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ESSAYS ON PENSION POLICY

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Doctoral Thesis in Economics

Copenhagen Business School
Department of Economics

Essays on Pension Policy

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

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Sincerely,
Tim D. Maurer

August 10, 2023

Summary

This thesis comprises three chapters on the effects of pension policies. The thesis starts with a theoretical chapter on the social welfare effects of fully-funded pensions in a model with accidental bequests. The second chapter offers a quantitative assessment of retirement reforms designed to achieve fiscal sustainability in the face of population ageing. The third chapter is empirical and documents the loss of redistribution in Danish public pensions when accounting for inequality in longevity.

Chapter I

The first chapter, entitled *Social Welfare Effects of Annuitization: The Case of Accidental Bequests*, is motivated by the trend among OECD countries to adopt fully-funded pensions to mandate saving in annuities. Against this background, I study the social welfare effects of saving in annuities in a small open model economy populated by two-period lived overlapping generations of families that are not altruistically linked. Annuities diversify longevity risk and offer an above-market return to survivors. Therefore, it is privately optimal to fully annuitize savings. On the other hand, increased saving in annuities reduces bequests left and received in equilibrium. These bequests represent transfers from the old to the young, for which there is a welfare case in a dynamically efficient economy. Consequently, full annuitization may not be socially optimal. I find that there exists a critical interest-rate threshold beyond which the costs associated with reducing accidental bequests (i.e., income received by the young) outweigh the aforementioned benefits of annuitization. When interest rates fall below this threshold, governments can achieve socially optimal allocations by directly mandating an interior share of savings to be invested in annuities. A government that instead chooses to mandate saving in annuities through fully-funded pensions cannot attain the same outcome, even when annuity markets are absent. Furthermore, I show that the social welfare implications of fully-funded pensions depend crucially on the distribution of accidental bequests. When accidental bequests are equally redistributed, fully-funded pensions can only improve social welfare if they are large enough to make agents borrowing constrained. However, if bequests are tied to families, fully-funded pensions can have positive social welfare effects, even when agents are not borrowing-constrained.

Chapter II

The second chapter, entitled *Population Aging, Public Finances, and Alternatives for Retirement Reform*, is written in collaboration with Frederik Bjørn Christensen. It is motivated by population ageing, which puts fiscal pressure on the pension systems of advanced economies. Given this context, we conduct counterfactual policy analysis to compare different retirement reforms designed to restore fiscal sustainability in the face of increasing longevity and decreasing fertility. As our main contribution, we consider a particular reform that uses fully-funded contributions as a means of lowering pay-as-you-go (PAYG) benefits indirectly through means testing. We compare this reform to three standard reforms: Increasing the retirement age, cutting public benefits, and raising taxes to finance increasing public pension expenditures. For the policy analysis, we develop a sophisticated structural life-cycle model incorporating a pension system with two pillars: a public PAYG scheme and a mandatory fully-funded scheme, which interact through means testing. Using the *Simulated Method of Moments*, we estimate all unobserved preference parameters by targeting Danish micro data on wealth and labour force participation over the life cycle. Our subsequent policy experiments show that increasing contributions to mandatory fully-funded pensions yields the highest welfare. Welfare gains arise because the fully-funded scheme gives access to otherwise missing fair annuities that insure against longevity risk and offer an above-market return to survivors. As a result, agents experience a positive wealth effect, which allows them to consume more and enjoy more leisure. Moreover, the expansion of the FF scheme limits the role of the return-dominated PAYG scheme. These positive welfare effects outweigh two negative effects related to the loss of income insurance through the public PAYG scheme and a crowding out of bequest income in equilibrium.

Chapter III

The third chapter, entitled *Redistribution in Public Pension Schemes: Evidence from Denmark*, also written with Frederik Bjørn Christensen, uses 41 years of register data and a microsimulation model to quantify how systematic inequality longevity limits redistribution in Danish public pensions. Our main contribution is to document redistribution among socioeconomic groups that are based on a so-called affluence measure. This measure is new to the literature on redistribution in public pensions and social security and combines income and wealth information to allocate individuals into socioeconomic groups. Using the affluence measure, we first estimate significant differences in mortality across these socioeconomic groups. Subsequently, we assess the extent of redistribution in the public pension system by computing and comparing the expected net present values of the implicit public pension contracts. To this end, we use full-population register data, which allows us to precisely estimate mortality rates and track a wide range of covariates over the individual life cycle. We focus on recently retired cohorts, for whom we employ a microsimulation that accounts for detailed tax and pension system components and takes historical and projected income and wealth data as inputs. Our analysis reveals a substantial loss of redistribution within the public pension system due to inequality in longevity. Notably, we find that the net present value of the implicit pension contract develops non-monotonically with affluence such that males in the middle affluence groups benefit more than the least affluent males. Meanwhile, only the top 30% of males have lower net present values than the least affluent males. Furthermore, females of specific affluence rank exhibit significantly higher net present values than similarly ranked males. An interesting finding also is that the affluence allocation mechanism matters for the estimated redistribution loss. When we conduct the same experiment using information on lagged income only, the observed redistribution loss due to inequality in longevity is smaller. Thus, 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.

Resumé

Denne afhandling består af tre kapitler om effekterne af pensionsreformer. Afhandlingen starter med et teoretisk kapitel om de samfundsmæssige velfærdseffekter af opsparingsbaserede pensioner i en model med utilsigtet arv. Det andet kapitel giver en kvantitativ vurdering af pensionsreformer, der er designet til at opnå finansiel holdbarhed i lyset af befolkningsaldring. Det tredje kapitel er empirisk og kvantificerer omfanget af omfordeling i den offentlige del af det danske pensionssystem, når der tages højde for ulighed i levetid.

Kapitel I

Det første kapitel, med titlen *Social Welfare Effects of Annuitization: The Case of Accidental Bequests*, er motiveret af tendensen blandt OECD-landene til at indføre opsparingsbaserede pensionsordninger. På den baggrund undersøger jeg de sociale velfærdseffekter af at spare op i livrenter i en lille åben, to-periode økonomi med overlappende generationer af familier, der ikke er altruistisk forbundet. På den ene side sænker livrenter levetidsrisikoen, og det er derfor individuelt optimalt at lade hele opsparingen bestå af livrenter. På den anden side reducerer øget opsparing i livrenter den arv, der overføres fra de ældre til de unge. I en økonomi, som er dynamisk efficient, vil der være et velfærdsargument for en sådan overførsel, men fuld annuitisering vil ikke altid samfundsmæssigt optimal. Jeg finder, at der eksisterer et kritisk renteniveau, hvor omkostningerne forbundet med at reducere den utilsigtede arv (dvs. indkomst modtaget af de unge) opvejer de førnævnte fordele ved annuitisering. Når renten falder under dette niveau, kan regeringer opnå socialt optimale fordelinger ved at bestemme andelen af opsparingen investeret i livrenter. En regering, der i stedet vælger at gennemtrumfe opsparing i livrenter gennem opsparingsbaserede pensioner, kan ikke opnå det samme resultat, selv når der ikke findes markeder for livrenter. Desuden viser jeg, at de sociale velfærdsimplikationer af opsparingsbaserede pensioner afhænger kritisk af fordelingen af utilsigtet arv. Når utilsigtet arv omfordeles ligeligt, kan opsparingsbaserede pensioner kun forbedre den sociale velfærd, hvis bidragene er store nok til at gøre agenterne lånebegrænsede. Men hvis arv er bundet op på familier, kan opsparingsbaserede pensioner have positive sociale velfærdseffekter, selv når agenterne ikke er lånebegrænsede.

Kapitel II

Det andet kapitel, med titlen *Population Aging, Public Finances, and Alternatives for Retirement Reform*, er skrevet sammen med Frederik Bjørn Christensen. Det er motiveret af befolkningsaldring, som lægger et finansielt pres på pensionssystemerne i avancerede økonomier. I denne sammenhæng gennemfører vi en kontrafaktisk analyse for at sammenligne forskellige pensionsreformer, der er designet til at genoprette den finansielle bæredygtighed givet stigende levetid og faldende fertilitet. Som vores vigtigste bidrag betragter vi en bestemt reform, der bruger opsparingsbaserede bidrag som et middel til at sænke pay-as-you-go (PAYG) ydelser indirekte gennem behovsvurderinger. Vi sammenligner denne reform med tre andre reformer: Forhøjelse af pensionsalderen, reduktion af offentlige ydelser og skattestigninger for at finansiere voksende offentlige pensionsudgifter. Til den politiske analyse udvikler vi en avanceret strukturel livscyklusmodel, der indbefatter et pensionssystem med to søjler: en offentlig PAYG-ordning og en obligatorisk, opsparingsbaseret ordning, som interagerer gennem behovsvurdering. Ved hjælp af den såkaldte Simulated Method of Moments estimerer vi alle ikke-observerede præferenceparametre ved at matche danske mikrodata om formue og arbejdsmarkedsdeltagelse over hele livsforløbet. Vores efterfølgende politiske eksperimenter viser, at øgede bidrag til obligatoriske opsparingsbaserede pensioner giver den højeste velfærd. Velfærdsgevinsten opstår, fordi den opsparingsbaserede ordning giver adgang til ellers fraværende retfærdige livrenter, der forsikrer mod levetidsrisiko og giver et afkast over markedet. Som et resultat oplever agenterne en positiv velstandseffekt, som giver dem mulighed for at forbruge mere og nyde mere fritid. Desuden begrænser udvidelsen af den opsparingsbaserede ordning den afkastdominerede PAYG-ordnings rolle. Disse positive velfærdseffekter opvejer to negative effekter relateret til tabet af indkomstforsikring gennem den offentlige PAYG-ordning og en fortrængning af arveindkomst i ligevægt.

Kapitel III

Det tredje kapitel med titlen *Redistribution in Public Pension Schemes: Evidence from Denmark*, som også er skrevet sammen med Frederik Bjørn Christensen, baserer sig på 41 års registerdata og bruger en mikrosimuleringsmodel til at kvantificere, hvordan systematisk ulighed i levetid begrænser omfordelingen i det offentlige, danske pensionssystem. Vores vigtigste bidrag er at dokumentere omfordelingen mellem socioøkonomiske grupper baseret på et såkaldt velstandsmål. Dette mål er nyt i litteraturen om omfordeling i offentlige pensioner og social sikring og kombinerer indkomst- og formueoplysninger for at opdele individer i socioøkonomiske grupper. Ved hjælp af velstandsmålet estimerer vi først signifikante forskelle i dødelighed på tværs af de socioøkonomiske grupper. Dernæst vurderer vi omfanget af omfordeling i det offentlige pensionssystem ved at beregne og sammenligne de forventede nettonutidsværdier af de implicitte offentlige pensionskontrakter. Til dette formål bruger vi registerdata for hele befolkningen, som giver os mulighed for præcist at estimere dødeligheden samt at spore en bred vifte af kovariater over den enkeltes livscyklus. Vi fokuserer på nyligt pensionerede kohorter, for hvem vi anvender en mikrosimuleringsmodel med detaljerede komponenter for skatte- og pensionssystemet, og som tager historiske og fremskrevne indkomst- og formuedata som input. Vores analyse viser et betydeligt tab af omfordeling inden for det offentlige pensionssystem grundet ulighed i levetid. Specielt finder vi, at nettonutidsværdien af den implicitte pensionskontrakt udvikler sig ikke-monotont med velstand, så mænd i de midterste velstandsgrupper drager større fordel end de mindst velstående mænd. Faktisk har kun de øverste 30% af mænd lavere nettonutidsværdier end de mindst velhavende mænd. Desuden har kvinder af en bestemt velstandsklasse betydeligt højere nettonutidsværdier end mænd i tilsvarende grupper. Et interessant resultat er også, at velstandsfordelingsmekanismen har betydning for det estimerede omfordelingstab. Når vi udfører det samme eksperiment ved kun at bruge information om indkomst, er det observerede omfordelingstab på grund af ulighed i levetid mindre. Derfor ville resultaterne fra anden forskning, der bruger fordeling efter indkomst eller uddannelse og rapporterer relativt små omfordelingstab, sandsynligvis være anderledes, hvis de havde brugt en mere informativ fordelingsmekanisme.

Contents

Introduction

This dissertation consists of three self-contained chapters on pension policy. While each chapter can be read independently, the topics they discuss overlap.

The first two chapters are motivated by population ageing putting budgetary pressure on the pay-as-you-go pension schemes of advanced economies. In such schemes, mandatory contributions from current workers finance retirees' benefits. Therefore, as expected lifetime increases and birth rates decline, governments increasingly struggle to guarantee adequate old-age benefits while maintaining sustainable finances. Governments have addressed this challenge by raising the statutory retirement age, increasing contributions, and lowering benefits. Moreover, some advanced economies are undertaking a fourth reform. This reform involves a shift from a dominant pay-as-you-go pension system towards a more balanced multi-pillar system, which includes a mandatory fully-funded pension scheme. In a fully-funded scheme, workers contribute to an individual market-based account, which can be annuitized or withdrawn as a lump sum at retirement. In this context, the OECD (2021) reports that out of 54 countries under surveillance, 20 have adopted such mandatory fully-funded defined contribution schemes.

Against this background, Chapter 1 studies the social welfare implication of annuitization of retirement savings through mandated fully-funded pension schemes. For the analysis, the chapter utilizes an analytically tractable overlapping generations model with non-altruistic families that face longevity risk. On the one hand, annuities are desirable because they offer longevity risk insurance and an above-market return to survivors. On the other hand, increased annuitization reduces accidental bequests left and received in equilibrium. These bequests constitute transfers from the old to the young, for which there is a welfare case in a dynamically efficient economy where the market return exceeds the economy's growth rate. Therefore, while it is privately optimal to annuitize all retirement savings, I show that this is excessive from a social welfare perspective.

Governments can implement socially optimal allocations by requiring agents to save exclusively in a portfolio with a pre-determined interior share invested in annuities. Governments that instead mandate annuities through fully-funded pensions cannot achieve the same. I prove this holds even when annuity markets are missing, and agents cannot undo the policy by borrowing against future pension benefits. This result comes about as fully-funded pensions only affect lifetime income but not the inter-temporal trade-offs because the pension benefits are lump-sum payments. Furthermore, I show that under the popular equal-bequest assumption and missing annuity markets, fully-funded pensions can only improve social welfare if they are large enough to push agents to their borrowing constraint. However, under the assumption of an unequal bequest distribution, which under the veil of ignorance, implies bequest income risk, I show that fully-funded pensions can improve social welfare even without pushing agents into the borrowing-constrained corner because they provide insurance against bequest income risk.

The findings of Chapter 1 mainly contribute to the literature that assesses the social welfare effects of mandated annuitization through fully-funded pensions. Most papers in this literature, including Hubbard and Judd, 1987, Imrohoroglu et al., 1995, Conesa and Krueger, 1999 and Hong and Ríos-Rull, 2007 among others, rely on computational models. I complement those quantitative papers by proving analytically under what conditions fully-funded pensions positively affect social welfare. A closely related paper also based on an analytically tractable model is Caliendo et al., 2014. This paper, however, focuses on the case in which the economy's growth rate equals the market return. For this special case, Caliendo et al. (2014) show that fully-funded pensions can achieve socially optimal allocations in the presence of a borrowing constraint. Chapter 1 proves that this is no longer true in the empirically more relevant case of dynamic efficiency, where the market return exceeds the economy's growth rate.

Chapter 2 assesses which pension reform designed to achieve fiscal sustainability in the face of an ageing population yields the best social welfare outcomes. Using counterfactual policy analysis, it tests the three common reforms of an increase in the statutory retirement age, a rise in contributions, and a reduction of benefits against the fourth reform of phasing in a mandatory fully-funded pension scheme. This phase-in can also alleviate fiscal pressure if the two pension schemes interact through means testing. That is if income from fully-funded pensions reduces public pay-as-you-go benefits. In this context, the OECD (2021) reports that 34 out of 38 OECD countries provide some means-tested pension benefit, which, on average, constitute 16% of gross average earnings. While the rise of fully-funded pensions has been studied, the interaction with the pay-as-you-go scheme through means testing has been overlooked. Chapter 2 fills this gap.

For the analysis, Chapter 2 develops a structural 71-period overlapping-generations model of a dynamically efficient small open economy, which is an extension of the two-period model in Chapter 1. It additionally incorporates tax-financed public pays-as-you-go pensions, endogenous retirement, uninsurable income risk, and large household heterogeneity. The novel feature of our model is that public pays-as-you-go pensions interact with fully funded pensions through a means-testing. Furthermore, the model is estimated to Danish micro data.

The main contribution of Chapter 2 is to show that expanding fully-funded pensions to indirectly lower public pensions yields higher social welfare than the three remaining reforms, which have previously been studied by De Nardi et al. (1999), Attanasio et al. (2007), Haan and Prowse (2014), and Laun et al. (2019). Among those three reforms, the analysis in Chapter 2 reveals that directly lowering public benefits outperforms hiking taxes and increasing the retirement age.

Social welfare gains from the fully-funded pensions scheme mainly arise as it gives access to otherwise missing fair annuities that offer longevity risk insurance and an above-market return. As an additional contribution to the literature, Chapter 2 carefully accounts for the accidental bequest channel studied in Chapter 1. Thus, the welfare gains of fully-funded pensions are mitigated by the social welfare costs of lowering accidental left and received in equilibrium.

Chapter 3 is motivated by another challenge that public pension scheme face, namely systematic inequality in longevity. This inequality threatens the typically intended redistribution in public pension schemes. The underlying mechanism at play is straightforward. Multiple studies, such as those by Olshansky et al. (2012), Kitagawa and Hauser (1973), and Chetty et al. (2016) have documented substantial socioeconomic inequality in longevity. With a universal statutory retirement age, this implies that the advantaged socioeconomic groups are expected to live longer on public pension benefits than others. While various research papers have addressed this concern, much of the focus has been on redistribution in US, where full population register data do not exist. Examples of such work include Garrett, 1995, Liebman, 2001, Whitehouse and Zaidi, 2008, Coronado et al., 2011, Auerbach et al., 2017, and Auerbach et al., 2019.

Based on this observation, Chapter 3 uses 41 years of micro data to document a significant loss of redistribution through Danish public pensions when carefully accounting for inequality in income and longevity. The analysis relies on a microsimulation model, which is applied to recently retired cohorts. The main contribution of the Chapter is to use a so-called affluence measure that combines income and wealth information to allocate individuals into socioeconomic groups. In contrast, the existing literature typically subdivides individuals based on averages of lagged income. The results of Chapter 3 show that affluence is a stronger separator of mortality than income. Furthermore, inequality in longevity subverts redistribution such that the worth of the implicit pension contract develops non-monotonically with affluence. That is, the implicit pension contract is worth more to the middle class than to the least and most affluent groups.

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Chapter 1

Social Welfare Effects of Annuitization: The Case of Accidental Bequests

Tim D. Maurer

Abstract

This paper studies the social welfare effects of saving in annuities in a small open model economy populated by two-period lived overlapping generations of non-altruistic families. On the one hand, annuities are desirable because they provide longevity risk insurance and an above-market return to survivors. However, increased annuitization lowers bequests left and received in equilibrium. These bequests represent transfers from the old to the young, for which there is a welfare case in a dynamically efficient economy. Therefore, while it is privately optimal to fully annuitize, I show that it is not socially optimal. Governments can implement socially optimal allocations by requiring agents to save exclusively in a portfolio with a pre-determined share invested in annuities. Governments that instead mandate annuities through fully-funded pensions cannot achieve the same. I prove that this holds even when annuity markets are missing, and agents cannot undo the policy by borrowing against future pension benefits. Finally, I show that fully-funded pensions become more desirable the more unequal accidental bequests are distributed.

1.1 Introduction

A well-known result of the standard life-cycle model is that non-altruistic people facing longevity risk should invest all their savings in annuities. The intuition behind this result established by Yaari (1965) is that lifetime annuities fully diversify the idiosyncratic longevity risk by making payments only to survivors. Annuities, therefore, offer a higher return than the market. Since Yaari's seminal contribution, several papers have assessed the individual annuity demand in less restrictive theoretical frameworks and confirm that considerable annuitization remains privately optimal (see, e.g., Davidoff et al., 2005).

Given these theoretical predictions, Modigliani (1986) drew the attention of policymakers to the so-called "annuitization puzzle", that is, the empirical fact that private annuity markets are very thin. After Modigliani's remark, numerous efforts have been made to explain this puzzle (see, e.g., Benartzi et al., 2011). These discussions implicitly support policies that implement high levels of annuitization. This notion, however, is based on a benefit-only assessment and neglects the potential social costs of annuitization. In a standard life-cycle model, increased annuitization lowers accidental bequests left and received in equilibrium. Such bequests represent transfers from the old to the young, for which there is a welfare case in a dynamically efficient economy (see Andersen and Gestsson, 2022). Consequently, the social welfare case for annuitization is not one-sided. It depends on how much the costs from reduced bequest income offset the gains from longevity risk hedging and above-market returns.

Against this background, I revisit the social welfare effects of annuitization by accounting for its costs and benefits. I am particularly interested in a cost-benefit analysis of mandated annuitization through fully-funded pension schemes. This emphasis is motivated by its policy relevance. Numerous governments have recently addressed budgetary pressure within public pension schemes through reforms that involve shifting from unfunded pension schemes with defined benefits to fully-funded pension schemes with defined contributions. The OECD (2021) reports that out of 54 countries under surveillance, 20 have adopted funded defined contribution pension plans.

I focus on small open economies and the empirically relevant case of dynamic efficiency in which the market return is greater than the economy's growth rate.[1] This constitutes an environment for which the social welfare implications of annuitization have been understudied. I use an analytical two-period model with overlapping generations (OLG) of non-altruistic families linked through accidental bequests. Prices in the model are exogenous. Agents are rational and face longevity risk. They work in the first period and retire in the second. Agents who die early (after the first period) may pass away with unclaimed

[1]For evidence supporting that most economies are dynamically efficient, see Abel et al., 1989 and Blanchard, 2019.

private savings that are left as accidental bequests and redistributed to the young. I begin by assuming that accidental bequests are anonymously and equally redistributed to the young. Thus, I abstract from links between parents and children, an assumption motivated by its popularity in quantitative macroeconomics using life-cycle OLG models.[2]

First, I show that in a dynamically efficient small open economy, an interest rate threshold exists above which the saving incentives and, consequently, the costs of crowding out bequest income become so high that they outweigh the benefits of saving in annuities. Below this threshold, I show that governments can implement socially optimal allocations by requiring agents to save exclusively in a portfolio with an interior share invested in annuities. This policy allows the government to directly determine the share of savings invested in annuities and, therefore, to improve the agents' inter-temporal choices (Euler equation). Mandated saving in annuities through fully-funded pensions, on the other hand, only affects lifetime income but not the inter-temporal trade-offs because pension benefits are paid lump-sum. Thus, I prove that a government that mandates annuities through fully-funded pensions cannot achieve the social optimum even when annuity markets are missing. Moreover, I demonstrate that fully-funded pensions harm welfare as long as borrowing constraints do not bind. However, I show that fully-funded pensions can improve social welfare at the borrowing-constrained corner. This is because, at the corner, fully-funded pensions increase lifetime income by mandating saving in the above-market return annuities without further reducing bequest income.

Then, I relax the equal-bequest assumption and, instead, assume a family-tied distribution of accidental bequests by linking children to their parents. Under the veil of ignorance, this more realistic assumption introduces individual bequest income risk, which arises due to the stochastic death of parents and parental savings that naturally vary over the life cycle. In this environment with an unequal bequest distribution, there is an additional social welfare case for saving in annuities because it reduces bequest income risk in equilibrium. Hence, I show that fully-funded pensions can improve social welfare under missing annuity markets even without forcing agents into the borrowing-constrained corner. This holds as long the interest rate is below a specific threshold that limits the desire for savings and, thus, the costs of reducing bequests through mandated annuitization.

Related Literature. This paper is related to different strands of literature. First, it contributes to the literature studying the individual welfare case of annuitization. A seminal contribution by Yaari (1965) showed that full annuitization of retirement savings is privately optimal because it eliminates survival risk from the savings decisions. Later work has challenged this result in settings with bequest motives (see, e.g., Lockwood, 2012), different types of risks (see, e.g., Reichling and Smetters, 2015), behavioral factors (see,

[2]See, e.g., Hubbard and Judd, 1987; Imrohoroglu et al., 1995; Conesa and Krueger, 1999; Huggett and Ventura, 1999; Hong and Ríos-Rull, 2007; Nishiyama and Smetters, 2007; Eggertsson et al., 2019.

e.g., Schreiber and Weber, 2016) and imperfect annuity markets (see, e.g., Finkelstein and Poterba, 2004; Davidoff et al., 2005). Rather than focusing on individual welfare, I assess the social welfare case of annuitization by accounting for the fact that increased annuitization implies reduced bequests left and received in equilibrium.

Second, the paper contributes to the literature using OLG models to assess the social welfare effects of mandated annuitization through unfunded and fully-funded pensions. Many papers within this literature, including Hubbard and Judd, 1987, Imrohoroglu et al., 1995, Conesa and Krueger, 1999, and Hong and Ríos-Rull, 2007 among others, provide a quantitative assessment of the usefulness of mandated lifetime annuities in closed economies with incomplete markets and different types of risks. I complement those quantitative studies of closed economies by illustrating analytically under what conditions fully-funded pensions positively affect social welfare in a small open economy.

The paper closest to mine is Caliendo et al., 2014, which studies the social welfare effects of actuarially fair fully-funded pensions in an analytical model of a small open economy. For tractability, the authors assume that the economy's growth rate equals the market return. In this special case, full annuitization is privately and socially optimal because no social costs are associated with crowding out accidental bequests. Consequently, they show that under missing annuity markets, fully-funded pensions cannot affect social welfare if borrowing constraints do not bind but can implement the socially optimal allocations if they bind. I contribute by studying the empirically more relevant case of dynamic efficiency where the market return exceeds the economy's growth rate. In this case, I demonstrate that fully-funded pensions harm welfare if borrowing constraints do not bind and cannot implement the socially optimal allocations if they bind. Moreover, I show that under some conditions, it is optimal not to annuitize any retirement savings even if mandated through optimal policy and not through fully-funded pensions offering lump-sum transfers that do not improve intertemporal trade-offs.

Finally, my paper relates to a small literature using computational OLG models with family ties that introduce bequest income risk (see, e.g., De Nardi and Yang, 2014; Yang, 2013; Cottle Hunt and Caliendo, 2022). Within this literature, the paper by Cottle Hunt and Caliendo (2022) is closely related to mine. They model family-tied bequest in a continuous time model. Rather than focusing on the welfare effect in equilibrium, as I do, they apply a sequential analysis to show that fully-funded social security in the US improves ex-ante expected utility by 3.4% of lifetime consumption for the second generation after introduction.

The remainder of the paper is organised as follows. Section 1.2 presents the model and the analysis. Within Section 1.2, Subsection 1.2.1 lays out the primitives of the model. Subsection 1.2.2 discusses the decision rules. Subsections 1.2.3 and 1.2.4 present the dynamics and the equilibrium under laissez-faire. Subsection 1.2.5 discusses the socially optimal allocation. In Subsection 1.2.6, I study the social welfare effects of fully-funded pensions. Finally, Section 1.3 concludes. The appendices at the end of the paper provide supporting information.

1.2 The Model

1.2.1 Primitives

Time in the model is discrete and indexed by t. In each period $t = 1, 2, .., \infty.$, a continuum of identical agents with unit mass is born. The economy's growth rate is zero as there is no population and productivity growth. Agents can live for up to two periods indexed by y (young) and o (old). The individual survival probability is $\psi \in (0, 1)$, which due to the Law of Large Numbers coincides with the fraction of young surviving into old age. Agents work and receive labor income w in the first period and retire in the second.

The standard asset in the model is a one-period riskless bond denoted a^B, which pays a gross interest rate, i.e., a market return R. The second type of asset is an annuity. I assume that annuity markets are competitive such that annuities a^A pay an actuarially fair return of

$$R^A = \frac{R}{\psi} > R.$$

The annuity return R^A is higher than the market return on bonds R because it is only paid to those who survive to the second period.

Assumption 1: (Dynamic efficiency)

$$R > 1$$

implies dynamic efficiency since there is no population and productivity growth (see Abel et al., 1989). The prices w and R are exogenous, which amounts to assuming a small open economy that takes the world interest rate and wage.

I assume that agents have no altruistic motives and suffer disutilities from work and death that are constant and disregarded for simplicity. Thus, the lifetime utility of agents born at time t is

$$U_t = u\left(c_t^y\right) + \beta\psi u\left(c_t^o\right)$$

where c_t^y $\left(c_t^o\right)$ is consumption when young (old), β is the subjective discount rate with $0 < \beta < 1$. The continuously differentiable utility function $u\left(c\right)$ fulfills all standard properties such as $u'(c) > 0, u''(c) < 0$ and the Inada conditions. Furthermore, I assume that U_t is homothetic.[3]

The budget constraint of the young is

$$c_t^y = w + b_t - a_t,$$

where b_t is the bequest income and a_t represent savings that equal the sum of asset holdings in annuities a_t^A and bonds a_t^B such that $a_t = a_t^A + a_t^B$. With a share $\lambda \in [0,1]$ of total savings a_t invested in annuities and a share $1-\lambda$ invested in bonds, the asset holdings are

$$\begin{aligned} a_t^A &= \lambda a_t \\ a_t^B &= (1-\lambda)\, a_t. \end{aligned}$$

This implies that the agents' savings a_t pay a gross return of

$$\overline{R} = \lambda R^A + (1-\lambda) R = R\left(1 - \lambda + \frac{\lambda}{\psi}\right),$$

which reduces to the actuarially fair annuity return $R^A = R/\psi$ under full annuitization ($\lambda = 1$) and to the bond return R under no annuitization ($\lambda = 0$). Hence, for a given λ, the budget constraint when old is

$$\begin{aligned} c_t^o &= \overline{R} a_t \\ &= R\left(1 - \lambda + \frac{\lambda}{\psi}\right) a_t. \end{aligned}$$

I assume that unclaimed savings in bonds of the agents who die early are equally and anonymously redistributed to the young as accidental bequests. Thus, accidental bequests of young agents born at time t yield

$$b_t = R(1-\psi)\, a_{t-1}^B \tag{1.1}$$
$$\quad = R(1-\psi)(1-\lambda)\, a_{t-1} \tag{1.2}$$

As mentioned in Section 1.1, this assumption of equal bequests is motivated by its popularity in the literature but will be relaxed later in the paper.

It is important to note that under existing private annuity markets, agents can optimally choose their share λ of savings to be invested in annuities. However, if private annuity markets are missing, agents can only access bonds a and $\lambda = 0$. In Subsection 1.2.5, I assume that a benevolent government controls λ. This implies that the government can force agents to save exclusively in a portfolio with a pre-determined asset allocation and a weight λ on annuities. In what follows, I thus present the agents' decision rules and the model's dynamics and equilibrium for a general $\lambda \in [0,1]$.

[3] The assumption of homothetic preferences allows me to prove the existence of a steady state. For $U \equiv U(c^y, c^o)$ to be homothetic there must exist a monotonic function $h : \mathbb{R} \to \mathbb{R}$ and a homogeneous function $f(c^y, c^o)$, so that $U(c^y, c^o) = h(f(c^y, c^o))$.

1.2.2 Decision Rules

For a given annuity share λ and bequest b_t, agents born in period t solve the following problem

$$\max_{c_t^y, c_t^o, a_t} U_t = u\left(c_t^y\right) + \beta\psi u\left(c_t^o\right) \tag{1.3}$$

$$s.t.$$

$$c_t^y = w + b_t - a_t \tag{1.4}$$

$$c_t^o = \overline{R}a_t. \tag{1.5}$$

The optimal savings level is determined by the Euler equation (first-order condition)

$$u'\left(c_t^y\right) = \beta\psi\overline{R}u'\left(c_t^o\right) \tag{1.6}$$

$$u'\left(w + b_t - a_t\right) = \beta\psi\overline{R}u'\left(\overline{R}a_t\right) \tag{1.7}$$

For later use, note that the agents' savings reaction to an increase in the interest rate reads

$$\frac{\partial a_t}{\partial R} = -\beta\psi\left(1 - \lambda + \frac{\lambda}{\psi}\right)u'\left(c_t^o\right)\left[\frac{1-\phi}{u''\left(c_t^y\right) + \beta\psi\overline{R}^2 u''\left(c_t^o\right)}\right]. \tag{1.8}$$

Thus, $\frac{\partial a_t}{\partial R} \geq 0$ holds when the relative risk aversion is less or equal to one

Assumption 2: (Relative risk aversion)

$$\phi \equiv -c\frac{u''(c)}{u'(c)} \leq 1,$$

which is a condition that is standard in the literature (see, e.g., Andersen and Bhattacharya, 2013). Henceforth, I assume that this condition holds.[4]

1.2.3 Dynamics and Equilibrium

The homotheticity of U_t implies that consumption and saving scales proportionally in wealth W_t (see Simon, Blume, et al., 1994), which is defined by the net present value of lifetime income and equals

$$W_t = w + b_t.$$

Consequently, there exists a share $\mu^*\left(R, \beta, \psi, \phi, \lambda\right) \equiv \mu^*$ of wealth W_t that is spent on c^y such that the allocation $\left[c_t^{y^*} = \mu^* W_t, a_t^* = \left(1-\mu^*\right)W_t, c_t^{o^*} = \left(1-\mu^*\right)RW_t\right]$ solves the

[4] Note that Assumption 2 implies that the substitution effect of an increase in R, which increases the reward to saving, dominates the income effect that decreases the savings needed to reach a given consumption level as old.

agents' problem in equations (1.3)-(1.5). The Inada conditions ensure that $a_t^* > 0$ and, thus, $0 < \mu^* < 1$. Hence, the law of motion of bequest in equation (1.1) can be written as

$$\begin{aligned} b_t &= R\,(1-\psi)\,(1-\lambda)\,a_t^* \\ &= R\,(1-\psi)\,(1-\lambda)\,(1-\mu^*)\,(w+b_{t-1})\,. \end{aligned} \tag{1.9}$$

Definition: *An equilibrium in this economy is characterized by an allocation* $\left[c_t^{y^*}, c_t^{o^*}, a_t^*\right]$ *that solves the agents' problem in equations (1.3)-(1.5), and accidental bequests* b_t^* *such that the law of motion in equation (1.11) holds for all* $t = 1, 2, .., \infty$.

For $\lambda > 0$, the dynamics of bequests in equation (1.9) crucially depend on the interest rate R. To see this, consider an increase in R at the beginning of period t. From equation (1.8) and Assumption 2, we know that agents of the generation born in t would react to a higher R by increasing their savings a_t. Given equation (1.9), these increased savings a_t would lead to higher accidental bequests b_{t+1} for the generation born in $t+1$. Agents of generation $t+1$ would react to their increased bequest income b_{t+1} by increasing their own savings a_{t+1} as

$$\frac{\partial a_{t+1}}{\partial b_{t+1}} = \frac{u''\left(c_{t+1}^y\right)}{u''\left(c_{t+1}^y\right) + \beta\psi\overline{R}^2 u''\left(c_{t+1}^o\right)} > 0. \tag{1.10}$$

These higher savings then increase bequest income for the next generation. For a high interest rate, this could lead to explosive dynamics, in which savings and accidental bequests and, thus, wealth in the economy are ever-increasing. A sufficient condition for convergence of accidental bequests determined by equation (1.9) is

Assumption 3: (Convergence)

$$R\,(1-\psi) < 1,$$

which I assume henceforth holds.[5] To see this, we can write the law of motion in equation (1.11) forward for an initial level of bequest b_o such that

$$b_t = w\sum_{i=1}^{t}\left[R\,(1-\lambda)\,(1-\psi)\,(1-\mu^*)\right]^i + \left[R\,(1-\lambda)\,(1-\psi)\,(1-\mu^*)\right]^t b_0,$$

which for $t \to \infty$ and under Assumption 3 converges to

$$b_\infty = b = \frac{R\,(1-\lambda)\,(1-\psi)\,(1-\mu^*)}{1-R\,(1-\lambda)\,(1-\psi)\,(1-\mu^*)}w.$$

[5] Note that explosive dynamics of accidental bequests would never arise in a closed economy, in which the interest rate is endogenous and negatively depends on aggregate savings.

Hence, for any starting point b_o and for a given λ, the economy converges to a unique steady state determined by (variables without a subscript t denote variables in steady state)

$$\begin{aligned} a &= (1-\mu^*)\,(w+b_\infty) \\ c^y &= w + b_\infty - a \\ c^o &= \mu^*\,(w+b_\infty)\,\overline{R}. \end{aligned}$$

1.2.4 The Laissez-faire Economy

Next, I further discuss the market economy in the absence of any government. I consider the cases of existing and missing private annuity markets.

Existing Private Annuity Markets

Under existing private annuity markets, agents have access to bonds and annuities and can, thus, optimally choose the share λ of their savings a_t to be invested in annuities. The effect of an increase in λ on individual lifetime utility is given by

$$\frac{\partial U_t}{\partial \lambda} = R\left(\frac{1}{\psi} - 1\right) a_t \beta \psi u'\left(c_t^o\right) > 0.$$

Since $\dfrac{\partial U_t}{\partial \lambda} > 0$, it is privately optimal to fully annuitize all retirement savings and, thus, to choose $\lambda = 1$. This is a cornerstone result in pension economics, which goes back to Yaari (1965) and arises as full annuitization eliminates the survival risk from the savings decisions. To see this, we can evaluate the Euler equation in (1.6) for $\lambda = 1$, which reads

$$u'\left(c_t^y\right) = \beta R u'\left(c_t^o\right),$$

and proves to be independent of the survival probability ψ. Furthermore, annuities offer the agents an above-market return $R^A = R/\psi > R$ as the unclaimed savings in annuities are redistributed to survivors within a cohort. Under full annuitization, this implies no accidental bequests (see equation (1.9) evaluated at $\lambda = 1$) such that

$$b_t = 0 \quad \forall t.$$

Missing Annuity Markets

Under missing annuity markets, the only assets available to the agents are bonds. Hence, all savings are in bonds such that $a_t = a_t^B$ as $\lambda = 0$. In this case, the intertemporal trade-off defined by the Euler equation in (1.6) reads

$$u'\left(c_t^y\right) = \beta \psi R u'\left(c_t^o\right)$$

and now depends on the survival probability ψ. The law of motion of accidental bequests now reads

$$
\begin{aligned}
b_t &= R(1-\psi)\, a_{t-1}^A && (1.11)\\
&= R(1-\psi)(1-\mu^*)(w+b_{t-1}), && (1.12)
\end{aligned}
$$

where the Inada conditions ensure that $b_t > 0$ for all t. For $t \to \infty$ the above accidental bequests converge to

$$b_\infty = b = \frac{R(1-\psi)(1-\mu^*)}{1-R(1-\psi)(1-\mu^*)} w > 0.$$

Note that from the perspective of agents born at time t, their unclaimed savings in bonds go unspent, which constitutes an inefficiency for them. However, for the next generation born in time $t+1$, the unclaimed savings of generation t represent accidental bequest income they only receive because generation t had no access to annuities. In a dynamically efficient economy, there exists a social welfare case for such transfers from old to young (accidental bequests) because \$1 contemporaneously transferred from an old to a young agent has an implicit cost of \$1 to the old while the young earn a return of $R > 1$. Hence, a benevolent government balances the benefits of saving in annuities, i.e., longevity risk insurance and above-market returns, with its social cost of crowding out accidental bequests in equilibrium.

1.2.5 Socially Optimal Annuitization

Next, I study the problem of a benevolent government that seeks to maximize social welfare measured by lifetime utility in steady state. In the model, the socially optimal level of annuitization can be achieved by a government that directly mandates a share λ of savings a to be invested in annuities. This is, the government only allows savings in a portfolio with a pre-determined asset allocation, where the weight on annuities is λ and $1-\lambda$ on bonds.

Under existing annuity markets, mandating λ is equivalent to taxing the "mortality premium" of annuities, i.e., the positive return difference between annuities and bonds $\left(R^A - R\right)$, at rate T_A, the revenue of which is distributed to the young. To see this, note that the tax rate $T_A = (1-\lambda)$ implies the same after-tax return on savings as under policy λ, which yields

$$R + \left[R^A - R\right](1-T_A) = R\left(1-\lambda+\frac{\lambda}{\psi}\right) = \overline{R}.$$

Also, the revenue directed to the young under policy T_A equals accidental bequests under policy λ as

$$\left[\frac{R}{\psi} - R\right] T_A \psi a_{t-1} = R(1-\lambda)(1-\psi)\, a_{t-1} = b_t.$$

Social welfare, defined by lifetime utility in steady state, is

$$\begin{aligned}\Omega(\lambda) &= u(c^y) + \beta\psi u(c^o) \\ &= u(w + b - a) + \beta\psi u(\overline{R}a)\end{aligned}$$

with steady-state accidental bequests that equal

$$b = R(1-\psi)(1-\lambda)a. \tag{1.13}$$

The socially optimal policy λ is defined by (after using equation (1.6))

$$\frac{\partial\Omega(\lambda)}{\partial\lambda} = \beta\psi R u'(c^o)\left((1-\psi)\left(\frac{1}{\psi} - \overline{R}\right)a + (1-\lambda)(1-\psi)\overline{R}\frac{\partial a}{\partial\lambda}\right) = 0.$$

Proposition 1: *In a model with accidental bequests, a directly mandated interior share $(0 < \lambda_{so} < 1)$ of retirement savings in annuities is socially optimal if the interest rate R is below a threshold $\hat{R}_{so} > 1$.*

Corollary 1: *In a model with accidental bequests, there exists an interest rate threshold $\hat{R}_{so} > 1$ above which it is socially optimal not to annuitize any retirement savings.*

Proof (of Proposition 1 and Corollary 1)**:** Consider the marginal social value of a change in λ when all retirement savings are in annuities, i.e., $\lambda = 1$

$$\frac{\partial\Omega(\lambda)}{\partial\lambda}|_{\lambda=1} = \beta\psi R u'(c^o)\left((1-\psi)\frac{1}{\psi}(1-R)a\right) < 0.$$

As $\frac{\partial\Omega}{\partial\lambda}|_{\lambda=1} < 0$, we can conclude that while full annuitization is privately optimal, it is not socially optimal.[6] Next, consider the marginal social value when no savings are in annuities

$$\frac{\partial\Omega(\lambda)}{\partial\lambda}|_{\lambda=0} = \beta\psi R u'(c^o)\left((1-\psi)\left(\frac{1}{\psi} - R\right)a + (1-\psi)\overline{R}\frac{\partial a}{\partial\lambda}|_{\lambda=0}\right). \tag{1.14}$$

Using

$$\frac{\partial a}{\partial\lambda} = -R(1-\psi)\frac{\left(u''(c^y) + \beta\overline{R}u''(c^o)\right)a + \beta u'(c^o)}{u''(c^y)\left[1 - R(1-\psi)(1-\lambda)\right] + \beta\psi\overline{R}^2 u''(c^o)}$$

and some basic algebra, equation (1.14) simplifies to

$$\frac{\partial\Omega(\lambda)}{\partial\lambda}|_{\lambda=0} = -\frac{R\beta^3(1-\psi)\psi^2\left(u'(c^o)\right)^2}{u''(c^y)\left[1 - R(1-\psi)\right] + \beta\psi R^2 u''(c^o)}\mathcal{B},$$

[6]This result has been established by Andersen and Gestsson (2022). However, they do not investigate under what condition some annuitization is optimal in a small open economy.

where $\mathcal{B} \equiv R^2 (1-\psi) + (1-R)\,\phi\,(c^o/c^y + R)$ defines the sign of $\left(\frac{\Omega(\lambda)}{\partial\lambda}|_{\lambda=0}\right)$. As

$$\lim_{R\to 1} \mathcal{B} > 0 \implies \lim_{R\to 1} \frac{\partial\Omega}{\partial\lambda}|_{\lambda=0} > 0,$$

we can conclude that there exists an interest rate threshold $\hat{R}_{so} > 1$ such that

$$\frac{\partial\Omega(\lambda)}{\partial\lambda}|_{\lambda=0} = \begin{cases} > 0 & R < \hat{R}_{so} \\ = 0 & R = \hat{R}_{so} \\ < 0 & R > \hat{R}_{so} \end{cases}.$$

The result $\frac{\Omega(\lambda)}{\partial\lambda}|_{\lambda=1} < 0$ together with $\frac{\Omega(\lambda)}{\partial\lambda}|_{\lambda=0} > 0$ for $R < \hat{R}_{so}$ proves Proposition 1. The result $\frac{\Omega(\lambda)}{\partial\lambda}|_{\lambda=0} < 0$ for $R > \hat{R}_{so}$ proves Corollary 1. □

For intuition behind Proposition 1 and Corollary 1, note the positive response of steady-state savings to an increase in the interest rate given by

$$\frac{\partial a}{\partial R} = -\frac{\left(1-\lambda+\frac{\lambda}{\psi}\right)\beta\psi u'(c^o)(1-\phi) - (1-\lambda)(1-\psi)\,a u''(c^y)}{[1-R(1-\lambda)(1-\psi)]\,u''(c^y) + \beta\psi\overline{R}^2 u''(c^o)} > 0,$$

which implies that accidental bequests increase in the interest rate as

$$\frac{\partial b}{\partial R} = (1-\psi)(1-\lambda)\left[a + \frac{\partial a}{\partial R}\right] > 0.$$

Furthermore, notice that the higher accidental bequests, the greater the cost of saving in annuities that crowds out the accidental bequest income. Consequently, if the interest rate R is higher than the threshold $\hat{R}_{so}$, the social costs of crowding out accidental bequest are so high that they outweigh the gains of saving in return-dominant annuities. In turn, if the interest rate R is smaller than $\hat{R}_{so}$, the welfare gains of saving in return-dominant annuities outweigh the social costs of crowding out some accidental bequests.

Propositions 1 and Corollary 1 can alternatively be interpreted as: In a model with accidental bequests and existing private annuity markets, full taxation of the "mortality premium" of annuities ($T_A = 1$) is socially optimal if $R > \hat{R}_{so}$ and an interior tax rate ($0 < T_A < 1$) on the "mortality premium" is socially optimal if $R < \hat{R}_{so}$.

At this point, it is instructive to take stock of what is known and lay out the path for where I am heading. I have shown that there exists an interest rate threshold above which the cost of reducing accidental bequests outweighs the benefits of annuitization. In this case, it is socially optimal for a benevolent government of small open economies not to mandate saving in annuities. If private annuity markets exist, the government should fully tax the "mortality premium" of annuities and redistribute the tax revenue to the young.

Suppose the interest rate is below a specific threshold. In that case, governments of small open economies with missing private annuity markets can implement the socially optimal allocations by directly mandating an interior share ($0 < \lambda_{so} < 1$) of savings to be invested in annuities. This can be achieved by requiring agents to save exclusively in a portfolio with a pre-determined interior share λ_{so} invested in annuities.

In practice, however, it may not be feasible for governments to directly mandate an annuity share λ of retirement savings. In fact, governments of advanced economies typically only indirectly affect the share of savings invested in annuities by mandating annuity benefits through an unfunded or fully-funded pension system. In the next section, I thus analyze the case of a government that needs to use fully-funded pensions to provide annuities and, hence, cannot directly mandate a share λ of savings to be invested in annuities. It is well-known that fully-funded pensions cannot improve social welfare if agents already have access to private annuity markets (see Eckstein et al., 1985 and Abel, 1986). Hence, I am studying the social welfare effects of fully-funded pensions under missing annuity markets. I do not explicitly model the reason for the absence of private annuity markets. However, the assumption of missing annuity markets may be appropriate, given that very few people privately buy annuities (see Benartzi et al., 2011 and Pashchenko, 2013).

1.2.6 Fully-funded Pensions

In this section, I analyze the social welfare effects of mandated fully-funded pensions in an economy without private annuity markets. I now assume that the benevolent government can only give agents access to annuities through a fully-funded pension system. In this system, the government mandates a fully-funded pension tax τ_t for young agents (with $0 < \tau_t < b_t + w$). In return, agents born in period t receive a fully-funded actuarially fair pension benefit f_{t+1} when old. Given the gross interest rate R, the pension benefit yields

$$f_t = R^A \tau_{t-1} = \frac{R}{\psi} \tau_{t-1}. \tag{1.15}$$

Following the literature on pension economics, I impose a non-negativity constraint on private savings, i.e., $a_t \geq 0$ (see, e.g., Andersen et al., 2021). Hence, in line with the legislation of many countries, agents cannot borrow against future pension income f_{t+1}. Note that under missing annuity markets, all private savings are invested in bonds, i.e., $a_t = a_t^B$, which pays the return R. Thus, agents born in period t solve the following problem

$$\max_{c_t^y, c_t^o, a_t \geq 0} U_t = u\left(c_t^y\right) + \beta\psi u\left(c_t^o\right) \tag{1.16}$$

$$s.t.$$

$$c_t^y = w + b_t - \tau_t - a_t \tag{1.17}$$

$$c_t^o = Ra_t + f_{t+1}. \tag{1.18}$$

The lifetime budget constraint yields

$$c_t^y + \frac{c_t^o}{R} = w + b_t + \left(\frac{1}{\psi} - 1\right)\tau_t$$

and illustrates that the fully-funded pension tax τ affects the present value of lifetime income. However, by mandating τ_t, and therefore a lump-sum annuity benefit f_{t+1}, the government cannot affect the intertemporal trade-off defined by the Euler equation

$$u'\left(c_t^y\right) = R\beta\psi u'\left(c_t^o\right), \tag{1.19}$$

which at the zero private saving corner reads

$$u'\left(c_t^y\right) > R\beta\psi u'\left(c_t^o\right).$$

An increase in fully-funded pension contributions τ_t crowds out private savings a_t. In general, I find that

$$\frac{\partial a_t}{\partial \tau_t} = -\frac{u''\left(c_t^y\right) + \beta R^2 u''\left(c_t^o\right)}{u''\left(c_t^y\right) + \beta\psi R^2 u''\left(c_t^o\right)} =< -1 \quad \text{for } a_t > 0 \tag{1.20}$$

implying that

$$\frac{\partial c_t^o}{\partial \tau_t} = R\left(1 - \psi\right)\frac{u''\left(c_t^y\right)}{\psi u''\left(c_t^y\right) + \beta\psi^2 R^2 u''\left(c_t^o\right)} > 0 \text{ for } a_t > 0.$$

Fully-funded pensions supplement the agent's private retirement savings in bonds a_t and provide access to above-market return assets. Agents realise that and respond by lowering their own savings a_t as mandated savings τ_t in annuities increase. As the mandated fully-funded saving pays a higher return than private saving, agents cut their private savings more than one-for-one – cf. eq. (1.20) – in response to an increase in the fully-funded pension contribution τ. This illustrates that from an individual's perspective, agents experience a positive income effect from mandated savings in annuities, which leads to an increase in their lifetime income and consumption. Consequently, the effect of a change in fully-funded pensions contributions τ_t on individual lifetime utility

$$\frac{\partial U_t}{\partial \tau_t} = u'\left(c_t^y\right)\left(-1 - \frac{\partial a_t}{\partial \tau_t}\right) + \beta\psi u'\left(c_0^o\right)\left(R\frac{\partial a}{\partial \tau} + R\frac{1}{\psi}\right),$$

which using the Euler equation (1.19) simplifies to

$$\frac{\partial U_t}{\partial \tau_t} = \beta\psi R u'\left(c_t^o\right)\left(\frac{1}{\psi} - 1\right) > 0 \text{ for } a_t > 0.$$

As $\frac{\partial U_t}{\partial \tau_t}$ for $a_t > 0$, full annuitization of retirement savings through a fully-funded pension scheme is privately optimal.

Can fully-funded pensions implement the socially optimal allocation? After proving that full annuitization is privately optimal, it is interesting to study whether it is socially optimal. Social welfare, i.e., lifetime utility in steady-state, the government aims to maximize by setting τ yields

$$\begin{aligned}\Omega(\tau) &= u\left(c^y\right) + \beta\psi u\left(c^o\right) \\ &= u\left(w + b - \tau - a\right) + \beta\psi u\left(Ra + f\right),\end{aligned}$$

where steady-state accidental bequests equal

$$b = R(1-\psi)\,a. \tag{1.21}$$

Definition: *A steady-state equilibrium in an economy with a government that sets policy* τ *is characterized by allocations* $\left[c^{y^*}, c^{o^*}, a^{y^*}\right]$ *that solve the agents' problem in equations (1.16)-(1.18), and aggregate bequests* b^* *such that equations (1.15) and (1.21) hold.*[7]

Steady-state savings a are determined by

$$\begin{aligned}u'\left(w + b - a - \tau\right) &= \beta\psi R u'\left(Ra + f\right) \\ u'\left(w + R(1-\psi)\,a - a - \tau\right) &= \beta\psi R u'\left(Ra + f\right)\end{aligned}$$

and crowded out by fully-funded pension contributions as

$$\frac{\partial a}{\partial \tau} = -\frac{u''\left(c^y\right) + \beta R^2 u''\left(c^o\right)}{\left[1 - R(1-\psi)\right]u''\left(c^y\right) + \beta\psi R^2 u''\left(c^o\right)} < -1, \tag{1.22}$$

where Assumption 3 rules out the implausible case for which fully-funded pensions lead to a wealth effect that increases savings and bequests in steady state. The response of steady-state bequest to an increase in pension contribution is negative and governed by

$$\frac{\partial b}{\partial \tau} = R(1-\psi)\frac{\partial a}{\partial \tau} = -R(1-\psi)\frac{u''\left(c^y\right) + \beta R^2 u''\left(c^o\right)}{u''\left(c^y\right)\left[1 - R(1-\psi)\right] + \beta\psi R^2 u''\left(c^o\right)} < 0.$$

Thus, in equilibrium, pension contributions crowd out bequests representing transfers from the old to the young, for which there is a welfare case in a dynamically efficient economy ($R > 1$). While fully-funded pensions provide longevity risk insurance and a higher return than bonds, they lower bequests left and received in equilibrium. The benevolent government, thus, conducts a cost-benefit analysis of annuitization through fully-funded pensions.

[7] In Appendix A, I prove the existence of a unique steady-state equilibrium, which this economy converges to.

Proposition 2: *In a model with equal accidental bequests, fully-funded pensions harm social welfare at an interior solution (positive private savings $a > 0$).*

From the above proposition directly follows that fully-funded pensions can only improve social welfare if they force agents to the zero-savings corner.

Corollary 2 (of Proposition 2)**:** *In a model with equal accidental bequests, a necessary condition for fully-funded pensions to improve social welfare is that they are generous enough to make agents borrowing constrained.*

Proof (of Proposition 2 and Corollary 2)**:** The response of social welfare to a change in the fully-funded pension tax τ is

$$\frac{\partial \Omega(\tau)}{\partial \tau} = u'(c^y)\left(-1 + R(1-\psi)\frac{\partial a}{\partial \tau} - \frac{\partial a}{\partial \tau}\right) + \beta\psi u'(c^o)\left(R\frac{\partial a}{\partial \tau} + \frac{R}{\psi}\right). \tag{1.23}$$

At an interior solution, the Euler equation in (1.19) holds. This allows to simplify equation (1.23) to

$$\frac{\partial \Omega(\tau)}{\partial \tau} = (1-R)(1-\psi)u'(c^y)\left(\frac{u''(c^y) + \beta\psi u''(c^o)}{u''(c^y)[1 - R(1-\psi)] + \beta\psi R^2 u''(c^o)}\right) < 0 \text{ for } a_t > 0, \tag{1.24}$$

which proves that fully-funded pensions harm welfare at interior solutions. □

Because Proposition 1 shows that full annuitization is not socially optimal, the condition that full annuitization of retirement savings through mandated fully-funded pensions is necessary to implement social welfare improvements implies that fully-funded pensions cannot achieve the socially optimal level of annuitization.

Proposition 3: *Fully-funded pensions cannot implement socially optimal allocations in a model with equal accidental bequests.*

Proof: First, consider the case of $R < \hat{R}_{so}$ for which a directly mandated interior share ($0 < \lambda_{so} < 1$) of saving in annuities is socially optimal. In this case, the socially optimal allocation $\left[c^y_{so}, c^o_{so}, a^\lambda_{so}\right]$ is defined by the following Euler equation

$$u'(c^y_{so}) = \left(1 - \lambda_{so} + \frac{\lambda_{so}}{\psi}\right) R\beta\psi u'(c^o_{so})$$
$$u'\left(w - [1 - R(1-\lambda_{so})(1-\psi)]\, a^\lambda_{so}\right) = R\left(1 - \lambda_{so} + \frac{\lambda_{so}}{\psi}\right)\beta\psi u'\left(R\left(1 - \lambda_{so} + \frac{\lambda_{so}}{\psi}\right)a^\lambda_{so}\right).$$

Next, consider a $\tau_\prime$ such that

$$u'(c^y_\prime) = R\left(1 - \lambda_{so} + \frac{\lambda_{so}}{\psi}\right)\beta\psi u'(c^o_\prime)$$
$$u'(w - \tau_\prime) = R\left(1 - \lambda_{so} + \frac{\lambda_{so}}{\psi}\right)\beta\psi u'\left(\frac{R}{\psi}\tau_\prime\right),$$

where the Inada conditions ensure that there exists a $\tau_{/} \in (0, w)$ that satisfies this equation. By construction $c_{/}^{y}$ and $c_{/}^{o}$ satisfy the agents' budget and

$$u'\left(c_{/}^{y}\right) = R\left(1 - \lambda_{so} + \frac{\lambda_{so}}{\psi}\right)\beta\psi u'\left(c_{/}^{o}\right) > R\beta\psi u'\left(c_{/}^{o}\right),$$

which implies that agents do not want to save under consumption allocation $[c_{/}^{y} c_{/}^{o}]$. Hence, if the consumption allocation $[c_{/}^{y} c_{/}^{o}]$ under policy $\tau_{/}$ is the same as consumption allocation $[c_{so}^{y}, c_{so}^{o}]$ under the socially optimal policy λ_{so}, fully-funded pensions can implement the first best allocation. Note that $c_{so}^{y} = c_{/}^{y}$ and $c_{so}^{o} = c_{/}^{o}$ imply

$$w + b_{so} - a_{so}^{\lambda} = w - \tau_{/}$$
$$R\left(1 - \lambda_{so} + \frac{\lambda_{so}}{\psi}\right) a_{so}^{\lambda} = R\frac{\tau_{/}}{\psi}$$

and, thus,

$$\left(1 - \lambda_{so}\right)\left(1 - \psi\right)\left(1 - R\right) = 0, \tag{1.25}$$

which is a condition that does not hold. Hence, in the case of $R < \hat{R}_{so}$, fully-funded pensions cannot achieve the social optimum. Second, consider the case of $R > \hat{R}_{so}$, in which no annuitization of retirement savings is socially optimal and a laissez-faire economy defines the social optimum. In this case, it is obvious that the socially optimal allocations can only be achieved in the absence of any fully-funded pension system ($\tau = f = 0$). This proves Proposition 3. □

Intuitively, Propositions 2 and 3 come about as fully-funded benefits are lump-sum transfers and only affect the present value of lifetime income but not the intertemporal trade-offs. As mandated savings in fully-funded pensions increase lifetime income, agents respond by increasing consumption and lowering private savings in bonds more than one-for-one (see equation (1.22)). In equilibrium, this reduction of private savings at the interior solution leads to the social cost of crowding out of bequest income, which outweighs the positive income effect from saving in return-dominant annuities. However, at the corner, where agents are borrowing-constrained, fully-funded pensions cannot crowd out any more private savings and bequests but still increase lifetime income by mandating savings in the above-market return annuities. Hence, there may be a social welfare case for fully-funded pensions at the zero-saving corner.

Can fully-funded pensions improve social welfare? After proving that fully-funded pensions cannot achieve socially optimal allocations, it is interesting to study if and under what conditions fully-funded pensions can improve social welfare. To do so, I assume logarithmic utility such that $u(c) = \log(c)$, which implies that $\phi = 1$.

Proposition 4: *In a model with equal accidental bequests and logarithmic utility, there is a social welfare case for fully-funded pensions as long as the interest rate R is below a specific threshold $\hat{R}_{\tau^*} > 1$.*

Proof: There is a welfare case for fully-funded pensions if social welfare under the optimal fully-funded pensions $\Omega(\tau)$ is greater than social welfare under laissez-faire Ω_{LF}. Corollary 2 shows that a necessary condition for fully-funded pensions to positively affect social welfare is that they are generous enough to constrain agents' borrowing. Hence, denoting $\hat{\tau}$ the fully-funded pension tax threshold above which agents are borrowing constrained, social welfare under fully-funded pensions $\Omega(\tau)$ can only be greater than laissez-faire welfare Ω_{LF} if the fully-funded pension tax satisfies $\tau \geq \hat{\tau}$. At the zero-savings corner ($\tau \geq \hat{\tau}$), social welfare under policy τ equals

$$\Omega(\tau) = \log(w - \tau) + \beta\psi\log\left(\tau\frac{R}{\psi}\right).$$

The policy τ that maximizes social welfare in the borrowing-constrained region ($\tau \geq \hat{\tau}$) is defined by

$$\frac{\partial\Omega(\tau)}{\partial\tau} = \frac{1}{w-\tau} - \beta\frac{\psi}{\tau} = 0$$

and equals $\tau^* = \dfrac{\psi\beta w}{1+\psi\beta}$. This policy τ^* implies the consumption allocation

$$\left[c^y_{\tau^*} = \frac{w}{1+\psi\beta}, \quad c^o_{\tau^*} = \frac{\beta R w}{1+\psi\beta}\right]$$

and social welfare of

$$\begin{aligned}\Omega_{\tau^*} &= \log\left(\frac{w}{1+\psi\beta}\right) + \beta\psi\log\left(\frac{\beta R w}{1+\psi\beta}\right) \\ &= \log\left(\frac{w}{1+\psi\beta}\right)(1+\beta\psi) + \beta\psi\log(R\beta).\end{aligned}$$

In Appendix B, I show that the consumption allocation under laissez-faire yields

$$\left[c^y_{LF} = \frac{w}{1+\beta\psi-(1-\psi)(\beta\psi R)}, \quad c^o_{LF} = \frac{w}{1+\beta\psi-(1-\psi)(\beta\psi R)}R\beta\psi\right],$$

which implies that social welfare under laissez-faire is

$$\Omega_{LF} = \log\left(\frac{w}{1+\beta\psi-(1-\psi)(\beta\psi R)}\right)(1+\beta\psi) + \beta\psi\log(\beta\psi R). \tag{1.26}$$

There is welfare case for fully-funded pensions if $\Omega_{\tau^*} > \Omega_{LF}$ and, thus, the condition

$$C \equiv \psi^{\beta\psi}\left(\frac{1+\psi\beta}{1+\beta\psi-(1-\psi)(\beta\psi R)}\right)^{1+\beta\psi} - 1 < 0 \tag{1.27}$$

holds. As $\lim_{R \to 1} C < 0$ holds for all $\beta \in (0, 1)$ and $\psi \in (0, 1)$[8], there exists an interest rate threshold $\hat{R}_{\tau^*} > 1$, below which there is a social welfare case for fully-funded pensions. $\square$

To gain more intuition, it helps to summarise the results using a graphical illustration. Figure 1.1 presents social welfare as a function of fully-funded pension contributions τ for the case in which the interest rate R is small enough so that some annuitization is socially optimal, i.e., $R < \hat{R}_{so}$. As shown in Proposition 2, fully-funded pensions harm social welfare at the interior solution. Thus, social welfare initially decreases in τ until the threshold $\hat{\tau}$ is reached, above which agents become constrained as they would like to but are not allowed to borrow against their fully-funded benefit f. Between $\hat{\tau}$ and τ^*, the present value of lifetime income and social welfare starts to increase as mandated savings in fully-funded pensions make agents richer by offering an above-market return without crowding out more bequest income because savings in bonds and bequest have already reached the zero corner. At point τ^*, social welfare is at the highest level Ω_{τ^*} that governments mandating fully-funded pensions can achieve. As shown in Proposition 3, this social welfare level Ω_{τ^*} is below the socially optimal level Ω_{so} but above social welfare in a laissez-faire economy Ω_{LF} for $R < \hat{R}_{\tau^*}$. For $\tau > \tau^*$, the present value of lifetime income still increases in τ, but social welfare decreases. This is the case because too many resources are now moved to the second period at the expense of consumption in the first period, for which the marginal utility is higher than for consumption in the second period. Figure 1.2 illustrates the case in which the interest rate is R is higher than the threshold $\hat{R}_{so}$, above which is socially optimal not to annuities any retirement savings. Hence, for any fully-funded pension tax $\tau > 0$, social welfare under fully-funded pensions is smaller than one under laissez-faire.

These results crucially depend on the empirically relevant assumption of dynamic efficiency, that is, $R > 1$. Suppose I instead followed Caliendo et al., 2014 and assumed that the interest rate equals the population growth rate, that is, $R = 1$. In this case, there would be no welfare case for transfers from old to young and, thus, accidental bequests. To see this, remember that \$1 contemporaneously transferred from an old to a young agent has an implicit cost of \$1 to the old and a benefit to the young of \$$R$ because they can invest the transfer and earn the market return R. If $R = 1$, this implicit cost to the old exactly equals the benefit to the young such that social welfare is unaffected by transfers from old to young. This implies that no social cost is associated with reducing accidental bequests through annuitization. Therefore, unlike under $R > 1$, full annuitization is privately and socially optimal under $R = 1$, and fully-funded pensions can achieve socially optimal allocations under a borrowing constraint if private annuity markets are missing. This is confirmed by the fact that the condition in equation (1.25) holds for $R = 1$.

[8]See Appendix C.

Figure 1.1: Social welfare as a function of τ for $R < \hat{R}_{so}$

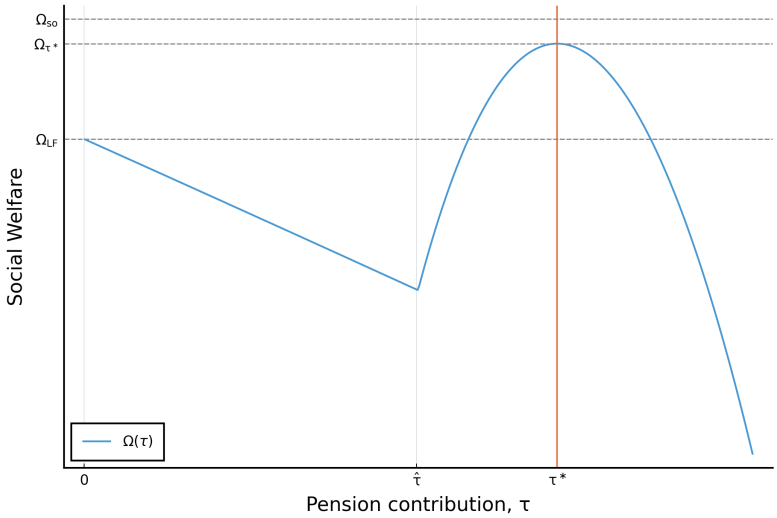
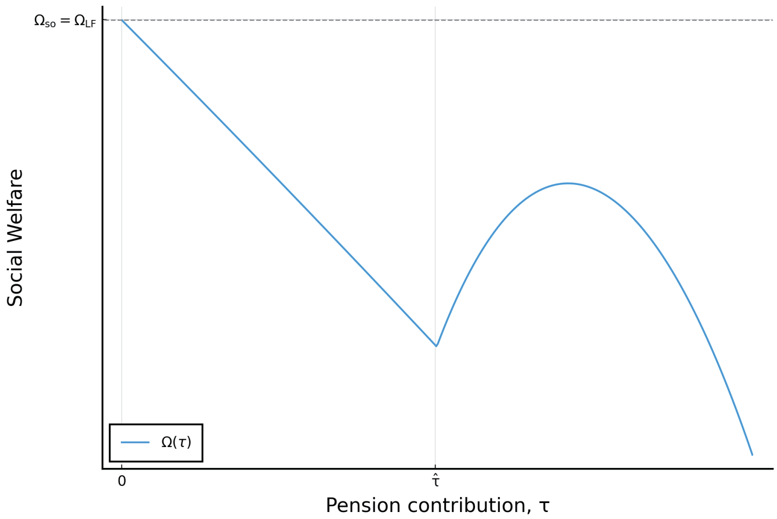


Figure 1.2: Social welfare as a function of τ for $R > \hat{R}_{so}$



1.2.7 Family-tied Distribution of Accidental Bequests

So far, I have assumed that unclaimed savings in bonds are anonymously and equally redistributed to the young, which implies a deterministic bequest income in equilibrium. As mentioned in the introduction, this assumption was motivated by its popularity in the macroeconomic literature on OLG models. However, it may not be very realistic. Thus, in this section, I relax the assumption by assuming a family-tied distribution of accidental bequests, which under the veil of ignorance, introduces individual bequest income risk. The focus remains on a small open economy with missing annuity markets and a restricted government that cannot directly mandate an interior share λ of savings to be invested in annuities. Thus, I study the problem of a benevolent government aiming to maximize social welfare by mandating savings in annuities through fully-funded pensions.

In this new setting, I assume that children whose parents survive to the second receive no bequest income because all agents consume all their resources in the second period. Furthermore, I make the simplifying assumption that all unclaimed savings in bonds are equally redistributed to children whose parents die early.[9] Given these family ties and due to the law of large numbers, accidental bequests equal

$$\begin{aligned} b_{t,n} &= 0 \text{ for fraction } \psi \\ b_{t,b} &= R\frac{(1-\psi)}{(1-\psi)}a_{t-1} = Ra_{t-1}\text{for fraction } 1-\psi, \end{aligned}$$

where subscript n stands for no bequests and subscript b stands for positive bequests. Furthermore,

$$a_t = \psi a_{t,n} + (1-\psi)\, a_{t,b}$$

represent aggregate private savings. As private annuity markets are missing, all savings are in bonds such that $a_t = a_t^B$. Before learning their type $i \in [n,b]$, agents have an expected lifetime utility of

$$U_t^d = \psi\left[u\left(c_{t,n}^y\right) + \beta\psi u\left(c_{t,n}^o\right)\right] + (1-\psi)\left[u\left(c_{t,b}^y\right) + \beta\psi u\left(c_{t,b}^o\right)\right]$$

and face risky bequest income with a mean and variance described by

$$\begin{aligned} E\left[b_t\right] &= R\left(1-\psi\right)\left(\psi a_{t-1,n} + (1-\psi)\, a_{t-1,b}\right) \\ \mathrm{Var}[b_t] &= (1-\psi)\,\psi\left[R\left(\psi a_{t-1,n} + (1-\psi)\, a_{t-1,b}\right)\right]^2. \end{aligned}$$

After learning their type $i \in [n,b]$, agents solve the problem

$$\max_{c_{t,i}^y, c_{t,i}^o, a_{t,i} \geq 0} U_{t,i} = u\left(c_{t,i}^y\right) + \beta\psi u\left(c_{t,i}^o\right) \tag{1.28}$$

$$s.t.$$

$$c_{t,i}^y = w + b_{t,i} - \tau_t - a_{t,i} \tag{1.29}$$

$$c_{t,i}^o = Ra_{t,i} + f_{t+1}, \tag{1.30}$$

which is essentially the same as in equations (1.16)-(1.18). The optimal level of saving in bonds $a_{t,i}$ is determined by

$$u'\left(c_{t,i}^y\right) = R\beta\psi u'\left(c_{t,i}^o\right) \tag{1.31}$$

and at the zero private saving corner by

$$u'\left(w_t + b_{t,i} - \tau_t\right) > R\beta\psi u'\left(f_{t+1}\right).$$

[9] The second assumption allows me to introduce individual bequest income risk without having to account for the mortality of ancestors beyond the parents' generation.

The Euler equation implies the following effect of fully-funded pensions on private savings

$$\frac{\partial a_{t,i}}{\partial \tau_t} = -\frac{u''\left(c_{t,i}^y\right) + R^2 \beta u''\left(c_{t,i}^o\right)}{u''\left(c_{t,i}^y\right) + R^2 \beta \psi u''\left(c_{t,i}^o\right)} < -1. \tag{1.32}$$

The effect of a change in fully-funded pensions contributions τ_t on $U_{t,i}$ is positive and yields (after using equation (1.19))

$$\frac{\partial U_{t,i}}{\partial \tau_t} = \beta \psi R u'\left(c_{t,i}^o\right)\left(\frac{1}{\psi} - 1\right) > 0 \text{ for } a_t > 0.$$

This illustrates that after learning their type i, individual welfare, like in the case of equal bequests, is maximized by full annuitization of retirement savings.

Social welfare the benevolent government aims to maximize is measured by expected lifetime utility in steady state and reads

$$\begin{aligned}\Omega^d(\tau) &= \psi\left[u\left(c_n^y\right) + \beta\psi u\left(c_n^o\right)\right] + (1-\psi)\left[u\left(c_b^y\right) + \beta\psi u\left(c_b^o\right)\right] \\ &= \psi\left[u\left(w - \tau - a_n\right) + \beta\psi u\left(Ra_n + R\frac{\tau}{\psi}\right)\right] + (1-\psi)\left[u\left(w + b_b - \tau\right) + \beta\psi u\left(Ra_b + R\frac{\tau}{\psi}\right)\right].\end{aligned}$$

While the bequest b_n of agents whose parents survive to the second period is always zero, the bequest b_b and savings a_b of children with parents who die early are determined in equilibrium. Steady-state bequest b_b yields

$$b_b = Ra = R\left(\psi a_n + (1-\psi) a_b\right). \tag{1.33}$$

Definition: A steady-state equilibrium in an economy with family-tied accidental bequests and a government that sets policy τ, is characterized by allocations $\left[c_i^{y^*}, c_i^{o^*}, a_i^{y^*}\right]$ of agents of type $i \in [n, b]$ that solves their problem in equations (1.28)-(1.30) and bequests b_b^* such that equations (1.33) and $f = \dfrac{R}{\psi}\tau$ hold.[10]

Proposition 5: *In a model with family-tied accidental bequests, fully-funded pensions improve social welfare even at an interior solution, as long as the interest rate R is below a threshold $\hat{R}_d > 0$.*

Proof: Under the bequest distribution, only the savings of agents whose parents die early are endogenous in equilibrium. In steady-state, private savings a_b of agents whose parents die early are determined by

$$u'\left(c_b^y\right) = R\beta\psi u'\left(c_b^o\right) \tag{1.34}$$

$$u'\left(w + R\left(\psi a_n + (1-\psi) a_b\right) - \tau - a_b\right) = R\beta\psi u'\left(Ra_b + R\frac{\tau}{\psi}\right), \tag{1.35}$$

[10] In Appendix D, I prove the existence of a unique steady-state equilibrium, which this economy converges to.

which implies the following effect of fully-funded pensions on equilibrium saving a_b of agents whose parents die early:

$$\frac{\partial a_b}{\partial \tau} = -\frac{u''\left(c_b^y\right) + \beta R^2 u''\left(c_b^o\right)}{\left[1 - R\left(1-\psi\right)\right] u''\left(c_b^y\right) + \beta \psi R^2 u''\left(c_b^o\right)} + \frac{R\psi u''\left(c_b^y\right)}{\left[1 - R\left(1-\psi\right)\right] u''\left(c_b^y\right) + \beta \psi R^2 u''\left(c_b^o\right)} \frac{\partial a_n}{\partial \tau} < 0, \quad (1.36)$$

where $\left(\frac{\partial a_n}{\partial \tau}\right)$ is determined by equation (1.32). The first term in equation (1.36) represents the crowding out effect of private savings of agents who receive bequest income, while the second term represents the crowding out of savings of the agents who do not receive bequest income. The welfare implication of introducing fully-funded pensions is

$$\begin{aligned}\frac{\partial \Omega^d\left(\tau\right)}{\partial \tau} = \psi &\left[u'\left(c_n^y\right)\left(-1 - \frac{\partial a_n}{\partial \tau}\right) + R\beta\psi u'\left(c_n^o\right)\left(\frac{\partial a_n}{\partial \tau} + \frac{1}{\psi}\right)\right] + \\ &\left(1-\psi\right)\left[u'\left(c_b^y\right)\left(-1 + R\psi\frac{\partial a_n}{\partial \tau} + \left[R\left(1-\psi\right) - 1\right]\frac{\partial a_b}{\partial \tau}\right) + R\beta\psi u'\left(c_b^o\right)\left(\frac{\partial a_b}{\partial \tau} + \frac{1}{\psi}\right)\right],\end{aligned}$$

which using the Euler equation (1.31) simplifies to

$$\frac{\partial \Omega^d\left(\tau\right)}{\partial \tau} = R\beta\left(1-\psi\right)\psi\left[u'\left(c_n^o\right) + u'\left(c_b^o\right)\left(\frac{1-\psi}{\psi} + R\psi\frac{\partial a_n}{\partial \tau} + \left[R\left(1-\psi\right)\right]\frac{\partial a_b}{\partial \tau}\right)\right]. \quad (1.37)$$

After inserting equations (1.36) and (1.32), I find that

$$\begin{aligned}\lim_{R\to 1}\frac{\partial \Omega^d\left(\tau\right)}{\partial \tau} =& \beta\left(1-\psi\right)\psi\left(u'\left(c_n^o\right) - u'\left(c_b^o\right)\right) \times \\ &\left[\frac{u''\left(c_n^y\right)u''\left(c_b^y\right) + \beta\psi u''\left(c_b^y\right)u''\left(c_n^o\right) + \beta u''\left(c_n^y\right)u''\left(c_b^o\right) + \beta^2\psi u''\left(c_n^o\right)u''\left(c_b^o\right)}{\left[u''\left(c_b^y\right) + \beta u''\left(c_b^o\right)\right]\left[u''\left(c_n^y\right) + \beta\psi u''\left(c_n^o\right)\right]}\right] > 0,\end{aligned} \quad (1.38)$$

implying that there exists a $\hat{R}_d > 1$ such that

$$\frac{\partial \Omega^d\left(\tau\right)}{\partial \tau} = \begin{cases} > 0 & R < \hat{R}_d \\ = 0 & R = \hat{R}_d \\ < 0 & R > \hat{R}_d \end{cases}.$$

The result that $\frac{\partial \Omega^d\left(\tau\right)}{\partial \tau} > 0$ for $R < \hat{R}_d$ proves Proposition 5, which states that under family-tied accidental bequests, FF pensions improve social welfare even for an interior solution if $R < \hat{R}_d$. $\square$

Proposition 5 shows that under family-tied bequests, unlike under the equal-bequest assumption, fully-funded pensions can improve social welfare at an interior solution. This is because, under family-tied bequests, an additional welfare case for fully-funded pensions arises from lowering the variance of the bequests

$$\frac{\partial \mathrm{Var}\left[b\right]}{\partial \tau} = 2R^2\psi\left(1-\psi\right)\left(\psi\frac{da_n}{d\tau} + \left(1-\psi\right)\frac{da_b}{d\tau}\right) < 0,$$

and thereby mitigating income risk. Like under the equal-bequest assumption, fully-funded pensions, however, still crowd out accidental bequests, as shown by

$$\frac{\partial E\left[b\right]}{\partial \tau} = R\left(1-\psi\right)\left(\psi\frac{da_n}{d\tau} + \left(1-\psi\right)\frac{da_b}{d\tau}\right) < 0.$$

Consequently, for $R > \hat{R}_d$, this social cost of crowding out of accidental bequests outweighs the positive social welfare effects of fully-funded pensions, i.e., saving in annuities, which provides longevity risk insurance, an above-market return and lowers bequest income risk.

The analysis in this section shows that for $R < \hat{R}_d$ family-tied bequests lead to a social welfare role for fully-funded pensions even at an interior solution because fully-funded pensions reduce the variance of the bequest income. That is, fully-funded pensions improve welfare at the interior solution because they provide insurance against bequest income risk, not longevity risk. Welfare gains from longevity risk insurance, like under the equal-bequest assumption, only occur if fully-funded pensions are large enough to push agents to the borrowing constraint.

1.3 Conclusion

The social welfare implications of the annuitization of retirement savings have been understudied. The likely reason for this is that Yaari-setting for life-cycle models has no market imperfections and allows individuals to fully insure their longevity risk, which suggests there is no case for policy intervention.

In this paper, however, I show that the social welfare case for annuitization is not one-sided under dynamic efficiency. I focus on a small open economy with overlapping generations of non-altruistic families facing longevity risk. On the one hand, there is a welfare case for annuities because they offer longevity risk insurance and an above-market return to survivors. However, in equilibrium, increased savings in annuities lead to reduced accidental bequests left and received. These bequests represent transfers from the old to the young that are desirable in a dynamically efficient economy. Therefore, less than full annuitization, which would prevail in competitive equilibrium, is socially optimal, and thus, there is a social welfare case for policy intervention even if private annuity markets exist.

I conduct a cost-benefit analysis of annuitization. First, I prove that if the interest rate is above a certain threshold, the social costs of crowding out bequest income become so high that they outweigh the benefits of saving in annuities. Below this interest rate threshold, governments can achieve socially optimal allocations by directly mandating an interior share of retirement savings to be invested in annuities. This requires the government to force agents to save exclusively in a portfolio with a pre-determined asset allocation and a weight λ on annuities. Then, I show that governments that instead mandate annuities through fully-funded pensions cannot achieve socially optimal allocations even when annuity markets are missing, and agents cannot undo the policy by borrowing against future pension benefits. Furthermore, I demonstrate that under the popular equal-bequest assumption and missing annuity markets, fully-funded pensions can only enhance social welfare if they are large enough to push agents to their borrowing constraint. However, under an unequal bequest distribution, which under the veil of ignorance, implies bequest income risk, I show that fully-funded pensions can improve social welfare even without pushing agents into the borrowing-constrained corner. In this case, welfare gains arise as fully-funded pensions provide insurance against bequest income risk.

In summary, this paper offers valuable insights into how interest rates and the distribution of bequests influence the social welfare outcomes of annuitization. Government should consider these findings when formulating pension policies. An exciting avenue for future research would be to extend my model by introducing heterogeneity in mortality. In this setting, one could account for the distributional consequences of fully-funded pensions pooling across different mortality risk classes and assess whether this would make fully-funded pensions more or less desirable from a social welfare perspective.

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Appendix A: Stationary Equilibrium under Fully-funded Pensions

Here, I prove that an economy with missing private annuity markets in which the government sets τ and accidental bequests are equally distributed converges to a unique steady state. First, I consider the case in which τ is small enough so that agents still save privately $(a_t > 0 \quad \forall t \implies b_t > 0 \quad \forall t)$. Due to the assumption of homothetic lifetime utility U_t, optimal consumption is proportional to the present value of the lifetime income, which in this economy equals $W_t^\tau \equiv w + b_t + (1/\psi - 1)\,\tau$. Consequently, there exists an optimal share $\mu^*(R, \beta, \psi, \phi) \equiv \mu^*$ of lifetime income spent on c^y implying the allocations

$$\begin{aligned}
c_t^{y^*} &= \mu^* W_t^\tau \\
a_t^* &= w + b_t - \tau - c_t^y \\
&= (1 - \mu^*)\, W_t^\tau - \frac{1}{\psi}\tau \\
c_t^{o^*} &= R a_t^* + f \\
&= R\,(1 - \mu^*)\, W_t^\tau,
\end{aligned}$$

which solve the agents' problem in equations (1.16)-(1.18). As the Inada conditions ensures that $c_t^{o^*} > 0$, we have that $0 < \mu^* < 1$. Thus, the law of motion of bequest can be written as

$$b_t = R\,(1 - \psi)\, a_{t-1}^* \tag{1.39}$$

$$= R\,(1 - \psi)\,(1 - \mu^*)\left[w + \frac{(1 - \psi)}{\psi}\tau\right] - \frac{1}{\psi}\tau + R\,(1 - \psi)\,(1 - \mu^*)\, b_{t-1} \tag{1.40}$$

Writing the above law of motion forward for an initial level of bequest b_0 yields

$$b_t = \left[w + \frac{(1 - \psi)}{\psi}\tau\right]\sum_{i=1}^{t}\left[R\,(1 - \psi)\,(1 - \mu^*)\right]^i - \frac{(1 - \psi)}{\psi}R\tau\sum_{i=0}^{t-1}\left[R\,(1 - \psi)\,(1 - \mu^*)\right]^i + \left[R\,(1 - \psi)\,(1 - \mu^*)\right]^t b_0$$

which for $t \to \infty$ and under Assumption 3 converges to

$$\begin{aligned}
b_\infty &= \frac{R\,(1 - \psi)\,(1 - \mu^*)}{1 - R\,(1 - \psi)\,(1 - \mu^*)}\left[w + \frac{(1 - \psi)}{\psi}\tau\right] - \frac{\dfrac{(1 - \psi)}{\psi}R\tau}{1 - R\,(1 - \psi)\,(1 - \mu^*)} \\
&= \frac{R\,(1 - \psi)\,(1 - \mu^*)}{1 - R\,(1 - \psi)\,(1 - \mu^*)}w - \left[\frac{1 - (1 - \psi)\,(1 - \mu^*)}{1 - R\,(1 - \psi)\,(1 - \mu^*)}\right]\frac{(1 - \psi)}{\psi}R\tau.
\end{aligned}$$

The policy τ, for which b becomes zero implying that savings are zero (see equation(1.39)) yields

$$\hat{\tau} = \frac{(1 - \mu^*)\,\psi}{1 - (1 - \psi)\,(1 - \mu^*)}w.$$

Hence, for any starting point b_o and for a given policy $\tau < \hat{\tau}$, the economy converges to a unique steady state determined by

$$\begin{aligned}
a &= (1-\mu^*)\left(w + b_\infty + \frac{(1-\psi)}{\psi}\tau\right) - \frac{1}{\psi}\tau > 0 \\
c^y &= \mu^*\left(w + b_\infty + \frac{(1-\psi)}{\psi}\tau\right) \\
c^o &= R(1-\mu^*)\left(w + b_\infty + \frac{(1-\psi)}{\psi}\tau\right).
\end{aligned}$$

Moreover, for any starting point b_o and for a given policy $\tau > \hat{\tau}$, the economy converges to a unique state state determined by

$$\begin{aligned}
a &= 0 \\
c^y &= w - \tau \\
c^o &= f = \frac{R}{\psi}\tau.
\end{aligned}$$

Hence, the economy always converges to a unique state. $\square$

Appendix B: The Laissez-faire Economy under Logarithmic Utility

In a laissez-faire economy with missing annuity markets, agents with logarithmic preferences solve the following problem in steady state

$$\begin{aligned}
&\max_{c^y, c^o, a} U = \log(c^y) + \beta\psi \log(c^o) \\
&s.t. \\
&c^y = w + b - a \\
&c^o = Ra.
\end{aligned}$$

The lifetime budget constraint equals

$$c^y + \frac{c^o}{R} = w + b, \tag{1.41}$$

where steady-state bequests are determined by

$$b = R(1-\psi)a. \tag{1.42}$$

The Euler equation here yields

$$c^o = \beta\psi R c^y. \tag{1.43}$$

Combining (1.41) and (1.43) yields

$$c^y = \frac{1}{(1+\beta\psi)}(w+b).$$

Inserting the above equation and (1.42) into the first-period budget constraint and solving for a yields

$$a_{LF} = \frac{\beta\psi}{(1+\beta\psi) - \beta\psi R(1-\psi)} w.$$

Inserting equation (1.3) into the budget constraints and using equation (1.42) to solve for the consumption bundle yields

$$c^y_{LF} = \frac{1}{(1+\beta\psi) - \beta\psi R(1-\psi)(1-\lambda)} w$$
$$c^o_{LF} = \frac{\beta\psi R}{(1+\beta\psi) - \beta\psi R(1-\psi)} w.$$

Social welfare under laissez-faire thus reads

$$\begin{aligned}
\Omega_{LF} &= \log(c^y_{LF}) + \beta\psi\log(c^o_{LF}) \\
&= \log\left(\frac{w}{(1+\beta\psi) - \beta\psi R(1-\psi)}\right) + \beta\psi\log\left(\frac{\beta\psi R w}{(1+\beta\psi) - \beta\psi R(1-\psi)}\right) \\
&= (1+\beta\psi)\log\left(\frac{w}{(1+\beta\psi) - \beta\psi R(1-\psi)}\right) + \beta\psi\log(\beta\psi R).
\end{aligned}$$

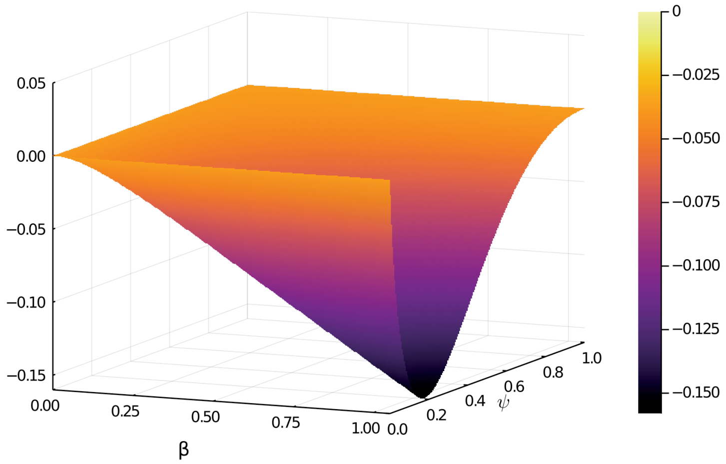
Appendix C: Condition $C < 0$

Figure 1.3, shows that the function

$$F(\psi,\beta) = \psi^{\beta\psi}\left(\frac{1+\psi\beta}{1+\beta\psi-(1-\psi)(\beta\psi)}\right)^{1+\beta\psi} - 1$$

is negative for $\beta \in (0,1)$ and $\psi \in (0,1)$ to illustrate that the condition $\lim_{R\to 1} C < 0$ holds.

Figure 1.3: $F(\psi,\beta)$



Appendix D: Stationary Equilibrium under Family-tied Accidental Bequests

Here, I prove that an economy with missing private annuity markets in which the government sets τ and accidental bequests are family-tied converges to a unique steady state. First, consider the case in which τ is small enough so that agents still save privately in bonds $(a_t > 0 \quad \forall t \implies b_{b,t} > 0 \quad \forall t)$. Due to the assumption of homothetic lifetime utility U_t, optimal consumption is proportional to the net present value of the lifetime income, which in this economy equals

$$W_{t,i} \equiv w + b_{t,i} + \left(\frac{1}{\psi} - 1\right)\tau$$

with $i \in [n, b]$. Consequently, there exists a share $\mu^*(R, \beta, \psi, \phi) \equiv \mu^*$ of lifetime income $W_{t,i}$ spent on $c^y_{i,t}$ implying the allocation

$$\left[c^y_{t,i} = \mu^*\left(w + b_{t,i} + \left(\frac{1}{\psi} - 1\right)\tau\right), a_{t,i} = (1-\mu^*) W_{t,i} - \frac{1}{\psi}\tau\right].$$

This implies that

$$a_{t,n} = (1-\mu^*)\left(w + \left(\frac{1}{\psi} - 1\right)\tau\right) - \frac{1}{\psi}\tau \tag{1.44}$$

$$= (1-\mu^*) W_{t,n} - \frac{1}{\psi}\tau, \tag{1.45}$$

$$a_{t,b} = (1-\mu^*)\left(w + b_{t,b} + \left(\frac{1}{\psi} - 1\right)\tau\right) - \frac{1}{\psi}\tau \tag{1.46}$$

and that aggregate private savings evolve according to

$$\begin{aligned} a_t &= \psi a_{t,n} + (1-\psi) a_{t,n} \\ &= \psi (1-\mu^*) W_{t,n} + (1-\psi)(1-\mu^*) W_{t,b} - \frac{1}{\psi}\tau \\ &= (1-\mu^*)\left(w + \left(\frac{1}{\psi} - 1\right)\tau\right) - \frac{1}{\psi}\tau + (1-\mu^*)(1-\psi) b_{t,b}. \end{aligned}$$

Thus, the dynamics of bequests of children whose parents die early reads

$$\begin{aligned} b_{t,b} &= R a_{t-1} \\ &= (1-\mu^*)\left(w + \left(\frac{1}{\psi} - 1\right)\tau\right) R - \frac{R}{\psi}\tau + R(1-\mu^*)(1-\psi) b_{t-1,b} \end{aligned}$$

Using equations (1.44) and (1.46) to write the above law of motion forward for a given starting value of $b_{0,b}$ yields

$$b_{t,b} = \left[(1-\mu^*)\left(w + \left(\frac{1}{\psi} - 1\right)\tau\right) R - \frac{R}{\psi}\tau\right] \sum_{i=0}^{t} \left[R(1-\psi)(1-\mu^*)\right]^i + \left[R(1-\mu^*)(1-\psi)\right]^t b_{0,b}, \tag{1.47}$$

which for $t \to \infty$ and under Assumption 3 converges to

$$b_{\infty,b} = b_b = \frac{(1-\mu^*)\left(w + \left(\frac{1}{\psi} - 1\right)\tau\right) - \frac{\tau}{\psi}}{1 - R(1-\psi)(1-\mu^*)} R.$$

The policy τ, for which b and a become zero yields

$$\hat{\tau} = \frac{(1-\mu^*)\psi}{1-(1-\psi)(1-\mu^*)} w.$$

Hence, for any starting point b_o and for a given policy $\tau < \hat{\tau}$, the economy converges to a unique steady state determined by

$$\begin{aligned}
a_b &= (1-\mu^*)\left(w + b_{\infty,b} + \left(\frac{1}{\psi} - 1\right)\tau\right) - \frac{1}{\psi}\tau \\
c_b^y &= \mu^*\left(w + b_{\infty,b} + \left(\frac{1}{\psi} - 1\right)\tau + b_b\right) \\
c_b^o &= (1-\mu^*)\left(w + b_{\infty,b} + \left(\frac{1}{\psi} - 1\right)\tau + b_b\right) \\
a_n &= (1-\mu^*)\left(w + \left(\frac{1}{\psi} - 1\right)\tau\right) - \frac{1}{\psi}\tau \\
c_n^y &= \mu^*\left(w + \left(\frac{1}{\psi} - 1\right)\tau\right) \\
c_n^o &= (1-\mu^*)\left(w + \left(\frac{1}{\psi} - 1\right)\tau\right).
\end{aligned}$$

For any starting point b_o and for a given policy $\tau > \hat{\tau}$, the economy converges to a unique state state determined by

$$\begin{aligned}
a_b &= a_n = 0 \\
c_b^y &= c_n^y = w - \tau \\
c_b^o &= c_n^o = f = \frac{R}{\psi}\tau.
\end{aligned}$$

Hence, the economy always converges to a unique state state. $\square$

Chapter 2

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.

2.1 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, the 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; 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; 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; 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 2.2 outlines our structural life-cycle model. Section 2.3 describes Denmark's institutional setup and the mirco data we use to estimate the model. Section 2.4 outlines the structural estimation strategy. Next, for estimated parameters, Section 2.5 analyzes the retirement reforms to restore fiscal sustainability. Finally, Section 2.6 concludes by summarizing and discussing key findings.

2.2 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 2.4.1. Preference parameters are estimated structurally in Section 2.4.2.

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.

2.2.1 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

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

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

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

[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.

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

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

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.

2.2.2 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

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

where β is the subjective discount factor and ψ^e_s 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

[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 2.5.3.

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:

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

where $v_t^e(m_t, w_t, d_t)$ 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) established by Iskhakov et al. (2017). This an extension of the Endogenous Grid Method, see Carroll, 2006, to a setting with a discrete labor choice. Although the solution method can handle non-convexities and multiple solutions to the Euler equation, we also consider a type-1 extreme-value taste shock, $\epsilon(d_t)$, with scale parameter, λ.[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 function for a worker, $d_t = 1$, can be written in the following recursive form

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

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},

[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.

following a log-normal distribution. We pin down the parameters of the log-normal shock distribution by a panel wage regression in Section 2.4.1. Meanwhile, b^e_{t+1} 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 2.5.2. 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

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

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

$$\mathbb{E}_t \left[V^e_{t+1}\left(m_{t+1}, w_{t+1}\right) \right] = \int EV^\epsilon_{t+1} \left[v^e_{t+1}\left(m_{t+1}, w_{t+1}, d_{t+1}\right) \right] dy,$$

where EV^ϵ_{t+1} 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

$$v_t^e\left(m_t, w_t, d_t > 1\right) = \max_{a_t \geq 0} \left\{u\left(c_t, 0, s_t\right) + \beta \cdot \psi_t^e \cdot v_{t+1}^e\left(m_{t+1}, w_{t+1}, d_t > 1\right)\right\}$$

$$\begin{aligned} & s.t. \\ m_t &= a_t + \left(1+\tau_c\right) c_t \\ m_{t+1} &= R a_t + \left(1-\tau_y\left(\cdot\right)\right)\left(\mathbb{I}_{t+1}^f f_{t+1}\left(w_t\right) + \mathbb{I}_{t+1}^p p_{t+1}\left(y_{t+1}^m\right) + \mathbb{I}_{t+1}^d q_0\right) \\ y_{t+1}^m &= \left(R-1\right) a_t + \mathbb{I}_{t+1}^f f_{t+1}\left(w_t\right) \\ w_{t+1} &= R_{t+1}^e w_t - \mathbb{I}_{t+1}^f f_{t+1}\left(w_t\right). \end{aligned}$$

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

2.3 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.

2.3.1 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 2.1 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.

[4]For evidence on the degree of means testing in other countries, see Figure 2.9 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%.

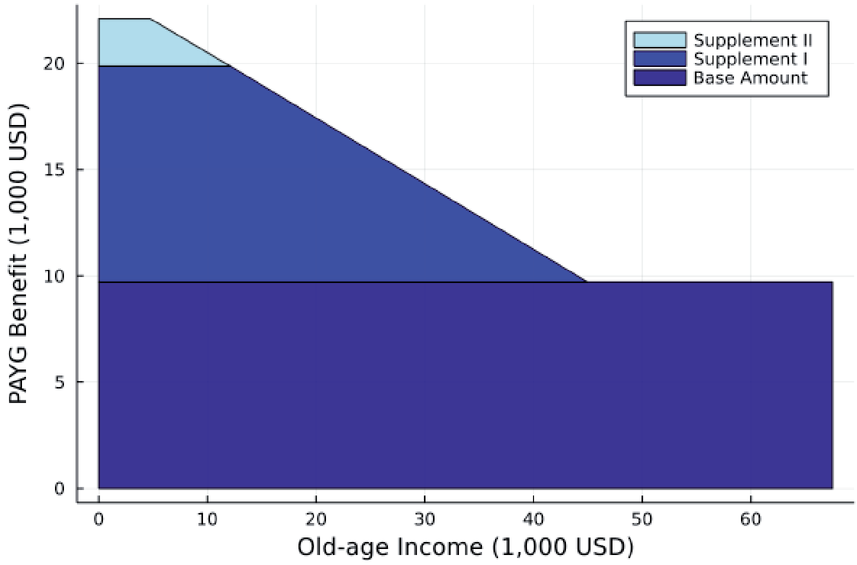


Figure 2.1: Means Testing. Stylized example based on 2015 rates for a retiree who lives alone and has no significant liquid wealth. Old-age income includes all income other than the public PAYG benefit.

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 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.

2.3.2 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.

2.4 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 2.4.1. In the second stage, we use the Simulated Method of Moments (SMM) to estimate all preference parameters as described in Section 2.4.2.

2.4.1 Estimation Outside the Model

This section covers the calibration of parameters determined outside the model. For a quick overview, see Table 2.1. 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 2.1: 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 2.2	DST Data, Lee-Li model
labor productivity			
$\{x_e\}$	Earnings potential	See Figure 2.3	DST Data, Wage regression
$\{\sigma_e\}$	Variance of productivity shock	$\{0.516, 0.501, 0.562\}$	DST Data, Wage regression
$Prob_{parents\mid children}$	Education transmission matrix	See Table 2.3	DST Data, Markov matrix
Taxes and Social Security			
$\tau_y(\cdot)$	Income tax function	See Figure 2.4	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 2.1	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 2.2. As expected, survival rates increase monotonically across education groups at all ages. The estimated survival rates are consistent with expected lifetimes of 80.8, 82.8, and 84.7 years for people of Low, Middle, and, High education. The differences in longevity are not only important for individual decisions. They also limit the scope for redistribution through the public pension system. This could have important consequences for the welfare response to different policies in the policy analysis.

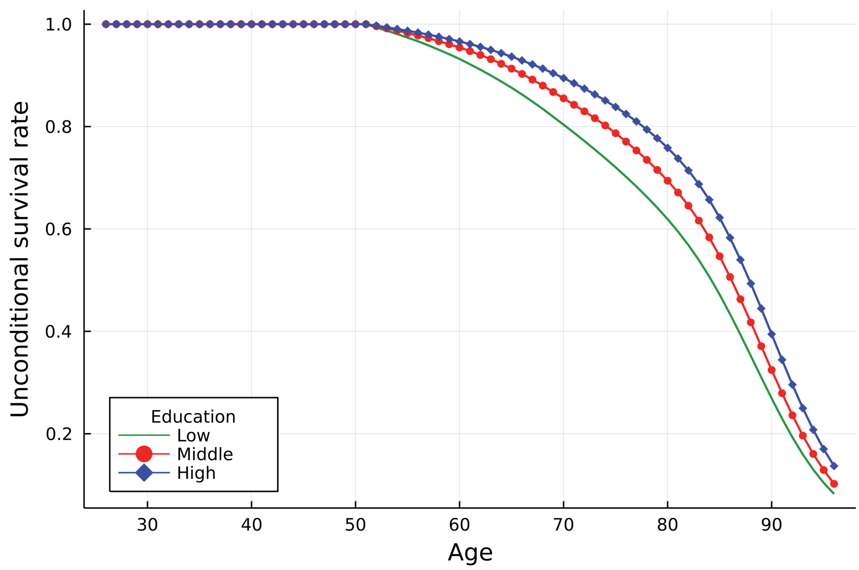


Figure 2.2: Education-specific Unconditional Survival Rates

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 2.3. 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 $\sigma_1 = 0.516, \sigma_2 = 0.501, \sigma_3 = 0.562$.

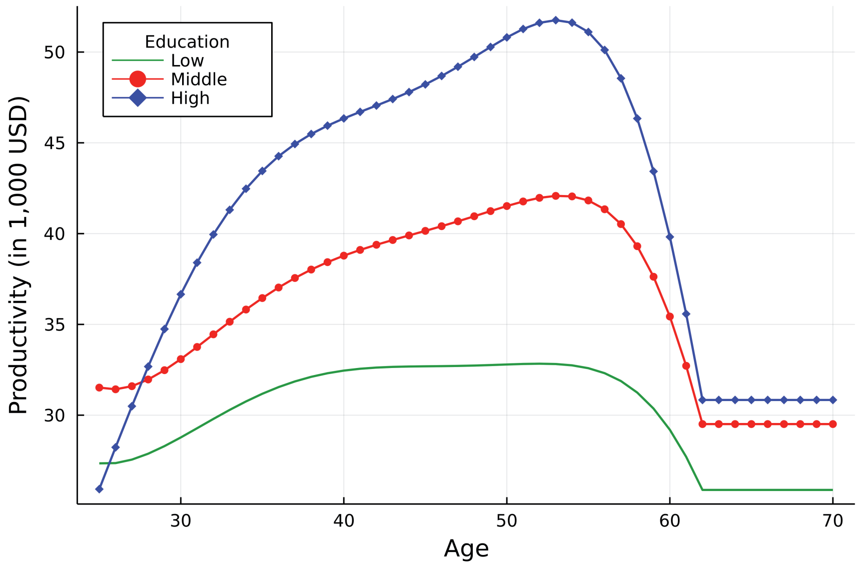


Figure 2.3: Education-specific Average Earnings

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 2.4. 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.

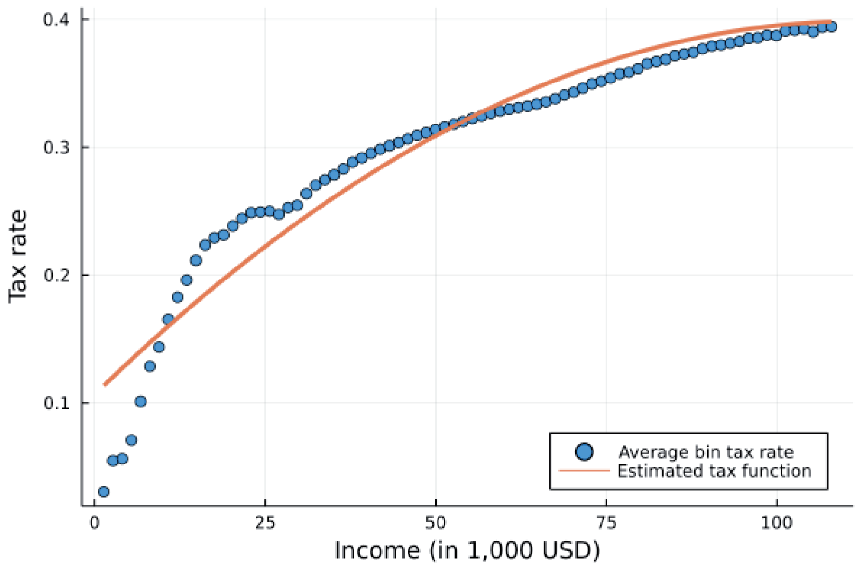


Figure 2.4: Tax Function

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 2.5 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.

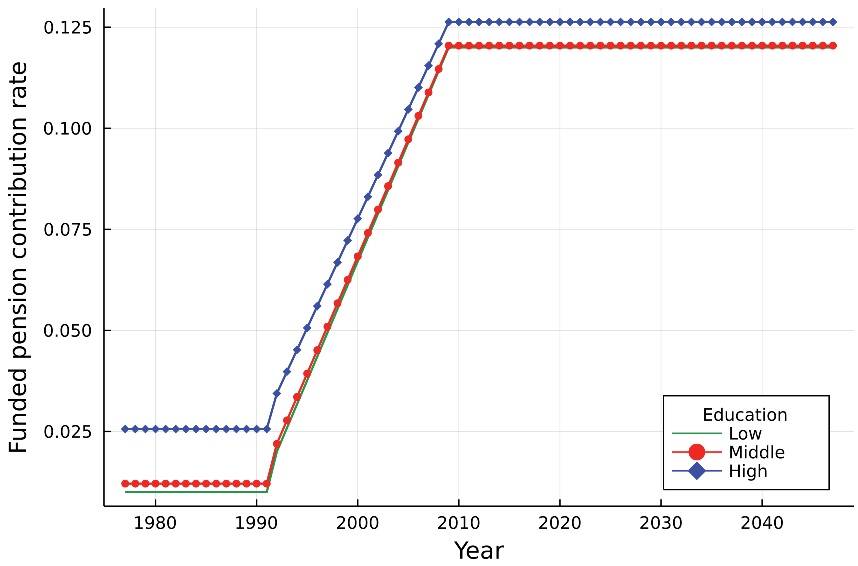


Figure 2.5: Funded Pension Contribution Rates

2.4.2 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 2.2. [8]

Table 2.2: 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.

2.4.3 Targeted Moments

In this section, we evaluate the model fit for targeted variables. First, Figure 2.6 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

[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.

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 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.

2.5 Policy Analysis

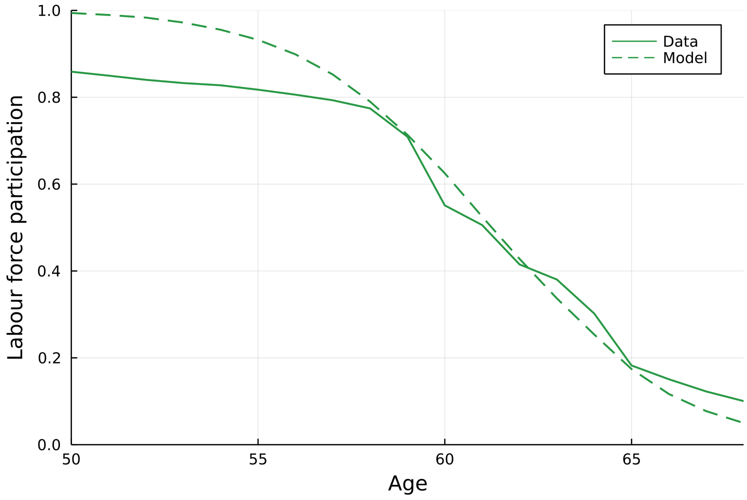
Having pinned down all the model parameters, we evaluate the economic and social impact of various reforms in the face of fiscal pressure deriving from increases in longevity and falling fertility. The reforms that we consider are: increasing taxes, increasing the retirement age, lowering public benefits 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.

[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 $n = 0.006$.

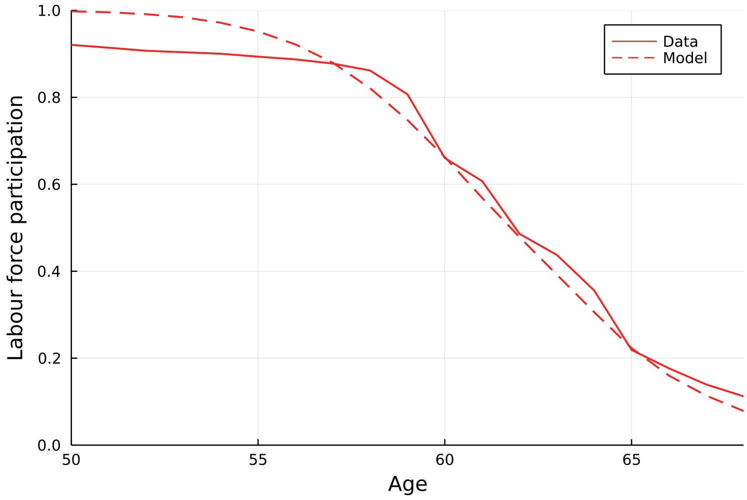
[10] Compared to the estimated model, we keep most parameters constant. However, instead of increasing pension contributions over the life cycle, we keep them constant at post-reform levels, i.e., after 2009. Furthermore, we adjust the age-specific earnings potential, x_t^e, for real wage growth.

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

(a) Low education



(b) Middle education



(c) High education

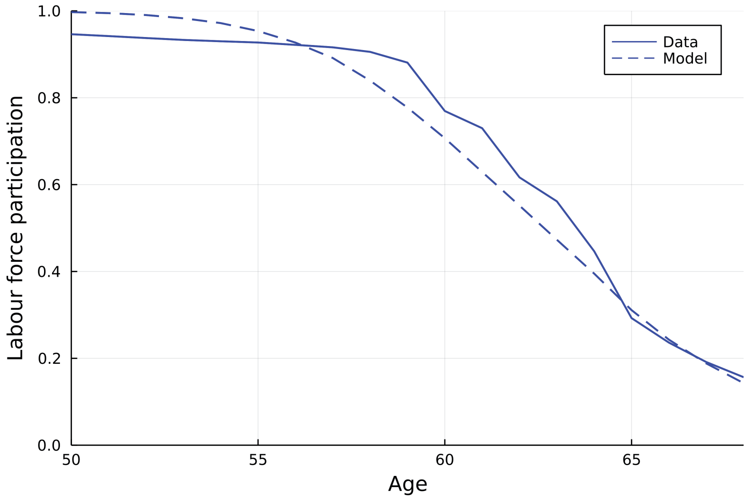


Figure 2.6: Labor Force Participation

2.5.1 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 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

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

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.

2.5.2 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

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

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 2.3 contains the resulting transition probabilities for the 1950 cohort of parents and their children.

Table 2.3: 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.

2.5.3 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 2.2.2, we add a positive constant, $\underline{u}$, to the instantaneous utility function. The constant does not affect individual decisions but merely ensures a positive value of life when doing welfare analysis. We calibrate this parameter to match empirical and legal estimates of the value of statistical life (VSL) in Denmark of $4,185,000$ USD (31 million DKK), (see Traaholt et al., 2016).[12]

2.5.4 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 2.4. 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 2.5 through 2.8. 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 2.12 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 2.8 contains the CV measure associated with each policy for every education group.

[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

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

As expected, given that utility and the value of life are positive, the welfare effect of an increase in longevity is also positive.

Table 2.4: 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% .

2.5.5 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.

2.5.6 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.

2.5.7 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.

2.5.8 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 2.5: 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 2.6: 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 2.7: 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 2.8: 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.

2.6 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:

$$\log\left(m_{t,a}^{g}\right) = \alpha_a^g + B_a K_t + \beta_a^g \kappa_t^g + \epsilon_{t,a}^g \tag{2.1}$$

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

$$K_t = c_1 + K_{t-1} + e_t, \tag{2.2}$$

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,

$$\kappa_t^g = c_2 + \gamma^g \kappa_{t-1}^g + v_t, \tag{2.3}$$

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 2.8 and 2.7 depict estimated and forecasted mortality rates and the life expectancy at age 40 for each education group.

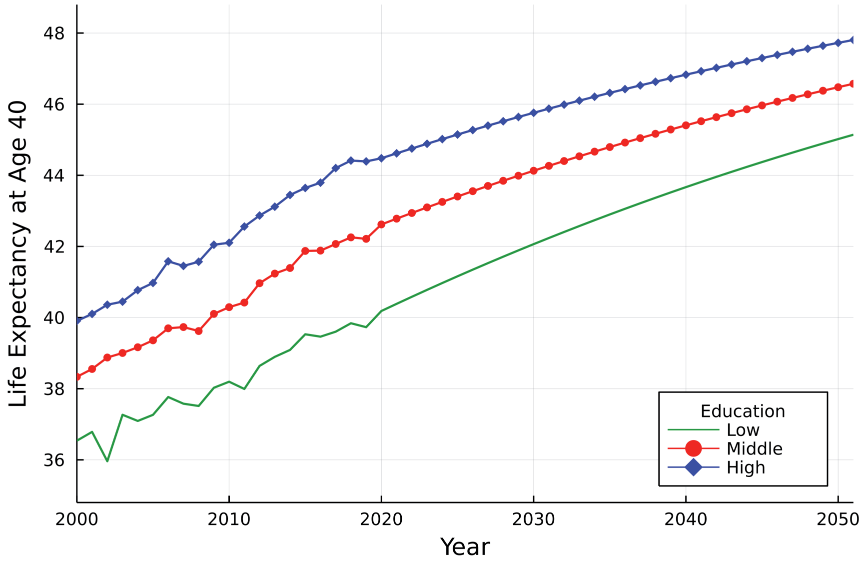


Figure 2.7: Life Expectancy at Age 40

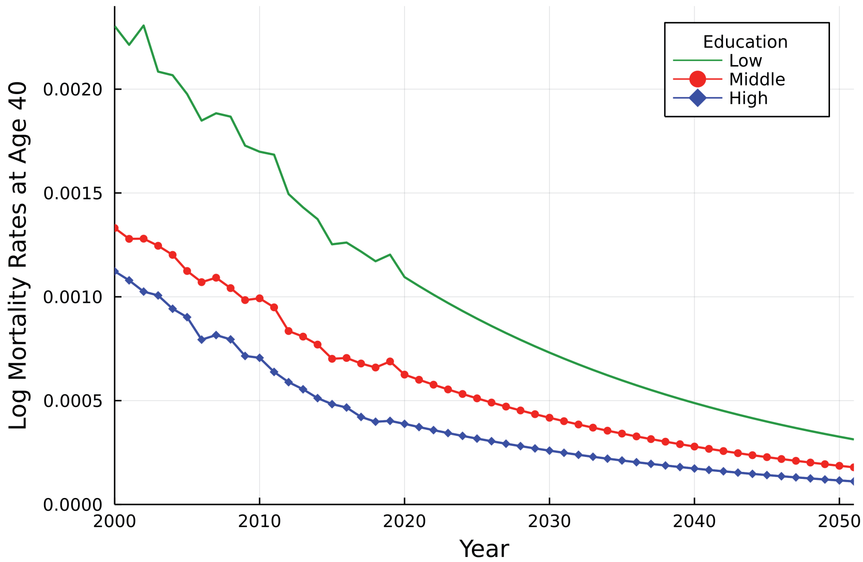


Figure 2.8: Log-mortality Rates at Age 40

Appendix C: Additional figures

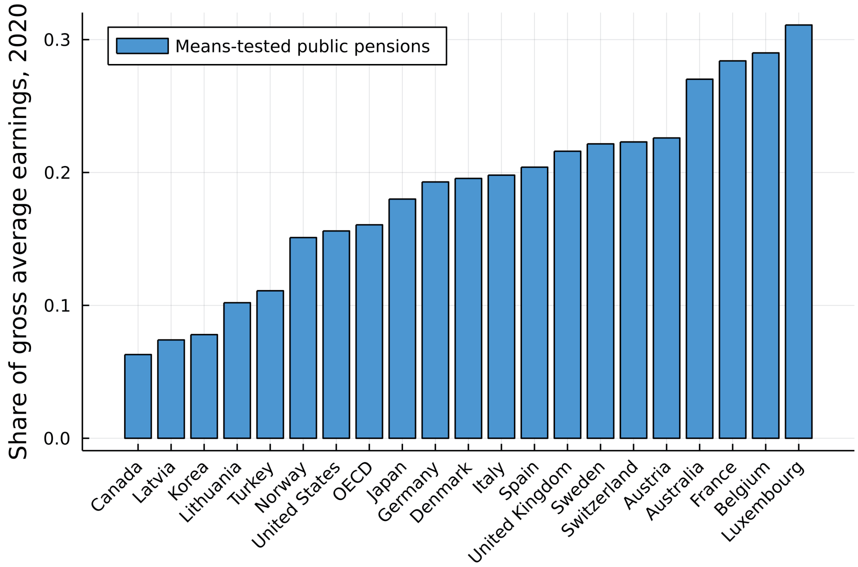


Figure 2.9: Means-tested Pensions in OECD countries. Source: OECD, 2021

Figure 2.10: After-tax Income, Low Education

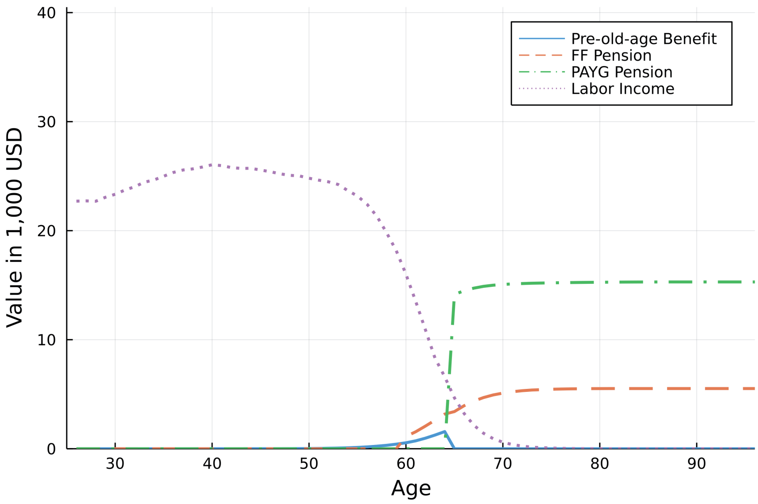


Figure 2.11: After-tax Income, Middle Education

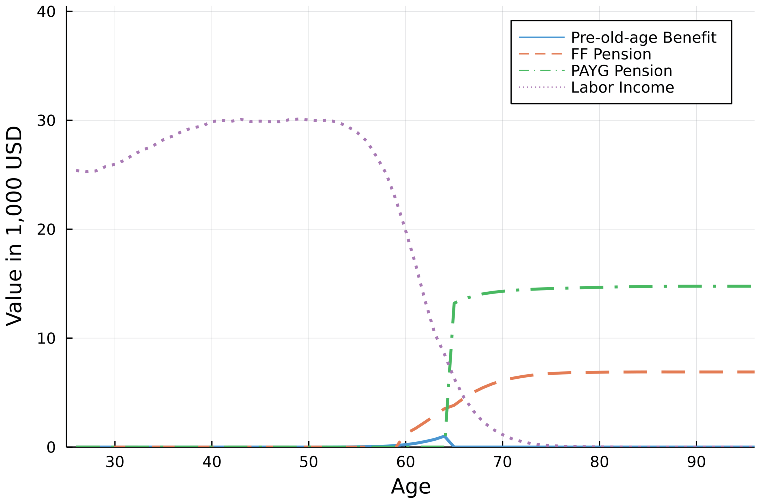


Figure 2.12: After-tax Income, High Education

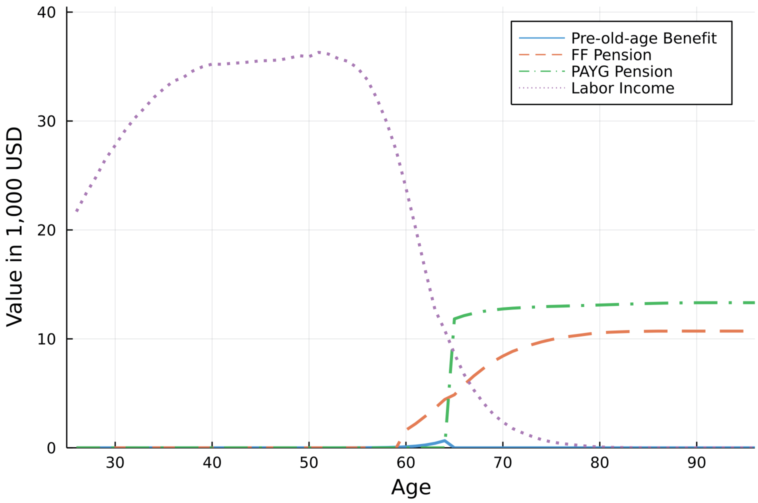


Figure 2.13: Consumption and Saving, Low Education

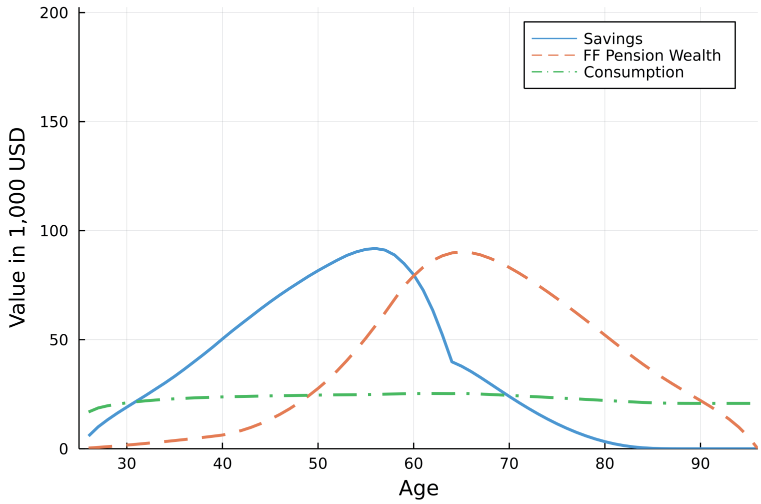


Figure 2.14: Consumption and Saving, Middle Education

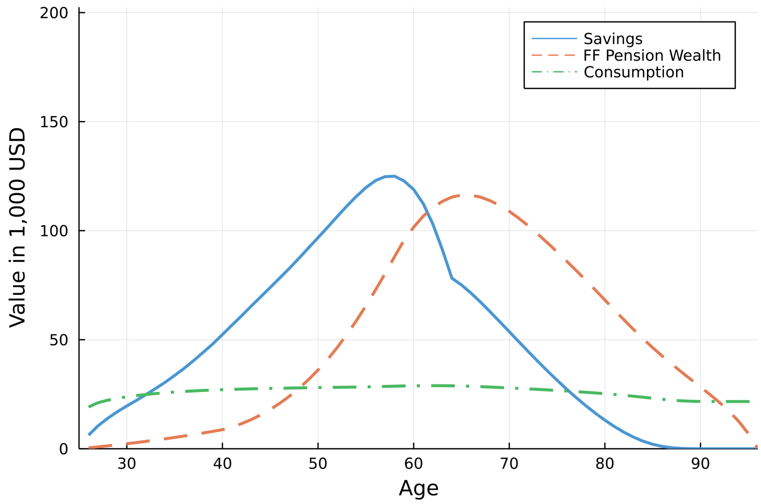
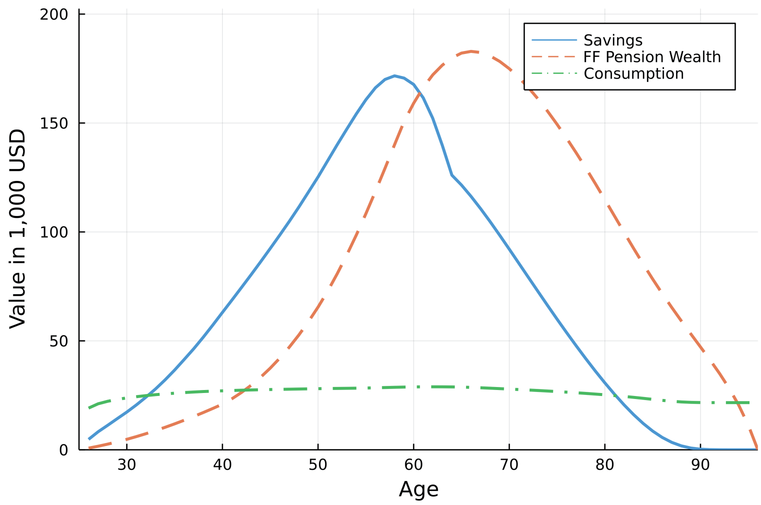


Figure 2.15: Consumption and Saving, High Education



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 2.9: 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 2.10: 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 2.11: 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 2.12: 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 3

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.

3.1 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; 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 also 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 3.2 reviews the related literature and points to some common shortcomings. Section 3.3 briefly outlines our experiment and the register data used to conduct it. Section 3.4 introduces the framework for estimating and forecasting mortality for gender-specific social classes. Section 3.5 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 3.6 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 3.7 concludes and discusses the merit of public pension schemes in light of our findings. The appendix provides supporting information and relevant robustness checks.

3.2 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 by 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.

3.3 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 3.4. 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:

$$NPV_{c,s,g} = \sum_{a=17}^{95} S_{c,a}^{s,g} \frac{B_{c,a}^{s,g} - C_{c,a}^{s,g}}{(1+r)^{a-64}} \tag{3.1}$$

Here, r denotes a constant discount rate, $B_{c,a}^{s,g}$ average benefits received by 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 3.4. Section 3.5 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 3.1 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 3.1: 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.

3.4 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.

3.4.1 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, the affluence index at age a is defined as household wealth $W^i_{c,a}$ plus $\mathcal{K}$ times the moving averages of order $n = 1$ over household labor income $Y^i_{c,a}$ in the preceding year.[2] As a robustness check, we consider different numbers of lags and find that this makes little difference 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. The affluence index reads:

$$A^i_{c,a} = W^i_{c,a} + \mathcal{K} \cdot Y^i_{c,a} \tag{3.2}$$

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 a 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 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

[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.

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.

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

$$m^{s,g}_{t,a} = \frac{D^{s,g}_{t,a}}{E^{s,g}_{t,a}} \tag{3.3}$$

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

[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.

3.4.3 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:

$$\log\left(m_{t,a}^{s,g}\right) = \alpha_a^{s,g} + B_a K_t + \beta_a^{s,g}\kappa_t^{s,g} + \epsilon_{t,a}^{s,g} \tag{3.4}$$

where α_a^i 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_a^i and $\kappa_t^{s,g}$ allow for subgroup slopes to deviate from the general population. For forecasting purposes, K_t follows a random walk with drift,

$$K_t = c_1 + K_{t-1} + e_t, \tag{3.5}$$

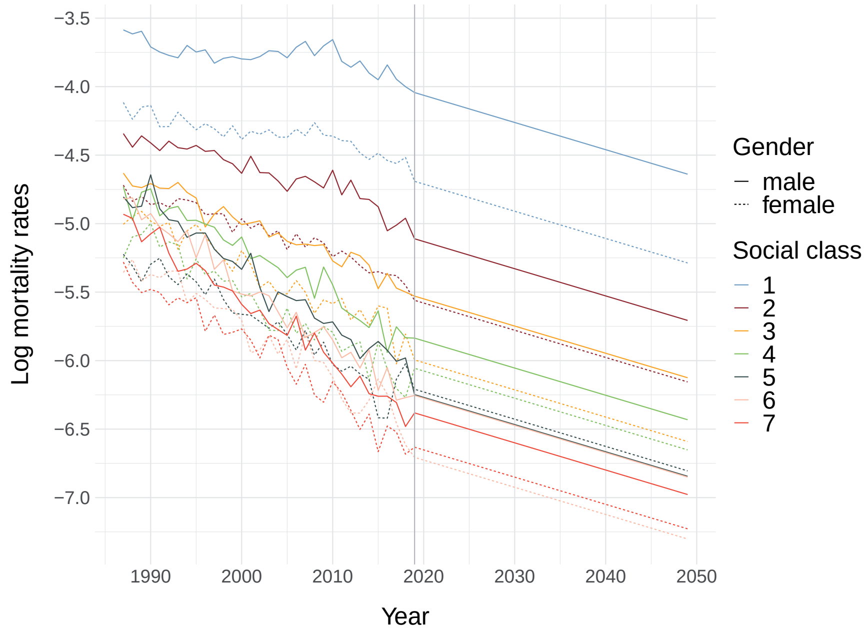
Here, $e_t \overset{iid}{\sim} \mathcal{N}\left(0, \sigma_e^2\right)$. Furthermore, $\kappa_t^{s,g}$ follows a trend-stationary AR(1) with a constant,

$$\kappa_t^{s,g} = c_2 + \gamma^{s,g}\kappa_{t-1}^{s,g} + vs, g_t, \tag{3.6}$$

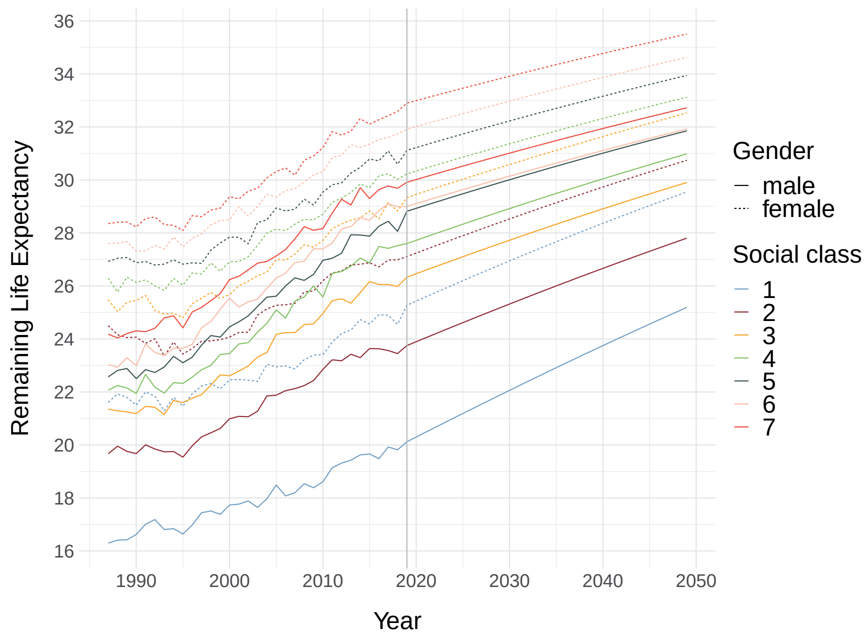
where $v_t \overset{iid}{\sim} \mathcal{N}\left(0, \sigma_v^2\right)$. Stationarity rules out random divergence in subgroup mortality, while the presence of a constant allows some group differences to persist in the long run. In line with Li and Lee (2005), we assume that the error terms are independent.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

Figure 3.1 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 3.1: 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.

3.5 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.

3.5.1 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 3.4 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 3.5.3 and 3.5.6. 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.

3.5.2 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.

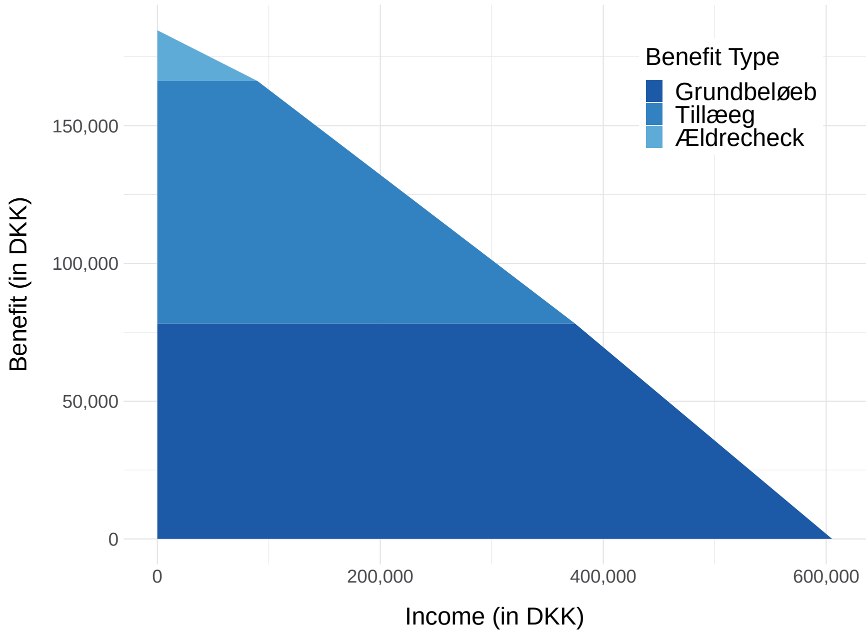
The yearly base amount was 78.216 DKK in 2020 and is practically a flat rate. However, the base amount is reduced at a penalty of 30% with all labor income in excess of a fairly large deductible. The supplement is subject to more means testing and depends on civil status. The maximum supplement is currently 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 3.2 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.

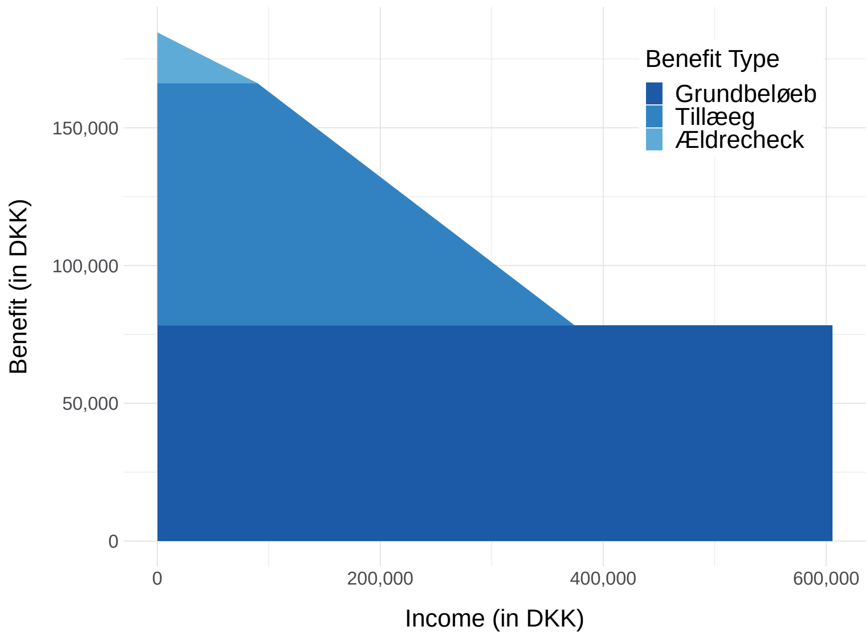
In forecasting benefits, we assume that all qualitative aspects of the pension system will remain unchanged. Thus, we essentially assume that the relative generosity of public pension benefits remains unchanged in the future. Specifically, we assume that maximum amounts and deductibles grow with forecasted 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 penalty rates. We do so knowing that it may be possible for some to postpone retirement

Figure 3.2: 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.

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.

3.5.3 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 3.5.2.

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.

The third pillar consists of private savings and voluntary pension arrangements. Al-

[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.

though 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.

3.5.4 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.

3.5.5 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.

3.5.6 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.

3.6 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.

3.6.1 Life-cycle Profile of Contributions and Benefits

To provide an overview of the individual interaction with the pension system, Figure 3.3 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.

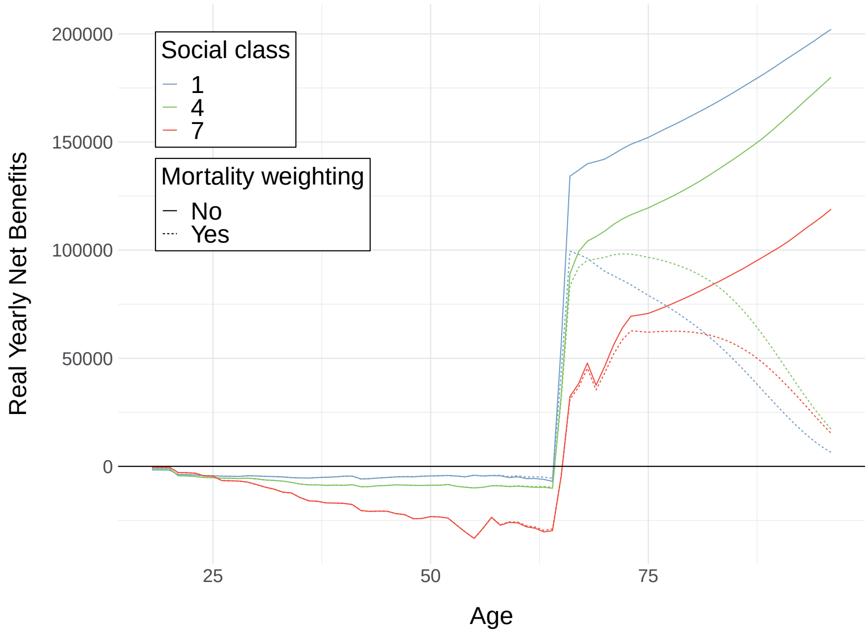
Thus, the life-cycle profiles illustrate that men tend to subsidize women via the public pension system for three reasons: Women i) contribute less, ii) receive higher benefits conditional on survival, and iii) tend to survive for longer receiving benefits. Later, we introduce more formal decompositions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

3.6.2 NPV and IRR of the Implicit Public Pension Contract

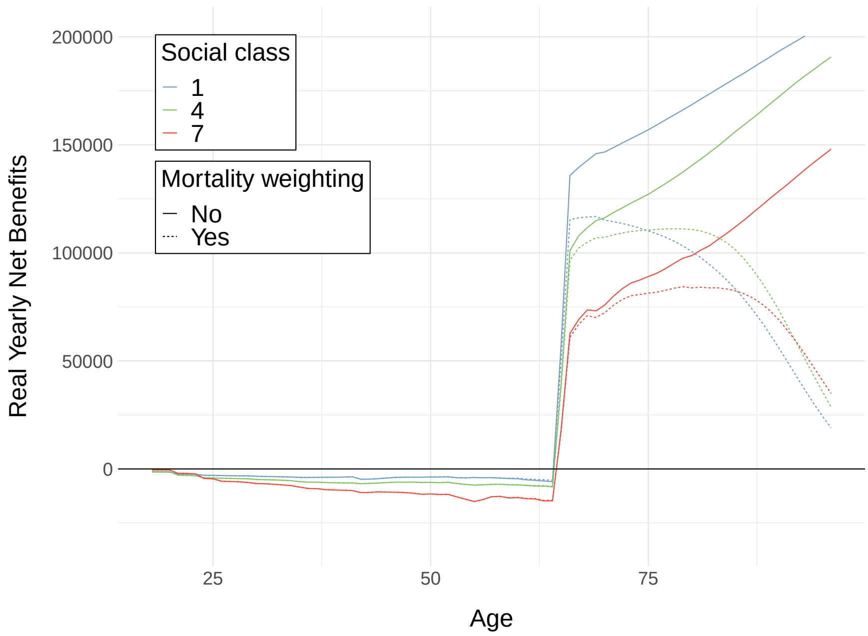
Using the definition in Section 3.3, we can compute the expected NPV of the implicit public pension contract. Figure 3.4 shows expected NPVs of different social groups for a spectrum of the discount rate. Subfigure 3.4a shows results for males, while Subfigure 3.4b shows results for females. For each group, the intersection with the zero line identifies the group-

Figure 3.3: 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.

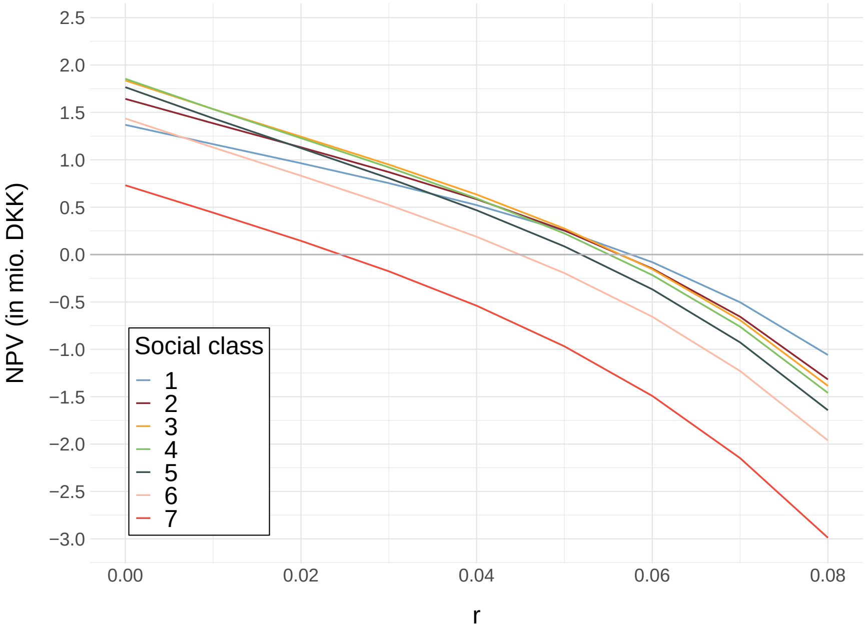
specific IRR. This is defined as the constant discount rate that drives the expected NPV of the implicit public pension contract to zero. In that sense, it can also be interpreted as a return requirement. The IRR is a "relative" measure.[9] Thus, if one cash flow has a higher IRR than another, this does 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 3.5. 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.

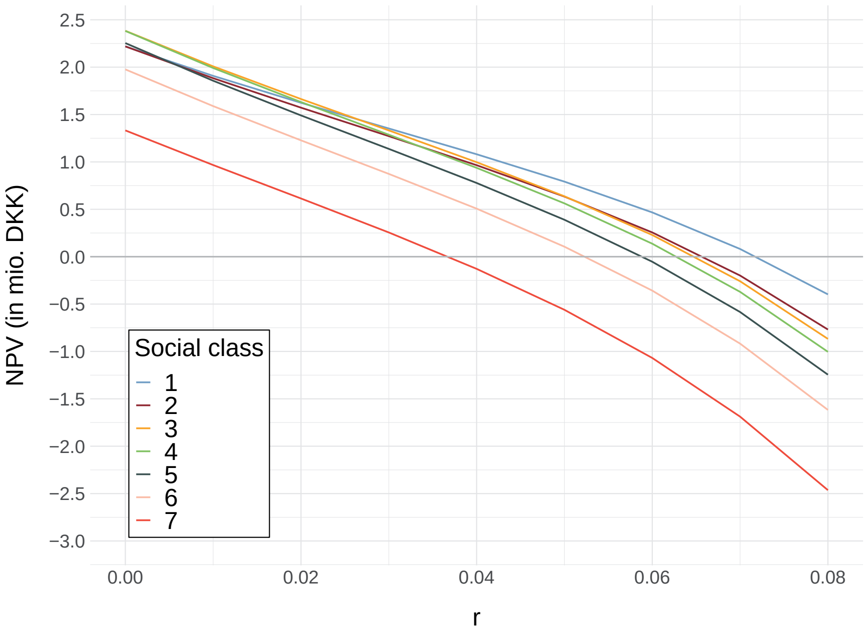
In Appendix B, we derive a decomposition of differences in NPVs relative to the least affluent men. Here, we decompose the total difference into contributions from differences in benefits, contributions, longevity, and a residual. Figure 3.6 shows this decomposition graphically for affluence groups 3 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 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

[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 3.4: Expected NPV for Different Discount Rates



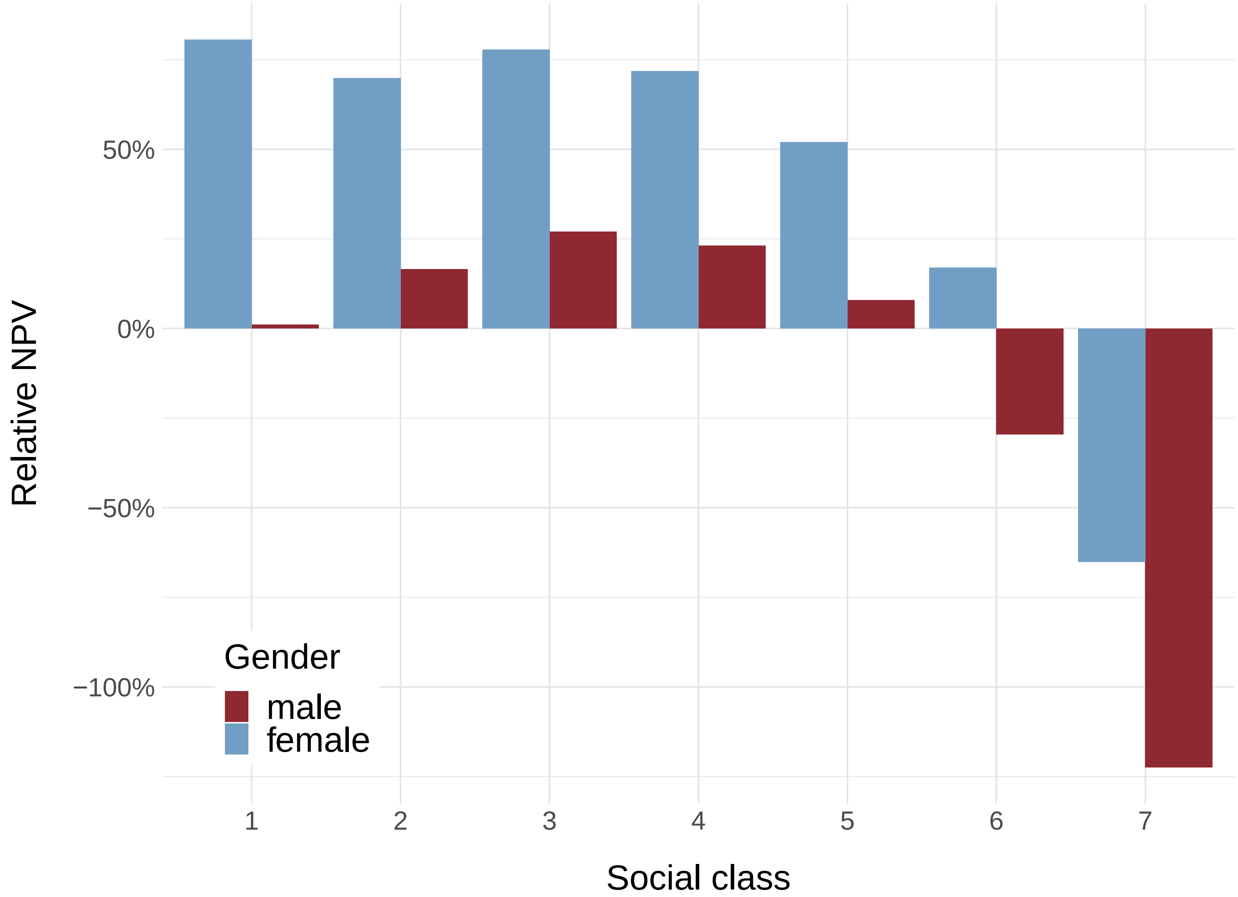
(a) Male



(b) Female

Notes: Panel (a) shows the mortality weighted NPV (see equation 3.1) of the public pension contract of males born in 1952 for different discount rates and social classes. Panel (b) shows the same for females.

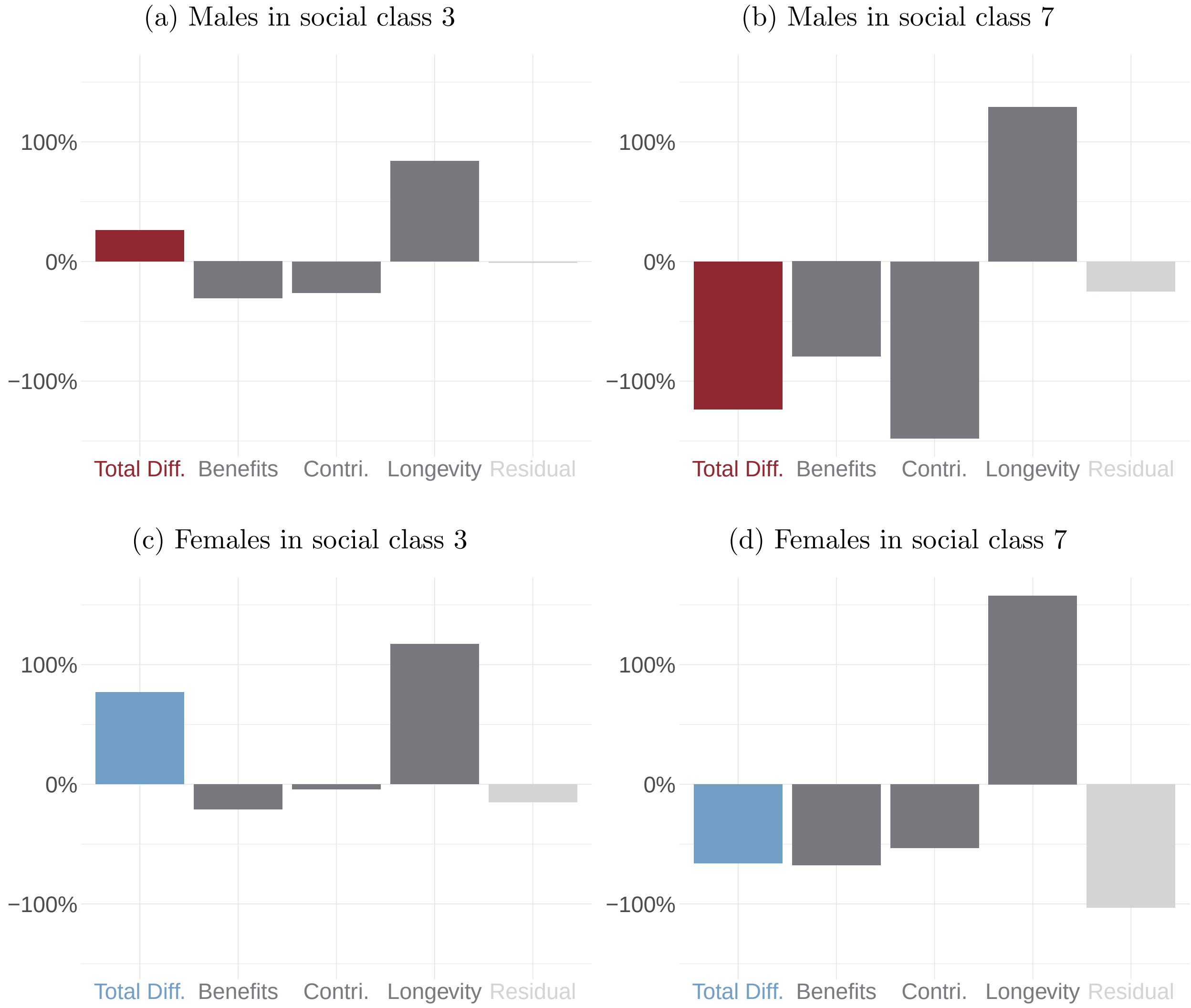
Figure 3.5: Expected NPV Relative to Men in Lowest Social Class (for r=3%)



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

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 3.6: Decomposition of NPV Differences Relative to Least Affluent Men

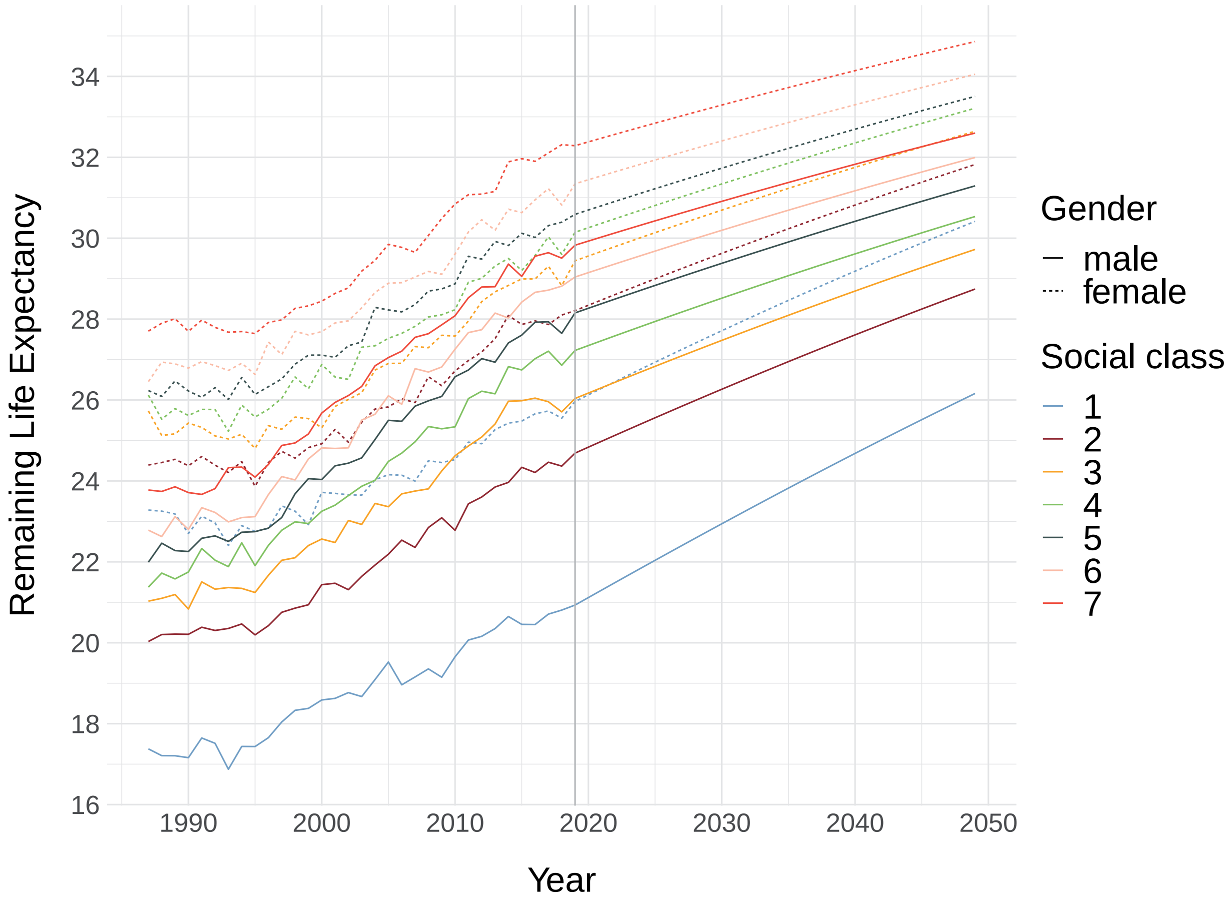


Notes: This figure plots a statistical decomposition of differences in expected NPVs relative to the least affluent men. The total relative difference is decomposed into differences in benefits, contributions, and longevity.

3.6.3 Income vs. Affluence

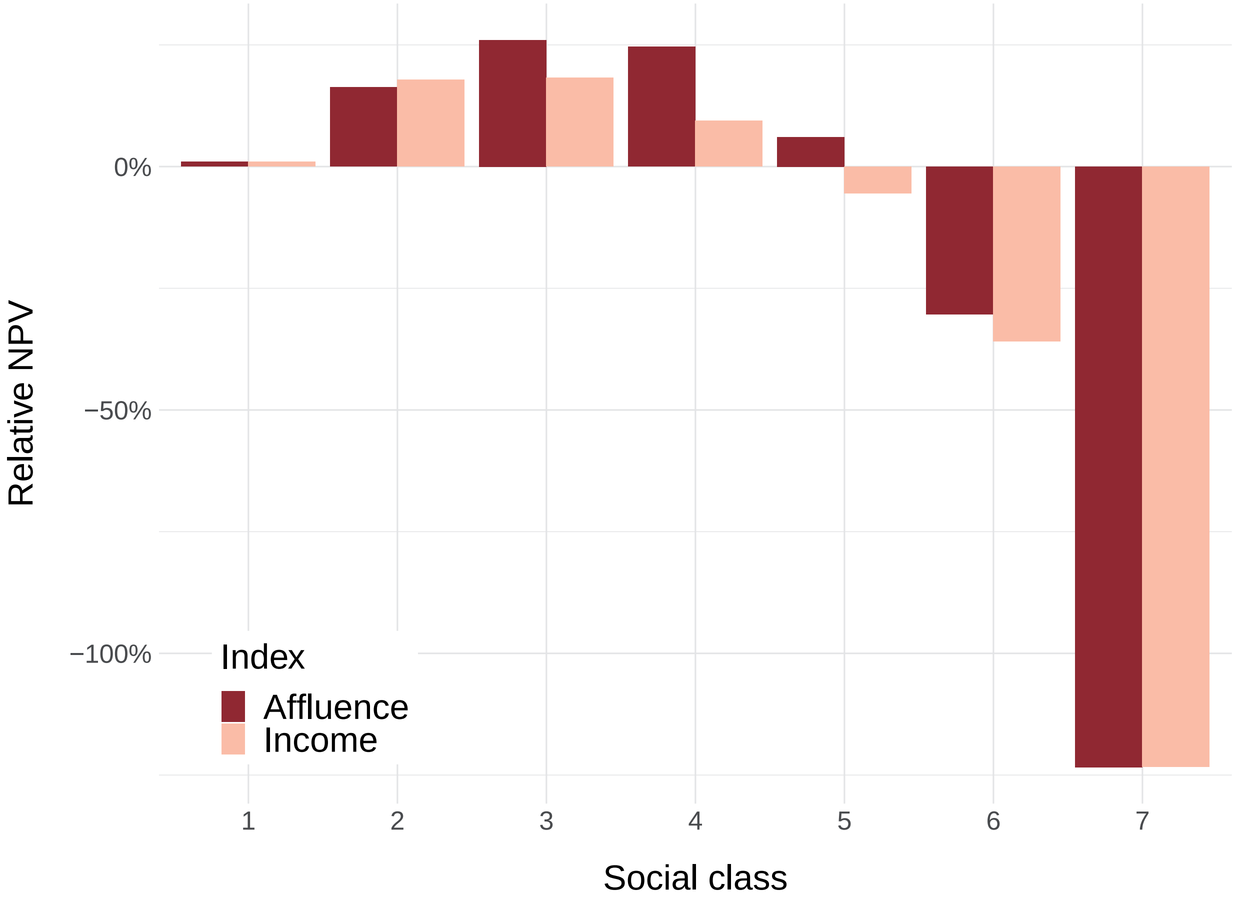
So far, we have considered redistribution solely across the affluence distribution. In the following, we adopt the traditional approach of measuring redistribution over the distribution of lagged income to highlight the importance of the allocation mechanism. Thus, we repeat the entire analysis while allocating individuals to socioeconomic groups based on lagged, ten-year averages of household labor income. Using this allocation mechanism, Figure 3.7 depicts remaining life expectancies at age 55 for males and females. Comparing this to its affluence-based counterpart in Figure 3.1a, 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 3.4, we conclude that affluence is a stronger separator of mortality than labor income.

Figure 3.7: Remaining Life Expectancy at 55 by Income Group



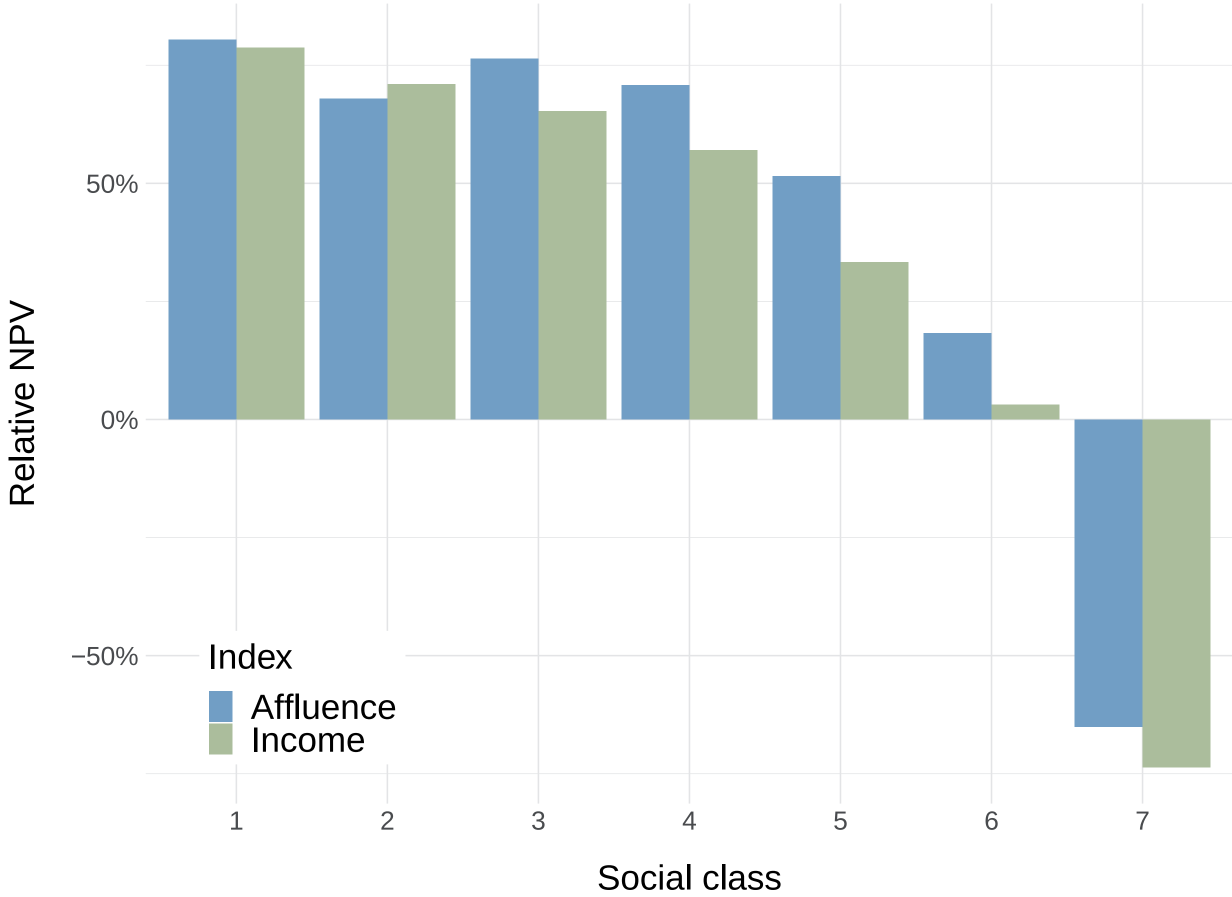
When using allocation by lagged labor income, our results for redistribution in the public pension system also change. As shown in Figure 3.8, using lagged income rather than affluence, we find less subversion of the redistribution among males, although the NPV profile is still hump-shaped. For women, as depicted in Figure 3.9, 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 3.8: Affluence vs Income, Expected NPV Relative to Males in Group 1 (r=3%)



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

Figure 3.9: Affluence vs Income, Expected NPV Relative to Memales in Group 1 (r=3%)



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

3.7 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 3.2 and 3.3 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 3.2: 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 3.3: Kendall's Tau - Women

To illustrate persistence in a different way, Table 3.5 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 3.4: 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 3.5: Switching Matrix for Men between 55 and 60

switch to neighboring groups. Jumping several groups is, however, unlikely. Table 3.5 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 3.1 and suppressing notation for cohort and gender, the NPV of some group s in the baseline cohort can be written as:

$$NPV^s = \sum_{x=17}^{67} \frac{1}{N} \sum_{i \in \mathcal{A}_{55}^s} S_x^i \frac{NI_x^i}{(1+r)^{x-64}} + \sum_{x=68}^{95} S_{x|67}^s \frac{1}{N} \sum_{i \in \mathcal{A}_{67}^s} \frac{NI_x^i}{(1+r)^{x-64}}$$

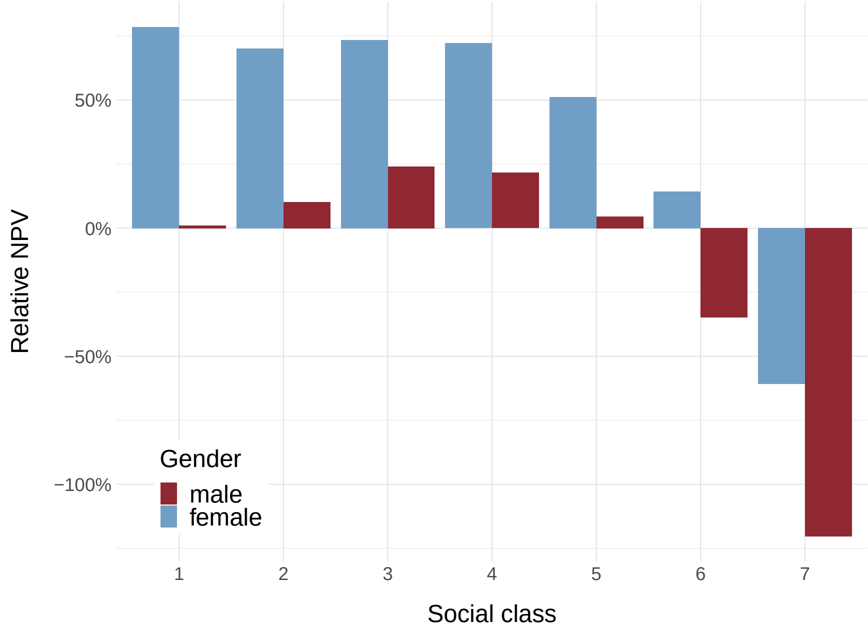
Here, $S_x^i \in (0,1)$ denotes realized individual survival rates for everyone before the last year of the data. Conversely, $S_{x|67}^s$ denotes group-specific, forecasted survival rates conditional on surviving to the last year of observation at age 67. Before the end of the data, NI_x^i denotes realized 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:

$$\Delta NPV^{s,g} = \sum_{x=17}^{95} \frac{\left(S_x^{s,g} - S_x^{1,m}\right) NI_x^{1,m} + S_x^{1,m} \left(B_x^{s,g} - B_x^{1,m}\right) - S_x^{1,m} \left(C_x^{s,g} - C_x^{1,m}\right)}{(1+r)^{x-64}} + \epsilon^{s,g} \quad (3.7)$$

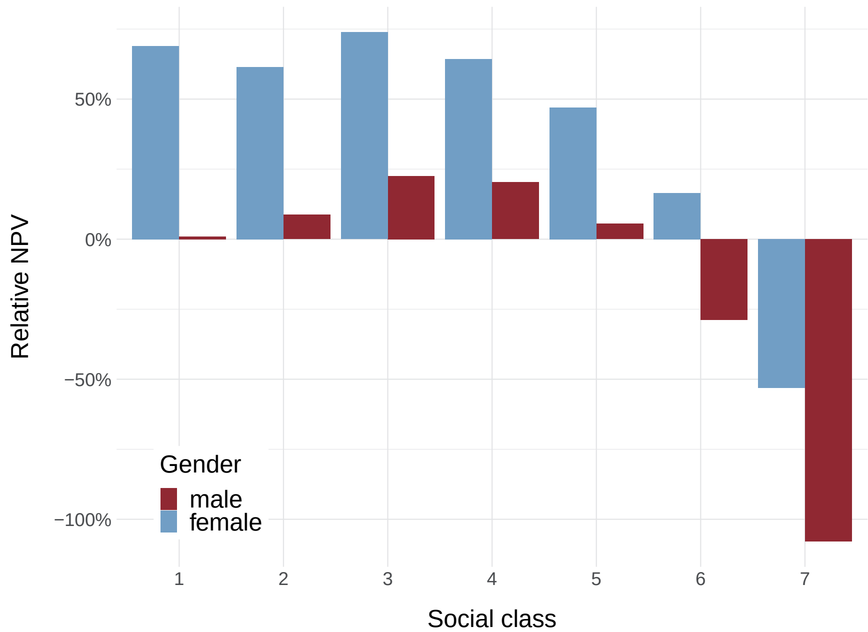
The first term captures differences due to differential mortality rates. The second and third terms capture differences in benefits and contributions, respectively. The fourth term is an error.

Appendix C: Robustness Check for More Cohorts

Figure 3.10: 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.

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