Essays on the Intergenerational Welfare State

Christensen, Frederik Bjørn

COPENHAGEN BUSINESS SCHOOL
SOLBJERG PLADS 3
DK-2000 FREDERIKSBERG
DANMARK

WWW.CBS.DK

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Frederik Bjørn Christensen
Supervisors: Svend Erik Hougaard Jensen, Torben M. Andersen, Joydeep Bhattacharya

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Sincerely,
Frederik Bjørn Christensen

July, 2023

Summary

This thesis comprises three chapters on different topics related to the intergenerational welfare state, which is a system of social policies providing economic security across generations. Although the chapters relate to different topics, public pension schemes constitute the unifying theme of the thesis.

Chapter I

The first chapter, entitled *Population Aging, Public Finances, and Alternatives for Retirement Reform*, is written in collaboration with Tim Dominik Maurer and motivated by advanced-economy pension systems coming under fiscal pressure due to population ageing. Against this background, we conduct counterfactual policy experiments to compare different retirement reforms that ensure sustainable public finances in the face of increasing longevity and decreasing fertility. As our main contribution, we consider a particular reform that increases fully-funded (FF) contributions to reduce pay-as-you-go (PAYG) benefits indirectly through means testing. We evaluate this against three standard reforms: increasing the retirement age, cutting public pension benefits, and increasing taxes to finance growing public pension expenditures. For the policy analysis, we build a sophisticated structural life-cycle model incorporating a pension system consisting of two pillars - a public PAYG scheme and a mandatory FF scheme - interacting through means testing. We estimate all unobserved preference parameters using the *Simulated Method of Moments* targeting Danish micro data on wealth and labor market participation. Our subsequent policy experiments suggest that increasing contributions to mandatory FF pensions is best for welfare. The positive welfare effects arise from the FF scheme giving access to fair annuities that offer higher returns and better longevity risk insurance than voluntary savings. This positive wealth effect allows agents to enjoy more consumption and leisure. Additionally, the expansion of the FF scheme reduces the relative importance of the return-dominated PAYG scheme. These positive welfare effects outweigh two negative effects related to the loss of income insurance through the public pension system and a crowding out of bequest income.

Chapter II

The second chapter, *Redistribution in Public Pension Schemes: Evidence from Denmark*, also with Tim Dominik Maurer, documents a loss of redistribution through Danish public pensions when accounting for inequality in longevity. While we focus on the Danish case, our results are relevant to other countries with pension systems that promote redistribution. As our main contribution, we use a so-called affluence measure combining income and wealth information to allocate individuals into socioeconomic groups. Using this measure, we first predict significant mortality differences across groups. Next, we assess redistribution via the public pension system by computing and comparing the expected net present values of the implicit public pension contract. To this end, we use detailed Danish register data for the entire population, allowing us to estimate mortality rates accurately and track a large set of covariates over the individual life cycle. Focusing on recently retired cohorts, we use a combination of historical and forecasted income and wealth data as inputs to a microsimulation model that includes detailed tax and pension system components. Our results indicate a significant loss of redistribution in public pensions due to inequality in longevity. Specifically, the present value of the pension contract develops non-monotonically with affluence, with males in the middle affluence groups benefiting more than the least affluent males. Only the top 30% males have lower net present values than the least affluent males. Moreover, females of a specific affluence rank have considerably higher net present values than similarly ranked males. Interestingly, the estimated redistribution loss depends on the allocation mechanism by affluence. When we repeat the experiment using only information on lagged income, we find a smaller redistribution loss – although inequality in longevity still implies that net present values develop non-monotonically. Thus, we argue that the results of other papers that use allocation by income or education and report relatively small redistribution losses would likely be different had they used a more informative allocation mechanism.

Chapter III

The third chapter, *Improving Welfare through Public Education*, is motivated by the student debt crisis in the United States and examines the economic consequences of implementing an optimal education subsidy. Here, I address two key questions: i) What is the welfare-maximizing education policy in the long run? and ii) How can policymakers ensure socially responsible implementation of such a policy in the short run? The findings demonstrate that a well-designed education subsidy reduces student debt, mitigates inequality, and enhances social welfare in the long run. The long-run welfare gains arise through three channels: a human capital externality, redistribution, and borrowing effects. Next, I show how the government can ensure socially responsible implementation by utilizing public pen-

sions as an instrument for intergenerational cost sharing. The analysis utilizes a calibrated partial-equilibrium overlapping-generations model, extending earlier models to incorporate a general number of overlapping generations, heterogeneous agents, probabilistic survival, and realistic demographics. The paper also presents two model extensions incorporating length-of-education choices and idiosyncratic income risk to demonstrate that the main insights hold in generalized settings. Thus, it contributes to the literature on public education by providing nuanced insights at both the micro and macro levels.

Resumé

Den nærværende afhandling består af tre separate kapitler, som relaterer sig til forskellige spørgsmål vedrørende den intergenerationelle velfærdsstat, som er et socialpolitisk system, der varetager omfordeling på tværs af generationer. Omend de individuelle kapitler beskæftiger sig med forskellige emner, udgør offentlige pensioner et samlende tema for afhandlingen.

Kapitel I

Det første kapitel, *Befolkningsaldring, Offentlige Finanser og Pensionsreformer*, er skrevet i samarbejde med Tim Dominik Maurer og er motiveret af, at udviklede økonomiers pensionssystemer er under stigende økonomisk pres fra befolkningsaldring. Med dette udgangspunkt foretager vi kontrafaktiske politikeksperimenter for at sammenligne de økonomiske effekter af forskellige pensionsreformer, der sikrer bæredygtige offentlige finanser i en verden med stigende levetider og faldende fertilitet. Som vores primære bidrag til litteraturen betragter vi en særlig reform, hvor regeringen øger bidragssatsen til fuldt finansierede (FF) arbejdsmarkedspensioner for indirekte at reducere offentlige pay-as-you-go (PAYG) pensioner gennem behovsprøvning. Vi sammenligner denne med tre standardreformer: en forøgelse af pensionsalderen, nedskæringer i de offentlige pensionsydelser og en forøgelse af skatten for at finansiere stigende offentlige pensionsudbetalinger. Til brug i vores politikeksperimenter bygger vi en sofistikeret strukturel livscyklusmodel, der inkorporerer et pensionssystem bestående af to søjler: en offentlig PAYG-ordning og en obligatorisk FF arbejdsmarkedsordning, som interagerer gennem behovsprøvning. Vi estimerer alle ikke-observerede præferenceparametre ved hjælp af den såkaldte *Simulated Method of Moments*, hvor vi matcher danske mikrodata på formue og tilknytning til arbejdsmarkedet. Vores efterfølgende eksperimenter indikerer, at øgede bidrag til obligatoriske FF arbejdsmarkedspensioner er bedst for den sociale velfærd. De positive velfærdseffekter opstår, fordi FF-ordningen giver adgang til fair livrenter, der sikrer et højere afkast og bedre forsikring mod levetidsrisiko end private opsparinger. Dermed bliver agenterne rigere og får råd til mere forbrug og fritid. Derudover reducerer udvidelsen af FF-ordningen den relative betydning af den afkastdominerede PAYG-ordning. De positive velfærdseffekter opvejer to negative

velfærdseffekter relateret til et tab af indkomstsikring gennem de offentlige pensioner og en fortrængning af opsparinger og arv.

Kapitel II

Det andet kapitel, *Omfordeling i Offentlige Pensioner: Evidens fra Danmark*, som ligeledes er udfærdiget i samarbejde med Tim Dominik Maurer, dokumenterer tabet af omfordeling gennem det danske Folkepensionssystem, når man indregner ulighed i forventede levetider. Selvom vi fokuserer på det danske tilfælde, er vores resultater relevante for andre lande med pensionssystemer, der promoverer omfordeling. Som vores primære bidrag til litteraturen anvender vi et velstandsmål, der kombinerer information om indkomst og formue til at inddele individer i socioøkonomiske grupper. Ved hjælp af dette mål påviser vi først store forskelle i dødelighed på tvær af disse grupper. Dernæst vurderer vi omfordelingen i det offentlige pensionssystem ved at beregne og sammenligne den forventede nutidsværdi af den implicitte offentlige pensionskontrakt på tværs af grupperne. Til det formål bruger vi detaljeret dansk registerdata, der muliggør nøjagtig estimering af dødelighedsrater og tillader os at følge et stort antal variable over individets livscyklus. Ved at fokusere på nyligt pensionerede årgange bruger vi en kombination af historiske og fremskrevne indkomst- og formuedata som input til en mikrosimuleringsmodel, der inkluderer detaljerede skatte- og pensionskomponenter. Vores resultater indikerer, at ulighed i levetid medfører et betydeligt tab af omfordeling via de offentlige pensioner. Specifikt udvikler nutidsværdien af den implicitte kontrakt sig ikke-monotonisk med socioøkonomisk status, således at mænd i middelklassen har højere nutidsværdier end de mindst velhavende mænd. Til sammenligning har kun de 30% mest velhavende mænd lavere nutidsværdier end de mindst velhavende mænd. Derudover finder vi, at kvinder har betydeligt højere nutidsværdier end mænd i en given socioøkonomisk gruppe. Vores resultater afhænger i nogen grad af allokeringsmekanismen. Når vi gentager eksperimentet kun ved brug af indkomstdata, finder vi et mindre tab af omfordeling - selvom ulighed i levetid stadig indebærer, at nutidsværdien udvikler sig ikke-monotont med velstand. Derfor argumenterer vi for, at resultaterne fra andre artikler, der konstruerer socioøkonomiske grupper på baggrund af indkomst eller uddannelse og rapporterer mindre tab af omfordeling, sandsynligvis ville se anderledes ud givet anvendelsen af en mere informativ allokeringsmekanisme.

Kapitel III

Det tredje kapitel, *Forbedring af den Sociale Velfærd gennem Offentlig Uddannelse*, er motiveret af studiegældskrisen i USA og undersøger de økonomiske konsekvenser ved implementeringen af et socialt optimalt uddannelsessubsidie. Her betragter jeg to centrale spørgsmål: i) Hvad er den velfærdsmaksimerende uddannelsespolitik på lang sigt, og ii)

Hvordan kan staten sikre en socialt ansvarlig implementering af en sådan politik på kort sigt? Resultaterne viser, at et veludformet subsidie nedbringer den samlede studiegæld, reducerer uligheden og forbedrer den sociale velfærd på lang sigt. De langsigtede velfærdsgevinster opstår gennem tre kanaler: humankapitaleksternaliteter, omfordeling og låneeffekter. Dernæst udforsker jeg muligheden for at implementere det optimale subsidie på en socialt ansvarlig facon ved brug af offentlige pensioner som et instrument for intergenerationel omkostningsdeling. Analysen anvender en kalibreret partiel ligevægtsmodel og udvider eksisterende modeller ved at inkorporere et generelt antal overlappende generationer, heterogene agenter, probabilistisk overlevelse og befolkningsvækst. Papiret præsenterer desuden to modeludvidelser, der tager højde for henholdsvis uddannelseslængde og idiosynkratisk indkomstrisiko for at demonstrere, at de gennemgående argumenter holder i en bredere kontekst. Dermed bidrager papiret til litteraturen om effekterne ved offentlig uddannelse ved at nuancere økonomiske forklaringsmekanismer på både mikro- og makroniveau.

Contents

Introduction

The intergenerational contract is perhaps the most important part of modern welfare states. Thus, I will refer to the *intergenerational welfare state* as an independent system of social policies that aim to provide economic support and security across generations. Intergenerational welfare state programs are normally age-dependent and, therefore, entail intergenerational redistribution. The young and the old are typically net beneficiaries. Meanwhile, the working middle-aged pay taxes and are net contributors. This suggests a two-armed generational contract working both backwards and forward in time. The two most critical components of this contract are public pension and education. Whereas the first two chapters of this thesis focus explicitly on public pensions, the third chapter focuses on public education using public pensions as an implementation tool.

Intergenerational welfare state programs typically also imply intragenerational redistribution through universal transfers or subsidies and progressive taxes. Thus, intergenerational welfare state policies must simultaneously consider the succession of generations and the struggle between social classes. In this light, this thesis investigates how pension and education policies should be designed to ensure sustainable public finances and a high level of social welfare both within and across generations.

In the backwards part of the intergenerational contract, public pension schemes provide financial security for individuals after retirement. Such schemes are typically financed on a pay-as-you-go (PAYG) basis. That is, mandatory contributions from current workers finance the benefits to current retirees. Hence, such a system relies crucially on intergenerational redistribution. Moreover, most modern pension systems incorporate elements of means testing and, thus, provide ex-ante income insurance through ex-post intragenerational redistribution. Furthermore, public pension schemes can improve social welfare by alleviating permanent inequality, incomplete markets, and individual myopia. However, current demographic trends make it increasingly difficult for public pension schemes to reconcile adequate social security coverage with fiscal sustainability. As expected lifetime increases and birth rates decline, the ratio of workers to retirees decreases, making it harder to finance traditional pension systems. To address this challenge, governments have considered different reforms, such as increasing the retirement age, lowering benefits, increasing contributions, and introducing complementary private pension plans.

Accordingly, economists must study the economic and social consequences of policies designed to restore fiscal sustainability. Thus, several papers, including Laun et al. (2019), Haan and Prowse (2014), Attanasio et al. (2007), and De Nardi et al. (1999), study the welfare effects of restoring sustainability in public pension schemes facing demographic pressure. They typically do so through counterfactual policy experiments using structural lifecycle models that incorporate one or more of the following elements: heterogeneous agents, endogenous consumption-saving decisions, endogenous labor-retirement choices, and idiosyncratic income, preference, health, and mortality risk. This literature predominantly focuses on reforms that target PAYG pensions directly. Against this background, Chapter I of the thesis adds a fully-funded (FF) scheme to the counterfactual policy analysis. The main contribution is to study a particular reform that increases contributions to the FF scheme, exploiting that public pension benefits can be means tested with private pension income. Significantly, this provides better welfare outcomes than any other reform we consider.

As mentioned, public pension schemes typically entail intragenerational redistribution. However, in this context, public pension schemes face another serious challenge, namely inequality in longevity, which can mitigate or entirely subvert redistribution. The mechanism is simple. First, several papers, including Chetty et al. (2016), Olshansky et al. (2012), and Kitagawa and Hauser (1973), have documented substantial socioeconomic inequality in longevity. Next, systematic inequality in longevity implies that advantaged groups live longer on public pension benefits. Several papers have examined this issue but focus almost exclusively on redistribution in US Social Security and rely on limited survey data. See for instance, Auerbach et al. (2019), Auerbach et al. (2017), Ayuso et al. (2017), Coronado et al. (2011), Whitehouse and Zaidi (2008), Liebman (2001), and Garrett (1995). Based on this observation, Chapter II uses high-quality Danish register data and a microsimulation model to document a significant redistribution loss when accounting for inequality in longevity. While most of the related literature allocates individuals to socioeconomic groups based on averages of lagged income, the main contribution of this chapter is to subdivide the sample according to a so-called affluence measure that combines data on income and wealth and provides a stronger separator of mortality.

In the forward part of the intergenerational contract, most welfare states provide public education. By taxing current workers and investing the proceeds in education for the young, governments can affect individual education decisions, overcome potential market failure, improve the overall education level, and increase equity and welfare. However, countries differ significantly in the extent of public education, especially at the post-secondary level. In this context, the United States poses an interesting case. Here, the lack of free post-secondary education combined with rapidly increasing college tuition levels has led to the so-called student debt crisis. Consequently, US politicians have suggested interventions ranging from structural education reform to short-term student debt forgiveness programs. According to an opinion poll by NPR/Ipsos (2022), 55% of Americans support forgiving up to 10,000 USD of student loan debt. However, at the same time, 82% of respondents prefer the government to prioritize making college more affordable over forgiving student loan debt.

Inspired by the student debt crisis and the call for structural education reform, Chapter III examines the welfare effects of implementing an optimal education subsidy in the United States. This chapter utilizes a partial-equilibrium overlapping-generations model with heterogeneous agents and endogenous human capital accumulation. In doing so, it investigates the potential for education policies to improve long-run welfare by lowering student debt, stimulating human capital, and reducing inequality. Inspired by Becker and Murphy (1988), Boldrin and Montes (2005), and Andersen and Bhattacharya (2017), it also considers the feasibility of implementing an optimal education subsidy in a socially responsible manner in the short run by using public pensions as a means of intergenerational cost sharing.

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Chapter 1

Population Aging, Public Finances, and Alternatives for Retirement Reform

Frederik Bjørn Christensen & Tim D. Maurer

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.

1.1 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 in different ways. The most prevalent reforms are to increase the statutory retirement age, lower public pension benefits, or increase contributions to accommodate growing pension expenditures. Moreover, some 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. The 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 conduct counterfactual policy analysis to compare reforms that restore fiscal sustainability in the face of population aging. Our main contribution is to consider a reform that uses FF contributions as an instrument to lower PAYG benefits through means testing. We test this reform against the most prevalent retirement reforms. To this end, we develop a structural life-cycle model that captures behavioral responses to retirement reform and allows for welfare analysis. We then compare welfare outcomes across reforms by modeling fiscal pressure from population aging and requiring the government to run a balanced budget. Our model includes a pension system consisting of a public PAYG pillar, a mandatory FF pillar, and a third pillar of voluntary retirement savings. The three pillars interact, as PAYG benefits are means tested on FF benefits and returns on voluntary savings. As we are also interested in the socioeconomic effects of retirement reform, the model incorporates exogenous agent heterogeneity in income profiles, preferences, and mortality risk, varying with education.

We estimate all preference parameters of the structural model using Denmark as our laboratory. We do this because Denmark collects high-quality micro data on all its citizens over the life cycle. The structural estimation procedure targets labor and savings moments for different education groups. Moreover, we use micro data to estimate some model parameters outside the model. Ultimately, we use the estimated model to compare reforms that restore fiscal sustainability amid population aging.

Our results suggest that increasing the mandatory contributions to the FF scheme is best for welfare. Welfare gains come from the fully-funded scheme giving access to fair annuities that provide a high return and insure against longevity risk but are missing in private markets. Moreover, this reform limits the role of the return-dominated pay-as-you-go scheme. As a result, agents become wealthier, consume more, and can afford more leisure. Together, the positive welfare effects outweigh two negative effects. First, indirectly diminishing the pay-as-you-go system leads to a reduction in redistribution and income insurance. Second, mandated savings in the fully-funded system crowd out bequest income. In contrast to adjusting FF pension contributions, adjusting the tax rate to finance public pension expenditure is the most detrimental to welfare, as it maintains a PAYG scheme with low returns while also making the young more borrowing constrained.

The paper contributes to 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), and Gustman and Steinmeier (1986)). Within this literature, a few papers specifically study the implications of means testing in social security (see Tran and Woodland (2014), Kudrna and Woodland (2011), Sefton et al. (2008), and 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 respects. Most importantly, our means-testing mechanism includes benefits from mandatory FF pensions. Moreover, we conduct policy analysis under the 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) and 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. The policy analysis considers 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. Section 1.2 outlines our structural life-cycle model. Section 1.3 describes Denmark's institutional setup and the mirco data we use to estimate the model. Section 1.4 outlines the structural estimation strategy. Next, for estimated parameters, Section 1.5 analyses the retirement reforms to restore fiscal sustainability. Finally, Section 1.6 concludes by summarizing and discussing key findings.

1.2 The Life-cycle Model

To study counterfactual pension reform in a framework with behavioral responses, we build a general 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 constant education type, e.

Because we are interested in the welfare effects of reforms across socioeconomic groups, we introduce ex-ante heterogeneity by allowing mortality rates, life-cycle income profiles, preferences for labor, and pension contribution rates 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 1.4.1. Preference parameters are estimated structurally in Section 1.4.2.

Consumption, c_t, is a continuous choice, albeit subject to a standard borrowing constraint. In contrast, the labor decision, l_t is discrete. Although the model can handle a general number of discrete labor supply choices, we focus on the extensive margin. Thus, 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 an additional decision, s_t, over whether to claim a pre-old-age social security benefit, q_0, at a utility cost, χ. When an early retiree reaches the statutory retirement age, the pre-old-age benefit ceases, and the disutility of claiming disappears. To formalize, the individual labor and retirement decisions, d_t, takes a finite set of elements, $\mathcal{D} = [1, 2, 3]$, which represents the following combinations of l_t and s_t

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

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 with income from FF pensions. The following sections provide nuance to each of these model components.

1.2.1 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 as part of voluntary savings. The same goes for other assets that could serve as retirement savings, e.g., housing. While the PAYG scheme pays out defined benefits financed by general taxes, the FF scheme mandates working agents to save on individual accounts to be 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 aligns 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). 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 PAYG Pensions

We model a PAYG benefit that has two components; a universal base amount, p_b, and a means-tested supplement, $p_s(y_t^m)$. The supplement is reduced linearly at a constant penalty rate, π, with means-testing income, y_t^m, including all FF 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

$$\begin{aligned} p_t &= p_b + p_s(y_t^m) \\ p_s(y_t^m) &= \max\{0, p_s - \pi y_t^m\}. \end{aligned}$$

As means testing depends on capital income, individuals must consider the impact on future public pensions when making consumption-saving decisions. For details, see Section 1.2.2. 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 welfare improvements through intergenerational risk-sharing channels. Although it is sometimes possible to postpone public pension benefits, we assume that the take-up rate is 100%. This assumption also applies to individuals who continue to work past the statutory retirement age.[1]

Pre-old-age Social Security

To have a channel for a 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 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, some agents self-retire, living solely off their voluntary savings and potentially FF pensions.

Fully-Funded Pensions

In the first period, individuals enter a mandatory FF pension scheme with zero 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 natural, as pension funds are often occupation-specific.

Individuals become eligible for FF pension benefits at age T_p. Suppose a worker stops working at some age, $r \geq T_p$. In every period thereafter, the individual has no labor income

[1] This simplification is rather innocuous, as very few people are eligible to postpone public pensions and only a fraction elect to do so. 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. In practice, this simplification is equivalent to limiting the scope of tax planning for a small population subset.

but instead receives an actuarially fair annuity based on wealth at retirement

$$f\left(w_r\right) = \frac{w_r}{\sum_{\tau=r}^{T} \frac{R_r^e}{\prod_{j=r}^{\tau} R_j^e}}.$$

The individual continues to receive this amount every year until his/her 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

$$w_{t+1} = R_{t+1}^e w_t - f\left(w_r\right).$$

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 the remaining pension wealth 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

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

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

1.2.2 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. This is given by

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

That is, instantaneous utility over consumption is a standard CRRA with the inverse elasticity of intertemporal substitution, ρ. In the special case where $\rho = 1$, the utility function 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 a reasonable point of departure for studying the welfare implications of population aging and pension system reform.[2] 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 function, propagating backwards 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, $\epsilon\left(d_t\right)$, with scale parameter, λ.[3] 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

[2]Without ensuring positivity, 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 1.5.3.

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

function for a worker, $d_t = 1$, can be written in the following recursive form

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

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 1.4.1. Meanwhile, b_{t+1}^e denotes income from 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 1.5.2. Furthermore, $\mathbb{I}$ denotes indicator functions for eligibility of different benefits, while $\tau_y(\cdot)$ is a 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

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

For a young worker who is ineligible for public pensions ($t < T_r$), this reduces to the standard case with no effects through means testing. 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

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

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

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

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

$$\begin{aligned}
v^e_t\left(m_t, w_t, d_t > 1\right) = \max_{a_t \geq 0} & \left\{u\left(c_t, 0, s_t\right) + \beta \cdot \psi^e_t \cdot v^e_{t+1}\left(m_{t+1}, w_{t+1}, d_t > 1\right)\right\} \\
& s.t. \\
m_t &= a_t + \left(1+\tau_c\right)c_t \\
m_{t+1} &= Ra_t + \left(1-\tau_y\left(\cdot\right)\right)\left(\mathbb{I}^f_{t+1} f_{t+1}\left(w_t\right) + \mathbb{I}^p_{t+1} p_{t+1}\left(y^m_{t+1}\right) + \mathbb{I}^d_{t+1} q_0\right) \\
y^m_{t+1} &= \left(R-1\right)a_t + \mathbb{I}^f_{t+1} f_{t+1}\left(w_t\right) \\
w_{t+1} &= R^e_{t+1} w_t - \mathbb{I}^f_{t+1} f_{t+1}\left(w_t\right).
\end{aligned}$$

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.

1.3 Danish Institutions and Data

We estimate our model using Denmark as a laboratory. Accordingly, this section provides background information on Danish institutions and the high-quality micro data that we use.

1.3.1 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, labor income, and other capital income. Figure 1.1 depicts a stylized version of the means-testing schedule in Denmark.[4] The plot includes the base amount and the two most significant components of the total supplement.[5] Although the supplement is somewhat targeted, a large majority of retirees receive a positive amount on top of the base amount.[6] Unlike US social security, the public scheme is financed entirely through general taxes. Thus, individual contributions to the public pension scheme are not directly available in the data.

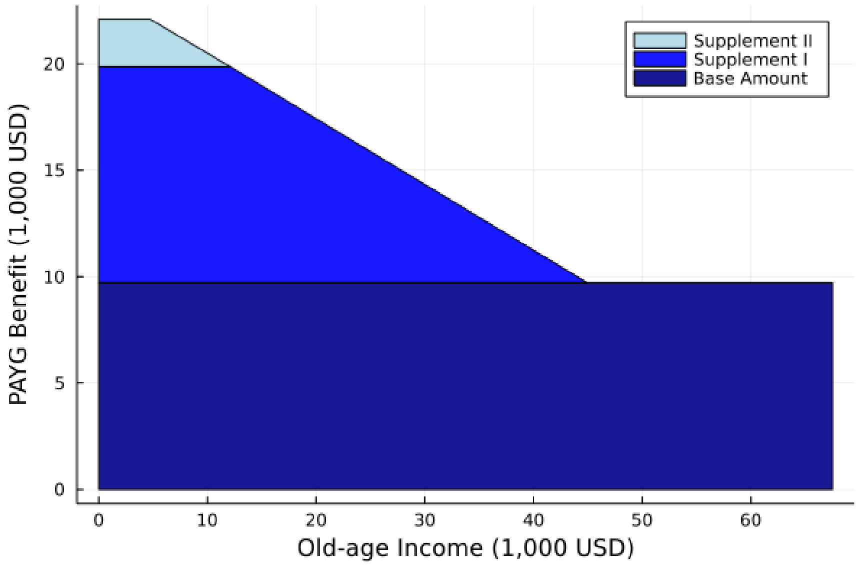

Figure 1.1: Means Testing. Stylized example based on 2015 rates for a retiree who lives alone and has no significant liquid wealth. Old-age income includes all income other than the public PAYG benefit.

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, contribution rates increase with average life expectancy in the fund. This partly reflects differences in annuity returns. Moreover, later labor market entry requires higher contribution rates to achieve a given

[4]For evidence on the degree of means testing in other countries, see Figure 1.9 in Appendix C.

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

[6]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%.

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 as 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 agreement's implementation a few years later, the importance of the occupational scheme increased substantially. 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 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.

1.3.2 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, and marital status. 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 life-cycle 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.

1.4 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 1.4.1. In the second stage, we use the Simulated Method of Moments (SMM) to estimate all preference parameters as described in Section 1.4.2.

1.4.1 Estimation Outside the Model

This section covers the calibration of parameters determined outside the model. For a quick overview, see Table 1.1. 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 bequests at 55 and stop receiving bequests 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 1.1: 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. from age j to $j+1$	See Figure 1.2	DST Data, Lee-Li model
labor productivity			
$\{x_e\}$	Earnings potential	See Figure 1.3	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 1.3	DST Data, Markov matrix
Taxes and Social Security			
$\tau_y(\cdot)$	Income tax function	See Figure 1.4	DST 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 1.1	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 a mechanism by which we allocate individuals in the data 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 1.2. 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.

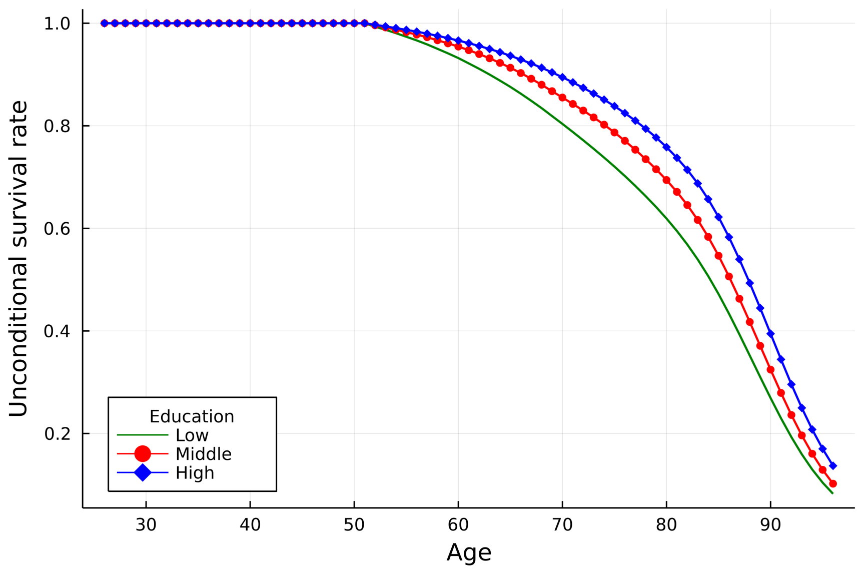

Figure 1.2: Education-specific Unconditional Survival Rates

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

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

where Y_t^i is 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 1.3. 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. Cocco et al. (2005) find a similar crossing-over of earnings profiles. 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 $\sigma_1 = 0.516, \sigma_2 = 0.501, \sigma_3 = 0.562$.

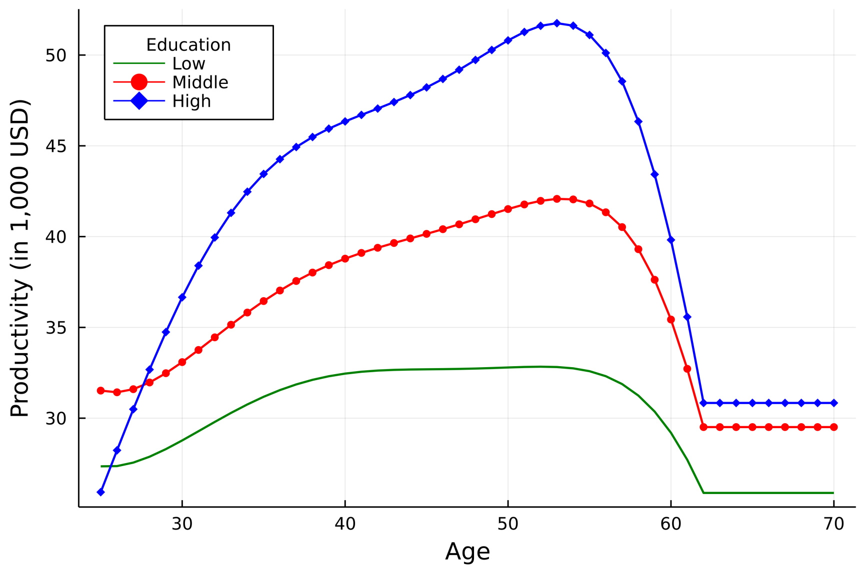

Figure 1.3: Education-specific Average Earnings

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 1.4. 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.

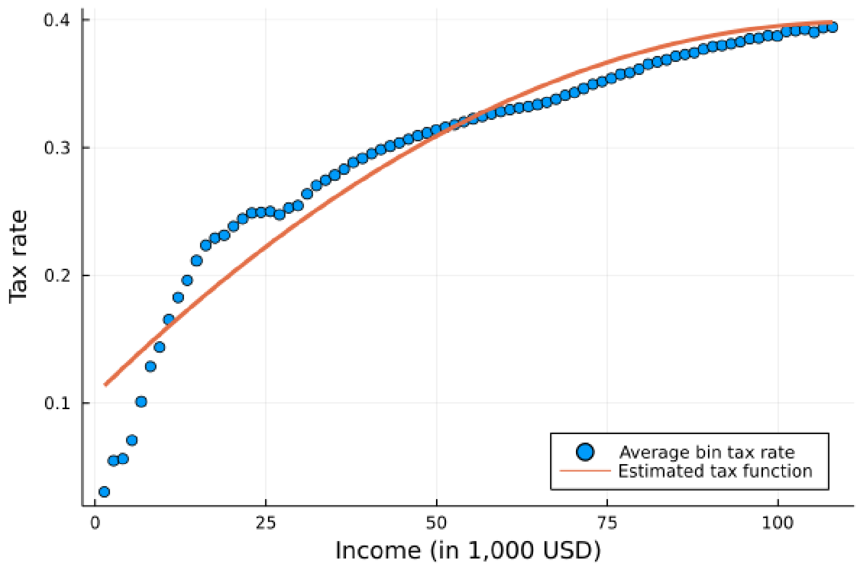

Figure 1.4: Tax Function

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 1.5 depicts the resulting contribution rates. Notably, contribution rates increased significantly for all groups between 1991 and 2009 and have remained constant ever since. Recalling the section on the institutional setup in Denmark, this increase resulted from a political agreement of 1987. The agreement was highly politicized 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.

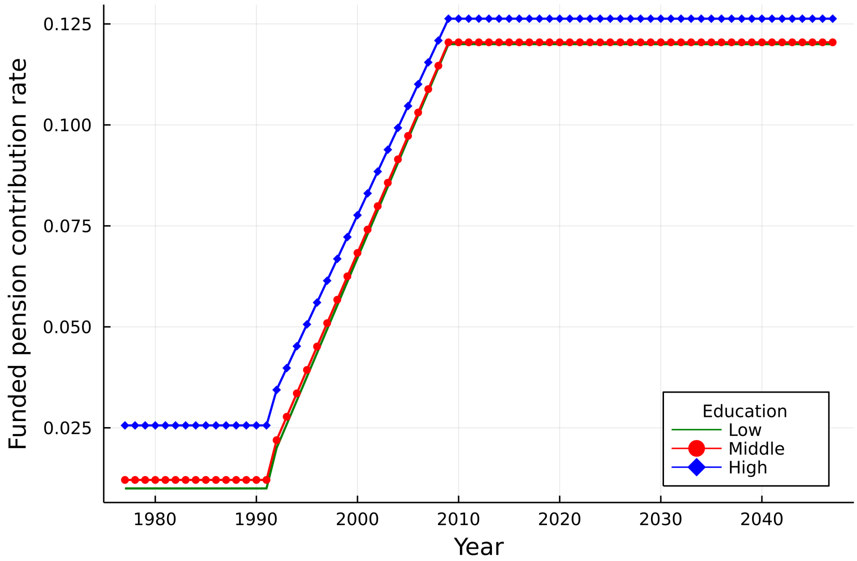

Figure 1.5: Funded Pension Contribution Rates

1.4.2 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 intertemporal 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 1.2. [8]

Table 1.2: 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 its outcomes. 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 begin to dissave liquid wealth early on before the illiquid FF pension wealth reaches its apex. As expected, better-educated individuals tend to consume the most and have the highest net worth.

1.4.3 Targeted Moments

In this section, we evaluate the model fit for targeted variables. First, Figure 1.6 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 or not. We use the same criterion to gauge total wealth. The model over-predicts labor supply by five to ten

[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.

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.

1.5 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 life expectancy by 2 years at the age of 40. Meanwhile, the cohort growth rate, n, adjusts to match expected changes in the Danish old-age dependency ratio between 2015 and 2025.[9,10] We then verify that the demographic change puts pressure on public finances as it increases old-age pension expenditure more than 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.

1.5.1 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, including

[9] According to the OECD, the Danish old-age dependency ratio was 33.0 in 2015 and is expected to increase to 37.7 in 2025. Given estimated mortality, this implies a drop in the cohort growth rate from $n = 0.008$ to $n = 0.006$.

[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.

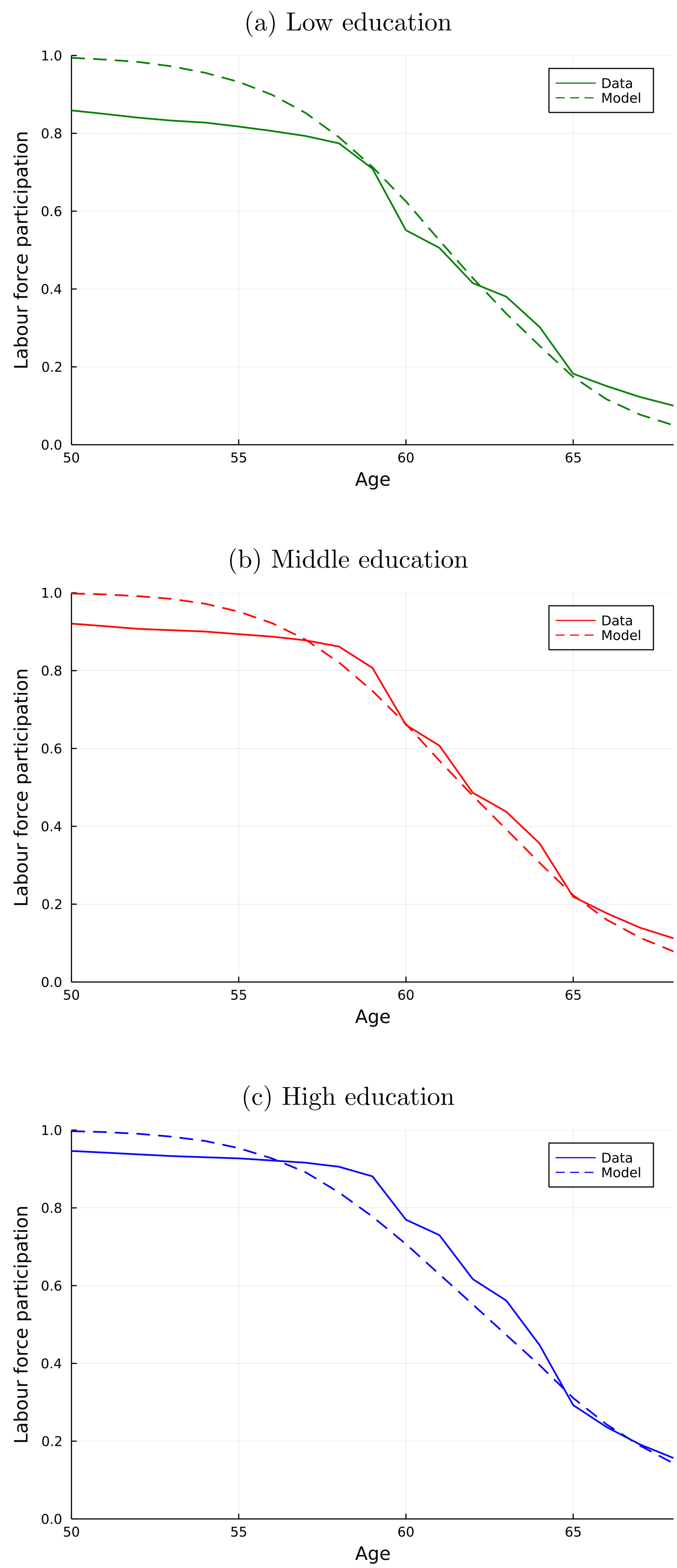

Figure 1.6: Labor Force Participation

healthcare, education, and infrastructure. 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 slow-down 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.

1.5.2 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. We argue that disregarding bequest is restrictive 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 ages T_l through T_u. Specifically, we assume that an individual of a specific education rank inherits the mean unclaimed savings of its probabilistic education-rank ancestors. That is, if parents with education type e' have probability $prob\,(e|e')$ of having a child with education type e, the bequest given to children of this type is given by

$$b^e_{t+1} = \frac{R\,(1-\tau_b) \sum_{\tau=1}^{T} \sum_e prob\,(e|e') \frac{\mathbb{E}\left(a^{e'}_\tau\right)\left(1-\psi^{e'}_\tau\right)\Psi^{e'}_{\tau-1}}{(1+n)^\tau}}{\sum_{\tau=T_l}^{T_u} \frac{\Psi^e_\tau}{(1+n)^\tau}}.$$

Note that τ_b is an inheritance tax, which we calibrate according to the Danish tax code. We use administrative data to link parents to their children. We then compute a Markov matrix containing education 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 1.3 contains the resulting transition probabilities for the 1950 cohort of parents and their children.

Table 1.3: 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, preserving 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.

1.5.3 Welfare Measurement

When evaluating the welfare effects 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 they observe any income shocks. Furthermore, as it is 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 average welfare. Intuitively, the CV is the amount an average individual would require as compensation at birth to support the worst policy. We pick this measure over constant consumption equivalent measures as it is not straightforward to clean expected utility for uncertain labor/retirement decisions and taste shocks. Recalling Section 1.2.2, we add a positive constant, $\underline{\mathrm{u}}$, 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 Traaholt et al. (2016)).[12]

1.5.4 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 decrease in the new steady state. We refer to this as the unfinanced steady state. For all the other cases where the government must run a balanced budget, we show the required policy changes in 1.4. For the unfinanced steady state and all subsequent policy experiments, we list the average and education-specific responses in voluntary savings, total savings (i.e., voluntary savings plus occupational pension wealth), labor supply, and welfare in Tables 1.5 through 1.8. Note that we report the results from all policy experiments relative to the outcomes of the tax reform, which provides the worst welfare outcomes for all education groups.

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 retirement years, 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 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, demographic change affects the consumption tax, the capital tax, the inheritance tax, and public expenditures on pensions and social security. In Table 1.12 in the appendix, we list how the demographic change affects each budget component. The combined result is a decrease in residual government consumption by 3.2% , indicating that demographic change threatens fiscal sustainability. For welfare, Table 1.8 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.

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

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

Table 1.4: 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	22,099 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% .

1.5.5 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 average tax rate to balance the budget without changing tax progressivity. We find that the average tax has to increase by 1.39 percentage points to 12.04%.

Compared to the unfinanced steady state, increasing the average 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%. Average labor increases by approximately 0.87% percentage points in response to the tax increase. This is the result of two competing effects. First, a higher tax rate makes individuals poorer and, hence, they 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. In total, this 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 larger income tax base and an associated downtick in expenditures on pre-old-age benefits. Regarding redistribution, ceteris paribus, 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 higher tax rate decreases after-tax pension benefits for everyone.

Compared to the remaining reforms, the tax reform yields the lowest welfare for all education groups. Accordingly, we use the tax reform as an anchor to compare outcomes across reforms. That is, we standardize the CV measure of welfare to 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.

1.5.6 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. Notably, balancing the budget requires a retirement age increase which is larger than the increase in expected lifetime. This owes to three effects. First, the new retirement age also reflects the increase in the old-age dependency ratio through fertility. Second, as preferences for leisure do not change, agents do not adjust their labor supply one-for-one with a change in the statutory retirement age. In extension, some agents respond to the change by going on early-retirement benefits. Laun et al. (2019) document a similar substitution of old-age benefits for pre-old-age benefits. Third, the fact that we simultaneously lower the tax rate shows that the required change would be less than 4 years in a continuous-time model.

From a life-cycle perspective, a higher retirement age puts upward pressure on voluntary savings. 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 total public pension benefits for everyone. However, those with low education or bad income shocks lose the most, as they would be eligible for higher means-tested benefits each year. Nonetheless, the retirement age reform leads to better welfare outcomes for all education groups than increasing the tax rate. To see this, the average CV measure is $3,882$ 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 taxes, and relies more on public benefits. Thus, they require a smaller compensation to accept a tax reform that keeps public benefits intact.

1.5.7 Decreasing Benefits

In a 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, lower benefits imply a loss of income, exerting 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, the average total 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 is higher for all education groups compared to the tax and retirement age reforms. The average individual requires compensation to the tune of $4,813$ USD to accept the tax reform over the benefits reform. The positive welfare implications go through several channels. First, it directly reduces turnover in the return-dominated public pension scheme. Furthermore, although there is still considerable redistribution across education groups, the insurance loss is limited as public pensions are already high, and as income risk is only transitory.

1.5.8 Increasing Contributions to FF Pensions

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

Saving in annuities via the FF scheme provides a higher return and better longevity insurance than voluntary savings. This represents a positive wealth effect. At the same time, increasing contribution rates defers individual income to later in life. Thus, the increase in forced savings crowds out voluntary savings and, thereby, bequest income. This represents a loss of income. In the estimated model, we find that the former effect dominates, such that individuals become wealthier. The increase in wealth allows individuals to consume more and enjoy more leisure. In the estimated model, the contribution rate reform implies the lowest voluntary savings and labor supply of any reform under consideration. However, total wealth increases because forced savings crowd out voluntary saving less than one-to-one. In total, the contribution rate reform has the highest average welfare of all the reforms considered for all education groups. To be precise, the average CV measure is $6,765$ USD.

Table 1.5: Aggregate Voluntary Savings

	Education			
	Low	Middle	High	Average
Baseline SS	0.9774	0.9563	0.9402	0.9551
New SS, unfinanced	1.0451	1.0445	1.0374	1.0417
Fiscally sustainable policies				
Tax increase, τ_0	1.0	1.0	1.0	1.0
Retirement age increase, T_r	1.1575	1.1475	1.1188	1.1381
Decreasing the benefit, p	1.0679	1.0891	1.09	1.084
Increasing FF contri., ϕ	0.9666	0.9456	0.9271	0.9433

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

Table 1.6: Aggregate Total Savings

	Education			
	Low	Middle	High	Average
Baseline SS	0.9418	0.9374	0.9343	0.9373
New SS, unfinanced	1.0069	1.0066	1.0047	1.0059
Fiscally sustainable policies				
Tax increase, τ_0	1.0	1.0	1.0	1.0
Retirement age increase, T_r	1.0404	1.0355	1.0243	1.0321
Decreasing the benefit, p	1.0167	1.0234	1.0256	1.0226
Increasing FF contri., ϕ	1.0875	1.0814	1.0751	1.0804

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

Table 1.7: Aggregate Labor Supply

	Education			
	Low	Middle	High	Average
Fiscally sustainable policies				
Tax increase, τ_0	1.0	1.0	1.0	1.0
Retirement age increase, T_r	1.0053	0.9998	0.9933	0.9993
Decreasing the benefit, p	0.9984	1.0008	1.0038	1.0011
Increasing FF contri., ϕ	0.9886	0.9886	0.9887	0.9886

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

Table 1.8: Welfare

	Education			
	Low	Middle	High	Average
Fiscally sustainable policies				
Tax increase, τ_0	0	0	0	0
Retirement age increase, T_r	2,867	5,070	4,065	3,882
Decreasing the benefit, p	4,842	5,912	3,971	4,813
Increasing FF contri., ϕ	7,032	9,109	4,745	6,765

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

1.6 Conclusion

Throughout this paper, we study a set of counterfactual pension reforms that restore fiscal sustainability in the face of demographic pressure. We document how each reform affects individual decisions and welfare. For our 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. We use Denmark as our laboratory, as the Danish government collects high-quality micro data on all its citizens. This data first allows us to estimate a series of model parameters outside the model using econometric methods. Second, we can use this data to pin down unobserved 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 individuals differently. Most notably, an increase in contributions to mandatory fully-funded pensions yields the highest average welfare. The relative welfare gains stem from the fully-funded scheme giving access to fair annuities that are missing in private markets. These annuities offer a high return and longevity risk insurance. Furthermore, this particular reform limits the importance of a return-dominated pay-as-you-go scheme. Consequently, individuals become wealthier, leading to increased consumption and leisure. In combination, the positive welfare effects outweigh two negative effects. Firstly, the indirect reduction of the pay-as-you-go system results in a decrease in redistribution and income insurance. Secondly, the mandated savings within the fully-funded system crowd out bequest income.

Out of the remaining policies, using the tax rate as an instrument to balance the government budget is the most detrimental to welfare, as it maintains a pay-as-you-go scheme with low returns and makes the young more borrowing constrained. Meanwhile, increasing the retirement age is slightly better for welfare than increasing taxes, whereas cutting benefits provides decent welfare outcomes. These insights should be of interest to all countries considering pension system reforms in response to population aging. In this context, our results on using the fully-funded scheme to lower public pension expenditure through means testing deserve special attention.

Throughout this paper, we have evaluated policies exclusively based on steady-state comparisons. As an avenue for future research, it would be interesting to examine the performance of the different reforms along the transition path between steady states with different demographics. Moreover, one could add more household heterogeneity, e.g., permanent labor income risk and financial return risk, thereby increasing the scope for redistribution and income insurance.

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Appendix A: Reannuitizing Pension Wealth

At the beginning of a retirement period, the pension wealth in the individual account is $\tilde{w}_t$. 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 re-annuitizing remaining pension wealth in every period. To see this, we annuitize the 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}:

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

Appendix 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:

$$\log\left(m_{t,a}^{g}\right) = \alpha_a^g + B_a K_t + \beta_a^g \kappa_t^g + \epsilon_{t,a}^g \tag{1.1}$$

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,

$$K_t = c_1 + K_{t-1} + e_t, \tag{1.2}$$

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,

$$\kappa_t^g = c_2 + \gamma^g \kappa_{t-1}^g + v_t, \tag{1.3}$$

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 1.8 and 1.7 depict estimated and forecasted mortality rates and the life expectancy at age 40 for each education group.

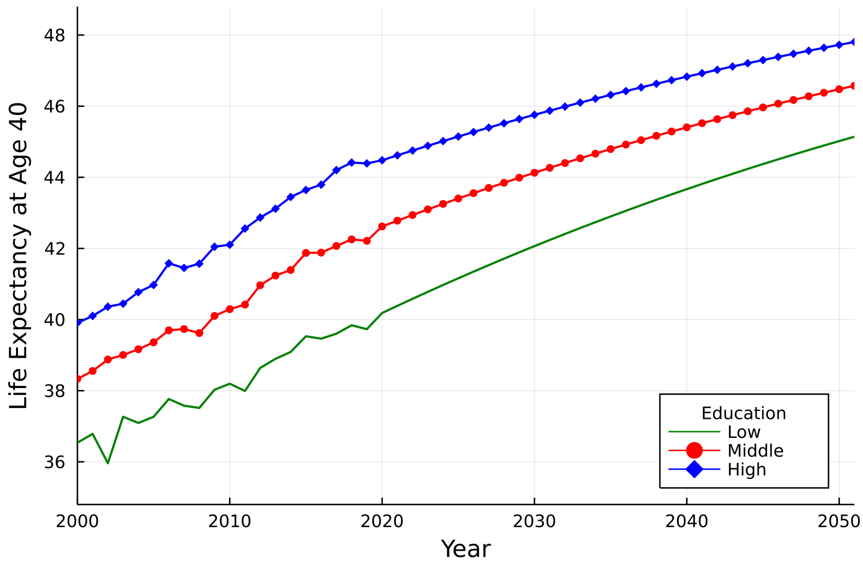


Figure 1.7: Life Expectancy at Age 40

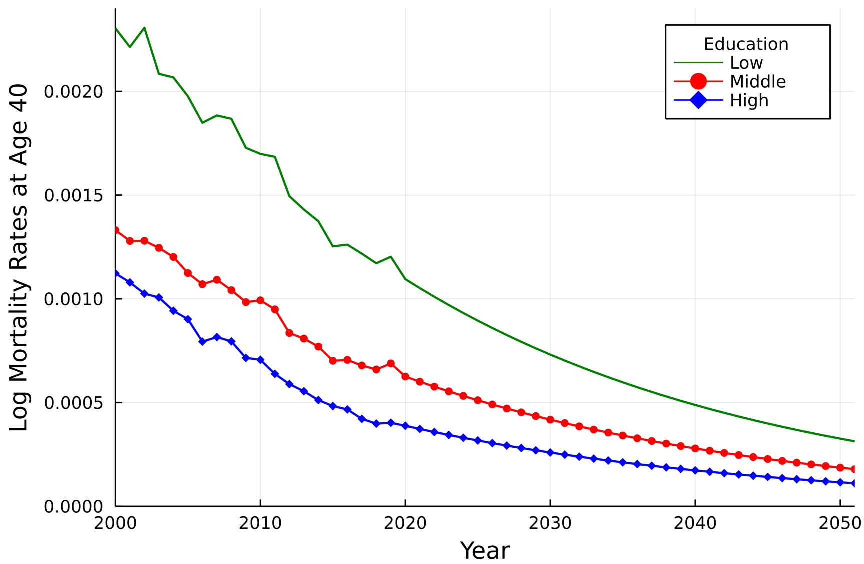


Figure 1.8: Log-mortality Rates at Age 40

Appendix C: Additional figures

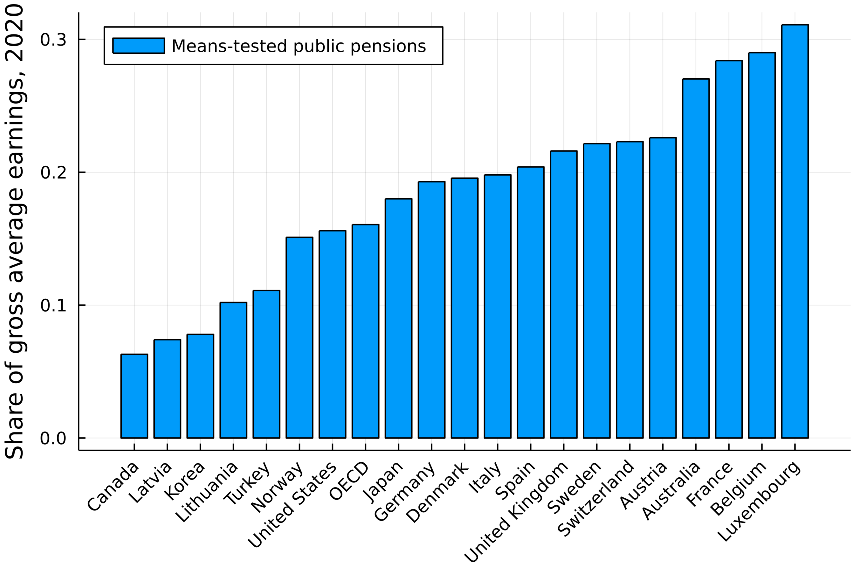


Figure 1.9: Means-tested Pensions in OECD countries. Source: OECD (2021)

Figure 1.10: After-tax Income, Low Education

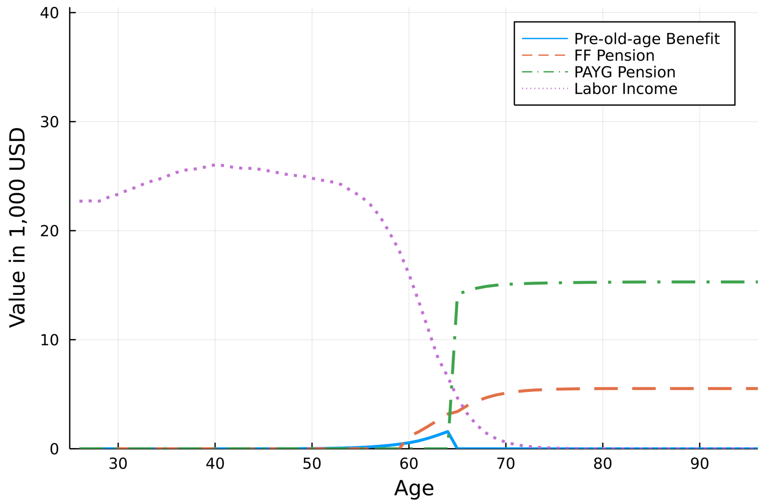


Figure 1.11: After-tax Income, Middle Education

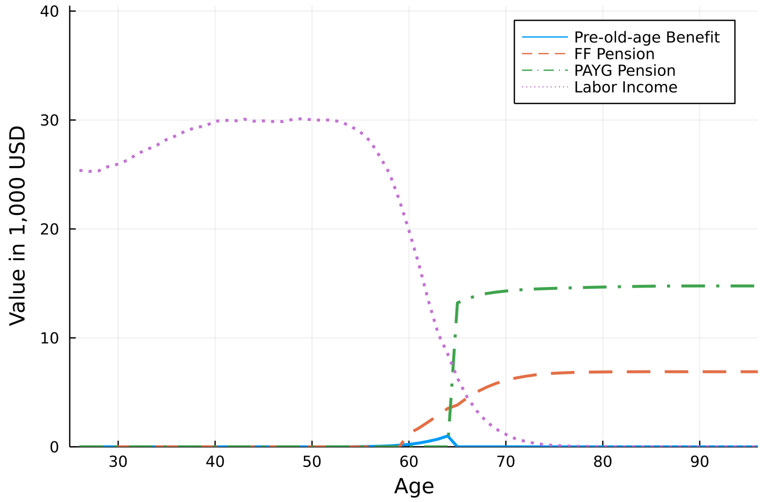


Figure 1.12: After-tax Income, High Education

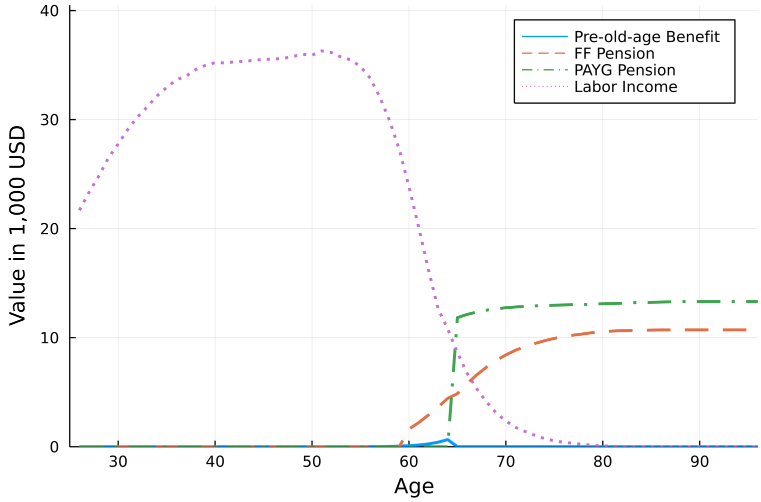


Figure 1.13: Consumption and Saving, Low Education

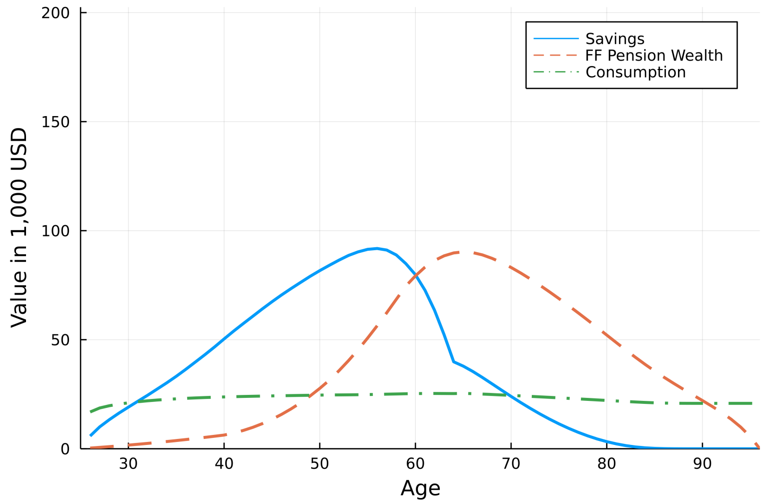


Figure 1.14: Consumption and Saving, Middle Education

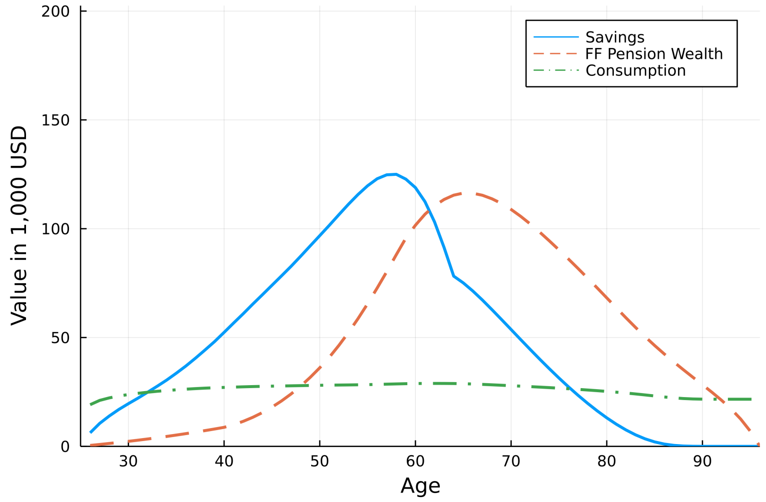
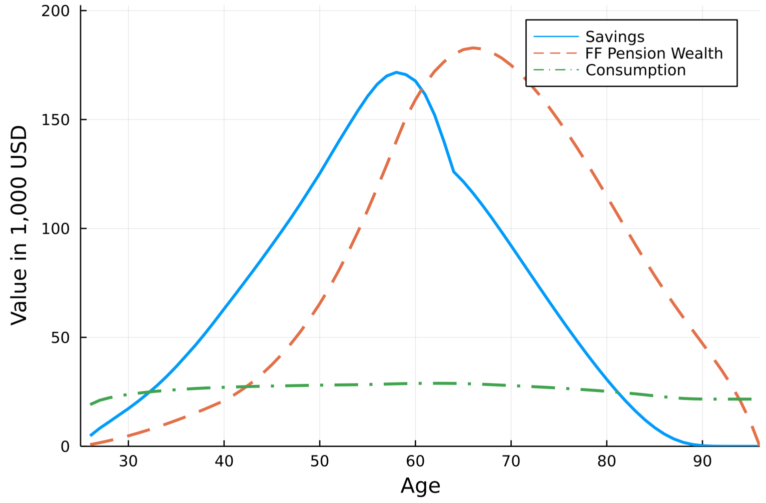


Figure 1.15: Consumption and Saving, High Education



Appendix D: Additional Policy Experiments

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

D1: Decreasing the Base Benefit

In the first additional experiment, we balance the budget by adjusting the base amount of public pensions, p_0, alone. 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 supply. 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.

Regarding 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 rather effective for welfare with a CV measure of $4,645$ USD. The positive welfare implications owe to 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% .

D2: 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 will be 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 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 $4,999$ USD relative to the tax reform.

D3: Increasing Means Testing

As an alternative to adjusting benefits, the government could balance the budget by increasing the penalty rate, 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 capital income. 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. The model predicts that an increase in the penalty rate results in average voluntary savings slightly higher than when decreasing the supplement. 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 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 $4,825$ USD. Again, the observed welfare response likely has to do with arguments of return dominance and limited scope for redistribution and insurance.

Table 1.9: Welfare of All Reforms

	Education			
	Low	Middle	High	Average
Baseline SS	-6,339	-11,509	-6,659	-7,846
New SS, unfinanced	9,148	11,079	6,570	8,783
Fiscally sustainable policies				
Tax increase, τ_0	0	0	0	0
Retirement age increase, T_r	2,867	5,070	4,065	3,882
Decreasing the base benefit, p_0	4,722	5,739	3,767	4,645
Decreasing the supplement, p_1	4,962	6,100	4,217	4,999
Increasing income-testing, π	5,187	5,768	3,774	4,825
Decreasing the benefit, p	4,842	5,912	3,971	4,813
Increasing FF contri., ϕ	7,032	9,109	4,745	6,765

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 1.10: Aggregate Voluntary Savings of All Reforms

	Education			
	Low	Middle	High	Average
Baseline SS	0.9418	0.9374	0.9343	0.9373
New SS, unfinanced	1.0069	1.0066	1.0047	1.0059
Fiscally sustainable policies				
Tax increase, τ_0	1.0	1.0	1.0	1.0
Retirement age increase, T_r	1.0404	1.0355	1.0243	1.0321
Decreasing the base benefit, p_0	1.0169	1.0234	1.0245	1.0221
Decreasing the supplement, p_1	1.0167	1.0237	1.0268	1.0232
Increasing income-testing, π	1.0166	1.0254	1.0279	1.0241
Decreasing the benefit, p	1.0167	1.0234	1.0256	1.0226
Increasing FF contri., ϕ	1.0875	1.0814	1.0751	1.0804

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

Table 1.11: Aggregate Labor Supply of All Reforms

	Education			
	Low	Middle	High	Average
Baseline SS	0.9631	0.963	0.9641	0.9634
New SS, unfinanced	0.9906	0.9911	0.9924	0.9914
Fiscally sustainable policies				
Tax increase, τ_0	1.0	1.0	1.0	1.0
Retirement age increase, T_r	1.0053	0.9998	0.9933	0.9993
Decreasing the base benefit, p_0	0.9983	1.0001	1.0013	0.9999
Decreasing the supplement, p_1	0.9987	1.0018	1.0062	1.0023
Increasing income-testing, π	0.9914	0.9969	1.0092	0.9994
Decreasing the benefit, p	0.9984	1.0008	1.0038	1.0011
Increasing FF contri., ϕ	0.9886	0.9886	0.9887	0.9886

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

Table 1.12: Government Budget Components

	$\mathcal{G}$	P	$\mathcal{T}_y$	$\mathcal{T}_a$	$\mathcal{T}_c$	$\mathcal{T}_b$
Baseline SS	17,443	3,796	11,795	2,696	5,673	31
New SS, unfinanced	16,883	4,448	12,378	2,897	6,026	29
Fiscally sustainable policies						
Tax increase, τ_0	17,443	4,429	13,031	2,880	5,931	29
Retirement age increase, T_r	17,443	3,591	12,029	2,973	5,998	34
Decreasing the base benefit, p_0	17,443	3,678	12,164	2,944	5,978	34
Decreasing the supplement, p_1	17,443	3,765	12,231	2,947	5,996	34
Increasing income-testing, π	17,443	3,719	12,196	2,945	5,986	34
Decreasing the benefit, p	17,443	3,710	12,188	2,950	5,981	34
Increasing FF contri., ϕ	17,443	4,205	12,476	3,112	6,036	24

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.

Chapter 2

Redistribution in Public Pensions: Evidence from Denmark

Frederik Bjørn Christensen & Tim D. Maurer

Abstract

We use 41 years of register data to document a significant loss of redistribution in Danish public pensions when accounting for inequality in longevity. Our main contribution is to deviate from the traditional approach of assessing redistribution along the distribution of income alone. Rather, we consider an affluence measure, which combines information on lagged income and wealth. Using this measure, we first document substantial inequality in longevity. Second, we measure redistribution in public pensions by comparing expected net present values of the implicit public pension contract. We find that inequality in longevity subverts redistribution such that net present values develop non-monotonically with affluence. Males in the middle group are 26% better off than the least affluent males. Meanwhile, only the top 30% males have lower net present values than their least affluent peers. Females of a specific affluence rank have considerably higher net present values than similarly ranked males. Compared to traditional measures of socioeconomic status, allocation by affluence is a stronger separator of mortality and implies a larger loss of redistribution.

2.1 Introduction

The public pension system is the largest public transfer program in most developed countries. For example, US Social Security accounted for close to 25% of federal tax revenue or around 5% of GDP in 2020. In comparison, public pensions accounted for 12% of the fiscal budget in Denmark in the same year. Although public pension schemes differ across countries, they typically aim to insure against longevity and income risk by providing annuities and redistributing from the rich to the poor. However, one factor that limits redistribution in public pensions is inequality in longevity. As longevity varies systematically with socioeconomic variables such as income, wealth, and education, advantaged groups tend to live longer on public pension benefits.

In this paper, we develop a microsimulation model and apply it to 41 years of register data to document a significant loss of redistribution through Danish public pensions when accounting for inequality in longevity. Our main contribution to the literature on redistribution in public pensions is to show that the estimated redistribution loss varies with the allocation mechanism to socioeconomic groups. In the related literature, most papers measure redistribution along the distribution of either income or education. In contrast, we compute redistribution along the distribution of a so-called affluence measure, which combines household income and wealth information.

Our main experiment has two components. First, we use full-population register data between 1984 and 2020 to estimate mortality across affluence groups and genders. Second, we evaluate redistribution by computing and comparing average, expected, net present values (NPV) of the implicit public pension contract across groups for given forecasted group-specific survival rates. In the second part, we track the pension contributions and benefits of recently retired cohorts from 1980 to 2020 and forecast group-specific survival-weighted net benefits. To compute future public benefits and contributions, we forecast private old-age income, wealth, and civil status and feed this into a detailed model of the tax and public pension benefit scheme.

We find that inequality in longevity implies that the estimated net present values develop non-monotonically with affluence. Specifically, for a yearly discount rate of 3%, we find that the NPV of the implicit public pension contract is hump-shaped along the affluence distribution for men. Males in the middle of the affluence distribution have a 26% higher NPV than males at the bottom. Only males in the top 30% of the affluence distribution have lower NPVs than their least affluent peers. The hump shape is less pronounced for females, with the least affluent females being approximately as well off as the middle class. Only the most affluent females have a lower NPV than the least affluent males. In general, females have significantly higher NPVs than males.

Inspired by the existing literature (see, e.g., Auerbach et al. (2017), Auerbach et al. (2019), Garrett (1995), Liebman (2001), and Chetty et al. (2016)), we then repeat the experiment constructing socioeconomic groups by using an allocation mechanism that abstracts from wealth but uses ten years of lagged income data. Despite the affluence index using only a one-year lag, we document that mortality is more dispersed in affluence than in income. Consequently, we find a smaller redistribution loss when using lagged income.

Most of the related literature focuses on the Bismarckian US social security system, where contributions are proportional while benefits depend on lifetime earnings. Thus, we contribute to the literature by providing evidence from a Beveridgian pension system where contributions are progressive while benefits are means tested on old-age income. Although we use Danish data, our results are relevant for other countries where the public pension system promotes redistribution. This is especially true in other countries with Beveridgian pension systems, such as Japan, Canada, Australia, Ireland, Netherlands, Finland, and Iceland. However, differential mortality also implies a redistribution loss in countries with Bismarckian pension systems. This includes the US, the UK, Germany, Korea, Belgium, Austria, France, Italy, Spain, Portugal, Sweden, and Norway.

Surely, these insights invite normative discussions on the fairness and merit of mandatory public pensions. However, the subversion of redistribution does not necessarily imply that public pensions are detrimental to social welfare or even welfare among the disadvantaged. This is because public pensions provide insurance and a means to restore missing annuity markets. Nonetheless, redistribution and insurance would improve by adopting policies where funds in public pensions are annuitized, considering systematic differences in survival probabilities

The remainder of the paper is organized as follows. First, Section 2.2 reviews the related literature and points to some common shortcomings. Section 2.3 briefly outlines our experiment and the register data used to conduct it. Section 2.4 introduces the framework for estimating and forecasting mortality for gender-specific social classes. Section 2.5 describes the assumptions and procedures used to compute public pension contributions and forecast future individual public pension benefits to gauge redistribution in public pensions. Under these assumptions, Section 2.6 presents results on the life-cycle profile of interaction between the individual and the government and the NPV of the implicit pension contract for the different social groups. Finally, Section 2.7 concludes and discusses the merit of public pension schemes in light of our findings. The appendix provides supporting information and relevant robustness checks.

2.2 Literature Review

Starting with Kitagawa and Hauser (1973), many papers have already documented the existence of socioeconomic gradients in longevity. Most prominently, Chetty et al. (2016) show a positive correlation between income and longevity over the entire income distribution in the US. In another highly cited paper, Olshansky et al. (2012) document vast differences in longevity by race and educational level. In a Danish context, Cairns et al. (2019) show that the expected lifetime of males varies systematically with affluence, while Kallestrup-Lamb et al. (2020) provides corresponding evidence for females. These results are, of course, interesting in and of themselves. However, we go one step further and ask how systematic differences in mortality affect the redistributive properties of public pension schemes. Several papers have already conducted similar exercises but often focus on US Social Security and rely on limited survey data.

In a recent paper, Auerbach et al. (2017) show that the life expectancy of men in the top income quintile increased by seven years between cohorts born in 1930 and 1960, while life expectancy stagnated for men in the lowest income quintile. They then estimate that this increased the gap in lifetime social security benefits by USD $130,000$ (in 2009 prices). In a follow-up paper, Auerbach et al. (2019) argue that US Social Security leads to inequality in remaining household lifetime consumption that is lower than that in income and wealth. Using data from the 2016 Federal Reserve Survey of Consumer Finances, they document high progressivity in the broader US tax and transfer system.

Garrett (1995) considers the 1925 birth cohort and computes net returns from interacting with Old-Age Survivors Insurance (OASI) for given mortality differences between the bottom 20% and top 80% of the income distribution. He finds that differential mortality eliminates the bulk of progressivity in OASI.

Liebman (2001) assesses redistribution in US social security, accounting for differential mortality by education, sex, and race. He uses panel data on historical contributions to the US Social Security system and predicts future benefits given current policy. To measure the extent of redistribution, he then computes group-specific net present values (NPV), net tax rates, and internal rates of interest (IRR) of the stream of discounted and mortality-weighted benefits net of contributions. The paper concludes that net transfers decrease slightly in income, indicating slight progressivity.

Coronado et al. (2011) use data on 1778 individuals from the Panel Study of Income Dynamics (PSID) to evaluate the progressivity of the retirement portion of Social Security. To this end, they consider net tax rates and Gini coefficients before and after taxes and transfers. They do so under the assumption of a steady-state pension system. Thus, all contributions and benefits are calculated based on the current pension system. They introduce differential mortality by allocating individuals into quantiles of the lifetime income distribution and find that the progressivity of social security decreases slightly. They consider household-level variables to avoid problems with non-working spouses of wealthy individuals recorded at zero income.

Whitehouse and Zaidi (2008) provides a survey of papers on differential mortality in isolation and as it pertains to public pensions. The paper also compares annuity rates of pension schemes across income tertiles for the UK (BHPS), the US (PSID), and Germany (Socio-economic Panel). The paper shows that the rich have higher annuity values than the poor in all three countries as a natural consequence of living longer. Moreover, it verifies the regularity that women live longer than men and that dispersion within male mortality is higher than for females. The paper suffers from the usual data limitations associated with small-sample panel surveys. Moreover, it does not consider differences in contributions and benefits over time.

Brown et al. (2009) use PSID data to measure intragenerational redistribution in OASI. As data is limited, they use econometric models to complete panels of income data in order to determine social security contributions before retirement. In retirement, benefits are paid out according to standard principles. In evaluating redistribution, benefits are weighted with differential mortality rates by education and race. Despite observing vast differences in life expectancy, they find that differential mortality matters only little for redistribution.

Goda et al. (2011) also assess the progressivity of the retirement portion of Social Security by calculating IRRs and NPVs given differential mortality. They, too, impose a steady-state assumption. Comparing this steady state to one derived under the assumption of homogeneous mortality across subgroups, they show that a sizeable part of progressivity is undone or even reversed by systematic differences in mortality.

Using a micro-simulation model, Goldman and Orszag (2014) find that differential mortality could have first-order effects on the progressivity of Social Security and Medicare benefits. To evaluate the progressivity of benefits, they assume a counterfactual, fixed-benefit scheme for three cohorts and quantify the consequences of increasing gaps in mortality for NPVs of Social Security for income quartiles. However, as they only consider simulated benefits under a counterfactual scheme and disregard contributions, this does not speak to the overall redistribution of Social Security for any actual cohorts.

Ayuso et al. (2017) instrumentalize the subversion of redistribution as an implicit tax. The implicit tax rate is motivated by the annuity value of accumulated pension wealth but reduces to a measure depending solely on life expectancy. They use this index to compute implicit tax rates based on the longevity predictions of Whitehouse and Zaidi (2008). Thus, they do not consider any forecasting exercises or conduct accounting exercises with actual data on contributions and benefits.

Tan and Koedel (2019) use data from the Survey of Income and Program Participation (SIPP) to predict Social Security contributions and benefits for cohorts of men born in the second half of the 20th century, and calculate IRRs for race-education groups. They find that OASI is only modestly progressive and that differential mortality is the main driver of missing redistribution. They do, however, not account for redistribution across genders or for spousal and survivor benefits.

Similar exercises have never been done for Denmark. In this paper, we do so using high-quality Danish register data. Accordingly, we contribute to the literature on redistribution in public pensions in two important ways: First, we provide evidence on the progressivity of a public pension system other than US Social Security. Second, rather than relying on survey data, we use high-quality administrative data covering many variables and allowing us to track individual tax payments. Thus, we can estimate both contributions and benefits to the pension system. Finally, as our main contribution, we use allocation according to an affluence measure, which provides a stronger mortality separator.

2.3 The Data and The Experiment

In the main experiment, we use Danish register data to track individual public pension contributions and benefits for recently retired cohorts. Based on a so-called affluence index, we subdivide each cohort into gender-specific social groups, $(s, g) \in S \times G$. Here, G is a set of genders, whereas S is a set of social groups. For details on this index, see Section 2.4. To assess redistribution in the Danish public pension scheme, we then compute and compare the average expected NPV of the implicit pension contract across the affluence groups. Expected NPV is the average of discounted streams of survival-weighted benefits net of contributions over all members of a group:

$$NPV_{c,s,g} = \sum_{a=17}^{95} S_{c,a}^{s,g} \frac{B_{c,a}^{s,g} - C_{c,a}^{s,g}}{(1+r)^{a-64}} \tag{2.1}$$

Here, r denotes a constant discount rate, $B_{c,a}^{s,g}$ average benefits received in cohort c at age a, $C_{c,a}^{s,g}$ average contributions paid, and $S_{c,a}^{s,g}$ survival rates. To compute NPVs in practice, we must first elicit these components for all individuals, both historically and in the future. While we use realized survival before the end of the data, we use forecasted survival rates for future years. The procedure used to estimate and forecast survival rates is described in Section 2.4. Section 2.5 describes the method we use to elicit public pension contributions and to forecast future means-tested pension benefits in detail.

At every turn, we make use of Danish register data. With register data, one can link a large set of variables to each individual through an anonymized personal number (PNR) via the Central Person Register. These features make register data ideal for conducting cross-section and panel-data studies, including many individuals, covariates, and time observations. The data also allows us to identify and track variables of partners and cohabitants. This feature is useful as both pension benefits and taxes depend on variables at the household level. In particular, we use information from the population register (BEF), the income and wealth register (IND), the death register (DOD), the migration event register (VNDS), the social-classification register (AKM), the wealth register (FORMGELD), the pension wealth register (PENSFORM), and the register for social pensions (SOCP). Table 2.1 shows the relevant variables from each register.

The registers we use are available from 1980 to 2020 (41 years of data)[1]. Hence, we cannot conduct a full cohort study, tracking contributions and benefits from cradle to grave. Instead, our research design emulates a cohort study by "completing" the data set using both forecasting and backcasting. Thus, we face a trade-off in selecting which cohorts to follow. If we consider young cohorts, we have good information on income during working life and, thereby, pension contributions but relatively few observations on pension benefits and deaths. Conversely, if we consider a generation that is relatively old at the start of the data, we have limited information on pension contributions but more observations on both pension benefits and deaths. To preserve political relevancy, we consider cohorts that became eligible for retirement shortly before the end of the data in 2020. Thereby, the paper is primarily an exercise in forecasting mortality and public pension benefits. Throughout the remainder of the paper, we consider a baseline cohort born in 1952 as an illustrative example. Members of this cohort are 67 at the end of the data and became eligible for public pensions at 65. Hence, we have three years of pension eligibility and can backtest the mechanisms used to forecast public pension benefits. For robustness, we run similar experiments on cohorts 1951 and 1953. The results of the robustness checks are included in Appendix C.

[1]BEF is only available from 1986.

Table 2.1: Register Variables

Register	DST variable name	Short description
BEF	PNR	Individual identification number
	ALDER	Age of individual
	KOEN	Gender
	FOED_DAG	Date of birth
	AEGTE_ID	Individual number of spouse
	FAR_ID	Individual number of father
	MOR_ID	Individual number of mother
	CIVST	Martial status
DOD	DODDATO	Date of death
IND	FORM	Net wealth balance, excluding pension assets (-1997)
	FORMREST_NY05	Net wealth balance, excluding pension assets (1997-)
	SLUTBID	Labor market contribution
	QTILPENS	Pension benefits from mandatory occp. funded scheme (ATP)
	ERHVERVSINDK_13	Total taxable employment income (incl. self-employed income)
	FORMUEINDK_BRUTTO	Capital income
	SKATMVIALT_13	Total taxes, labor market contributions and special pension
	SKATTOT_13	SKATMVIALT_13 excluding labor market contributions
	QTJPENS	Civil servant's pension
	QANDPENS	Occupational pension benefits (excl. QTJPENS)
	OMFANG	Level of tax liability
	PRIVAT_PENSION_13	QANDPENS + QTJPENS + QTILPENS, tot. private pens.income
ARM	SOCIO13	Socioeconomic classification
SOCP	GRUNDBELOEB	Basic first pillar pension benefit
VNDS	PNR	Individual number
	HAEND_DATO	Date of migration
	INDUD_KODE	Indicator for leaving or entering DK

Notes: Please see https://www.dst.dk/en/ for more detailed variable descriptions.

2.4 Forecasting Mortality

This section describes the procedure to allocate individuals into social groups, how to compute age-specific mortality rates for each group using register data, and how to use these to produce differential mortality forecasts.

2.4.1 Creating Socioeconomic Groups

Producing mortality forecasts for gender-specific socioeconomic groups requires a well-defined allocation mechanism. In the spirit of Cairns et al. (2019), we create equally sized socioeconomic groups using an affluence measure, combining income and wealth information. Like many other potential allocation mechanisms, allocation by affluence is likely to reflect some degree of double causality or spuriosity. On the one hand, differences in affluence lead to differences in health and, therefore, longevity. On the other, differences in health may affect earnings potential. Alternatively, outside factors such as cognitive ability or preference may drive health and income simultaneously. In assessing redistribution in public pensions, the direction of causation is not a major issue. Regardless, the result is that disadvantaged individuals receive public old-age benefits for a shorter period.

For each individual, i, in some cohort, c, we define the affluence index at age a as a linear combination of lagged moving averages over labor income, $Y^i_{c,a}$, and wealth, $W^i_{c,a}$, within the household.[2] The affluence index reads:

$$A^i_{c,a} = \mathcal{K} \cdot Y^i_{c,a} + W^i_{c,a} \tag{2.2}$$

In the main experiment, we follow Cairns et al. (2019) and assume a simple lag structure with moving averages of order $n = 1$ and calibrate the coefficient on lagged household income to $\mathcal{K} = 15$. In a series of robustness checks, we consider different coefficients and numbers of lags and find that this makes only minor differences for our mortality forecasts and results on redistribution.

The affluence index builds on household-level variables to avoid stay-at-home individuals with wealthy partners being recorded at zero affluence, as discussed in Brown et al. (2009). There are clear advantages to an allocation mechanism that incorporates lagged values of both income and wealth. First, the lag structure and the inclusion of the wealth stock limit volatility, making the allocation mechanism less prone to short-term fluctuations due to temporary illness or unemployment. For the same reasons, it limits selection effects where dying people of all walks of life are allocated to the lowest social groups due to income changes occurring just before death. Second, we allocate individuals who live predominantly on capital income to more appropriate social groups than would a mechanism solely based on labor income.

We compute the affluence measure for every individual at a given age between a minimum age, $a_{min} = 50$, and a maximum age, $a_{max} = 95$ at the beginning of each calendar year. As such, we restrict our mortality data set to people that survive to a_{min}.

Whereas papers such as Waldron (2007) allocate individuals according to quantiles of the earnings distribution, we allocate people according to quantiles of the affluence distribution. Another option would be to allocate based on the length of education. However, we posit that affluence ranking is more suitable, as it ensures equally sized groups. Affluence ranking also avoids drift in the general level of education. In practice, we subdivide each cohort into septiles (seven equally sized groups) of the affluence distribution[3]. For the cohorts we consider, the cohort size at a_{min} is approximately 70.000. Thus, each gender-specific

[2] Chetty et al. (2016) use a similar approach to allocate individuals to income groups based on income but consider a lag of two years.

[3] The choice of septiles reflects a trade-off between granularity and having actual observations on both exposure and deaths in every social group at every age in every calendar year.

socioeconomic group contains approximately 5000 individuals. The number of exposures then declines with age as people gradually die off.

Following Cairns et al. (2019), individuals can move freely between affluence groups until some lockdown age. After that, individuals stay in the group they were allocated to at the lockdown age. Later, in evaluating the value of the implicit pension contract, we assign appropriate survival rates to specific cohorts based on gender and socioeconomic group affiliation at lockdown. We choose a specific lockdown age of $\overline{a} = 55$. The specific choice of lockdown age reflects a trade-off between social group mobility and pre-retirement mortality.[4] As a_{max} is larger than $\overline{a}$, some generations are already older than $\overline{a}$ in the first year that the register data is available. Therefore, it is not possible to lock all individuals down at the desired lockdown age. Instead, we lock these cohorts down at the youngest age we observe them in the register data.

For the affluence index to be a suitable allocation mechanism, affluence rank and social-group affiliation should be reasonably persistent over the life cycle. To show persistence, we compute rankings assuming no lockdown. Under this assumption, we illustrate persistence/immobility in two different ways. First, we compute Kendall's Tau rank correlations at different lags and leads. Second, we construct Markov switching matrices at different lags and leads. Appendix A shows the results, which indicate that current affluence rank and social-group affiliation are good predictors for both past and future ranks. Hence, group affiliation at 55 is a good predictor of quality of life. Provided that group affiliation correlates with longevity, we can use affluence to allocate people into socioeconomic groups with distinct mortality characteristics. As will become evident in the coming section, the affluence index does so very efficiently.

2.4.2 Age- and Group-specific Mortality Rates

Mortality modeling requires exposure and death data at many ages in many calendar years. Fortunately, register data allows us to identify yearly age-specific exposures and deaths each year since 1985. The mortality data set includes ages $a \in [50, 51, \ldots, 94, 95]$, and calendar years $t \in [1985, 1986, \ldots, 2019, 2020]$. We use this data to compute age-specific mortality rates.[5] The number of exposures within a social group, $E^{s,g}_{t,a}$, is then simply the number of living individuals in subgroup (s, g) who are of age a in calendar year t. Similarly, we

[4] If we increase the lockdown age, we effectively restrict the sample to people who survive longer. Consequently, we would lose information on individuals who die before the end of the data. On the other hand, if we lower the lockdown age, people might move around in the affluence distribution.

[5] We are more precise than, e.g., the Human Mortality Database, which counts deaths according to the age at the last birthday at the time of death.

denote group-specific deaths by $D^{s,g}_{t,a}$. Age-specific mortality rates are then given by:

$$m^{s,g}_{t,a} = \frac{D^{s,g}_{t,a}}{E^{s,g}_{t,a}} \tag{2.3}$$

As the registers do not record deaths abroad, we exclude individuals leaving or entering Denmark within a calendar year.

2.4.3 Forecasting Mortality Rates

To produce coherent sub-population mortality forecasts, we use a standard Li and Lee (2005) model, which builds on the well-known Carter and Lee (1992) model. The Lee-Li model reads:

$$\log\left(m^{s,g}_{t,a}\right) = \alpha^{s,g}_a + B_a K_t + \beta^{s,g}_a \kappa^{s,g}_t + \epsilon^{s,g}_{t,a} \tag{2.4}$$

where α^i_a denotes a time-stationary pattern over the life cycle for group i. Moreover, B_a is an age-dependent slope parameter which is multiplied by a time-dependent process K_t. These correspond to the Lee-Carter estimates for the general population. Finally, β^i_a and $\kappa^{s,g}_t$ allow for subgroup slopes to deviate from the general population. For forecasting purposes, K_t follows a random walk with drift,

$$K_t = c_1 + K_{t-1} + e_t, \tag{2.5}$$

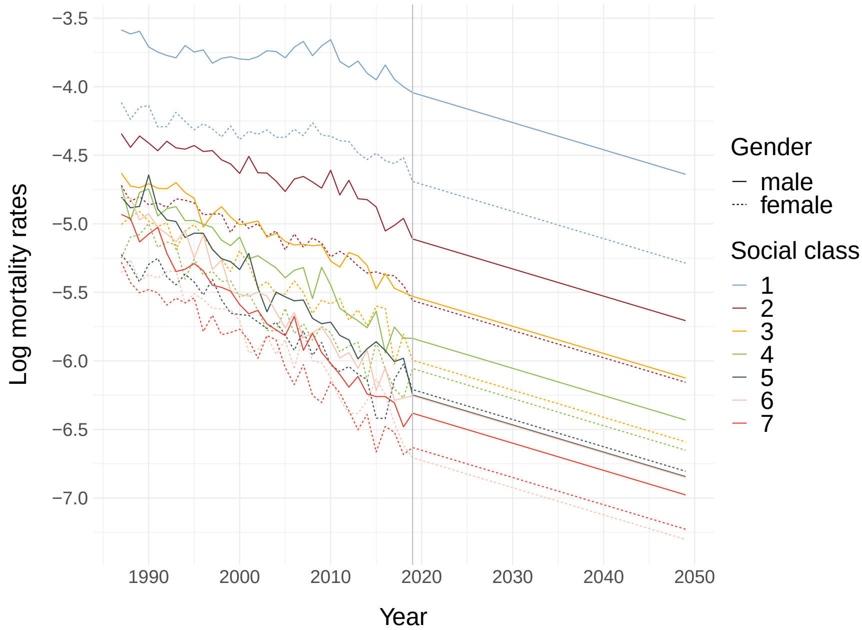
Here, $e_t \overset{iid}{\sim} \mathcal{N}(0, \sigma^2_e)$. Furthermore, $\kappa^{s,g}_t$ follows a trend-stationary AR(1) with a constant,

$$\kappa^{s,g}_t = c_2 + \gamma^{s,g}\kappa^{s,g}_{t-1} + vs, g_t, \tag{2.6}$$

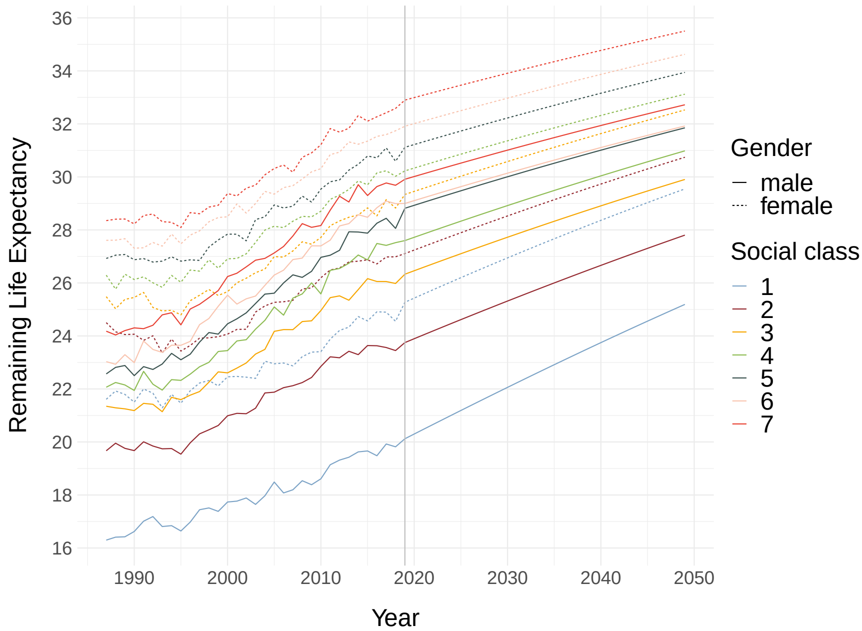
where $v_t \overset{iid}{\sim} \mathcal{N}(0, \sigma^2_v)$. Stationarity rules out random divergence in subgroup mortality, while the presence of a constant allows some group differences to persist in the long run. In line with Li and Lee (2005), we assume that the error terms are independent. To estimate 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 both the unit root processes for the common term and the auto-regressive process for individual subgroups.

Figure 2.1 depicts estimated and forecasted mortality rates and life expectancy at age 55 for each social group for both males (solid) and females (dashed). As expected, mortality rates exhibit a downward trend over time for both males and females. Conversely, life expectancy exhibits an upward time trend. Moreover, females live longer on average than males. Longevity increases monotonically over the social groups, and the curves never cross over within a gender. This speaks to the usefulness of the affluence index in capturing the socioeconomic gradient in mortality.

Figure 2.1: Mortality and Life Expectancy Projections at Age 55



(a)



(b)

Notes: Panel (a) shows fitted and forecasted mortality rates at age 55. Panel (b) shows the remaining life expectancy at age 55.

The affluence-longevity gradient is steepest at the bottom of the affluence distribution. In other words, discrepancies tend to disappear at higher income levels; An empirical regularity previously documented by, e.g., Cairns et al. (2019). For males, differences between affluence groups are especially pronounced. In 2020, the least affluent 55-year-old men expect to live to 76, while the most affluent expect to live to 85. As shown, the model predicts current discrepancies to remain largely unchanged for the foreseeable future. Comparing female affluence groups, the picture is qualitatively similar to that of males. However, group-specific life expectancies display less dispersion, particularly at the bottom of the affluence distribution. This verifies another empirical regularity that female mortality is less dispersed than male mortality. Given these mortality forecasts, we conduct a reduced-form accounting experiment to evaluate the redistributive properties of public pensions in the next section.

2.5 Computing Net Public Pension Benefits

This section describes how we compute and forecast yearly net public pension benefits. Understanding this procedure requires a basic understanding of the Danish pension system. Thus, we continue with a brief overview.

Like many other pension systems, the Danish pension system consists of three pillars: (1) public pensions, (2) mandatory occupational pensions, and (3) voluntary private pension savings. We focus on public pensions in the first pillar. The public pension system is financed on a pay-as-you-go (PAYG) basis and includes several different components that are all means tested on either income or wealth and may also depend on civil status. Therefore, it is essential to produce reliable forecasts for each variable. Moreover, we must make reasonable assumptions regarding the future pension system, including the size of maximum amounts, deductibles, and penalty rates. This is the aim of the subsequent subsections.

2.5.1 Forecasting Deaths of Partners

Civil status matters for public pension benefits in two ways. First, different maximum amounts, deductibles, and penalty rates occasionally apply for singles versus couples. Second, inherited wealth and income from inherited pension contracts may matter for means testing of public pension benefits. Therefore, it is necessary to consistently forecast the deaths of potential partners.[6] To this end, we reuse the mortality rates computed for different social groups and genders in Section 2.4 and apply them to partners. This approach allows us to assign mortality rates to partners aged $a_{min} = 50$ or above at the end of the data. This assignment covers 99.7% of partners in the baseline cohort. For the remainder, we assume that a very young (under a_{min}) partner outlives the reference individual with certainty. Under these assumptions, we simulate the deaths of partners of all ages, genders, and social groups by a binomial process. Upon the simulated death of a partner, the reference individual inherits wealth and inheritable pension contracts according to default principles. For details, see Sections 2.5.3 and 2.5.6. Simultaneously, the reference individual

[6] We assume that no divorces occur in old age. Thus, a relationship between two elderly partners only terminates following the death of one partner.

changes civil status from "couple" to "single", becomes subject to less means testing, and receives larger benefits.

2.5.2 Public Pension Benefits

To keep the analysis tractable, we focus on the three largest components of the first pillar; (1) base amount (folkepensionens grundbeløb), (2) supplement (folkepensionstillæg), (3) elderly check (ældrecheck). All benefits are available after the statutory retirement age. The retirement age is currently 65 for all cohorts born before 1954 but will increase with expected lifetime for subsequent cohorts.

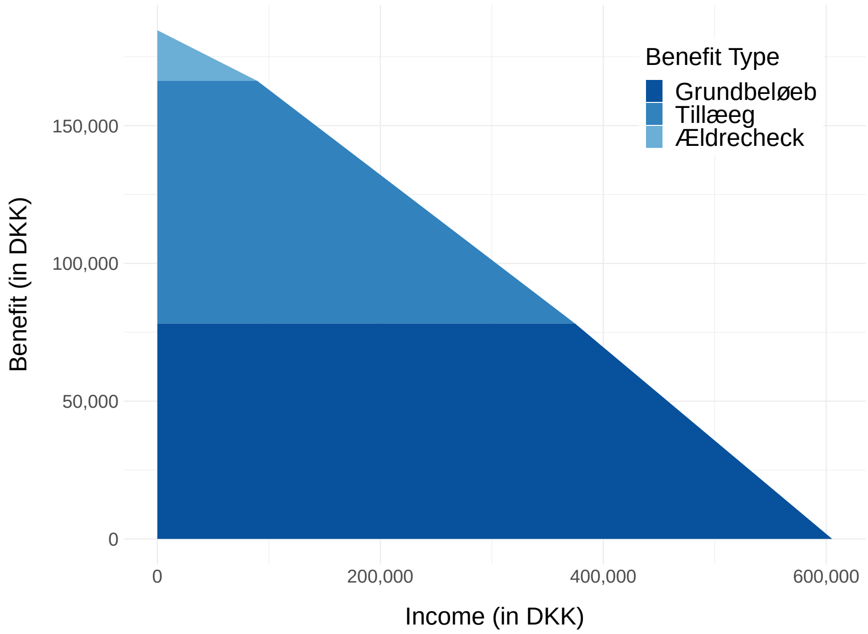
The yearly base amount was 78.216 DKK in 2020 and is practically a flat rate. However, the base amount is reduced at a penalty of 30% with all labor income in excess of a fairly large deductible. The supplement is subject to more means testing and depends on civil status. The maximum supplement is currently set to 88.020 DKK for singles and 44.484 DKK for each member of a couple. These amounts are then reduced at penalty rates with all income (including non-labor income) that exceeds certain deductibles. However, despite the means testing, the vast majority receive some supplement, while a slight majority receive the full amount. The elderly check is targeted at the poorest pensioners, and the current maximum amount is 18.400 DKK regardless of civil status. Again, this amount is reduced at a penalty rate with all income (including non-labor income) above some deductible. Importantly, receiving any amount of elderly check is conditional on liquid household wealth being less than 91.900 DKK. This poses a potential challenge for the quality of our forecasted benefits, as eligibility depends crucially on the predicted (dis)saving pattern.

To develop some intuition, Figure 2.2 depicts two stylized examples of how total public pensions decrease with individual income. In both examples, the elderly check runs out before the supplement and the base amount are reduced. After the elderly check is fully eroded, the supplement begins to decrease. Whether or not the base amount is also reduced depends on the nature of income. The base amount is only reduced if the individual earns labor income in excess of a large deductible after formally retiring.

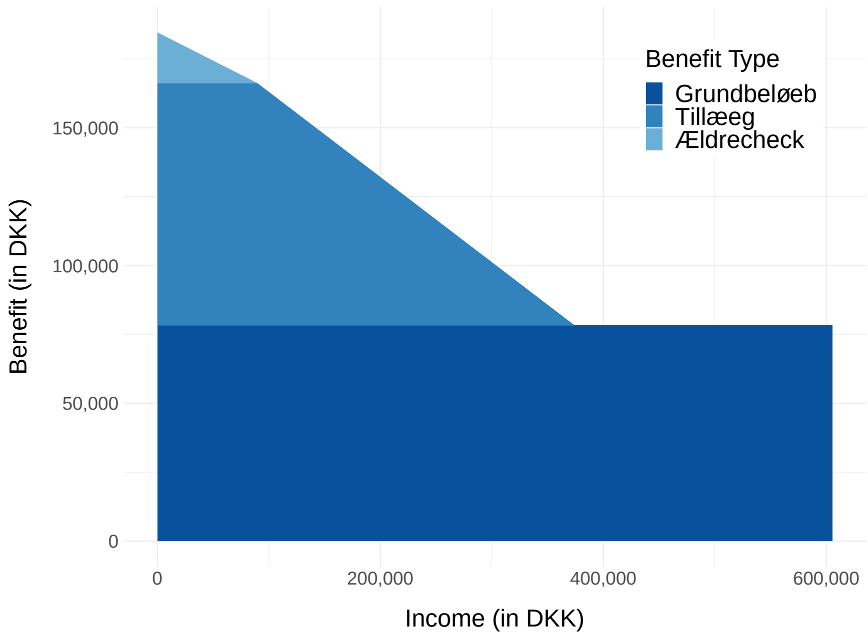
In forecasting benefits, we assume that all qualitative aspects of the pension system will remain unchanged. Thus, we essentially assume that the relative generosity of public pension benefits remains unchanged in the future. Specifically, we assume that maximum amounts and deductibles grow with forecasted real GDP. On the contrary, we assume that penalty rates will remain unchanged. This assumption seems reasonable, as penalty rates have remained unchanged for many years.

For simplicity, we assume that the take-up rate for Folkepension is 100%. Meanwhile, people who continue to work after retirement have their benefits reduced at the relevant

Figure 2.2: Stylized Illustration of Means Testing in First-pillar Pensions



(a)



(b)

Notes: Panel (a) shows means testing in public pension benefits for an individual who lives alone and is eligible for public pensions but continues to have some occupational income. Panel (b) shows the means testing in public pension benefits applying to an individual who lives alone and has fully retired. In both cases, individual wealth is smaller than the threshold that would disqualify them from receiving ældrecheck.

penalty rates. We do so knowing that it may be possible for some to postpone retirement to receive larger pension benefits later in life. Thus, we are likely to induce an upward bias in total pension benefits in the years immediately after the retirement age. Postponement is particularly alluring to the rich and healthy. Thus, we will also likely introduce a bias in the benefit distribution. We argue, however, that the bias is negligible for three reasons. First, only 10% of people meet the requirements to seek postponed pensions in the first place. Among those eligible, only one-third elect to postpone.[7] Second, the bias will likely disappear with age, as more people will have left the labor market. Third, we disregard increases in future pensions earned by postponing, thus counteracting the initial overestimation of benefits immediately after retirement. Backtesting our model for predicting pension benefits on 2018-2020 reveals that we overestimate the base amount by approximately 600 DKK or about 1%. Fortunately, however, we can use actual rather than predicted pension benefits in this period.

2.5.3 The Second and Third Pension Pillars

In addition to public pension benefits, retirees may have income from private pensions in the second and third pillars. Private pension benefits are important for the experiment, as they can lead to reductions in the supplement and the elderly check as described in Section 2.5.2.

Second-pillar pensions consist of public labor market pensions (ATP) and occupational pensions.[8] Although both are funded schemes, they differ in several respects. Public labor market pension benefits are paid out as lifelong annuities. In the pension wealth register, we observe the guaranteed individual benefit. Thus, we forecast by simply writing forward the guaranteed amount indefinitely. Occupational pensions include contracts in pension funds, banks, insurance companies and special pensions for civil servants. Particularly for contracts in pension funds, banks, and insurance companies, we observe accumulated pension wealth in the pension wealth register. We also observe the type of individual contracts (whether the annuity has a finite or infinite horizon). Based on this, we forecast occupational pension benefits by annuitizing each type of pension wealth according to standard principles. The registers also contain information on civil servant pension wealth. For people who retire fully before the last year of data, we predict future benefits by writing forward the current benefits we observe. For people who do not retire fully, however, we again annuitize observed pension wealth with payments starting the following year. In line with standard principles, an individual inherits 71% of a partner's potential civil servant pension.

[7] ATP Report: Age 65-74

[8] ATP is essentially a public scheme. Thus, it is occasionally considered part of the first pillar. However, as ATP serves no redistributive purpose, we consider it solely because it affects PAYG pension benefits.

The third pillar consists of private savings and voluntary pension arrangements. Although less prevalent, these could still be important for means-tested benefits. Consequently, we include third-pillar pension wealth in the experiment. We forecast third-pillar benefits using techniques similar to those applied for second-pillar benefits.

2.5.4 Public Pension Contributions

We need both historical and forecasted contributions to compute expected net interactions between the individual and the pension scheme over the life cycle. In this context, it is important to note that contributions are "hidden" in general taxes. To gauge hidden contributions, we suppose that the public pension scheme runs a balanced budget. Under this assumption, we elicit contributions based on the expenditure share of public pensions. That is, for in-sample years, we multiply actual tax payments with actual government expenditure shares to compute individual contributions. Conversely, we rely on predicted tax payments, public pension expenditures, and budget shares for out-of-sample years. To predict future contributions, we let the budget expenditure shares increase over time to account for the increasing fiscal pressure due to demographic change. In practice, contribution rates gradually increase from 12% to 14%, as projected by the Danish Ministry of Finance.

If an individual has a spouse or a cohabiting partner, we assume that contributions are shared equally within the household. In the main experiment, we also assume that income taxes on government transfers contribute fully to the public pension scheme. This assumption implies that we consider a partial study of redistribution in the public pension system, given that all other government programs are fair.

2.5.5 General Tax System

To compute future contributions to the public pension scheme, we rely on forecasted tax payments. Hence, we create a comprehensive model of the Danish tax system. Here, many different deductibles and tax rates come into play. We abstract only from items that are generally irrelevant to pensioners. As with the pension system, we assume that all tax deductibles grow with nominal GDP. Meanwhile, all tax rates remain unchanged. For capital income taxes, we subdivide capital income into income on equity and non-equity income. We do this as equity income is taxed separately from all other income. Given the listed assumptions and forecasted income series, we then compute the total contribution as the predicted total tax payment times the predicted expenditure share for Folkepension, as described in the previous section.

2.5.6 Forecasting Income and Wealth

To keep things simple, we assume that real annual wage (provided that the individual has any at the end of the data) decreases linearly from retirement to age 72. At this age, only approximately 5% of individuals in previous cohorts were still active in the labor market in some capacity.

For wealth, we assume that household wealth stays unchanged going forward. This captures the fact that many people do dis-save in retirement. This is particularly true for the highest social classes, where wealth typically remains high after retirement. At the other end of the spectrum, the poor have no significant savings and can hardly dis-save. Only for the middle class, the assumption of unchanged wealth is somewhat unrealistic, as we do see significant dissaving within this group. Nevertheless, this effect is largely irrelevant in predicting future pension benefits as household wealth only matters for the elderly check, which does not target the middle class in the first place. As household wealth is constant, we assume that household wealth income also remains constant. This assumption may be less innocuous, as wealth income reduces the supplement and factors into taxable income, determining pension contributions. Thus, we might understate net benefits for the middle class.

For the baseline cohort, income and tax data is available only from age 27. As this cohort consists predominantly of people with little education, it is reasonable to assume that most members contributed to the pension system earlier in life. Hence, we backcast income and taxes before the age of 27. In doing so, we take into account average wage growth at young ages. We also use data on the individual length of education to account for well-educated individuals working and contributing for fewer years.

2.6 Results

We consider two different methods to assess the impact of the affluence-longevity gradient on redistribution in old-age pensions. First, we compute and compare the average expected net interactions for different social groups on a yearly basis. We do so, assuming both full-population and group-specific survival rates. Second, we compute the expected NPV of net interactions with the pension scheme for each group, assuming different discount rates. The NPV method also allows us to compute and compare each group's internal rate of interest (IRR) of the public pension scheme.

2.6.1 Life-cycle Profile of Contributions and Benefits

To provide an overview of the individual interaction with the pension system, Figure 2.3 depicts the life-cycle profile of the real average annual net interaction for both males and females for groups 1, 4, and 7. To highlight the significance of mortality for expected future pension benefits, we do so both with and without correcting for mortality risk in our forecasts of expected net benefits.

Before the statutory retirement age, the representative individual in every group contributes to the scheme. Contributions grow over time, reflecting increases in taxable income over the life cycle, real wage growth, and increasing expenditure shares for public pension over time. Naturally, more affluent social groups make larger contributions, as they have more taxable income on average. By similar arguments, females generally contribute less than males.

After the statutory retirement age, the representative individual in every group begins to receive benefits. Here, means testing implies that more affluent social groups receive smaller benefits conditional on survival. Survival-contingent benefits increase over time for all groups due to projected increases in maximum amounts, decreasing means testing due to the forecasted decreases in labor income, and a gradual transition to single-individual households due to the simulated deaths of partners.

However, mortality risk decreases the expected benefit for every age group. As the cumulative survival rate falls with age, expected benefits eventually go to zero. Importantly, inequality in mortality implies that benefits decrease faster among the least affluent social groups. This tendency eventually leads to cross-overs in expected benefits, such that more affluent people expect larger annual benefits than their less affluent peers. This provides a useful preliminary illustration of the mechanisms that mitigate redistribution. As women generally live longer than men, the expected benefits are generally higher for women.

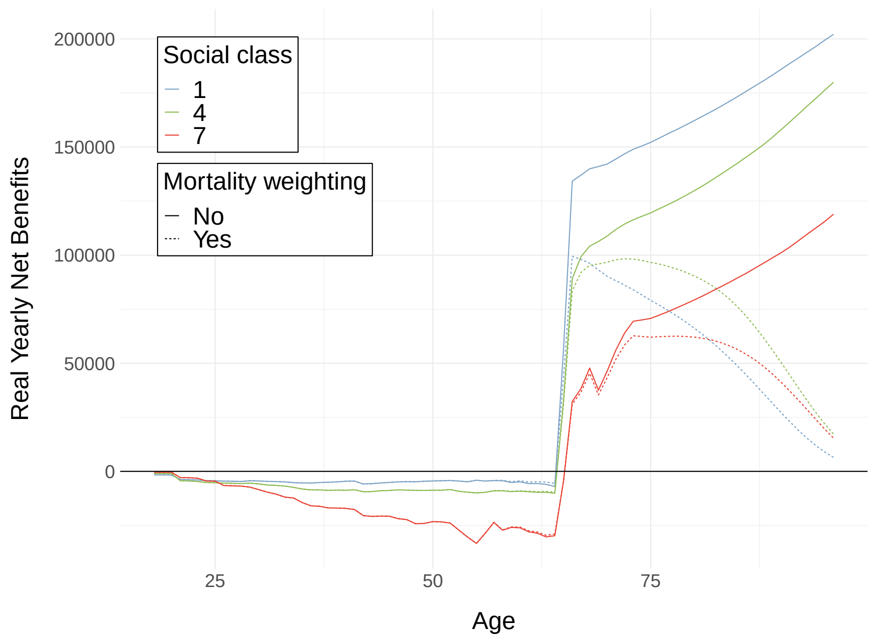
Thus, the life-cycle profiles illustrate that men tend to subsidize women via the public pension system for three reasons: Women i) contribute less, ii) receive higher benefits conditional on survival, and iii) tend to survive for longer receiving benefits. Later, we introduce more formal decompositions of the NPV to elaborate on the relative importance of these three channels across affluence rank and gender.

2.6.2 NPV and IRR of the Implicit Public Pension Contract

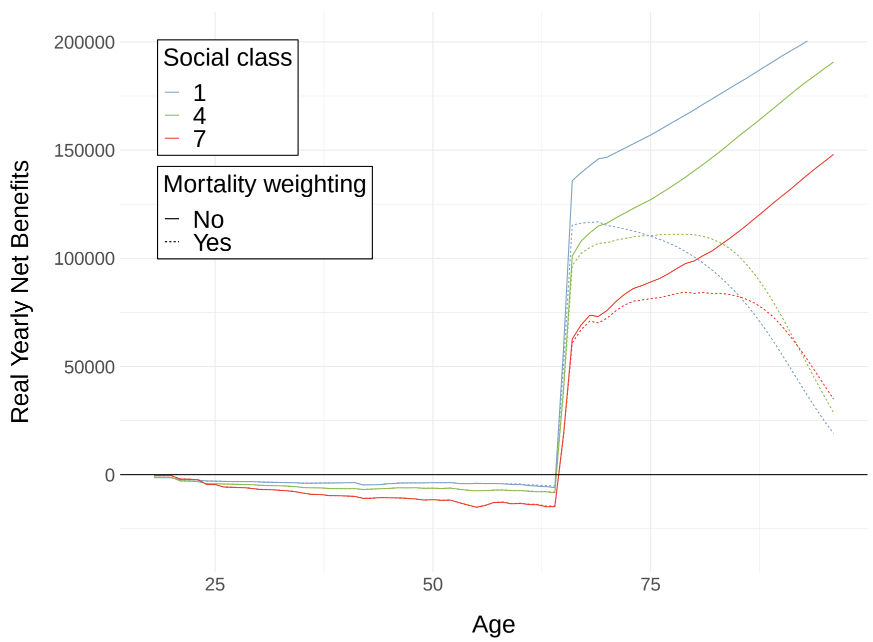
Using the definition in Section 2.3, we can compute the expected NPV of the implicit public pension contract. Figure 2.4 shows expected NPVs of different social groups for a spectrum of the discount rate. Subfigure 2.4a shows results for males, while Subfigure 2.4b shows

Figure 2.3: Real Annual Net Public Pension Benefits

(a) Male



(b) Female



Notes: Panel (a) shows the yearly real net public pension benefits, once weighted with the survival probability (solid line) and once none weighted (dashed line), of males born in 1952 and belonging to different social classes. Panel (b) shows the same for females.

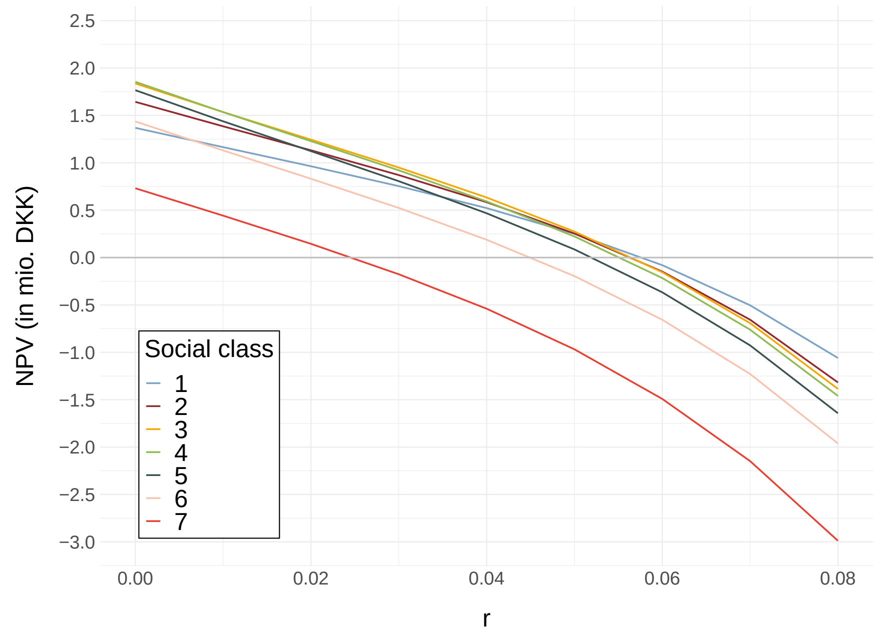
results for females. For each group, the intersection with the zero line identifies the group-specific IRR. This is defined as the constant discount rate that drives the expected NPV of the implicit public pension contract to zero. In that sense, it can also be interpreted as a return requirement. The IRR is a "relative" measure.[9] Thus, if one cash flow has a higher IRR than another, this does not necessarily imply that the absolute return is higher at every other discount rate. With this property in mind, the figure holds several valuable insights. First, IRRs decrease monotonically with affluence for females. For males, on the other hand, the picture is somewhat muddier. Here, the IRR is approximately the same for groups 1 to 4 but then decreases with affluence for the remaining groups. Thus, it is reasonable to say that male IRRs are weakly decreasing in affluence. In isolation, this bodes well for the redistribution through public pensions both for males and females. However, even though the IRR measure indicates weakly positive redistribution, inequality in longevity still implies a loss of redistribution compared to the counterfactual with equal longevity.

For males, the group-specific NPV curves cross over for several social groups. This pattern reveals that the pension scheme is more likely to favor the middle and upper classes over the poor if the discount rate is relatively low. A qualitatively similar pattern applies to females. However, in comparison, NPVs are generally higher for females. The pension system generally favors females over similarly ranked males regardless of the discount rate. The crossing over of NPV curves begs the question of the appropriate discount rate. Throughout the remainder of the paper, we use a discount rate of 3% and depict the expected NPV of all groups and genders relative to the lowest social group of men as shown in Figure 2.5. At this discount rate, starting with males, NPVs develop non-monotonically across the affluence distribution. Specifically, males in the middle of the affluence distribution have a 26% higher NPVs than males at the bottom. Only males in the top 30% of the affluence distribution have lower NPVs than their least affluent peers. For females, the hump shape is less pronounced, with the least affluent females being approximately as well off as the middle class. In general, females have significantly higher NPVs than males. Only the most affluent females have a lower NPV than the least affluent males.

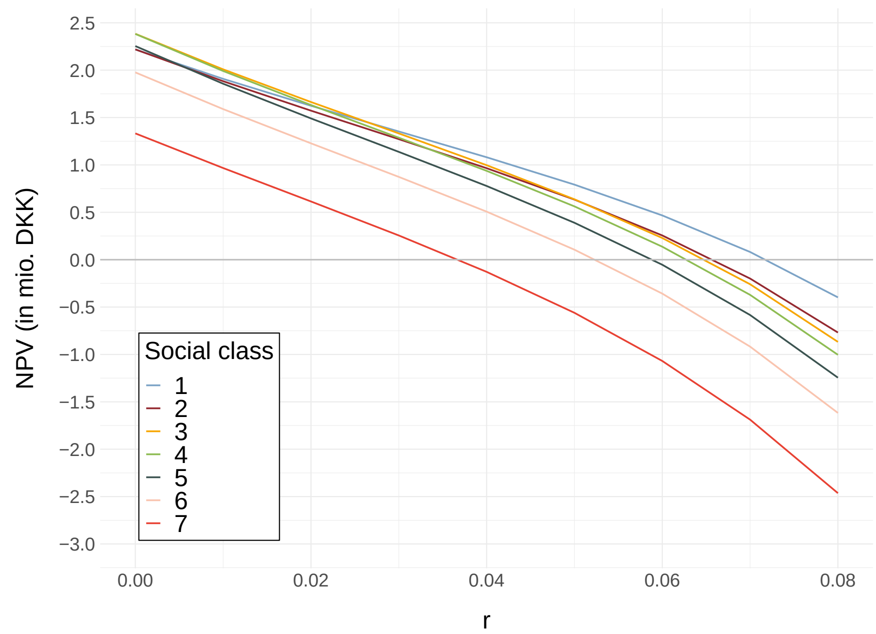
In Appendix B, we derive a decomposition of differences in NPVs relative to the least affluent men. Here, we decompose the total difference into contributions from differences in benefits, contributions, longevity, and a residual. Figure 2.6 shows this decomposition graphically for affluence groups 3 and 7 both for males and females. Panel (a) shows that males in group 3 contribute more and benefit less than the least affluent males. However, at the same time, they live sufficiently long on benefits to have a positive premium. The residual is negligible. The picture is somewhat similar for the most affluent males in group

[9] To see this, imagine that some groups make no contributions but still receive public pensions. In that case, the IRR would be infinite by definition.

Figure 2.4: Expected NPV for Different Discount Rates



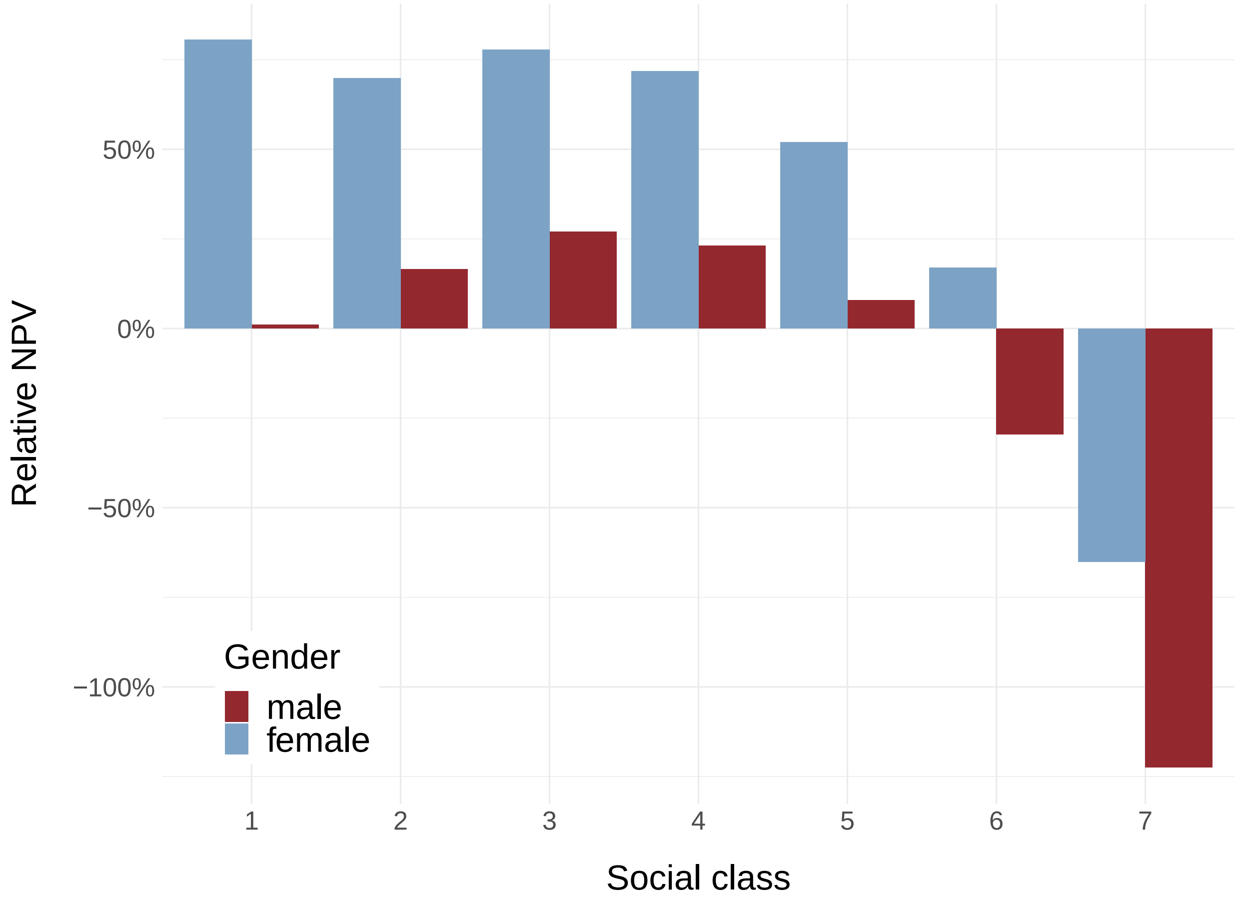
(a) Male



(b) Female

Notes: Panel (a) shows the mortality weighted NPV (see equation 2.1) of the public pension contract of males born in 1952 for different discount rates and social classes. Panel (b) shows the same for females.

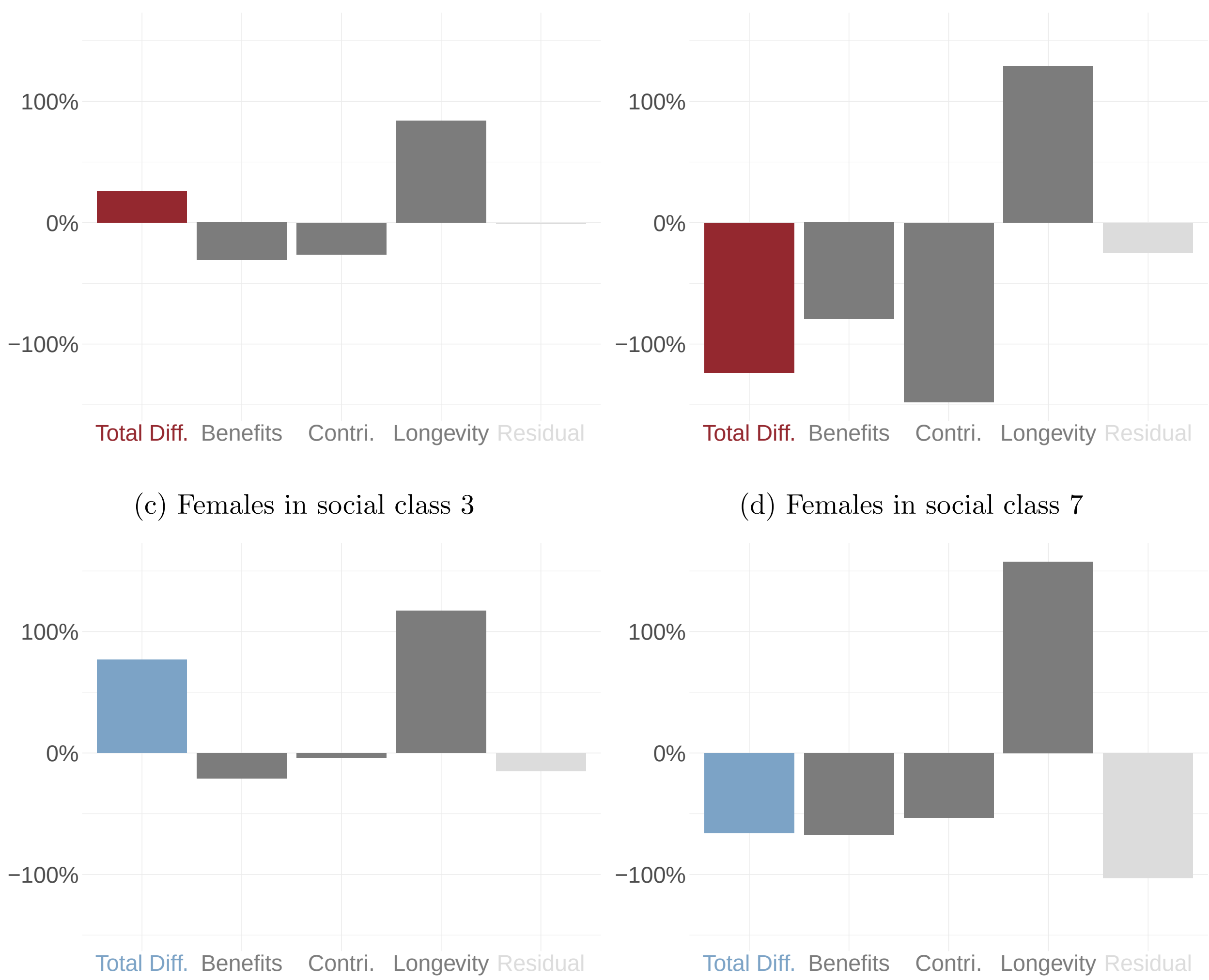
Figure 2.5: Expected NPV Relative to Men in Lowest Social Class (for r=3%)



Notes: The chart shows the NPVs relative to men in the lowest social class for the cohort born in 1952.

7, as shown in Panel (b). However, the most affluent males benefit much less and contribute much more. They also live much longer lives. However, for this group, differences in survival are not large enough to overturn the two negative effects. As shown in Panel (c), the picture is qualitatively similar for females in group 3. However, females contribute less, benefit more, and live longer than males in a similar affluence group. Panel (d) shows that the most affluent women in group 7 contribute more and benefit less than their less affluent peers while gaining more from higher longevity.

Figure 2.6: Decomposition of NPV Differences Relative to Least Affluent Men



(a) Males in social class 3

(b) Males in social class 7

(c) Females in social class 3

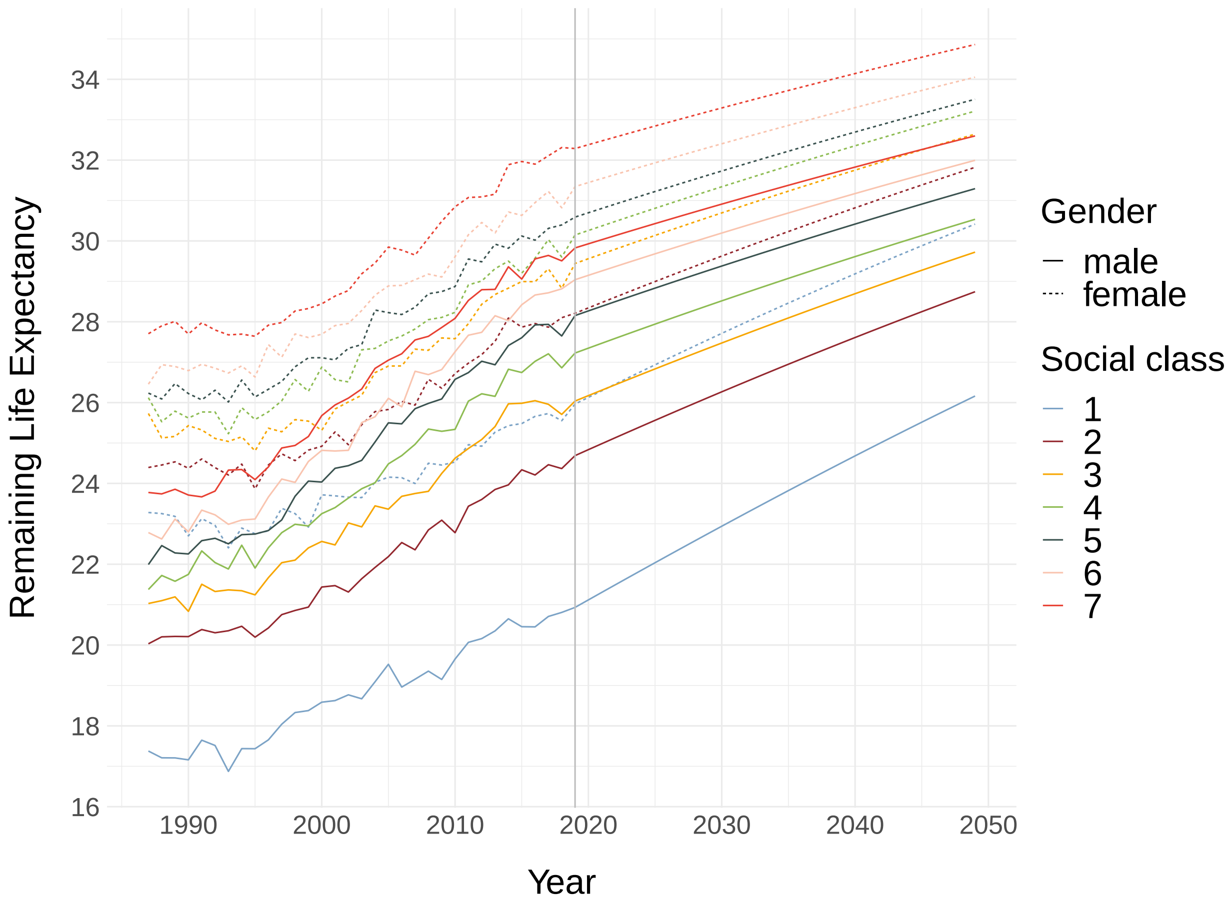
(d) Females in social class 7

Notes: This figure plots a statistical decomposition of differences in expected NPVs relative to the least affluent men. The total relative difference is decomposed into differences in benefits, contributions, and longevity.

2.6.3 Income vs. Affluence

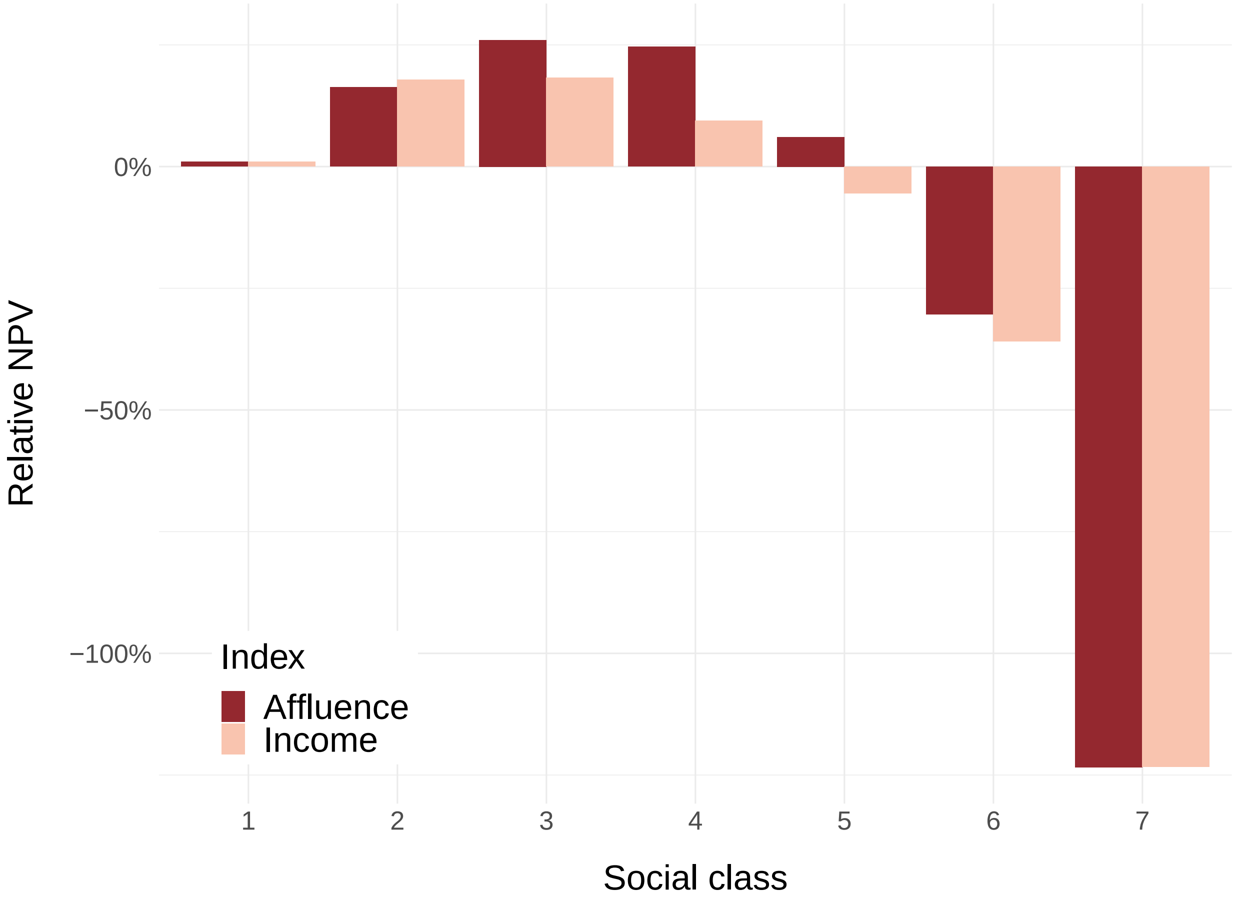
So far, we have considered redistribution solely across the affluence distribution. In the following, we adopt the traditional approach of measuring redistribution over the distribution of lagged income to highlight the importance of the allocation mechanism. Thus, we repeat the entire analysis while allocating individuals to socioeconomic groups based on lagged, ten-year averages of household labor income. Using this allocation mechanism, Figure 2.7 depicts remaining life expectancies at age 55 for males and females. Comparing this to its affluence-based counterpart in Figure 2.1a, we now predict less dispersion in longevity. For instance, the difference between the most and the least affluent males in 2019 has decreased from ten to nine years. For women, the corresponding numbers are approximately eight and six years. Consequently, and in line with the arguments of Section 2.4, we conclude that affluence is a stronger separator of mortality than labor income.

Figure 2.7: Remaining Life Expectancy at 55 by Income Group



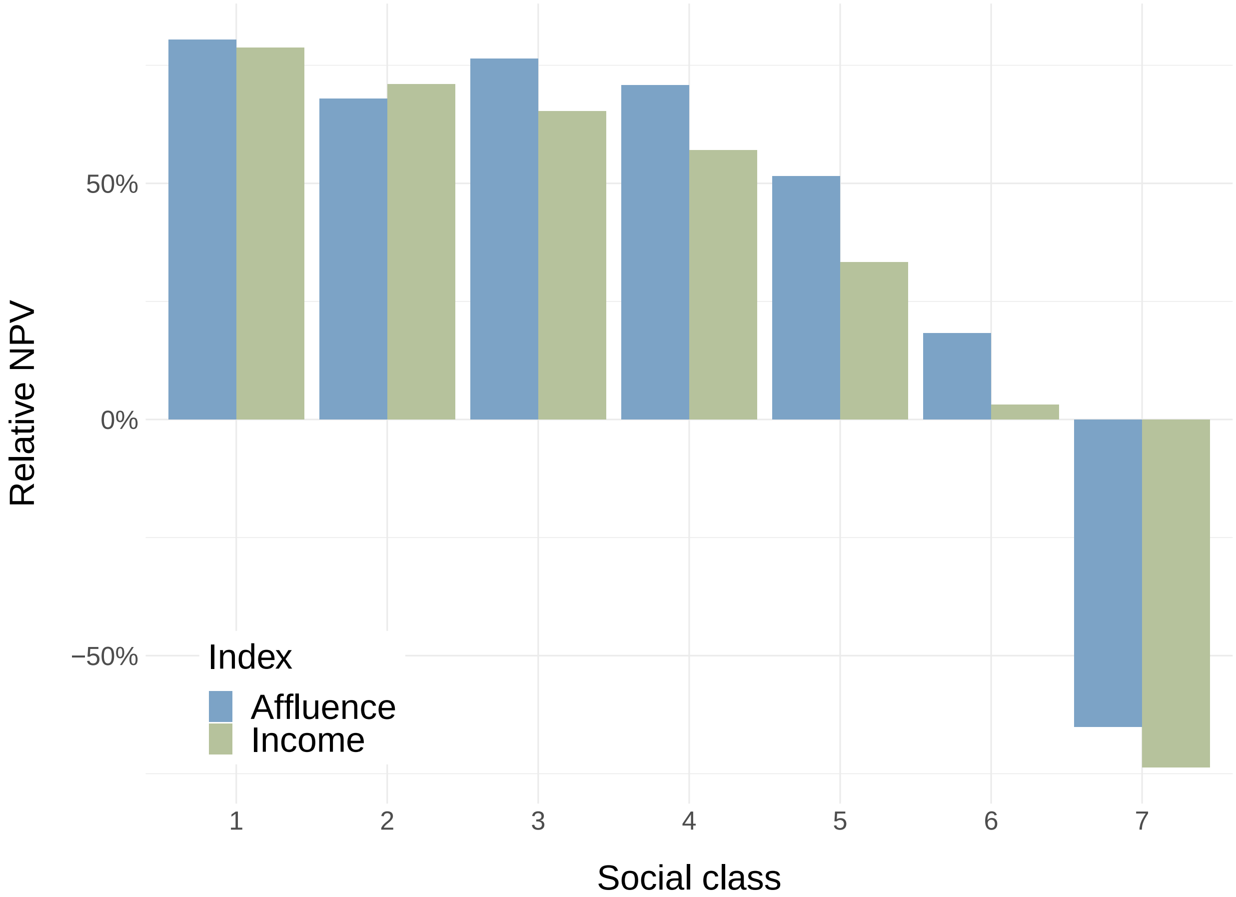
When using allocation by lagged labor income, our results for redistribution in the public pension system also change. As shown in Figure 2.8, using lagged income rather than affluence, we find less subversion of the redistribution among males, although the NPV profile is still hump-shaped. For women, as depicted in Figure 2.9, the NPV profile becomes monotonic, displaying positive redistribution over the entire distribution of lagged income. Hence, while there is still a redistribution loss due to differences in longevity, it is smaller than documented along the affluence distribution. Overall, the observed differences illustrate that the choice of allocation mechanism plays a role when assessing the redistribution loss caused by inequality in longevity.

Figure 2.8: Affluence vs Income, Expected NPV for Males (r=3%)



Notes: The chart shows NPVs for men relative to men in group 1 for the cohort born in 1952 along affluence and income groups.

Figure 2.9: Affluence vs Income, Expected NPV for Females (r=3%)



Notes: The chart shows NPVs for females relative to males in group 1 for the cohort born in 1952 along affluence and income groups.

2.7 Conclusion

In this paper, we quantify the loss of redistribution in the Danish public pension system caused by inequality in longevity. As the first step, we estimate and forecast mortality rates for different socioeconomic groups based on an affluence measure that combines information on income and wealth. This exercise verifies the empirical regularity that mortality differs systematically across socioeconomic groups and genders. Moreover, our forecasts predict differences in mortality to persist over the coming years. In a subsequent accounting exercise, we compute and compare NPVs and IRRs of the implicit pension contract for different socioeconomic groups, using forecasted survival, income, wealth, and civil status to compute expected net benefits.

We find that NPVs develop non-monotonically across the affluence distribution. That is, the worth of the pension contract does not always decline with higher affluence. Hence, we conclude that inequality in longevity partially subverts redistribution in public pensions.

Nonetheless, there is redistribution from the rich to the poor and the middle class. We also find that females gain substantially more from public pensions than their male counterparts. This is true as females, on average, contribute less through income taxes, benefit more from means-tested transfers, and live longer on public pension benefits.

We conduct two additional exercises to distinguish the drivers of differences in NPVs. First, we show that means-tested benefits contribute to positive redistribution conditional on survival. However, weighing benefits with group-specific survival rates completely subverts redistribution in expected terms. Second, we decompose differences in NPVs relative to the least affluent males into differences in contributions, survival-contingent benefits, and longevity.

Drawing inspiration from the literature, we replicate the main experiment by employing a group allocation measure that abstracts from wealth. Instead, we base socioeconomic status solely on labor income. Specifically, we group individuals according to a lagged ten-year average of household labor income. We show that mortality exhibits less dispersion in lagged average labor income than in affluence. As a result, we find a smaller redistribution loss over the lagged average labor income distribution.

So far as this is possible, we refrain from making normative statements. Nonetheless, we emphasize that our results do not necessarily imply that the public pension scheme is welfare-reducing. Any evaluation of the welfare consequences would also have to include a trade-off between returns, insurance, myopia, and distortions of individual choices. Moreover, one could argue that it is okay for the old-age pension system to exhibit little or even negative redistribution as long as other schemes provide progressive social assistance.

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Appendix A: Testing The Affluence Index

It is evident that the affluence index performs well in separating groups with distinct mortality patterns. However, to provide some additional insights into the index, this section describes some of its properties in the given sample. First, to characterize the persistence of the affluence index, Table 2.2 and 2.3 shows Kendall's Tau rank correlations of individual affluence ranks for the baseline cohort at different leads and lags and for both genders. A Tau of -1 signifies perfect inversion, 0 Independence, and 1 perfect coherence.

Age	45	50	55	60	65
45	1				
50	0.64	1			
55	0.54	0.65	1		
60	0.45	0.52	0.62	1	
65	0.31	0.35	0.42	0.52	1

Table 2.2: Kendall's Tau - Men

Age	45	50	55	60	65
45	1				
50	0.65	1			
55	0.53	0.64	1		
60	0.41	0.48	0.58	1	
65	0.32	0.35	0.41	0.50	1

Table 2.3: Kendall's Tau - Women

To illustrate persistence in a different way, Table 2.5 shows a Markov switching matrix containing probabilities of switching to and from social groups between the age of 50 and 55. As the numbers illustrate, individuals are very likely to stay in their original group or

S. class	1	2	3	4	5	6	7	Total
1	70.69	14.03	5.29	3.30	2.13	1.43	3.14	100.00
2	16.02	44.94	18.99	10.21	4.76	2.97	2.09	100.00
3	5.25	22.47	39.58	17.85	7.92	4.66	2.27	100.00
4	2.63	8.98	21.55	38.67	18.77	6.83	2.55	100.00
5	1.69	4.72	8.14	21.45	40.14	19.28	4.58	100.00
6	0.96	2.95	4.24	6.51	21.85	46.83	16.64	100.00
7	2.75	1.89	2.21	2.01	4.42	17.99	68.72	100.00
Total	14.29	14.29	14.29	14.29	14.29	14.29	14.28	100.00
N	34824							

Table 2.4: Switching Matrix for Men between 50 and 55

S. class	1	2	3	4	5	6	7	Total
1	61.18	23.95	8.32	2.98	1.09	0.72	1.75	100.00
2	18.64	25.41	29.97	17.48	5.07	2.55	0.88	100.00
3	11.55	18.07	20.58	23.93	20.60	3.46	1.80	100.00
4	6.18	15.37	16.42	19.67	27.21	13.41	1.73	100.00
5	2.71	10.53	11.49	19.35	19.45	31.34	5.13	100.00
6	1.56	5.69	8.14	11.49	17.00	33.50	22.63	100.00
7	1.21	1.92	5.16	4.60	8.63	13.83	64.65	100.00
Total	14.29	14.29	14.28	14.29	14.28	14.29	14.28	100.00
N	33632							

Table 2.5: Switching Matrix for Men between 55 and 60

switch to neighboring groups. Jumping several groups is, however, unlikely. Table 2.5 shows transition probabilities between ages 55 and 60. Here, the pattern is qualitatively similar, but persistence is somewhat smaller in quantitative terms.

Appendix B: Details on NPV

Rewriting equation 2.1 and suppressing notation for cohort and gender, the NPV of some group s in the baseline cohort can be written as:

$$NPV^s = \sum_{x=17}^{67} \frac{1}{N} \sum_{i \in \mathcal{A}^s_{55}} S^i_x \frac{NI^i_x}{(1+r)^{x-64}} + \sum_{x=68}^{95} S^s_{x|67} \frac{1}{N} \sum_{i \in \mathcal{A}^s_{67}} \frac{NI^i_x}{(1+r)^{x-64}}$$

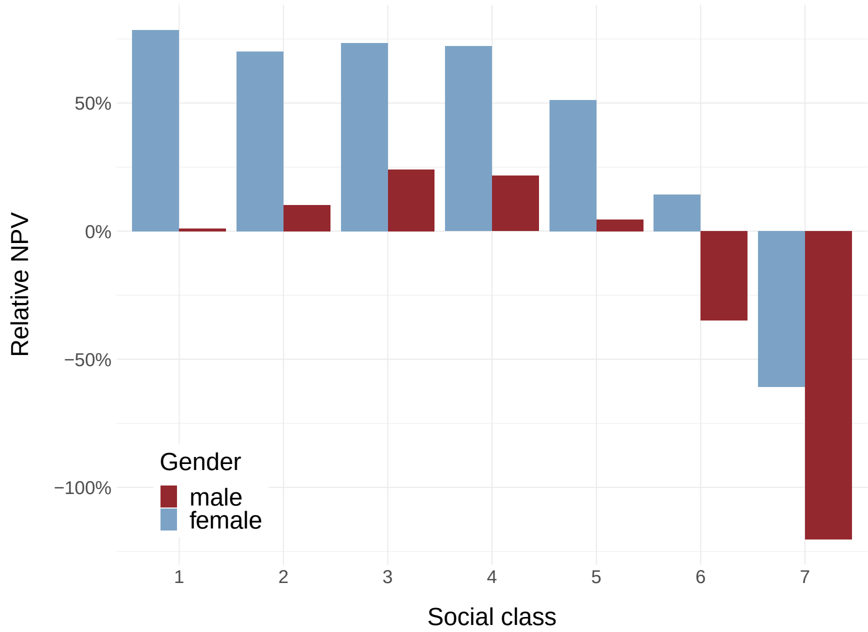
Here, $S^i_x \in (0,1)$ denotes realized individual survival rates for everyone before the last year of the data. Conversely, $S^s_{x|67}$ denotes group-specific, forecasted survival rates conditional on surviving to the last year of observation at age 67. Before the end of the data, NI^i_x denotes realized net interactions while it denotes forecasted net interactions after the end of the data. To shed some light on the drivers of differences in NPVs relative to the poorest men, we decompose differences in NPV into four terms:

$$\Delta NPV^{s,g} = \sum_{x=17}^{95} \frac{\left(S^{s,g}_x - S^{1,m}_x\right) NI^{1,m}_x + S^{1,m}_x \left(B^{s,g}_x - B^{1,m}_x\right) - S^{1,m}_x \left(C^{s,g}_x - C^{1,m}_x\right)}{(1+r)^{x-64}} + \epsilon^{s,g} \quad (2.7)$$

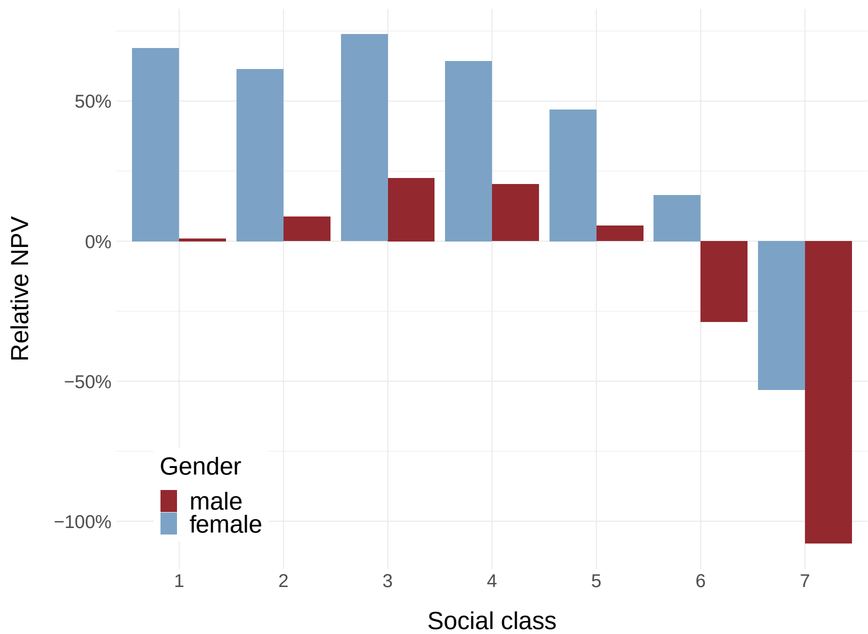
The first term captures differences due to differential mortality rates. The second and third terms capture differences in benefits and contributions, respectively. The fourth term is an error.

Appendix C: Robustness Check for More Cohorts

Figure 2.10: Robustness: Expected NPV Relative to Men in Lowest Social Class (for r=3%)



(a) Cohort 1951



(b) Cohort 1953

NPVs relative to men in lowest social class for cohort 1951 and 1953.

Chapter 3

Improving Welfare through Public Education

Frederik Bjørn Christensen

Abstract

This paper evaluates the welfare effects of introducing an optimal education subsidy in the United States in light of the student debt crisis. To this end, it uses a calibrated partial-equilibrium overlapping-generations model with heterogeneous agents, endogenous human capital accumulation, a general number of generations, probabilistic survival, and population growth. The paper contributes to a largely theoretical literature on public education by providing nuance on both the micro and the macro level. The results illustrate that an appropriately designed education policy boosts economic activity, lowers student debt, limits inequality, and improves social welfare in the long run. Furthermore, in a short-run perspective, the results show how optimal education policy can be implemented under a modified intergenerational Pareto criterion, using public pensions as a means of intergenerational cost sharing.

3.1 Introduction

Public education is a crucial part of the intergenerational welfare state. However, countries differ significantly in public education provision, particularly at the post-secondary level.

In the United States, a lack of public post-secondary education combined with rising college tuition fees has led to the so-called student debt crisis and rising political pressure for education system reform. According to an opinion poll from Politico (2019), more than two-thirds of Americans view student debt as a major economic threat. Moreover, PewResearch (2020) reports that 63% of voters favor universal and tuition-free colleges. According to another survey by NPR/Ipsos (2022), 55% of Americans support forgiving up to 10,000 USD of student loan debt. Meanwhile, 82% prefer the government to prioritize making college more affordable over forgiving student debt.

Consequently, policymakers have proposed various interventions, ranging from comprehensive education system reform to short-term initiatives for forgiving student loan debt. For economists, it should, therefore, be of interest to assess how different education reforms affect student debt, the overall education level, economic activity, inequality, and welfare. As a follow-up, it is also interesting to evaluate whether such policies can be implemented in a socially responsible manner. That is, as education policy typically entails intergenerational redistribution, reforms could necessitate corrective measures to ensure fairness or political support in the short run.

In this paper, I consider the economic effects of introducing a socially optimal post-secondary education subsidy using a calibrated overlapping-generations (OLG) model with endogenous education. In doing so, I also consider the scope for responsible implementation in the short run. With this outline, the paper proceeds by reviewing two bodies of literature: i) A political economy literature on the challenges of sustaining a politico-economic equilibrium between cohorts and ii) A theoretical literature on public education and human capital. In both cases, the literature is extensive. Therefore, I focus on papers that address intergenerational aspects of education policy.

Starting from a political economy perspective, it is well-known that policies that entail intergenerational redistribution are prone to generational conflicts of interest. This is true for both *forward intergenerational goods* (FIGs), such as public education, and *backward intergenerational goods* (BIGs), such as public pensions. Despite such conflicts, Cooley and Soares (1999) find that a public pension scheme (a BIG) may arise as an equilibrium outcome of a political process with sincere voting by rational and non-altruistic cohorts who employ reputational trigger strategies in repeated games. In a one-off game, all generations, apart from the one just about to retire, would oppose pension benefits. In a repeated game, however, each generation realizes it will be punished for deviating from the implicit social contract. Therefore, a pension scheme may be sustained in equilibrium.

Conversely, Rangel (2003) shows that the same does not hold for FIGs due to the reverse nature of the timing of exchange. Specifically, once a generation receives a FIG, it has no incentive to support the continuation of the scheme. However, it is sometimes possible to sustain FIGs when considering the possible interplay between FIGs and BIGs. That is if trigger strategies are tied to an implicit contract where eligibility for a BIG requires supporting an FIG. The combined scheme can be sustained, provided that the value of receiving the BIG exceeds the cost of complying. Although these results rely on somewhat crude assumptions, they intuitively illustrate the political forces in sustaining FIGs such as public education.

Next, I consider a more classical economic literature on education policies and their implementation tools. Here, inspired by Pogue and Sgontz (1977) and Becker and Murphy (1988), Boldrin and Montes (2005) build an OLG model with a central government, running a combined education-pension (EP) scheme. In this model, incomplete credit markets lead to sub-optimal education investment among the young and under-diversification of retirement funds among the old. Consequently, the decentralized equilibrium differs from the social optimum. Therefore, within both branches of government, the potential for welfare-improving intervention rests solely on the social planner's ability to restore the complete market allocation.

In a somewhat similar setting, Andersen and Bhattacharya (2017) assume complete markets but point to a *human capital externality* (HCE) and a so-called *borrowing effect* (BE) as independent arguments for a public education subsidy. While the former represents a spillover of marketable human capital across generations, the latter is a budgetary effect that arises as young individuals who receive a subsidy must take up and service less student debt.[1] In their model, individuals live for three periods; one in education, one in the labor market, and one in retirement. This intuitively reflects the life-cycle hypothesis of Brumberg and Modigliani (1954). The authors show that appropriate education subsidies increase social welfare in the long run. Conversely, they find that PAYG pensions are detrimental to long-run social welfare, confirming the usual interpretation of Aaron (1966) that unfunded schemes are return-dominated in dynamically efficient economies. Nevertheless, due to features of intergenerational redistribution inherent to a PAYG system, the authors show that the government can use public pensions as a compensation tool in implementing an education subsidy under the intertemporal Pareto criterion. Andersen and Bhattacharya

[1]The spillover effect is largely consistent with mechanisms emphasized by Lucas (1988) and identified empirically by Blundell et al. (1999) and Acemoglu and Angrist (2001).

(2020) later showed how the government can implement a similar scheme, using government debt as a vessel for intergenerational cost sharing.

Another noteworthy paper, which combines elements from the political economy literature with elements from the classical literature, is Kaganovich and Zilcha (2012). They consider a three-period OLG model with a human capital function that displays an HCE and where public policy arises endogenously through a formal process of sincere voting. As a distinguishing feature, individuals are heterogeneous and vote according to their self-interest. As a limiting assumption, however, the setup presupposes that public capital is necessary in producing human capital and neglects private aspects of education decisions.

Although the reviewed models are compelling and capture several qualitative features of education choice and policy, they all suffer from one or more caveats. First, throughout the bulk of the reviewed literature, the assumption of homogeneous individuals rules out individual differences in educational attainment and, thereby, income inequality and scope for redistribution.[2] This calls for a generalization to a case with agent heterogeneity and endogenous human capital formation. Second, in all reviewed papers, the life-cycle structure is simplistic and gives rise to crude savings profiles. This calls for a generalization of the life-cycle setup. Third, the standard setup entails no realistic longevity and fertility components, limiting the quantitative applicability of the model. This calls for a generalization of the demographic setup. The present paper resolves all these issues within a single model.

Fortunately, the remedies to these issues are conceptually straightforward. First, the paper models agent heterogeneity by introducing intrinsic variation in the ability for acquiring human capital. Naturally, intrinsic inequality in ability leads to inequality in education and income, which, in turn, introduces redistribution concerns into public policy analysis. To address the second issue, I embed a richer life cycle into the standard model. Specifically, I generalize both the number of overlapping generations and the retirement age. Finally, to tackle the third issue, I introduce realistic survival patterns, population growth, and a life-cycle productivity process for human capital.

The paper strives to answer the two nested questions; i) What is the welfare-maximizing education policy in the long run? and ii) Can the welfare-maximizing policy be implemented in a socially responsible manner in the short run? As to the first question, the analysis shows that appropriate education policies improve economic performance and social welfare in the long run. Moreover, such a policy can be implemented under a modified version of the intertemporal Pareto criterion, using public pensions to offset the up-front costs by redistributing downstream welfare gains from current beneficiaries to current benefactors.

[2]Only Kaganovich and Zilcha (2012) have agent heterogeneity.

The paper proceeds in the following steps. First, Section 3.2 describes the general model setup, conditions for short- and long-run equilibria, and the effects of public policy using comparative statics. Section 3.3 then presents a closed-form solution for the *laissez-faire* economy along with a numerical solution strategy for the regulated economy given assumed functional forms. Next, Section 3.4 simulates the dynamic transition path between steady states with and without public education policy for a calibrated version of the model and presents results on the welfare effects. It also shows how the government can ensure responsible implementation using public pensions for intergenerational cost sharing. Subsequently, Section 3.5 shows how results carry over to two distinct model extensions, I) One with an education length choice and II) One with idiosyncratic income risk. Finally, Section 3.6 concludes and provides suggestions for future research.

3.2 Model

A simple outline of the model goes as follows. Time is discrete and indexed by $t \in T$. At the beginning of every period, a new cohort enters the economy. Cohort age is discrete and indexed by $j \in \mathcal{J}$. Each cohort consists of a continuum of heterogeneous individuals indexed by $i \in \mathcal{I}$. Before entering the labor market, individuals enroll in education to acquire human capital and improve future labor earnings. Upon graduation, individuals enter the labor market and work until the exogenous retirement age, r. Once retired, agents tear through their savings, leaving no intentional bequest at the maximum age, d. Thus, the life-cycle setup reduces to the standard two-period framework whenever $r = 1$ and $d = 2$. There are no explicit reasons for the individual to retire. Rather, the exogenous retirement age emulates a stylized fact in a tractable fashion.

3.2.1 Demography

The model includes population growth and probabilistic survival. These demographic parameters are quantitatively important, as they affect the relative relationship between the number of people receiving government support and the number of taxpayers. In this context, let n_t denote the current cohort size, and ν_t the exogenous gross growth rate between two cohorts. Then, the size of the cohort born at time t can be expressed as:

$$n_t = n_0 \prod_{j=0}^{t-1} \nu_j$$

where n_0 is the initial population size. The exact cohort size is unimportant. As every cohort consists of a continuum of individuals, the Law of Large Numbers ensures that all aggregates equal their expected values regardless of cohort size. Intuitively, a higher population growth rate makes it more challenging to finance a given education subsidy but easier to finance a given public pension benefit. Given population growth, I later growth correct the model when solving for steady states.

Probabilistic survival implies that an individual could potentially die at any age. Individuals know the probability of surviving at each age but cannot accurately foresee their time of death. For the cohort born at time t, the unconditional probability of living to age j is the product of all conditional survival probabilities up to that age:

$$\Psi_{t,j} = \prod_{s=1}^{j} \psi_{t,s}$$

An increase in survival generally makes it easier to finance a given education subsidy. On the other hand, increases in survival rates at ages after retirement increase the old-age dependency ratio, making it more difficult to finance a given pension benefit. This is important to note, as I later use public pensions as a compensation tool when implementing an education subsidy. Note that the survival pattern is exogenously given and universal. In reality, however, survival rates are heavily correlated with socioeconomic factors.[3] Thus, the model could include socioeconomic differences in mortality. Nonetheless, as an endogenous income-longevity gradient only strengthens the welfare argument for government intervention, I omit systematic differences in longevity to focus on the direct effects of an education subsidy on individual income formation and welfare.

3.2.2 Exogenous Factors and Factor Prices

All factors and factor prices are exogenous. Labor supply is inelastic and normalized to unity in every period before retirement. In a standard fashion, effective labor hours are proportional to a measure for marketable individual human capital, h_t^i. For every unit of marketable human capital supplied, a worker aged j, born in period t, earns the wage, $w_{t,j}$, allowing for general cohort-specific productivity patterns over the life cycle. The model does not account for the accumulation of physical capital or its use in production. This is, however, not restrictive for individual wealth, as agents can save and borrow via perfectly competitive international capital markets. Thus, apart from being subject to the natural debt limit, individuals are never borrowing constrained. Finally, individuals have access to actuarially fair annuities.[4] Thus, conditional on surviving to age s, an individual born at time, t, receives an annual return of:

$$\tilde{R}_{t,s} = \frac{R}{\psi_{t,s}}$$

[3]Bosworth (2018) provides an overview of the main determinants for disparities in mortality between socioeconomic groups. See also Chetty et al. (2016) and Cairns et al. (2019).

[4]For reference, see e.g. Rios-Rull (1996), Chakraborty (2004), and Kaganovich and Zilcha (2012)

where R is the underlying gross interest rate. This assumption may be somewhat unrealistic, as returns for the elderly are inflated. Nonetheless, actuarial fairness presents a convenient way of preserving resources in the economy by implicitly redistributing accidental bequests among the living.

3.2.3 Heterogeneous Human Capital

To assess the impact of public education policy, it is necessary to formalize a process for human capital as a function of education choice. In the main model, the education decision is a one-off and takes place ahead of the first period in the labor market. That is, agents enter the labor market at the same time regardless of their post-secondary education choice. Likewise, the model does not distinguish between different fields of study. Later, in Section 3.5.1, I generalize the main model to allow agents to choose also the length of education. In the main model, income is deterministic and proportional to human capital. However, in Section 3.5.2, I generalize the model to a setting with idiosyncratic income risk and show that this only strengthens the welfare case for an education subsidy. As I am interested in the socioeconomic impact of public education policy, human capital is heterogeneous. Specifically, individuals have varying intrinsic abilities, x_t^i, that I draw from an independent and time-invariant distribution:

$$x \overset{iid}{\backsim} f(\cdot)$$

with support on $\mathbb{R}^+$. Note that the model contains no biological links between parents and their children. Consequently, it does not characterize the formation of ability but merely considers realized ability when individuals reach the age of entering post-secondary education. Accordingly, the model is unable to identify social mobility.

For a given level of ability, individual human capital propagates through a human capital function that depends on total education investment undertaken by or on behalf of the individual, e_t^i, and a spill-over of average human capital from the previous generation, $\overline{h}_{t-1} = \mathbb{E}\left[h_{t-1}^i\right]$. Until otherwise is stated, the expectation operator reflects the expectation over the ability distribution. In general terms, the human capital function reads:

$$h_t^i = H\left(x_t^i, e_t^i, \overline{h}_{t-1}\right)$$

The total education investment is the sum of the subsidy, g, and private contributions, d_t^i. Thus, I assume private and public education are perfect substitutes. This avoids the assumption that public funds are somehow necessary or overly productive in the production of human capital. Furthermore, it allows for crowding out of public onto private education spending, which affects the scope of public policy. The human capital function obeys the following assumptions:

Assumption 1

$$H_x > 0,\ H_e > 0,\ H_h > 0,\ H_{ee} < 0,\ H_{hh} < 0$$

$$H_{eh} \geq 0,\ H_{ex} \geq 0,\ H_{hx} \geq 0$$

$$lim_{e \longrightarrow 0}\ H_e = \infty$$

A couple of these properties are important. First, all first-order derivatives are positive. Here, the HCE embodied in H_h is central. As agents are atomistic, they fail to internalize the positive effect they exert on the human capital of others. Thus, the social return to education is higher than the private return, implying socially inadequate education investment in the laissez-faire equilibrium. Accordingly, there is scope for welfare-improving intervention for reasons other than redistribution and the BE.[5] As the externality works through average human capital, there are no economies of scale.[6] Therefore, model economies that differ only in terms of size converge to the same equilibrium. As for the second-order effects, the human capital function exhibits decreasing returns to the total education investment and the spillover from preexisting human capital. Meanwhile, the second-order effect of ability is left unrestricted. All cross-derivatives are non-negative. Later, I show that the stability of the human capital process depends crucially on the sign and size of cross derivatives. Finally, I impose that the marginal product of education investment goes to infinity as investment approaches zero. This limiting property precludes corner solutions for private investment in the unregulated economy. The same is not true in a regulated economy, where the private education decision becomes discontinuous across an ability cutoff. See Section 3.2.6.

3.2.4 Individual Problem

Each individual is atomistic, and hence, maximizes expected lifetime utility, taking aggregate variables as given. Expected lifetime utility is taken to be an additively time-separable function over an instantaneous utility function, $u(\cdot)$, which satisfies the standard Inada conditions.[7] Preferences are homogeneous and time consistent, ruling out paternalistic arguments for public education policy. Specifically, the individual maximizes a sum of probability-weighted, subjectively discounted, instantaneous utilities subject to a set of

[5] With a small HCE, simple redistribution likely dominates. This is so, as the subsidy applies to all individuals, including those with low ability, who would prefer a cash transfer.

[6] It is easy to show that $\mathbb{E}\left[d\bar{h}_t/dn_t\right] = 0$, as the ability distribution does not depend on population size.

[7] $u'(c) > 0$, $u''(c) < 0$, $lim_{c \longrightarrow 0}\ u'(c) = \infty$, and $lim_{c \longrightarrow \infty}\ u'(c) = 0$

budget constraints:

$$\begin{aligned}
\max_{\{d_t^i, c_{t,j}^i\}} U_t^i &= \sum_{j=1}^{d} \beta^j \cdot \Psi_{t,j} \cdot u\left(c_{t,j}^i\right) \\
st. & \\
c_{t,1}^i &= \left(1-\tau_{t+1}\right) w_{t,1} l_{t,1} h_t^i - \tilde{R}_{t,1} d_t^i - a_{t,1}^i \\
c_{t,j}^i &= \left(1-\tau_{t+j}\right) w_{t,j} l_{t,j} h_t^i + \tilde{R}_{t,j} a_{t,j-1}^i - a_{t,j}^i
\end{aligned}$$

In the first period, the individual earns labor income, pays taxes, services student debt, consumes, and saves. In every period thereafter, the individual faces mortality risk. Thus, only conditional on surviving, the individual continues to work until retirement, allocating disposable resources over consumption and savings. For ease of exposition, $l_{t,j}$ is an indicator of labor market status. While in retirement, individuals allocate accumulated wealth over their remaining lifetime. At the end of period d, all living individuals die with certainty, leaving $a_d^{i,t} = 0$ intentional bequest. Importantly, individuals can borrow up to the natural borrowing constraint in any other period. Thus, student debt can be carried into the future for consumption-smoothing purposes. By recursive elimination, the period-by-period budget can be written in the following consolidated form:

$$\sum_{j=1}^{d} \frac{c_{t,j}^i}{\prod_{s=1}^{j} \tilde{R}_{t,s}} = h_t^i \sum_{j=1}^{d} \frac{\left(1-\tau_{t+j}\right) w_{t,j} l_{t,j}}{\prod_{s=1}^{j} \tilde{R}_{t,s}} - d_t^i$$

That is, the present value of consumption in any survival-contingent life-cycle plan must equal the present value of all income net of taxes and debt servicing. The present value of income is closely related to indirect utility. This is helpful in characterizing the welfare effects of policy. Therefore, I denote the present value of income by y_t^i and term it *lifetime income.*

3.2.5 The Public Budget

Unless otherwise stated, the government runs a balanced budget in every period. Thus, current public expenditure on education must equal total tax revenue from all individuals who are alive and working. This implies that the education tax rate can be written as:

$$\tau_t = \frac{g \cdot n_t}{\sum_{j=1}^{r} n_{t-j} \Psi_{t-j,j} w_{t-j,j} \overline{h}_{t-j}}$$

This expression holds several intuitive insights. Ceteris paribus, the tax rate is increasing in the size of the subsidy and decreasing in total income. In general, a change in policy affects the former directly and the latter indirectly through the equilibrium response in human capital. Provided that a reform increases average human capital, it is entirely possible that the long-run tax rate decreases with a larger subsidy. The tax rate increases with population growth as the ratio of students to taxpayers increases, and vice versa for survival rates. Later, I generalize the public budget to account for compensatory public pension benefits as a means for intergenerational cost sharing.

3.2.6 Equilibrium

Using the period-by-period budget constraints, the individual optimization problem can be rewritten as an unconstrained problem in d_t^i and the sequence of savings, $\left\{a_{t,j}^i\right\}$. Hence, optimality is defined by a set of d first-order conditions. For consumption, the individual first-order conditions constitute a set of standard Euler equations:

$$u'\left(c_{t,j}^i\right) = \beta R \cdot u'\left(c_{t,j+1}^i\right) \text{ for all } j \in [1, d-1] \tag{3.1}$$

Meanwhile, the second-order conditions are satisfied due to the properties of the instantaneous utility function. The first-order condition for student debt, on the other hand, is less standard. Using Equation 3.1 and the individual budget in a recursive fashion, this can be written as a fork:

$$\begin{cases} 1 = H_e\left(x_t^i, e_t^i, \overline{h}_{t-1}\right) \sum_{j=1}^r \dfrac{\left(1-\tau_{t+j}\right) w_{t,j}}{\prod_{s=1}^j \tilde{R}_{t,s}} & \text{if } x_t^i > x_t^c \\ \\ 1 > H_e\left(x_t^i, e_t^i, \overline{h}_{t-1}\right) \sum_{j=1}^r \dfrac{\left(1-\tau_{t+j}\right) w_{t,j}}{\prod_{s=1}^j \tilde{R}_{t,s}} & \textit{otherwise} \end{cases} \tag{3.2}$$

For a given subsidy, the education decision is discontinuous across some ability cutoff, x_t^c. The cutoff is defined as the ability level at which the education subsidy alone satisfies the individual first-order condition for total education investment. While those above the cutoff top off the public education subsidy with a positive private investment, those below the cutoff rely solely on the subsidy, as even an incremental education investment cannot recoup the interest cost of borrowing. Hence, only above the cutoff, the discounted income gain from a marginal education investment equals the interest cost of borrowing. Provided that Equation 3.2 binds, one can determine the effects of a marginal increase in ability onto private education investment and human capital by total differentiation:

$$\begin{aligned} \frac{dd_t^i}{dx_t^i} &= -\frac{H_{ex}\left(x_t^i, e_t^i, \overline{h}_{t-1}\right)}{H_{ee}\left(x_t^i, e_t^i, \overline{h}_{t-1}\right)} > 0 \\ \frac{dh_t^i}{dx_t^i} &= H_x\left(x_t^i, e_t^i, \overline{h}_{t-1}\right) + H_e\left(x_t^i, e_t^i, \overline{h}_{t-1}\right) \frac{dd_t^i}{dx_t^i} > 0 \end{aligned}$$

Thus, education investment increases directly with ability. Human capital, on the other hand, increases both directly with individual ability and indirectly due to the endogenous increase in education investment. If the condition does not bind, on the other hand, the effect is null. Importantly, the limiting properties of the human capital function ensure that the first-order condition binds for everyone in the absence of intervention.

With the cutoff, average human capital can be subdivided into contributions from those who top off the subsidy and those who do not. Using conditional expectation notation, one can write average human capital as a weighted sum of two truncated distributions:

$$\overline{h}_t = F\left(x_t^c\right) \cdot \mathbb{E}\left[H\left(x, g, \overline{h}_{t-1}\right) | x < x_t^c\right] + \left(1 - F\left(x_t^c\right)\right) \cdot \mathbb{E}\left[H\left(x, d_t^i + g, \overline{h}_{t-1}\right) | x > x_t^c\right]$$

where $F\left(x_t^c\right)$ is the cumulative distribution function for x evaluated at the cutoff. The discontinuity also reveals that a government providing a universal education subsidy risks overinvesting in education on behalf of agents with very low abilities. This effect must thus also factor into the optimal policy decisions of the government. In reality, the problem with overinvestment would likely be smaller as low-ability individuals are less likely to enroll in post-secondary education. In Section 3.5, I address this issue by extending the model to allow agents to choose the number of years in education.

3.2.7 The Unregulated Steady State

To develop some intuition, it is useful to consider some properties of the steady state with no education subsidy, $g = 0$, in which case the cutoff is trivial. For there to be a steady state in the unregulated economy, the survival pattern must have become stable, and all individual and aggregate variables must have subsequently converged. As there are no intergenerational links in the absence of the subsidy and no economies of scale, it is not necessary to impose any restrictions on population growth. The limiting property of the human capital function ensures that $d^i > 0$. Thus, steady-state levels of student debt and human capital are given by the interior solution to the following system of equations:

$$1 = H_e\left(x^i, d^i, \overline{h}\right) \sum_{j=1}^{r} \frac{w_j}{\prod_{s=1}^{j} \tilde{R}_s} \text{ for all } i$$
$$\overline{h} = \mathbb{E}\left[H\left(x^i, d^i, \overline{h}\right)\right]$$

It is straightforward to show that individual human capital depends on individual ability as well as on the entire distribution of abilities, while aggregate human capital depends only on the distribution.[8] By total differentiation, it is possible to derive a condition for the system to have a stable steady state:

$$\left.\frac{d\overline{h}_t}{d\overline{h}_{t-1}}\right|_{LF} = \mathbb{E}\left[H_h\left(x_t^i, d_t^i, \overline{h}_{t-1}\right) - H_e\left(x_t^i, d_t^i, \overline{h}_{t-1}\right) \frac{H_{eh}\left(x_t^i, d_t^i, \overline{h}_{t-1}\right)}{H_{ee}\left(x_t^i, d_t^i, \overline{h}_{t-1}\right)}\right]\Bigg|_{LF} < 1 \qquad (3.3)$$

[8] Letting $g(X)$ denote a non-standard transformation of the ability distribution, and defining a collection of exogenous prices, Π, individual and aggregate human capital can be written as $H^i = f\left(X^i, g(X), \Pi\right)$ and $\overline{H} = \overline{f}\left(g(X), \Pi\right)$.

As human capital drives all other processes, the stability of the entire economy is also ensured under the above condition. Due to the concavity of the human capital function, any stable equilibrium is also unique. Given the existence of a unique, stable solution and the sign restrictions imposed on the human capital function, one can derive and sign several steady-state effects of changes in exogenous parameters as shown in Appendix A. For instance, one can show that the effect on average human capital of increasing the wage at age k, $\frac{d\bar{h}}{dw_k}$, is positive. Naturally, this is associated with more individual spending on education, more consumption, and higher utility. Similarly, the effect of an increase in the interest rate on average human capital, $\frac{d\bar{h}}{dR}$, is negative, as a higher interest cost on student debt lowers the incentive to invest in education. Moreover, the effect of an increase in the survival probability from age $k-1$ to k, $\frac{d\bar{h}}{d\psi_k}$, is positive for $k \leq r$ and zero otherwise. Hence, human capital only increases if the increase in longevity occurs at ages before retirement. In welfare terms, an increase in survival probability before retirement affects expected utility directly but also indirectly by increasing human capital. On the other hand, increases in survival probabilities after retirement only have direct effects on welfare.

3.2.8 The Regulated Steady State

Having analyzed the unregulated steady state, it is natural to examine its regulated counterpart. Unlike in the unregulated case, the existence of a steady state with policy now also requires fertility growth to be constant, as generations are now linked through the education-tax scheme. Imposing this assumption, it is straightforward to show that the regulated equilibrium depends on the ability distribution and the policy parameter.[9] Due to the discontinuity in the education decision, the stability condition becomes somewhat more complicated. Formally, as a small change in preexisting human capital does not induce a change in the cut-off, local stability requires:

$$\left.\frac{d\bar{h}_t}{d\bar{h}_{t-1}}\right|_{SS} = \mathbb{E}\left[H_h\right] - \left(1 - F\left(x_t^c\right)\right) \cdot \mathbb{E}\left[\frac{H_e H_{eh}}{H_{ee}} - \frac{H_e H_e}{H_{ee}} \frac{\sum_{j=1}^{r} \left.\frac{d\tau_{t+j}}{d\bar{h}_{t-1}}\right|_{SS} \frac{w_j}{\prod_{s=1}^{j} \tilde{R}_s}}{\sum_{j=1}^{r} \frac{w_j}{\prod_{s=1}^{j} \tilde{R}_{t,s}}} \middle| x \geq x_t^c \right] < 1 \tag{3.4}$$

Naturally, this reduces to Equation 3.3 whenever $g = 0$. Section 3.3.1, revisits the issue of stability given assumed functional forms. For now, the stability condition is simply assumed to hold anywhere on the adjustment path. Again, it is possible to derive steady-state effects from changes in exogenous parameters. However, due to the discontinuous nature of the

[9] For a given education subsidy, g, individual and aggregate human capital can be written as $h^i = h^i\left(x^i, f(x), \Psi, g\right)$ and $\bar{h} = \bar{h}\left(f(x), \Psi, g\right)$.

education decision and the endogenous changes in the budget, the expressions become much more complex and impossible to sign.

3.2.9 Social Welfare

According to the political economy literature reviewed in the introduction, public education policy is potentially haunted by coordination problems. In the following, I abstract from such problems to study the impact of education policy in a positive experiment with a social planner that maximizes steady-state social welfare given a cardinal social welfare function. To this end, I assume that social welfare within a cohort is captured by average utility. This definition has the interpretation of expected utility behind the veil of ignorance, see Rawls (1971). That is, ceteris paribus, the unborn would prefer to be born into a world with higher expected utility and lower variance. This utilitarian approach also has the advantage of being less controversial than classical Rawlsian measures of social welfare. However, in terms of implementation, simply introducing an education subsidy at a random point in time naturally results in lower welfare for the current taxpayers, who did not receive any subsidy when they were young. Thus, I consider compensatory pensions as an implementation strategy that ensures fairness under the veil of ignorance for all cohorts on the transition path. In this exercise, I apply a modified *intertemporal Pareto criterion* that requires each cohort to have at least the same remaining expected utility on average as it would have had absent any intervention.[10] For the cohort of initial taxpayers aged k at the time of implementation, this requires:

$$\mathbb{E}\left[\sum_{j=k}^{d} \beta^j \cdot u\left(c_{t,j}^{i,LF}\right) \cdot \frac{\Psi_{t,j}}{\Psi_{t,k}}\right] \leq \mathbb{E}\left[\sum_{j=k}^{d} \beta^j \cdot u\left(c_{t,j}^{i,Policy}\right) \cdot \frac{\Psi_{t,j}}{\Psi_{t,k}}\right]$$

It is easy to show that the modified Pareto criterion can be evaluated based on expected utility at birth. To see this, one can add the stream of discounted utilities from past consumption to either side, keeping in mind that $c_j^{i,LF} = c_j^{i,Policy}$ for $j < k$. Thus, the above condition is equivalent to $\mathbb{E}\left[U_{LF}^t\right] \leq \mathbb{E}\left[U_{Policy}^t\right]$. The same condition applies to cohorts born after the reform.

3.2.10 Welfare Effects of Public Policy

This section examines the steady-state welfare effects of marginal public policy. Here, I utilize that indirect utility is a function of lifetime income, $V\left(y_t^i\right)$. To gauge the effects of public policy on individual welfare, it, therefore, suffices to examine the change in lifetime

[10]Unlike the standard Intertemporal Pareto criterion for homogeneous-agent models, the modified criterion still relies on the social welfare function.

income. Consider first the steady-state effect on individual lifetime income of introducing an incremental education subsidy when the economy is initially in the LF steady state:

$$\left.\frac{dy^i}{dg}\right|_{LF} = 1 + H_h \left.\frac{d\overline{h}}{dg}\right|_{LF} \sum_{j=1}^{r} \frac{w_j}{\prod_{s=1}^{j} \tilde{R}_s} - \left.\frac{d\tau}{dg}\right|_{LF} h^i \sum_{j=1}^{r} \frac{w_j}{\prod_{s=1}^{j} \tilde{R}_s}$$

The first term reflects the BE, the second reflects the HCE, and the third represents the loss of lifetime income due to taxes. Overall, the effect is ambiguously signed. However, the effect is more likely to be positive at lower human capital levels, as the total tax payment is smaller for individuals with lower incomes and higher marginal utilities. Thus, there is a welfare argument for redistribution via the public education system. If one were to shut off all three channels and examine a case with homogeneous agents, no externality, and a zero real interest rate, there would be no scope for welfare improvements. In that case, the best the government can do is to replicate the laissez-faire equilibrium by setting $g = d_{LF}$. Any other positive subsidy would be detrimental to social welfare. Returning to the more general case, the effect of an incremental subsidy on human capital is, however, unambiguously negative:

$$\left.\frac{de^i}{dg}\right|_{LF} = \frac{1}{\overline{h} \sum_{j=1}^{o} \frac{\Psi_j w_j}{\nu^j}} \frac{H_e}{H_{ee}} - \frac{H_{eh}}{H_{ee}} \left.\frac{d\overline{h}}{dg}\right|_{LF} < 0$$

$$\left.\frac{d\overline{h}}{dg}\right|_{LF} = \frac{\mathbb{E}\left[\frac{H_e H_e}{H_{ee}}\right]}{1 - \mathbb{E}\left[H_h - \frac{H_e H_{eh}}{H_{ee}}\right]} \left.\frac{d\tau}{dG}\right|_{LF} < 0$$

$$\left.\frac{d\tau}{dg}\right|_{LF} = \frac{1}{\overline{h} \sum_{j=1}^{o} \frac{\Psi_j w_j}{\nu^j}} > 0$$

This is because the tax crowds out private investment and induces a negative human capital externality. In other words, an incremental subsidy crowds out private investment more than one-for-one. For comparison, Andersen and Bhattacharya (2017) find exactly one-for-one crowding out, as they consider only lump-sum taxes. The above results indicate the existence of peculiar scenarios where an incremental subsidy decreases human capital while social welfare improves due to the combined gains from the BE and redistribution. Once we consider non-incremental packages, however, public policy can easily trigger positive externalities and activate yet another channel for social welfare improvements. To see this, note that, with a preexisting education policy, a marginal increase in the education subsidy implies the following change in average human capital:

$$\frac{d\overline{h}}{dg} = \frac{F\left(x^c\right) \cdot \mathbb{E}\left[H_e \middle| x \leq x^c\right] + \left(1 - F\left(x^c\right)\right) \cdot \frac{d\tau}{dg} \frac{1}{1-\tau} \cdot \mathbb{E}\left[\frac{H_e H_e}{H_{ee}} \middle| x \geq x^c\right]}{1 - \left[\mathbb{E}\left[H_h\right] - \left(1 - F\left(x^c\right)\right) \cdot \mathbb{E}\left[\frac{H_e H_{eh}}{H_{ee}} \middle| x \geq x^c\right]\right]}$$

Provided that the stability condition in Equation 3.4 holds, the effect must be positive for a sufficiently large subsidy. To see this, consider a subsidy large enough to fully crowd out private education investment. Such a subsidy exists as the cutoff always grows with a higher subsidy:

$$\frac{dx^c}{dg} = \frac{H_e\left(x^c, g, \overline{h}\right)}{H_{ex}\left(x^c, g, \overline{h}\right)(1-\tau)}\frac{d\tau}{dg} - \frac{H_{ee}\left(x^c, g, \overline{h}\right)}{H_{ex}\left(x^c, g, \overline{h}\right)} - \frac{H_{eh}\left(x^c, g, \overline{h}\right)}{H_{ex}\left(x^c, g, \overline{h}\right)}\frac{d\overline{h}}{dg} > 0$$

In that case, $F(\cdot) = 1$, and human capital grows, as there can be no further crowding out. Consequently, sufficiently ambitious policies are ensured to activate a positive externality. Thus, it could be that smaller subsidies decrease both human capital and social welfare, while larger subsidies lead to increases in both.

As I later use public pensions to satisfy the intertemporal Pareto criterion when implementing an education subsidy, it is also worth considering the effects of pension policy. Assuming that the government runs a PAYG pension scheme and that the economy is initially in the LF steady state, total differentiation yields:

$$\left.\frac{dy^i}{dp}\right|_{LF} = \left[\left.\frac{d\overline{h}}{dp}\right|_{LF} H_h - \left.\frac{d\tau}{dp}\right|_{LF} h^i\right]\sum_{j=1}^{o}\frac{w_j}{\prod_{s=1}^{j}\tilde{R}_s} + \sum_{j=o+1}^{d}\frac{1}{\prod_{s=1}^{j}\tilde{R}_s}$$

$$\left.\frac{d\overline{h}}{dp}\right|_{LF} = \frac{\mathbb{E}\left[\dfrac{H_e H_e}{H_{ee}}\right]}{1-\mathbb{E}\left[H_h - \dfrac{H_e H_{eh}}{H_{ee}}\right]}\left.\frac{d\tau}{dP}\right|_{LF} < 0$$

$$\frac{d\tau}{dp}|_{LF} = \frac{\sum_{j=o+1}^{d}\dfrac{\Psi_j}{\nu^j}}{\overline{h}\sum_{j=1}^{o}\dfrac{\Psi_j w_j}{\nu^j}} > 0$$

Multiple effects come into play. First, pensions directly increase income after retirement, while associated taxes directly decrease income before retirement. Second, the tax distorts the education decision, which triggers a negative externality that amplifies the initial response in human capital. Again, the effect on individual welfare is ambiguous and depends on ability. As before, welfare is more likely to increase for those with low abilities. Hence, it is entirely possible that PAYG pensions can increase social welfare solely due to redistribution, thus generalizing the usual interpretation of Aaron (1966). This makes it an appealing policy tool for intergenerational compensation.

3.3 Solving the Model for Assumed Functional Forms

The goal of this section is to determine the transition path of the economy in response to the introduction of an education subsidy. To this end, I first define a set of functional forms in

Section 3.3.1. Second, I derive a closed-form solution for the unregulated economy in Section 3.3.2. The unregulated equilibrium will later serve as the benchmark for evaluating public policy. In Section 3.3.3, I introduce the numerical solution methods used to compute the adjustment path toward a new steady state following a shock to education policy. Finally, Section 3.3.4 describes the calibration of the model and the policy experiment.

3.3.1 Functional Forms

The instantaneous utility function takes a standard, constant-relative-risk-aversion form:

$$u\left(c_{t,j}^{i}\right) = \frac{\left(c_{t,j}^{i}\right)^{1-\sigma}}{1-\sigma}$$

where σ is the inverse of the elasticity of intertemporal substitution. This homothetic specification implies that the consumer problem always has an analytical solution for given aggregates, prices, and policies. The entire life-cycle contingent consumption-saving plan can be obtained by combining the Euler equation and the consolidated budget.

Conforming to Andersen and Bhattacharya (2017), the human capital function is Cobb-Douglas:

$$h_t^i = x_t^i \left(e_t^i\right)^{\eta} \left(\overline{h}_{t-1}\right)^{\kappa}$$

This function satisfies Assumption 1 provided that $1 > \eta > 0$ and $1 > \kappa > 0$. Recalling Equation 3.3, it also satisfies the stability criterion of the laissez-faire economy for $\kappa + \eta < 1$. That is when the human capital function exhibits less than constant returns to scale. Due to the forward-looking nature of the problem, there is no closed-form condition for stability in the regulated economy. However, for a large subsidy that crowds out all private education investment, stability is ensured under the less stringent condition that $\kappa < 1$.

Realized abilities are modeled as linear transformations of realizations of an underlying, beta-distributed, random variable:

$$x_t^i = \theta + \gamma \cdot z_t^i$$
$$z \sim B\left(\mathcal{A}, \mathcal{B}\right)$$

The beta distribution is useful, as it is flexible and has support on the unit interval, ensuring that $x_t^i \geq 0$. Thus, $\gamma \geq 0$ scales the underlying distribution, while $\theta \geq 0$ shifts its mean. Consequently, individual ability is bounded from below at θ and from above at $\theta + \gamma$. To avoid year-to-year variations due to random sampling, I draw a large set of abilities at the beginning of the experiment and reuse this vector to compute the growth-adjusted equilibrium in every subsequent year.

3.3.2 A Closed-Form Solution for the Unregulated Economy

Using the first-order condition for consumption, the first-order condition for optimal education investment can be written as:

$$d_t^i = \eta \cdot h_t^i \cdot \sum_{j=1}^{r} \frac{w_{t,j}}{\prod_{s=1}^{j} \tilde{R}_{t,s}}$$

This implies that every young individual invests the same fraction, η, of the present value of lifetime income in education. Likewise, it implies that student debt is a fraction of the natural borrowing constraint. Plugging this result into the human capital function yields a closed-form solution for individual human capital:

$$h_t^i = \left(x_t^i \left(\eta \sum_{j=1}^{d} \frac{w_{t,j}}{\prod_{s=1}^{j} \tilde{R}_{t,s}} \right)^{\eta} \overline{h}_{t-1}^{\kappa} \right)^{\frac{1}{1-\eta}}$$

From here, it is clear that individual human capital increases convexly in ability in equilibrium, although the human capital function itself is linear in ability. To reiterate, this owes both to the direct effect of ability and the indirect effect of incentivizing education investment. Hence, for any distribution of ability, the distribution of human capital within a cohort is always more right-skewed. This offers a simple solution to Pigou's paradox by mapping non-linearly from ability to income.[11] This also means that, for a given η, a reasonable human capital distribution can be attained by adjusting the ability distribution. Due to the stability condition derived in Section 3.2, individual human capital only grows concavely with preexisting human capital.

It is easy to show that all individual variables can be written as a linear function of individual human capital. Therefore, one can write the within-cohort Gini coefficient for any variable as:

$$\mathcal{G}^{LF} = \frac{\int \int \left| x^{\frac{1}{1-\eta}} - \tilde{x}^{\frac{1}{1-\eta}} \right| f(x) \cdot f(\tilde{x}) \cdot dx \cdot d\tilde{x}}{2 \cdot \int x^{\frac{1}{1-\eta}} f(x) \cdot dx}$$

Thus, inequality is age-independent and depends only on the ability distribution and the productivity of education investment. The more productive education investment is in generating human capital, the more severe is inequality. An important takeaway is that, within a cohort, there is no excess inequality in any variable on top of that in labor income. Conversely, from an intergenerational perspective, all excess inequality arises due to life-cycling. This feature presents a potential shortcoming in two respects. First, empirical evidence

[11] Pigou (1932) wondered how a symmetric distribution of physical and mental abilities could possibly lead to the right-skewed distribution of income observed empirically. A similar question was later raised by Mincer (1958).

suggests that the within-cohort wealth distribution is more skewed than the within-cohort labor income distribution. See, for instance, Piketty and Goldhammer (2014). Second, time-independent within-cohort income inequality is at odds with the empirical regularity that income dispersion and skewness increase with age. See Huggett et al. (2006) and OECD (2017). In later sections, I discuss how the current framework could be extended to better capture empirical inequality. For now, I simply posit that the model tractably captures the main structural aspects of ability, education, human capital, income, and inequality.

3.3.3 A Numerical Solution for the Regulated Economy

The current section characterizes the dynamic equilibrium conditions for the regulated economy. Moreover, it explains the numerical solution method used to compute equilibria with public policy both in the short and long run. Using the definition of the human capital function in the first-order condition for education investment reads:

$$e_t^i = \begin{cases} \eta \cdot h_t^i \cdot \sum_{j=1}^{r} \dfrac{\left(1-\tau_{t+j}\right) w_{t,j}}{\prod_{s=1}^{j} \tilde{R}_{t,s}} & \text{if } x_t^i > x_t^c \\ g & \text{if } x_t^i \leq x_t^c \end{cases}$$

Hence, there is a non-trivial ability cutoff. The cutoff is identified as the ability level at which the individual is exactly indifferent about investing a marginal amount. This yields:

$$x_t^c = \frac{g^{1-\eta}}{\eta \left(\overline{h}_{t-1}\right)^{\kappa} \sum_{j=1}^{r} \dfrac{\left(1-\tau_{t+j}\right) w_{t,j}}{\prod_{s=1}^{j} \tilde{R}_{t,j}}}$$

The cutoff may change endogenously over time in response to exogenous changes to policy via the HCE and the tax rate. Thus, the change in the cutoff may be qualitatively different depending on the size of the education subsidy. For policies that induce a positive externality, the initial cutoff will be high but will then decrease as human capital grows and the tax rate decreases. Conversely, a small subsidy that causes a downward reaction in human capital initially gives a small cutoff that then increases over time.

In the policy experiment, I assume that the economy is initially in an unregulated steady state when an optimal education subsidy is introduced. To prevent preemptive action by perfectly foresighted individuals, the shift in policy is assumed to be both sudden and unexpected. That is, I introduce an MIT shock to education policy and then examine the transition path toward a new steady state. Here the main challenge is that the problem is infinitely forward-looking. That is, human capital today depends on future taxes, while future taxes depend on future human capital. To overcome this challenge, I use an Auerbach and Kotlikoff (1987) type algorithm to truncate the problem at a finite horizon. After this finite horizon, the economy is assumed to be in a new steady state with policy. The new steady state with policy is obtained by solving a set of static equations using standard numerical methods. The algorithm to obtain the adjustment path goes as follows:

1. Make an initial guess for the transition path for taxes between two steady states
2. For every period, t, until some finite horizon, T:
   a) Solve for h_t^i and $\overline{h}_t$ given $\overline{h}_{t-1}$ and future taxes
   b) Update the guess for the current tax rate, τ_t, via the government budget condition
3. Repeat step 2 until the entire adjustment path converges up to some tolerance level
4. Update consumption and saving for agents born before the intervention

3.3.4 Calibration

This section considers the calibration of parameters. The model is calibrated to match the US, which is taken as an informal proxy for an economy with no post-secondary education subsidy. Mortality rates come from the Social Security Administration. In order to focus entirely on the effects of education policy, I restrict the model to a setting with a constant demographic pattern. In particular, I assume that the mortality pattern remains unchanged cohort after cohort while I calibrate the population growth rate to match the US OADR in 2020. This requires setting $\nu_t = \nu = 1.0068$. In terms of the functional forms, parameters are calibrated as shown in Table 3.1. For simplicity, the life-cycle productivity profile is assumed to be flat over the entire life cycle.

Parameter	Description	Value	Origin
Preferences			
β	Discount factor	1/R	Flat consumption profile
σ	EIS of consumption	2	Literature standard
Human Capital			
η	Productivity of investment	0.05	Share of lifetime income invested in education
κ	HCE	0.05	Stability
$\mathcal{A}, \mathcal{B}$	Symmetric Distribution	$\{2, 2\}$	Matching LF inequality
θ	Shift parameter	0	Ease of exposition
γ	Scale parameter	1	Ease of exposition
Factor Prices			
R	Gross interest rate	1.02	Literature standard
w	Life-cycle Productivity Profile	Flat	Ease of exposition
Demography and Life-cycle			
d	Maximum model age	80	Realism
r	Model retirement age	45	Realism
$\{\psi_{t,s}\}$	Mortality pattern	SSA	Data
ν	Cohort growth rate	1.006	Matching OADR

Table 3.1: Calibration

The parameters of the ability distribution, $(\mathcal{A}, \mathcal{B}, \gamma, \theta)$, are largely free. For ease of exposition, I set the distribution shift parameter, θ, to zero. In that case, the scaling parameter, γ, only matters in levels but not in terms of relative model moments such as the Gini coefficient. Hence, I normalize it to unity. As ability is often assumed to be symmetrically distributed, I assume a symmetric beta distribution with $\mathcal{A} = \mathcal{B}$. To calibrate the underlying parameters, we exploit that the within-cohort Gini coefficient in the special case where the government undertakes all education investment has the closed form, $\mathcal{G} = \frac{2 \cdot B(2\mathcal{A}, 2\mathcal{B})}{\mathcal{A} \cdot B(\mathcal{A}, \mathcal{B})^2}$. A good proxy for an economy where only the government invests in education is Denmark. Thus, the ability distribution is calibrated to match the Danish Gini coefficient of 0.25. This is achieved by setting $\mathcal{A} = \mathcal{B} = 2$. In terms of the human capital function, note that η corresponds to the share of the present value of lifetime income invested in education in the laissez-faire economy. To provide a numerical anchor, I calibrate η such that any individual invests exactly 5% of the present value of its lifetime income in the unregulated economy. Meanwhile, κ is set to 0.05. The exact calibration is rather arbitrary but ensures dynamic stability. For the utility function, the risk-aversion parameter, σ, is chosen according to literature standards. For tractability, I assume that $R = \beta^{-1}$, such that consumption profiles are flat. The interest rate is set to 2%.

3.4 Simulation

This section examines how introducing an optimal public education subsidy affects the economy in the short and long run. To illustrate this, I consider the adjustment paths of average human capital, the tax rate, the ability cutoff, average lifetime income, and utility. Moreover, I compare savings profiles and distributional moments across steady states. To separate the effects of education policy from regular transition dynamics in human capital, I assume that the economy is initially in an unregulated steady state when the government suddenly and unexpectedly enforces an education subsidy. To calculate the adjustment path of all the aforementioned variables in response to the introduction of the subsidy, I then use the solution strategy described in Section 3.3.3. In each case, I consider an initial distribution of abilities for 10000 individuals and account for population growth along the growth-adjusted transition path.

For completeness, the subsidy is designed to maximize social welfare in the long-run steady state. The welfare-maximizing subsidy is determined using numerical optimization methods. For the given parameter configuration, optimality implies setting $g \approx 1.6 \cdot \overline{d}_{LF}$. Thus, the optimal policy is to set the subsidy at a 60% markup over the average education investment in the unregulated equilibrium. A policy of this size is interesting, as it ensures the activation of a positive HCE. This is depicted in Figure 3.1. Here, Panel a) shows that average human capital increases immediately due to a direct increase in the total education investment. In the following periods, the externality transpires until human capital subsides at a higher steady-state level. As shown in Panel b), at the time of implementation, the subsidy causes the ability cutoff to increase sharply above zero. However, the subsequent upward reaction in human capital causes a slight downward reaction in the ability cutoff over time. Thus, as the general education level increases, more and more agents top up the subsidy with a positive private education investment. For the transition of the public sector, Panel c) depicts the balanced-budget tax rate. To begin with, taxes are relatively large. However, as subsidized cohorts with more human capital replace non-subsidized cohorts, the tax base increases and the tax rate decreases. Ultimately, the tax rate converges to a long-run level of 5.2%. Altogether, average lifetime income increases by 1.7% compared to the unregulated equilibrium. This is shown in Panel d).

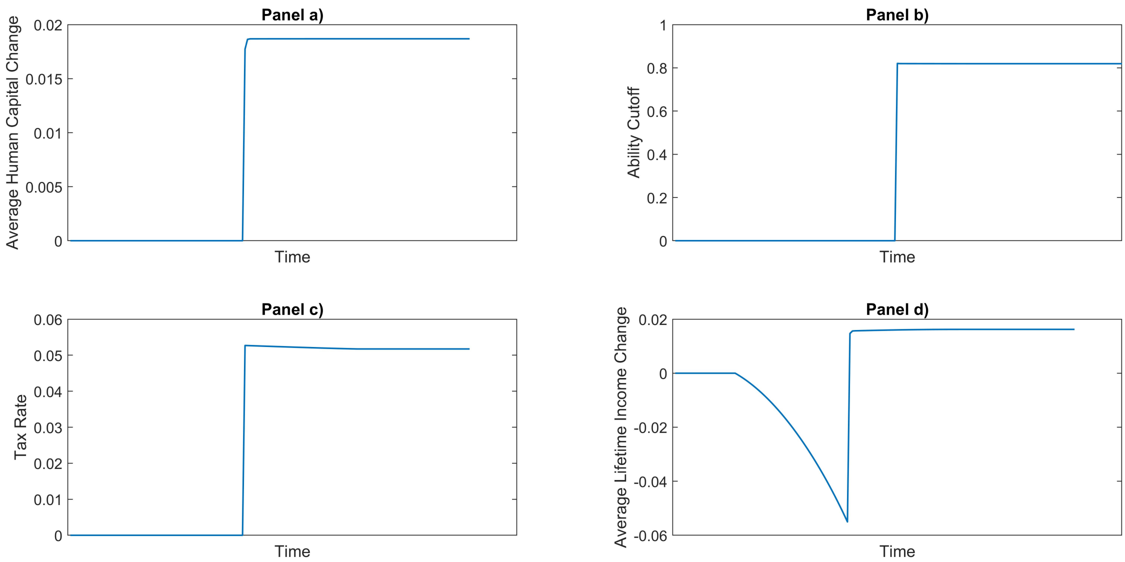


Figure 3.1: Transition Dynamics

Next, Figure 3.2 compares the human capital distributions in the regulated long-run steady state and the unregulated baseline. Here, Panel a) shows histograms of human capital levels with and without policy. In both cases, human capital is unevenly distributed and displays right skewness. Thus, this verifies the analytical result that even a symmetric ability distribution maps into a right-skewed income distribution due to the double effect of individual ability. Comparing the distributions across the two steady states, we see that an optimal education subsidy increases the mean of human capital in the long run and decreases dispersion. In terms of labor income dispersion, Panel b) depicts the Lorenz curve with and without policy. Here, the baseline steady state is associated with a labor-income Gini coefficient of around 0.28, matching American labor income inequality data. In comparison, the Gini-coefficient for labor income declines to 0.27 in the regulated steady state. Thus, there are efficiency gains due to gains in average labor income and due to redistribution. However, these gains are, of course, somewhat offset by increasing taxes.

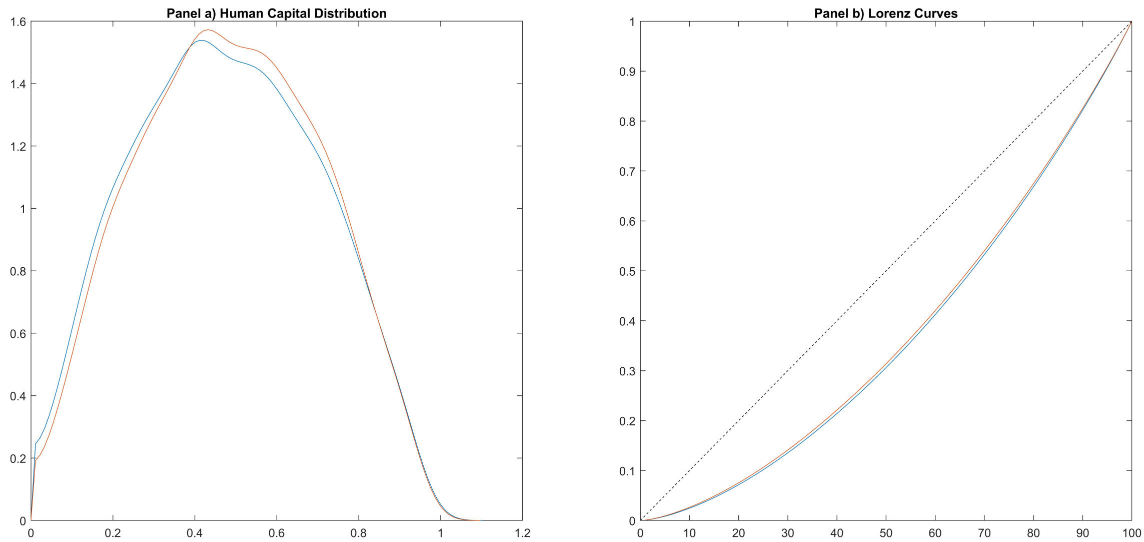


Figure 3.2: The Human Capital Distribution and Income Inequality

To see the impact of the education subsidy on student debt, Figures 3.3 depicts a series of boxplots for planned savings at different ages with and without policy. In both cases, the red line denotes the savings trajectory of the most gifted individual, while the blue line denotes that of the least gifted individual. Note that, in a steady state, one can interpret these figures either as the *period* or the *cohort* pattern of savings. In the following, I apply the latter interpretation. Thus, in the unregulated steady state in Panel a), individuals with both high and low ability take up some student debt early in life. But, because higher ability implies a higher return on education, more gifted individuals take up more student debt. Over the following periods, individuals allocate their annual income to consumption and to service student debt and, eventually, become net savers. Interestingly, this happens at the same instance for everyone, and from this point onward, the pattern reverses, such that more gifted individuals now have the largest savings. Although it is difficult to elicit from the figure, the intergenerational Gini coefficient is unchanged from year to year, confirming previous analytical results. To reiterate, this underlines the property that the only excess skewness in the overall wealth distribution is due to life cycling. With the education subsidy, the steady-state profiles of planned savings in Panel b) show that every individual takes up less debt than in the unregulated equilibrium. With the socially optimal education subsidy, student debt is almost completely eliminated as almost every individual is below the ability cutoff. Only individuals above the cutoff go into some student debt, and the most gifted individual would again borrow the most. Meanwhile, the opposite does not apply to the least gifted individual, who now starts life with the smallest positive savings among those below the cutoff. Over time, the pattern again converges qualitatively to the unregulated case, with the most gifted individual having the largest wealth and vice versa.

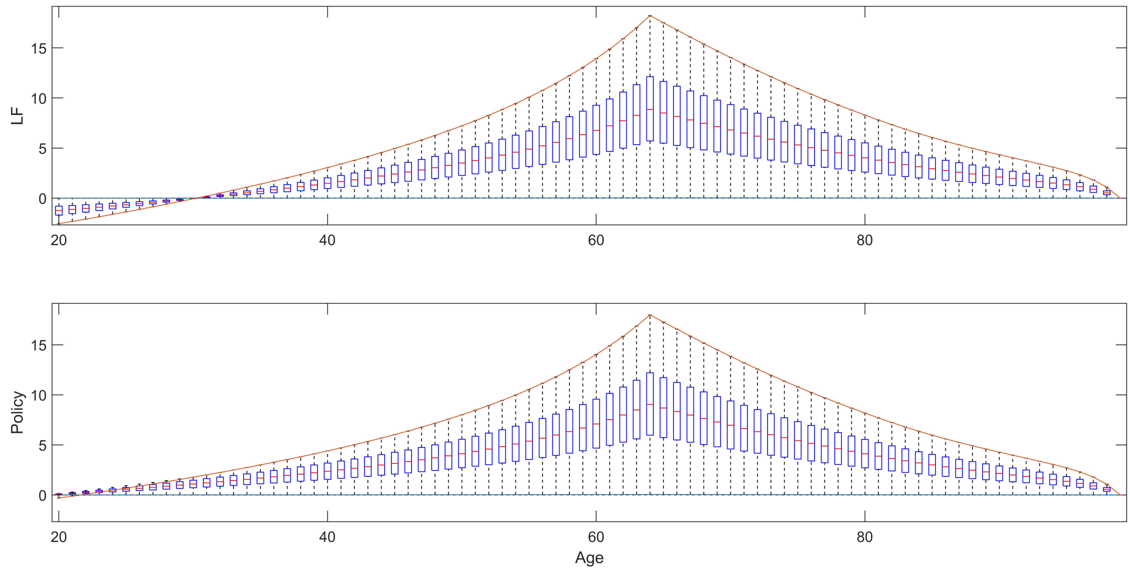


Figure 3.3: Savings Distribution over the Life Cycle, in Average Incomes

We have yet to consider what happens to social welfare along the adjustment path. Accordingly, Figure 3.4 depicts the trajectory of average utility in terms of the gain for each generation compared to the unregulated outcome. As the figure shows, all cohorts who are working age at the time of implementation stand to lose. This is so, as these cohorts are now required to pay taxes, but did not receive any subsidies while young. Quite intuitively, the negative effect is stronger, the more periods a particular generation has left in the labor market, paying taxes. The absolute size of the negative effect is convexly increasing due to the concavity of the utility function. This illustrates quite clearly the challenges of enacting education reform both as a benevolent social planner and in a democracy. Accordingly, I now consider using public pensions to compensate the initial generations of taxpayers, who suffer an income loss under an isolated education scheme.

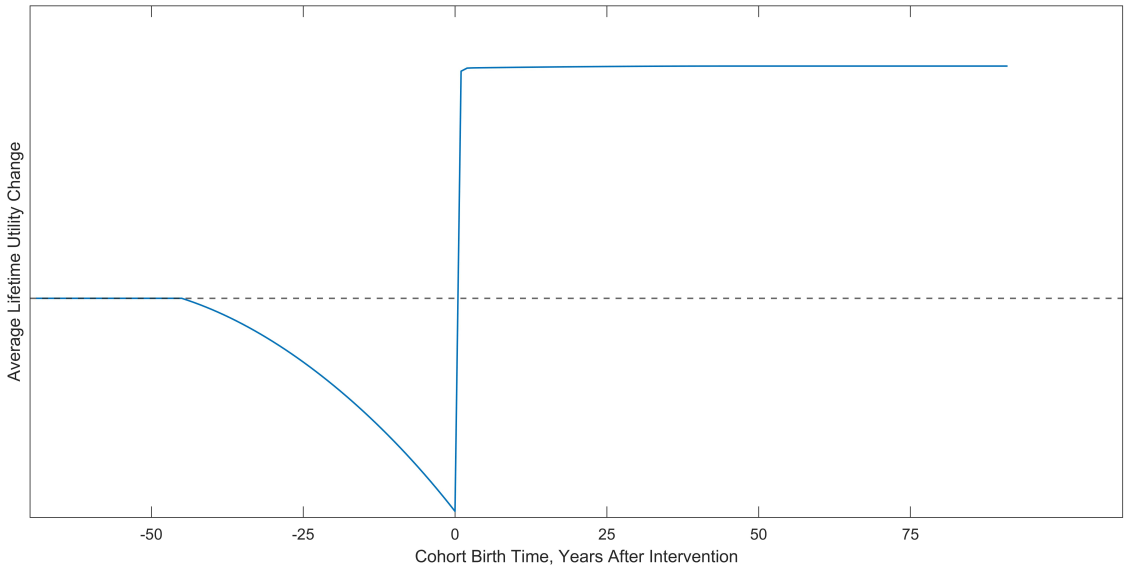


Figure 3.4: Implementation Problem

3.4.1 Solving The Implementation Problem by Public Pensions

In this section, I investigate the potential for using public pensions to overcome the challenge of implementing the optimal education subsidy. In this context, I invoke the intertemporal Pareto criterion, which ensures that $\overline{U}_{t-j}^{Pol} \geq \overline{U}_{t-j}^{LF}$, to identify appropriate pension benefits for each cohort. Looking at Figure 3.4, this clearly requires compensation for all generations in the labor market at the time of implementation. However, it is ex-ante uncertain whether compensation is also needed for the generations entering the labor market after implementation. Hence, I consider a general case, where every cohort could potentially be entitled to public pension benefits. The benefit is universal within each generation but may differ from cohort to cohort, as the appropriate compensation varies. Specifically, surviving members of the generation born in period t receive a fixed pension benefit every year in retirement. Thus, in any year, t, the cohort born in $t-j$ receives p_{t-j}. Altogether, this necessitates a generalization of the public budget, which one can write both in trending and growth-adjusted terms:

$$\tau_t = \frac{g \cdot n_t + \sum_{j=r+1}^{d} n_{t-j}\Psi_{t-j,j}p_{t-j}}{\sum_{j=1}^{r} n_{t-j}\Psi_{t-j,j}w_{t-j,j}\overline{h}_{t-j}} = \frac{g + \sum_{j=r+1}^{d} \frac{\Psi_{t-j,j}}{\prod_{s=t-j}^{t-1}\nu_s}p_{t-j}}{\sum_{j=1}^{r} \frac{\Psi_{t-j,j}w_{t-j,j}}{\prod_{s=t-j}^{t-1}\nu_s}\overline{h}_{t-j}}$$

By numerical methods, one can then identify a vector of pension benefits, $\{p_t\}_{T-r}^{T-1}$, just large enough to satisfy the intertemporal Pareto criterion for every cohort. This policy rule generates more intricate transition paths, as shown in Figure 3.5. First, the flat part of the average change in lifetime utility in Panel d) illustrates that the intertemporal Pareto criterion is satisfied. Next, for the first subsidized cohort, expected utility jumps because of the direct investment, the BE, and redistribution. As the externality has not yet been activated, and as the inaugural generations anticipate high taxes, expected utility is lower than in the long-run steady state. For the second cohort, utility continues to increase due to the activation of the externality and as the pension system is still relatively small. However, for the next couple of generations, the gradual roll-out of the pension system causes taxes to increase, as depicted in Panel c). Over time, this induces a gradual decrease in average utility. However, the pension system is eventually phased out again, and the tax rate decreases, while the education level in Panel a) increases even further until the economy reaches the socially optimal equilibrium. The resulting pattern of pension benefits is qualitatively consistent with the "rise-and-fall of PAYG" discussed by Andersen and Bhattacharya (2017). This concludes the analysis of using public pensions to implement education policy.

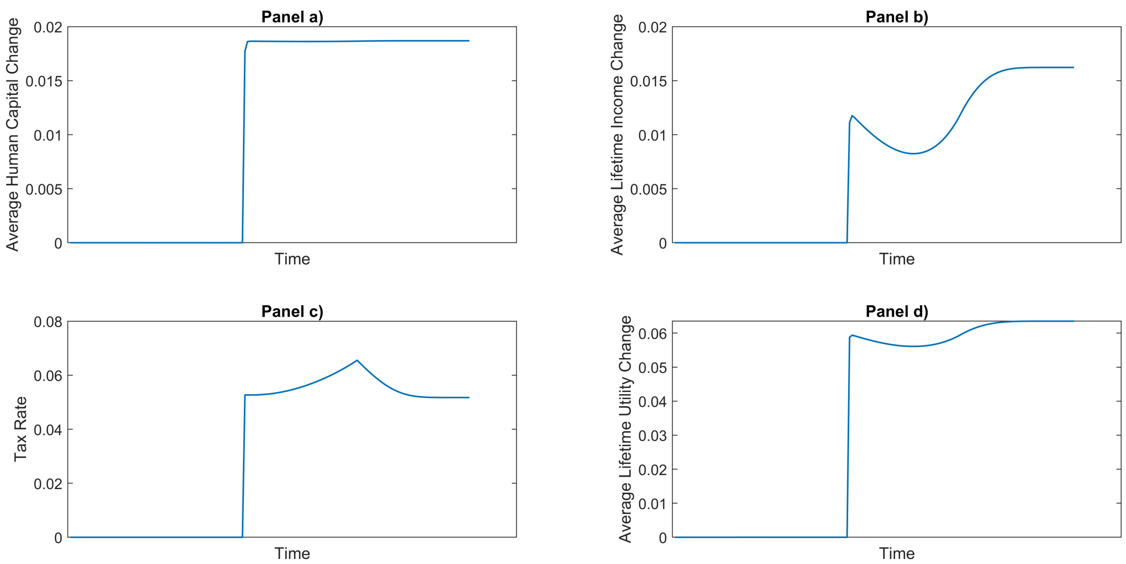


Figure 3.5: PAYG Pensions

3.5 Extensions

This section considers two separate model extensions and shows that the results hitherto obtained can be reproduced under generalized settings. First, Section 3.5.1 considers a model where individuals choose both their length of education and their yearly education investment. Second, Section 3.5.2 investigates a version of the main model generalized to include idiosyncratic income risk.

3.5.1 Introducing Length of Education

Although the human capital function of the main model captures some compelling features of education, it crudely neglects the time spent in education. Thus, an obvious extension is to capture the trade-off between working and studying by introducing time in education as an explicit choice variable. Accordingly, this section introduces a discrete choice with respect to the length of education. Thus, when agents enter the model, they choose not only the quality of education (yearly tuition) but also the quantity (years of education).

In the extended model, agents actively choose when to leave school and start working. Formally, this happens at a discretionary age, $s_t^i \in S$. If agents choose no post-secondary education, $s_t^i = 1$. In that case, they then enter the labor market already in the first period and earn an unskilled wage, Λ. If, on the other hand, agents choose to enroll in post-secondary education, they temporarily give up labor income and enter the labor market s_t^i years later, earning a higher wage. Specifically, while enrolled, agents build up human capital according to a generalized version of the human capital function:

$$h_t^i = x_t^i \cdot \left(s_t^i - 1\right)^{\phi} \cdot \left(d_t^i + g\right)^{\eta} \cdot \left(\overline{h}_{t-1}\right)^{\kappa}$$

Apart from the length of education, human capital is again a function of ability, total education investment, and the externality. Human capital allows individuals to earn a premium on the unskilled wage, such that the total income is determined by $\Lambda + h_t^i$. Accordingly, the education decision now reflects a trade-off between education and the outside option to work at a lower wage. To ensure that expected lifetime utilities are comparable across groups with different lengths of education, agents now also consume and save while in education. Thus, the new utility maximization problem reads:

$$\underset{\left\{c_{t,j}^i, d_t^i, s_t^i\right\}}{Max} \; U_t^i = \sum_{j=1}^{d} \beta^j \cdot \Psi_{t-j,j} \cdot u\left(c_{t,j}^i\right)$$

$$st.$$

$$c_{t,j}^i + a_{t,j}^i = \left(1 - \mathbb{I}\left(s_t^i > j\right)\right)\left(1 - \tau_{t+j}\right) w_{t,j} l_{t,j} \left(\Lambda + h_t^i\right) + \tilde{R}_{t,j} a_{t,j-1}^i - d_t^i \cdot \mathbb{I}\left(s_t^i > j\right)$$

The solution strategy for the individual problem is quite similar to that of the simpler model. For each possible education length, agents solve a problem over the yearly private education investment and the saving profile over the life cycle. Agents then choose the discrete length of education that maximizes individual utility. However, with different lengths of education, there are now several ability cut-offs, $x_{t,s}^c$, one for each element in S:

$$x_{t,s}^c = \frac{g^{1-\eta} \sum_{\tau=1}^{s-1} \dfrac{1}{\prod_{s=1}^{\tau} \tilde{R}_{t,s}}}{\eta \cdot (s-1)^{\phi} \left(\overline{h}_{t-1}\right)^{\kappa} \sum_{\tau=s}^{o} \dfrac{\left(1 - \tau_{t+\tau}\right) w_{t,\tau}}{\prod_{s=1}^{\tau} \tilde{R}_{t,s}}}$$

In Appendix B, I provide a detailed solution to the individual problem in the unregulated economy, including closed-form expressions for all education lengths. In addition, I show first-order conditions for individual optimality in the regulated economy. On the aggregate level, the current model extension also calls for updating the tax function, which can be written as:

$$\tau_t = \frac{g \cdot \sum_{j=1}^{r} \frac{\Psi_{t-j,j}\gamma_{t-j,j}}{\prod_{s=t-j}^{t} \nu_s}}{\sum_{j=1}^{r} \frac{\Psi_{t-j,j} w_{t-j,j} \left(1-\gamma_{t-j,j}\right)}{\prod_{s=t-j}^{t} \nu_s} \cdot \mathbb{E}\left[h_{t-j}^{i} | s_{t-j}^{i} \leq j\right]}$$

where $\gamma_{t-j,j}$ is the share of cohort $t-j$ still in education at age j, and $\mathbb{E}\left[h_{t+j-1} | s_{t+1-j} \leq j\right]$ reflects that less skilled individuals enter the labor market earlier, implying that average human capital among the working members of a cohort increases over time.

To provide a reasonable starting point for the extended model, I recalibrate the model parameters. Unlike in the main model, η no longer has the interpretation of education investment as a share of lifetime income. However, η now represents the limit for education investment as a share of lifetime income as ability increases. Therefore, it is reasonable to again set this parameter to 0.05. Next, I adjust the parameters κ, ϕ, Λ, $\mathcal{A}$, and $\mathcal{B}$ to match nine model moments to corresponding data moments. I specifically target two types of data moments; education group shares and average, group-specific wage premia over the unskilled wage. For the education group shares, I define the targets using data on educational attainment from the U.S. Census Bureau (2023a). In the model, $s = 1$ then corresponds to "High School or Less", $s \in [2, 3]$ to "Some College, no Degree" or "Associate's Degree", $s \in [4, 5]$ to a "Bachelor's Degree", $s = 6$ to a "Master's Degree", and $s = 7$ to a "Professional or Doctoral Degree". For the average group-specific income shares, I use the same group definitions and target group-specific income premia over the unskilled using data from U.S. Census Bureau (2023b). In both cases, I specifically target data moments for individuals aged 25 to 39. The new parameter configuration is listed in Table 3.2, while 3.3 shows the associated model fit.

Table 3.2: Structurally Estimated Parameters

Parameter	Description	Value
$\mathcal{A}$	Ability Distribution Parameter	0.5
$\mathcal{B}$	Ability Distribution Parameter	1.0
κ	Size of HCE	0.09
ϕ	Productivity of Education Length	0.50
Λ	Unskilled Wage	1.5

Notes: The parameters are outputs of a brute-force procedure based on nested loops over exogenous grids for each parameter. If optimal points are on the endpoint of grids, the grids are made larger.

Table 3.3: Targeted Moments

Moment	Model	Data
Share, High School or less	0.3076	0.3200
Share, Some College but no Degree or Associate's Degree	0.3253	0.2500
Share, Bachelor's	0.2153	0.2500
Share, Master's	0.0949	0.1300
Share, Professional or Doctorate	0.0569	0.0500
Wage Premium, Some College, no Degree or Associate's Degree	1.2008	1.3300
Wage Premium, Bachelor's Degree	1.7758	2.1900
Wage Premium, Master's Degree	2.6348	2.5400
Wage Premium, Professional or Doctoral Degree	3.9589	3.3300

Notes: Data moments are based on weighted averages of the U.S. Census Bureau data over different age groups.

Given the addition to the model of the unskilled wage and the length of education, κ is different from the main case. This is unsurprising, as the nature of the education decision is now very different and much more intricate. The choice variable d_t now represents yearly tuition, and each student can potentially go to school for many years. Moreover, the outside option of earning an unskilled wage also affects incentives for education. Furthermore, we target premia on the unskilled wage, which were infinite by definition in the basic model. Hence, there is not much reason to think that the parameters should be similar to those obtained from the earlier calibration exercise. The estimate of ϕ implies that for a given ability and yearly tuition, the marginal return to a year of education is positive but decreasing.

For the given parameters, the optimal policy is to set $g = 1.13 \cdot d_{LF}$. Again, this is sufficient to trigger a positive human capital externality. This shows, that also when education takes place over several years, a public education subsidy can improve welfare. However, it is easy to imagine that the scope for fair implementation is now smaller. This is so, as the subsidy increases the average number of years in education, which means that agents must give up some labor income early in life. At the same time, the direct increase in the tax base is also mitigated by the loss of income early in life. I leave a thorough analysis of the implementation scope to future research.

To show the impact of such a subsidy, Figure 3.6 first shows a bar plot over the group shares with different lengths of education with and without policy. The figure shows that the optimal subsidy generally increases the length of education. In isolation, this shift induces an increase in human capital. However, at the same time, the subsidy again crowds out the yearly private education investment putting downward pressure on human capital. In the current example, the overall effect on human capital is positive.

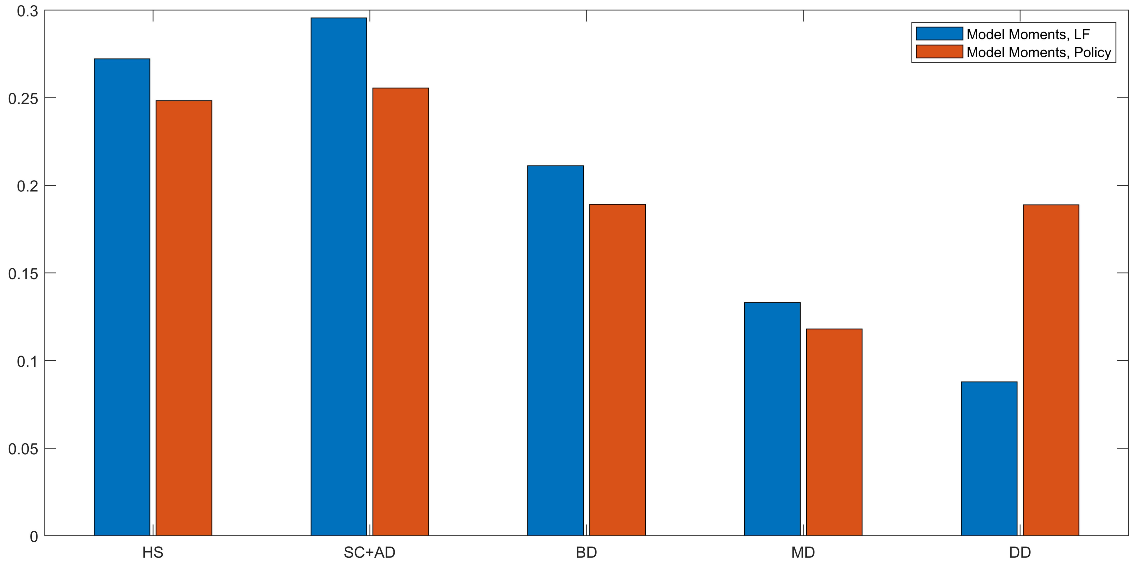


Figure 3.6: Length of Education

Next, Figure 3.7 depicts savings profiles with and without the subsidy. Focusing on the LF economy in the top panel, the savings profiles now look somewhat different to those of the main model. Most notably, agents build up large initial debt, as they are now generally in education for several years. During this time they also consume in a consumption-smoothing way, which leads to large negative student debt for the young. This is rather unrealistic and could indicate that young individuals are subject to stricter borrowing constraints or that the model otherwise fails to capture important aspects of student debt such as support from parents or lifecycle-specific preferences that allow for lower consumption while young. Another crucial difference from the main model is that some agents choose no post-secondary education and start to build up savings already in the first period. However, in qualitative terms, the picture is similar to the main model. Specifically, agents with higher abilities enter the labor market with the most student debt but use their higher wages to pay back student debt and to build up positive wealth. Inspecting the economy with education policy in the second panel, the subsidy again decreases student debt, limits inequality, and increases average wealth at retirement, representing the three channels for welfare improvements.

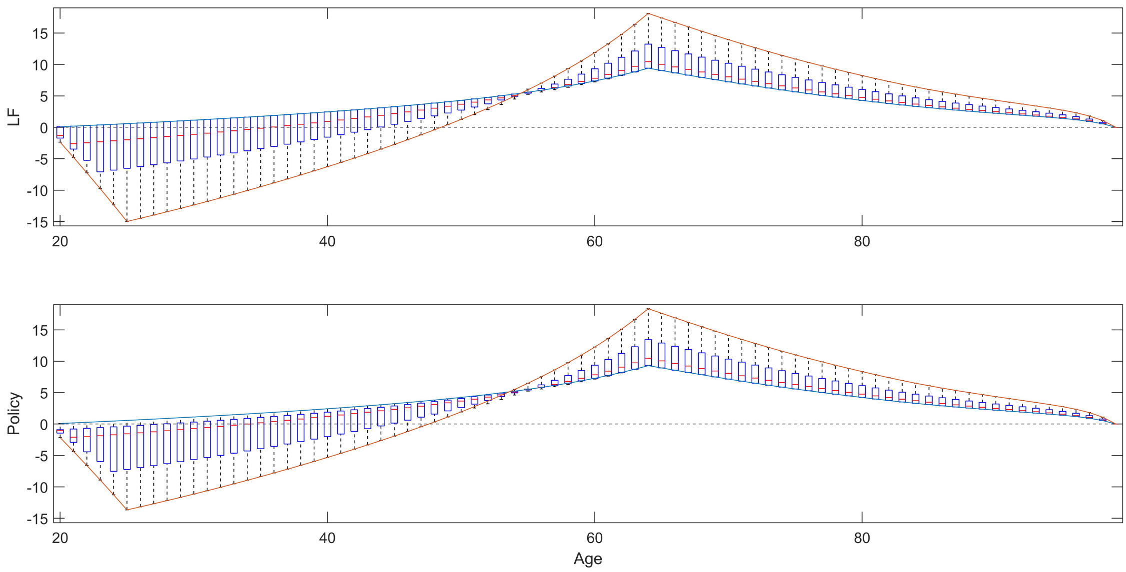


Figure 3.7: Saving Profiles

3.5.2 Life-cycle Model with Idiosyncratic Income Risk

One factor that is often thought to affect investment decisions - including education decisions - is idiosyncratic income shocks. To address this, I return to a setting, where the education decision takes place in a single period but add an idiosyncratic income shock to the individual decision problem. Like in most life-cycle models, income risk implies that agents have a precautionary savings motive. In relation to education decisions, the precautionary motive implies that private education investment decreases with income risk, as student debt represents negative private savings. Accordingly, the scope for welfare-improving intervention increases with risk, as the government can overcome the private underinvestment in education through a policy that also provides income insurance through universal transfers and proportional taxes. Consequently, the optimal subsidy derived in the main model without risk can be perceived as a lower bound for a more general analysis that includes a simple income risk process.

In every period, the individual solves a dynamic programming problem for a given subsidy and a given tax rate. For an individual aged t with human capital, h, and cash on hand, m_t, the Bellman equation reads:

$$V_t(m_t, h) = \underset{c_t}{max}\left\{\frac{c_t^{1-\rho}}{1-\rho} + \beta \cdot \psi_t \cdot \mathbb{E}_t\left[V_{t+1}(m_{t+1}, h)\right]\right\}$$
$$s.t.$$
$$m_{t+1} = (1-\tau_{t+1}) \cdot h \cdot l_{t+1} \cdot y_{t+1} + \tilde{R}_t(m_t - c_t)$$
$$a_t \geq -\lambda_t \cdot h$$

where y_{t+1} is idiosyncratic income, which takes a finite set of values, $y_{t+1} \in \mathcal{Y}$. To allow agents to have student debt, λ_t represents the natural borrowing constraint, i.e., the level of debt at which receiving the worst-case shock from now until retirement results in zero consumption. Conveniently, the value function scales in human capital. Thus, I define the normalization, $\tilde{z}_t = \frac{z_t}{h}$. Using this, it is easy to show that the final-period value function depends exclusively on normalized cash on hand:

$$v_T(\tilde{m}_T) = \frac{\tilde{m}_T^{1-\rho}}{1-\rho}$$

In the spirit of backward induction, one can then show that the value function for every previous period can be normalized to:

$$v_t(\tilde{m}_t) = \underset{\tilde{c}_t}{max}\left\{\frac{\tilde{c}_t^{1-\rho}}{1-\rho} + \beta \cdot \psi_t \cdot \mathbb{E}_t\left[v_{t+1}(\tilde{m}_{t+1})\right]\right\}$$
$$s.t.$$
$$\tilde{m}_{t+1} = (1-\tau_{t+1}) \cdot l_{t+1} \cdot y_{t+1} + \tilde{R}_t(\tilde{m}_t - \tilde{c}_t)$$

This problem generally does not scale in tax rates, as taxes are dynamic along the transition path. Hence, one would have to recompute value functions every time one updates the transition path for taxes. In fact, the problem only scales in tax rates when the tax rate is constant. Thus, I focus on the long-run effects of an education subsidy using steady-state comparisons. For now, it should suffice to add that I solve the problem in the steady state using the *Endogenous Grid Method* (EGM) originally developed by Carroll (2006). A detailed solution to the steady state problem is given in Appendix C. In the education period, for a given subsidy and a preexisting level of human capital, the education investment problem for an agent with ability x reads:

$$V_0(x) = \underset{d}{max}\left\{\mathbb{E}_0\left[v_1(\tilde{m}_1)\right] \cdot h^{1-\rho}\right\}$$
$$s.t.$$
$$\tilde{m}_1 = (1-\tau_1) \cdot l_1 \cdot y_1 - \tilde{R}_t \cdot \frac{d}{h}$$
$$h = x \cdot (d+g)^{\eta} \cdot \overline{h}^{\kappa}$$

This shows that the education problem generally does not scale in x or $\overline{h}$. Only when $g = 0$, is normalization possible. Again, a detailed solution is relegated to Appendix C. Finally, the government runs a balanced budget. Accordingly, steady-state taxes have to satisfy:

$$\tau = \frac{g}{\mathbb{E}\left[y\right] \cdot \overline{h} \cdot \sum_{j=1}^{r} \frac{\Psi_j}{\nu^j}}$$

For tractability, all parameters are as in the main experiment of the paper, and the shock process has three states (low and high) and a mean of one. Specifically, I assume that individuals face income states given by $y = [0.5, 1.5]$, which occur with equal probability. This ensures that expected lifetime income remains unchanged across the two models if individuals invest the same amount in education. Note that the extended model reproduces the outcomes of the main model whenever all shock nodes are equal to one. Thus, any differences in education choice relative to the main model solely reflect the fact that income risk affects education choices. To illustrate this mechanism, I first compare private education decisions with and without risk for an income shock process with the same mean and $g = 0$. Given this calibration, each worker invests approximately 3% less in education when income is risky. Thus, both individual and aggregate human capital depends negatively on income risk across the entire ability distribution.

To provide further insights into the role of risk, I compute the optimal subsidy with and without risk. This reveals that the optimal subsidy is higher in a world with income risk. At the same time, the tax base decreases with income risk. Accordingly, the optimal education tax also increases with risk. This underlines that a simple stochastic income process only strengthens the welfare arguments for an education subsidy. As argued at the beginning of this section, this implies that the optimal subsidy in the model without risk is a lower bound for optimal policy in a generalized setting with risk.

3.6 Conclusion

Throughout this paper, I have shown how optimal education policy improves average welfare in the long run by exploiting a human capital externality, redistribution, and a borrowing effect associated with lower student debt. In a short-run perspective, I have also illustrated how such a policy can be implemented under a modified, intertemporal Pareto criterion, using public pensions to redistribute downstream gains to those who bear the up-front cost. Subsequently, I considered two model extensions. First, I introduced time spent in education as an explicit decision variable to capture the trade-off between working and studying for the young. Calibrating this model to match data moments on US educational attainment shares and education-specific income premia, I then showed that a public education subsidy can still improve long-run welfare. Next, I considered a version of the main model with idiosyncratic income risk. Due to precautionary saving motives, income risk implies that individuals take up less student debt to invest in education. Thus, there is a separate welfare argument for public education subsidies to collectively insure against idiosyncratic income risk. Hence, the optimal subsidy grows with income risk, and the optimal subsidy from the main model has an interpretation as a lower bound for a more general setting with risk.

Nevertheless, both the main model and its two extensions are based on assumptions that could be generalized. First and foremost, factors of production and factor prices are all exogenous. Here, inelastic labor supply is a strong assumption for two reasons. First, it rules out that individual heterogeneity may lead to differences on the intensive margin, and, second, it precludes taxes from distorting labor choice. Consequently, endogenous labor would likely decrease the socially optimal subsidy. In terms of physical capital, exogeneity rules out that public policy affects individual decisions via changes in the real interest rate and the real wage. Thus, it would be beneficial to extend the model to a general equilibrium setting where factor prices are determined by the amount of savings in the economy. In that case, there could be a backlash to education reform via changes in savings leading to changes in factor prices. Also, as discussed, the model does not generate sufficient within-cohort wealth inequality. To resolve this issue, one could introduce persistent shocks to labor earnings and/or capital income. For an overview of papers that consider such mechanisms, see Nardi and Fella (2017). However, stochastic explanations arguably yield little intuition regarding the causal mechanisms that drive wealth inequality, and, therefore, it could make sense to consider more systematic mechanisms. Here, several papers, often inspired by Becker and Tomes (1979), consider dynastic wealth accumulation under explicit bequest motives. Others take a more paternalistic stance and resort to preference heterogeneity, see, e.g., Krusell and Smith (1998). To provide an explanation for excess wealth inequality that is less paternalistic, others consider non-homothetic preferences to generate a nonlinear transformation from income to wealth. Another compelling mechanism is found in Gabaix et al. (2016), which incorporates so-called *scale* and *type dependence* in returns to capital. Here, the former signifies a positive relationship between the size of wealth and returns, while the latter implies that individual returns differ persistently due to fixed effects such as financial literacy. Fagereng et al. (2016) and Fagereng et al. (2020), later substantiated these mechanisms empirically.

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Appendix A: Comparative Statics

This appendix shows some analytical results for the main model without government intervention. First off, one can show that both individual and aggregate human capital depend positively on wages:

$$\frac{d\overline{H}}{dw_k} = \mathbb{E}\left[\frac{-\dfrac{H_E H_E}{H_{EE}}}{1-\left[H_H - \dfrac{H_E H_{EH}}{H_{EE}}\right]} \frac{\dfrac{1}{\prod_{s=1}^{k}\tilde{R}_j}}{\sum_{j=1}^{o}\dfrac{w_j}{\prod_{s=1}^{j}\tilde{R}_j}}\right] > 0$$

One can also show that individual and aggregate human capital levels depend negatively on the interest rate:

$$\frac{d\overline{H}}{dR} = \frac{\mathbb{E}\left[\dfrac{H_E}{H_{EE}}\right]}{1-\mathbb{E}\left[H_H - \dfrac{H_E H_{EH}}{H_{EE}}\right]} \frac{\sum_{j=1}^{o}\dfrac{j}{R}\dfrac{w_j}{\prod_{s=1}^{j}\tilde{R}_j}}{\left(\sum_{j=1}^{o}\dfrac{w_j}{\prod_{s=1}^{j}\tilde{R}_j}\right)^2} < 0$$

where the sign follows from the stability condition in (3.3). One can also show that higher survival rates before the time of retirement increase human capital, but that increases after retirement have no effect on the education decision:

$$\frac{d\overline{H}}{d\psi_k} = \begin{cases} \dfrac{-\mathbb{E}\left[\dfrac{H_E H_E}{H_{EE}}\right]}{\psi_k\left(1-\mathbb{E}\left[H_H - \dfrac{H_E H_{EH}}{H_{EE}}\right]\right)} \dfrac{\sum_{j=k}^{o}\dfrac{w_j}{\prod_{s=1}^{j}\tilde{R}_j}}{\sum_{j=1}^{o}\dfrac{w_j}{\prod_{s=1}^{j}\tilde{R}_j}} > 0 & \text{for } k \in [1,\ldots,r] \\ 0 & \text{for } k > r \end{cases}$$

Appendix B: Extension with Education Length

This appendix reviews the solution method applied to solve the model where agents can also choose their length of education both with and without policy. In a standard way, the Euler equation reads:

$$u'\left(c_{t,j}^{i}\right)=\beta R\cdot u'\left(c_{t,j+1}^{i}\right)\Longleftrightarrow u'\left(c_{t,j}^{i}\right)=u'\left(c_{t,1}^{i}\right)\frac{1}{\left(\beta R\right)^{j-1}}$$

Without Policy

Using the Euler equation, the first-order condition with respect to education reads:

$$d_t^i=\eta\cdot h_t^i\cdot\frac{\sum_{j=s_t^i}^{d}\frac{w_{t,j}l_{t,j}}{\prod_{s=1}^{j}\tilde{R}_{t,j}}}{\sum_{j=1}^{s_t^i-1}\frac{1}{\prod_{s=1}^{j}\tilde{R}_{t,j}}}$$

For a given education level, s_t^i, there exists a closed-form solution for the individual education investment and human capital:

$$d_t^i=\left(\eta\cdot x_t^i\cdot\left(s_t^i-1\right)^{\phi}\cdot\left(\overline{h}_{t-1}\right)^{\kappa}\frac{\sum_{j=s_t^i}^{d}\frac{w_{t,j}l_{t,j}}{\prod_{s=1}^{j}\tilde{R}_{t,j}}}{\sum_{j=1}^{s_t^i-1}\frac{1}{\prod_{s=1}^{j}\tilde{R}_{t,j}}}\right)^{\frac{1}{1-\eta}}$$

$$h_t^i=\left(x_t^i\cdot\left(s_t^i-1\right)^{\phi}\cdot\left(\overline{h}_{t-1}\right)^{\kappa}\left(\eta\frac{\sum_{j=s_t^i}^{d}\frac{w_{t,j}l_{t,j}}{\prod_{s=1}^{j}\tilde{R}_{t,j}}}{\sum_{j=1}^{s_t^i-1}\frac{1}{\prod_{s=1}^{j}\tilde{R}_{t,j}}}\right)^{\eta}\right)^{\frac{1}{1-\eta}}$$

The optimal length of education is then given as the argument, s_t^i, that maximizes lifetime income:

$$y_t^i\left(s_t^i\right)=\left(\Lambda+\left(1-\eta\right)h_t^i\right)\sum_{j=s_t^i}^{d}\frac{w_{t,j}l_{t,j}}{\prod_{s=1}^{j}\tilde{R}_{t,s}}$$

With Policy

With a non-zero subsidy, the problem becomes somewhat more complicated. For a given, s_t^i, the first-order condition for education investment is given by:

$$e_t^i=\begin{cases}d_t^i & \text{if } x^i\leq x_t^c\left(s_t^i\right)\\ \eta\left[h_t^i-\Lambda\right]\frac{\sum_{\tau=s_t^i}^{o}\frac{\left(1-\tau_{t+\tau}\right)w_{t,\tau}}{\prod_{s=1}^{\tau}\tilde{R}_{t,s}}}{\sum_{\tau=1}^{s_t^i-1}\frac{1}{\prod_{s=1}^{\tau}\tilde{R}_{t,s}}} & \text{if } x^i>x_t^c\left(s_t^i\right)\end{cases}$$

Like in the main model, the education investment decision is discontinuous across a cutoff. Above the cutoff, the first-order condition for education investment reads:

$$e_t^i = \left[\eta \cdot x_t^i \cdot \left(s_t^i - 1\right)^{\phi} \cdot \left(\overline{h}_{t-1}\right)^{\kappa} \frac{\sum_{j=s_t^i}^{o} \frac{\left(1-\tau_{t+j}\right) w_{t,j}}{\prod_{s=1}^{j} \tilde{R}_{t,s}}}{\sum_{j=1}^{s_t^i - 1} \frac{1}{\prod_{s=1}^{j} \tilde{R}_{t,s}}} \right]^{\frac{1}{1-\eta}}$$

One can then find the cutoff at every level of education, $x_t^c\left(s_t^i\right)$, by setting $e_t^i = g$.

Appendix C: Idiosyncratic Income Risk

This appendix reviews the solution method applied to solve the model with idiosyncratic income risk both with and without policy.

Without Policy

In the special case where, $g = 0$, and assuming that we are in the long-run steady state without policy, the dynamic programming problem is rather simple. In the final period of life, the normalized value function reads:

$$v_T(\tilde{m}_T) = u(\tilde{m}_T)$$

In any other period, the Bellmann equation reads:

$$\begin{aligned} v_t(\tilde{m}_t) &= \underset{\tilde{c}_t}{max}\left\{u(\tilde{c}_t) + \beta\cdot\psi_t\cdot\mathbb{E}_t\left[v_{t+1}(\tilde{m}_{t+1})\right]\right\} \\ &s.t. \\ \tilde{m}_{t+1} &= l_{t+1}\cdot y_{t+1} + \tilde{R}(\tilde{m}_t - \tilde{c}_t) \end{aligned}$$

This has the following first-order condition:

$$u'(\tilde{c}_t) = \beta R\cdot\mathbb{E}_t\left[\frac{\partial v_{t+1}(\tilde{m}_{t+1})}{\partial\tilde{m}_{t+1}}\right]$$

Now, using the Envelope theorem, we have:

$$v_t'(\tilde{m}_t) = u'(\tilde{c}_t^*)\frac{\partial\tilde{c}_t^*}{\partial\tilde{m}_t} + \beta\cdot\mathbb{E}_t\left[v_{t+1}'(\tilde{m}_{t+1})\left[R - R\frac{\partial\tilde{c}_t^*}{\partial\tilde{m}_t}\right]\right] = \beta R\cdot\mathbb{E}_t\left[v_{t+1}'(\tilde{m}_{t+1})\right]$$

Thus, the Euler condition implies:

$$\begin{aligned} v_t'(\tilde{m}_t) &= u'(\tilde{c}_t) \\ v_{t+1}'(\tilde{m}_{t+1}) &= u'(\tilde{c}_{t+1}) \end{aligned}$$

Accordingly, we can write the Euler as:

$$u'(\tilde{c}_t) = \beta R\cdot\mathbb{E}_t\left[u'(\tilde{c}_{t+1})\right]$$

It is straightforward to solve this problem using the EGM. In the education period, the normalized value function reads:

$$\begin{aligned} v_0 &= \underset{\tilde{d}}{max}\left\{\mathbb{E}_0\left[v_1(\tilde{m}_1)\right]\tilde{d}^{\frac{\eta(1-\rho)}{1-\eta}}\right\} \\ &s.t. \\ \tilde{m}_1 &= l_1 y_1 - R\cdot\tilde{d} \end{aligned}$$

This problem has the first-order condition:

$$\tilde{d} = \frac{\eta(1-\rho)}{R(1-\eta)} \frac{\mathbb{E}_0[v_1(\tilde{m}_1)]}{\mathbb{E}_0[v_1'(\tilde{m}_1)]}$$

Using the result that $v_t'(\tilde{m}_t) = u'(\tilde{c}_t)$, this allows us to write:

$$\tilde{d} = \frac{\eta(1-\rho)}{R(1-\eta)} \frac{\mathbb{E}_0[v_1(\tilde{m}_1)]}{\mathbb{E}_0[u'(\tilde{c}_1(\tilde{m}_1))]}$$

I solve this equation numerically. Having found the optimal normalized education investment, I obtain closed-form expressions for $\overline{h}$ and h. Given this, the optimal education investment is given by $d = \tilde{d} \cdot h$. The non-normalized value function is given by:

$$V_0(x) = v_0 \cdot \left(x \cdot \overline{h}^{\kappa}\right)^{\frac{1-\rho}{1-\eta}}$$

With Policy

Assuming that the economy is in the long-run steady state with policy and Introducing the scaling $\tilde{z}_t = \dfrac{z_t}{1-\tau}$, we can write the last-period value function as:

$$v_T(\tilde{m}_T) = \frac{\tilde{m}_T^{1-\rho}}{1-\rho}$$

Consequently, in any other period, we have that:

$$v_t(\tilde{m}_t) = \max_{\tilde{c}_t} \left\{ \frac{\tilde{c}_t^{1-\rho}}{1-\rho} + \beta \cdot \psi_t \cdot \mathbb{E}_t[v_{t+1}(\tilde{m}_{t+1})] \right\}$$

$$s.t.$$

$$\tilde{m}_{t+1} = l_{t+1} \cdot y_{t+1} + R(\tilde{m}_t - \tilde{c}_t)$$

which we do not have to recompute if τ changes. In the education period, for a given subsidy and a given preexisting level of human capital, the education investment problem reads:

$$V_0(x) = \max_{d} \left\{ \mathbb{E}_0[v_1(\tilde{m}_1)] \cdot ((1-\tau_1)h)^{1-\rho} \right\}$$

$$s.t.$$

$$\tilde{m}_1 = l_1 y_1 - R \cdot \frac{d}{(1-\tau)h}$$

$$h = x \cdot (d+g)^{\eta} \cdot \overline{h}$$

Has FOC:

$$d = \frac{\eta(1-\rho)}{R} \cdot \frac{\mathbb{E}_0[v_1(m_1)]}{\mathbb{E}_0[u'(c_1)]} \cdot (1-\tau_1) \cdot h - g$$

The general-equilibrium tax rate satisfies:

$$\tau = \frac{g}{\mathbb{E}[y] \cdot \overline{h} \cdot \sum_{j=1}^{r} \frac{\Psi_j}{\nu^j}}$$

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