changes only slightly.

In terms of welfare, the expected present value of public pension benefits decreases for everyone. However, as lump-sum decreases matter more for poor individuals in utility terms, this adversely affects average welfare by limiting redistribution between education groups and, by extension, decreasing income insurance coverage. However, lowering the pension benefit seems to be very effective for welfare. The CV measure is 4,489 USD. The positive welfare implications likely have to do with the public PAYG scheme being return dominated. Thus, when lowering the benefit, the government has to finance less expenditure inefficiently. Furthermore, the insurance loss is likely to be negligible as public pensions are already high, and as we do not model any permanent or even persistent income shocks.

	Before	After	Change
Decreasing the base benefit, p_0	9,715 USD	7,304 USD	-24.8%
Decreasing the supplement, p_1	12,384 USD	10,087 USD	-18.5%
Increasing income-testing, π	30.9%	42.3%	11.4 p.p.

Notes: The increase in the retirement age also comes with a lower tax rate, τ_0, of 10.36% .

D.2 Decreasing the Supplement

Another way to balance the budget is to decrease the pension supplement, p_1. This requires the supplement to decrease by 18.5%. Reducing the supplement affects voluntary savings in two ways. First, consumption-smoothing motives cause upward pressure on savings in the face of decreasing old-age income. Second, the income effect on savings is negative. The reform also affects labor supply through two channels. First, the individual could try to offset the loss of pension income by working more. Second, as the penalty is unchanged, the reform shifts more people to a part of the benefit schedule where the penalty rate is zero. Hence, extra labor income and extra pension wealth is penalized less, improving labor incentives. In the estimated model, a lower supplement leads to slightly higher savings than when lowering the base amount. At the same time, labor force participation is higher than compared to all other reforms. Regarding welfare, the supplement reform limits redistribution and insurance by taking away resources from those who rely the most on the supplement. However, due to considerable improvements in labor incentives, welfare is higher for all education groups compared to all of the reforms considered so far. Individuals require compensation to the tune of 4,846 USD relative to the tax reform.

D.3 Increasing Means Testing

As an alternative to adjusting the supplement level, the government could balance the budget by increasing the degree of means testing, π. This approach necessitates an increase in the penalty rate from 0.309 to 0.423. Stronger means testing directly decreases incentives to save because of the negative income effect and because public pensions are means tested on income on capital. On the other hand, consumption smoothing motives work to increase savings when pension income declines in response to more means testing. At the same time, a higher penalty rate reduces the incentive to work, as labor income is channeled into the funded scheme where it is eventually paid out as FF pension benefits, increasing means testing of public pension benefits on income from funded pensions. For given parameters, the model predicts that an increase in the penalty rate results in average voluntary savings that are slightly higher than when decreasing the supplement. In fact, the penalty rate reform results in the lowest savings of any reform, except for the reform that increases FF pension contributions. Like the supplement reform, the penalty rate reform provides relatively strong labor incentives. However, whereas labor supply increased at all education levels under the supplement reform, the penalty rate reform lowers labor supply for the least educated compared to the tax reform. In terms of welfare, a higher penalty rate tends to lower both redistribution and insurance. This is because the policy hits low-income individuals the hardest. While low-income individuals tend to be on the means-tested part of the benefit schedule, those with high incomes are already at zero supplements and cannot be means tested further. However, the overall welfare response is almost as good as when lowering the supplement. The average CV measure is 4,763 USD. Again, the observed welfare response likely has to do with arguments of return dominance and limited scope for redistribution and insurance.

Table 9: Welfare of All Reforms

	Education			
	Low	Middle	High	Average
Baseline SS	-25,753	-35,643	-23,734	-28,116
New SS, unfinanced	9,279	11,206	6,641	8,894
Fiscally sustainable policies				
Tax increase, τ_0	0	0	0	0
Retirement age increase, T_r	2,612	4,887	4,006	3,715
Decreasing the base benefit, p_0	4,467	5,565	3,722	4,489
Decreasing the supplement, p_1	4,722	5,929	4,163	4,846
Increasing income-testing, π	5,123	5,700	3,721	4,763
Decreasing the benefit, p	4,595	5,740	3,922	4,658
Increasing FF contri., ϕ	7,206	9,252	4,799	6,890

Notes: Welfare is measured as the compensating variation, CV, relative to the new tax-financed steady state. CV is measured in 1,000 USD.

Table 10: Aggregate Voluntary Savings of All Reforms

	Education			
	Low	Middle	High	Average
Baseline SS	0.9202	0.9153	0.9145	0.9163
New SS, unfinanced	1.0069	1.0062	1.0051	1.0059
Fiscally sustainable policies				
Tax increase, τ_0	1.0	1.0	1.0	1.0
Retirement age increase, T_r	1.0424	1.036	1.0249	1.0331
Decreasing the base benefit, p_0	1.0197	1.0256	1.0258	1.0241
Decreasing the supplement, p_1	1.0193	1.0257	1.0285	1.0252
Increasing income-testing, π	1.0184	1.0266	1.0294	1.0256
Decreasing the benefit, p	1.0194	1.0255	1.0271	1.0246
Increasing FF contri., ϕ	1.0859	1.0787	1.0735	1.0784

Notes: Savings are measured relative to the new tax-financed steady state.

Table 11: Aggregate Labor Supply of All Reforms

	Education			
	Low	Middle	High	Average
Baseline SS	0.9563	0.9569	0.9594	0.9576
New SS, unfinanced	0.9907	0.9908	0.9927	0.9914
Fiscally sustainable policies				
Tax increase, τ_0	1.0	1.0	1.0	1.0
Retirement age increase, T_r	1.0056	0.9996	0.9937	0.9995
Decreasing the base benefit, p_0	0.9994	1.0005	1.0015	1.0005
Decreasing the supplement, p_1	0.9996	1.002	1.0065	1.0028
Increasing income-testing, π	0.991	0.9957	1.009	0.9988
Decreasing the benefit, p	0.9994	1.0011	1.004	1.0016
Increasing FF contri., ϕ	0.9889	0.9881	0.9888	0.9886

Notes: Labor is measured relative to the new tax-financed steady state.

Table 12: Government Budget Components

	$\mathcal{G}$	P	$\mathcal{T}_y$	$\mathcal{T}_a$	$\mathcal{T}_c$	$\mathcal{T}_b$
Baseline SS	17,443	3,729	11,586	2,648	5,572	31
New SS, unfinanced	16,566	4,669	12,282	2,911	6,015	26
Fiscally sustainable policies						
Tax increase, τ_0	17,120	4,650	12,931	2,894	5,920	25
Retirement age increase, T_r	17,137	3,801	11,934	2,990	5,985	30
Decreasing the base benefit, p_0	17,154	3,868	12,062	2,964	5,966	30
Decreasing the supplement, p_1	17,153	3,953	12,125	2,967	5,983	30
Increasing income-testing, π	17,153	3,908	12,092	2,965	5,974	30
Decreasing the benefit, p	17,130	3,913	12,078	2,968	5,967	30
Increasing FF contri., ϕ	17,116	4,426	12,377	3,121	6,023	21

Notes: This table shows government budget components per capita in USD. $\mathcal{G}$ is the residual government consumption, and, P^e_τ are public pension and pre-old-age social security expenditures $\mathcal{T}^e_{y,\tau}$ are income taxes, $\mathcal{T}^e_{c,\tau}$ are consumption taxes, $\mathcal{T}^e_{a,\tau}$ are capital income taxes, and, $\mathcal{T}^e_{b,\tau}$ are inheritance taxes.