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ABSTRACT

Efficiency versus Insurance: Capital Income Taxation and Privatizing Social Security*

We study the interactions between capital income tax and social security privatization in the context of rising longevity. In an economy with idiosyncratic income shocks, redistributive defined benefit social security provides some insurance against income uncertainty. This insurance comes at the expense of efficiency loss due to labor supply distortions. The existing view in the literature states that reducing this distortion by introducing (partially funded) defined contribution social security would reduce welfare because the loss of insurance and the transitory fiscal gap dominate the efficiency gains. However, prior research financed the transitory costs of the reform by taxing consumption. We show that in the context of longevity, capital income taxation provides a superior alternative: welfare gains are sufficient to outweigh the loss of insurance and transitory fiscal gap. We provide explanations for a mechanism behind this result and we reconcile our results with the earlier literature.

JEL Classification: C68, D72, E62, H55, J26

Keywords: social security reform, capital income taxation, longevity, fiscal policy, welfare effects

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1 Introduction and motivation

In this paper, we study the taxation of capital in the context of reforming social security. Rising longevity leads to deficits in the current social security in the US, which under status quo is expected to reach a deficit as high as 24% of its scheduled payouts by 2034 (SSA 2021). These demographic developements trigger policy debates about replacing the current defined benefit system (redistributive and financed on a pay-as-you-go basis), with a defined contribution system, partially or fully funded (referred to as social security privatization, see Diamond 1993, Diamond et al. 2016).[1] Current redistributive social security, such as the defined benefit systems, provides partial insurance against income shocks but at the expense of efficiency.

The so-called privatized social security affects efficiency through three channels. The first channel stems form a strengthened the link between contributions and pension benefits: distortion in the labor market is reduced. However, this occurs at the expense of propagating the shocks from the working period into the old ages (reduced insurance). The second channel concerns pension wealth: pension benefits are increased given contribution rates. The third channel relates to taxes. Continuing with the current social security in the US necessitates a rise in taxes in the long run to finance the social security deficit. By contrast, a social security reform allows to avoid this permanent tax hike, but it necessitates a transitory rise in taxes to honor the pension obligations towards cohorts which contributed to the current system. These three channels jointly constitute the source of efficiency gains from the social security reform. A consensus emerged in the literature that these efficiency gains do not outweigh the insurance loss (e.g. Davidoff et al. 2005, Nishiyama and Smetters 2007, Fehr et al. 2008, Harenberg and Ludwig 2019). In this paper we argue that closing the reform using capital income taxation may be particularly advantageous, amplifying the original efficiency gains of the reform. We provide novel insights on the trade-offs between efficiency, taxation and insurance in an economy with overlapping generations, idiosyncratic income shocks and rising longevity.

We show that rising life expectancy *motivates individuals to raise savings*, hence lowering their responsiveness to the hikes in capital income tax. This makes capital income an interesting candidate for taxation. We thus extend the prior literature which presented the case for positive capital income tax (Garriga 2001, Findeisen and Sachs 2017, Krueger et al. 2021).[2] Furthermore, the so-called privatization of social security amplifies this mechanism because reduced insurance in social security pushes motivates individuals to acquire precautionary savings. Combined with improved labor supply incentives and faster capital accumulation, this lower responsiveness to tax hikes tilts the balance between the insurance against income shocks (redistribution) and efficiency of social security reform.

Our paper offers three contributions to the literature. First, we contest the existing consensus that insurance motive dominates the efficiency gains. We show that – under longevity – financing social security reform with taxing capital income gains increases the efficiency gains relative to other fiscal closures. We demonstrate that the key mechanism behind this result relies on reduced (semi) elasticity of capital with respect to capital income tax rate. Second, we decompose the aggregate welfare effect to the insurance loss and efficiency gain to aggregate welfare. We show that the insurance loss is not large for plausible calibrations of the US economy. Third, we reconcile our results with the earlier

[1] McGrattan and Prescott (2017) as well Shourideh and Hosseini (2019) study the case of removing social security, the former shows Pareto-improving ways of phasing out and the latter proposes replacing social security with age specific subsidies to earned interest.

[2] While the direct welfare effects of taxing capital are likely to remain small (Golosov et al. 2013) and the sign depends on agents' heterogeneity (in particular the heterogeneity of preferences, Lockwood and Weinzierl 2015), the effects for efficiency may be considerable. Fehr and Kindermann (2015) argue that the relatively high levels of optimal capital taxation follow from applying a utilitarian welfare criterion in the prior literature.

literature by providing a broad overview of the welfare implications of improving the solvency of the social security with a variety of fiscal instruments. These instruments were typically considered in isolation in earlier studies.

The cornerstone of this analysis lies in recognizing the role of increasing longevity for capital taxation in the context of social security. If the US economy continues with the current social security, the size of the necessary fiscal adjustment is indeed large: to balance, an increase in contribution rates by roughly 20% (Braun and Joines 2015) or an approx. 40% reduction in replacement rates (Fehr 2000) will be needed. Such a substantial increase in taxes would have immediate welfare effects (e.g. Kotlikoff et al. 1999, Huggett and Ventura 1999, Genakoplos et al. 2000). In addition, the current US system redistributes through progressive replacement rates, depending on AIME (Average Indexed Monthly Earnings): the replacement rate is high for low incomes (90%), and it declines step-wise (to 15%) for high incomes.

Whereas increasing longevity is the primary driver of the social security reform, it also makes savings less responsive to capital income taxation because a longer old-age life-span necessitates higher accumulation of assets. In addition, linking social security payouts to individual contributions increases lifetime income risk. Accordingly, greater variance of the lifetime income raises the need for precautionary savings, making capital relatively less responsive to taxation. Therefore, in the context of rising longevity, adjusting the fiscal imbalances due to social security reform through taxing capital income may be especially harmless in the transition period and particularly beneficial in the long run.

To study these well-founded intuitions quantitatively, we build an overlapping generations model with idiosyncratic income shocks, calibrated to the US economy. In the initial steady state, the economy has a defined benefit system financed on a pay-as-you-go basis, reflecting the features of the US social security. We introduce capital income taxation as a fiscal closure for this reform of social security.[3] We also formalize the strength of capital reaction to changes in the taxation of capital income gains through the analysis of elasticity of capital with response to taxation across these scenarios. Across all those counterfactual simulations, we compare the scenario of taxing consumption and taxing capital income.

The key result of our study is that with rising longevity, the privatization of social security with partial funding raises aggregate welfare if capital income taxation is used to finance the transition costs. This result proves robust to many sensitivity checks. We show that without a rise in longevity, there is little or no value in privatizing the pension system: without the fiscal costs associated with rising longevity, the benefits of privatization do not outweigh the loss of insurance, regardless of the fiscal closure.

We isolate the insurance loss channel from the aggregate welfare effect. The earlier literature has argued that the insurance motive implicit in redistributive social security plays a major role in determining the welfare effects of privatizing social security (e.g. Nishiyama and Smetters 2007, Heer 2018). Linking the old-age benefits with the labor supply in the working ages reduces distortion to labor supply and thus raises efficiency in the economy, but at the expense of reducing the insurance against the idiosyncratic income shocks with individualized (and in this sense privatized) pensions (Conesa and Krueger 1999). In a study carefully calibrated to the case of the U.S., Nishiyama and Smetters (2007) demonstrate that privatization of the social security entails aggregate welfare gain in a deterministic setup (due to the efficiency gain), but becomes detrimental to welfare in a stochastic setup due to the insurance loss (see also Davidoff et al. 2005, Fehr et al. 2008, Harenberg and Ludwig

[3]To the best of our knowledge, only Keuschnigg et al. (2012) in a report for the World Bank consider capital income taxation, but as a measure accompanying the reform rather than a fiscal closure.

2019).[4]

We relate our findings to the literature: in addition to capital income taxation, we also study the fiscal closures considered in the past. These include within social security (parametric adjustments in the contribution rate and replacement rate) and outside social security (consumption tax). Our model also replicates the conventional findings that with no rise in longevity and with consumption taxation as a fiscal closure, efficiency gains are insufficient to compensate for the loss of insurance inherent in the US pension system (Davidoff et al. 2005, Nishiyama and Smetters 2007, Fehr et al. 2008, Harenberg and Ludwig 2019). Given that welfare gains arise with capital income taxation, we show that the existing consensus is a special case rather than a universal result. Indeed, the choice of a particular fiscal instrument generates welfare effects on its own. We show that capital income taxation amplifies the efficiency gains of the reform, whereas previously used consumption taxation attenuates them.[5]

Our paper is structured as follows. The model is presented in section 2. Since the crux of the mechanisms studied in this paper relates to *changes* along the transition path, we move directly to full general equilibrium setup. Section 3 describes calibration and the simulation scenarios in detail. We present the results in section 4, together with sensitivity checks. The final section concludes, emphasizing the contribution to the literature and the policy recommendations emerging from this study.

2 The model

We build a general equilibrium, overlapping generations model with idiosyncratic income shocks (*ex post* within cohort heterogeneity). In the baseline scenario an economy follows the current US social security (pay-as-you-go defined benefit with redistribution through AIME and OADSI). We denote this system interchangeably as baseline or status quo. In such economy, rising longevity deteriorates fiscal balance in social security.

In the reform scenario, we gradually replace the status quo with a partially funded defined contribution (DC) social security. The two key features of the DC system are that (a) it strengthens the link between *individual* labor supply and future pension benefits and (b) aging implies no fiscal adjustments to the net fiscal balance of the social security. The gradual implementation of partially funded DC in the place of status quo implies that this fiscal relief is not immediate. The efficiency gain due to linking labor supply and pension benefits is realized immediately. (Partial) Funding generates further efficiency gains under the condition that return on capital exceeds the payroll growth (the notorious $r > g$).

[4]The extent of efficiency gain may depend on a number of factors including the extent of time inconsistency (Imrohoroglu et al. 2003, Fehr et al. 2008, Fehr and Kindermann 2010), labor supply (Bagchi 2015), financial market imperfections (Nishiyama and Smetters 2007, De la Croix et al. 2012, Caliendo et al. 2014), aggregate risks (Harenberg and Ludwig 2015), etc. See also reviews by Lindbeck and Persson (2003), Fehr (2009, 2016).

[5]This observation did not receive much attention in the earlier literature, though studies differ substantially in how the reforms are financed on the fiscal side. For example, Auerbach and Kotlikoff (1987) adjust the contribution rates, whereas Fehr et al. (2008), Keuschnigg et al. (2012), Fehr and Kindermann (2010), Ludwig and Vogel (2010) interchangeably employ labor tax and contribution rate adjustments. By contrast, Nishiyama and Smetters (2007) use a consumption tax and Okamoto (2005) uses a lump-sum tax. Table A summarizes examples of the studies devoted to parametric and pension system reforms, synthesizing the stark differences in the fiscal closures used. Reportedly, this literature focuses on fundamental questions – e.g., fiscal stability of the pension system, welfare, political support – leaving aside "technicalities" such as fiscal closures (Lindbeck and Persson 2003, Fehr 2009). Due to rising longevity, both the status quo of the current redistributive pension system and the policy reforms necessitate fiscal adjustments: change in tax rates, contribution rates or pension benefits (Feldstein et al. 2016, Diamond et al. 2016).

2.1 The environment

Population dynamics Agents live for $j = 1, 2..., J$ periods and are heterogeneous with respect to age j, one period corresponds to five years. Agents are born at the age of $j = 1$, which is equivalent to 20 years of age in the data and allows the model to abstract from timing the labor market entry and educational choices. Consumers face age and time specific survival rates $\pi_{j,t,t+i}$, which is a conditional probability in period t of surviving to age $j+i$. At all points in time, consumers who survive until the age of $J = 16$ die with certitude. The share of population surviving until older age is increasing, to reflect rising longevity. The data on mortality comes from the United Nation projection until 2100. The data on the number of births come from the U.S. Census Bureau projection until 2060. Population structure eventually becomes stationary in the final steady state; the yearly population growth amounts to 1.002 with a stable age structure.[6]

Intra-cohort heterogeneity Each agent is born with an identical labor productivity $\omega_{1,t} = 1$, for all t. However, productivity evolves over lifetime according to $\omega_{j,t} = e^{\eta_{j,t}}$, where a random component $\eta_{j,t}$ follows an AR(1) process with persistence parameter ϱ and $\varepsilon_{j,t} \sim \mathbf{N}(0, \sigma^2)$.

$$\eta_{j,t} = \varrho\eta_{j-1,t-1} + \varepsilon_{j,t} \tag{1}$$

We approximate this process above by a first order Markov chain with a transition matrix $\Pi(\eta_{j,t}|\eta_{j-1,t-1})$.

2.2 Consumer, producer and the government

Budget constraint Agents at an age lower than the retirement age earn gross labor income $\omega_{j,t}w_t l_{j,t}$, where w_t is the marginal productivity of aggregate labor, $l_{j,t}$ denotes labor supply and $\omega_{j,t}$ is idiosyncratic component of labor productivity. Labor income is subject to social security contribution τ_t and progressive labor income tax with the elasticity of post-tax to pre-tax income equal $1-\lambda$ and average tax rates determined by τ_l. Note that social security contributions are exempt from labor taxation. Labor income tax base $y_{j,t}$ of agent at age j at the time t is given by: $y_{j,t} = (1-\tau_t)w_t\omega_{j,t}l_{j,t}$. $\mathcal{T}(y_{j,t}) = y_{j,t} - (1-\tau_l)y_{j,t}^{1-\lambda}$ denotes the labor tax due at income level $y_{j,t}$ (Benabou 2002).

In addition to salary, the income of the individuals consists of after-tax capital gain $(1-\tau_{k,t})r_t a_{j,t}$ (with $\tau_{k,t}$ denoting capital income tax rate, r_t the interest rate and $a_{j,t}$ denoting assets held at age j). For brevity, denote $\tilde{r}_t = (1-\tau_{k,t})r_t$. Once she reaches retirement age $\bar{J}$, she receives pension benefits $b_{j,t}$,[7]. Agents have no bequest motive, but since survival rates $\pi_{j,t,t+i}$ are lower than one, in each period t certain fraction of cohort j leaves unintended bequests, which are distributed within the birth cohort, $\Gamma_{j,t}$.[8] The discount factor is denoted by δ. Income is used to purchase consumption goods $\tilde{c}_{j,t} = (1+\tau_{c,t})c_{j,t}$ (with $\tau_{c,t}$ denoting tax on consumption) and to accumulate assets $a_{j+1,t+1}$. Assets markets are incomplete; only assets with risk free interest rate r_t are available and asset holdings cannot be negative. Hence, agents face the following instantaneous budget constraint:

$$a_{j+1,t+1} + \tilde{c}_{j,t} = y_{j,t} - \mathcal{T}(y_{j,t}) + b_{j,t} + (1+\tilde{r}_t)a_{j,t} + \Gamma_{j,t}, \text{ with } a_{j,t} \geqslant 0. \tag{2}$$

[6] Due to the 5 year period, population growth is recalculated and model input is $n = 1.002^5 = 1.0104$

[7] Note that later in text $b_{j,t}$ is characterized by superscripts. In the baseline social security has $b_{j,t} = b^A_{j,t}$, whereas in the reform scenarios it is $b_{j,t} = b^I_{j,t} + b^{II}_{j,t}$. Analogously, the following notation applies two pension wealth: $f_{j,t} = f^A_{j,t}$ in baseline scenario, $f_{j,t} = f^I_{j,t}$ in reform scenario without funding, and $f_{j,t} = f^I_{j,t} + f^{II}_{j,t}$ in reform scenario with funding. Without loss of generality, there is no income tax on pension benefits.

[8] Bequests further increase the motivation to accumulate assets (De Nardi and Yang 2014), which would amplify the mechanisms described in our paper.

Consumer problem Consumer in our model derives instantaneous utility from consumption and leisure, as given by:

$$u(c_{j,t}, 1-l_{j,t}) = \frac{1}{1-\theta}\left(c_{j,t}^{\phi}(1-l_{j,t})^{1-\phi}\right)^{1-\theta}, \tag{3}$$

with $1-\phi$ and θ denoting leisure preference and risk preference, respectively.

An individual state of each agent $s_{j,t} = (a_{j,t}, f_{j,t}, \eta_{j,t}) \in \Omega_t$ consists of the level of private assets $a_{j,t}$, pension wealth $f_{j,t} = (f_{j,t}^{A}, f_{j,t}^{I}, f_{j,t}^{II})$[9] and individual productivity determined by $\eta_{j,t}$. Let $\mathbb{P}_{j,t}$ denote the probability measure over the state space consistent with transition probabilities $\Pi(\eta_{j,t}|\eta_{j-1,t-1})$ and policy functions. An agent enters the economy with no assets ($a_{1,t} = 0$) and the agent at the state $s_{j,t}$ maximizes the expected value of the lifetime utility. We define the optimization problem of the consumer in a recursive form as:

$$V_{j,t}(s_{j,t}) = \max_{c_{j,t}, l_{j,t}, a_{j+1,t+1}} u(c_{j,t}, l_{j,t}) + \delta\pi_{j,t,t+1}\mathbf{E}\big(V(s_{j+1,t+1}) \mid s_{j,t}\big) \tag{4}$$

subject to the budget constraint given by equation (2). The productivity process given by equation (1). The total time endowment is normalized to one.

Production Using capital and labor, the economy produces a composite consumption good. Production function takes a standard Cobb-Douglas form $Y_t = K_t^{\alpha}(z_t L_t)^{1-\alpha}$ with labor augmenting exogenous technological progress, $z_{t+1}/z_t = \gamma_t$. Capital depreciates at the rate d. Standard maximization problem of the firm yields the return on capital and real wage

$$r_t = \alpha K_t^{\alpha-1}(z_t L_t)^{1-\alpha} - d \quad \text{and} \quad w_t = (1-\alpha)K_t^{\alpha} z_t^{1-\alpha} L_t^{-\alpha}, \tag{5}$$

The government There are four types of taxes: labor income tax, capital income tax, consumption tax and lump sum tax. Tax revenue or change in public debt D_t is used to finance spending on public goods and services G_t, balance social security, and service debt $r_t D_{t-1}$, with $\Delta D_t \equiv D_t - D_{t-1}$. We assume that in the baseline scenario public spending is constant as a share of GDP: $G_t = \varsigma Y_t$. In the reform scenario, we keep public spending the same as in baseline scenario in per capita terms, thus the amount of spending does not differ between baseline and reform scenarios. The government budget constraint follows

$$\begin{aligned} G_t + subsidy_t + r_t D_t &= T_t + \Delta D_t, \\ \text{where } T_t &= \sum_{j=1}^{\bar{J}-1} N_{j,t} \int_{\Omega} \mathcal{T}\big(y_{j,t}(s_{j,t})\big) d\mathbb{P}_{j,t} + \tau_{k,t} r_t A_t + \tau_{c,t} C_t, \end{aligned} \tag{6}$$

and L_t, C_t and A_t denote aggregate labor supply, aggregate consumption and aggregate assets, respectively. We set the initial debt D_t at par with the data to 110% of GDP. Public debt is kept constant as ratio to GDP, to avoid welfare effects stemming from permanent changes in public debt ratio.

Social security In the baseline, we replicate the main features of the current U.S. social security design: average index of monthly wages accumulation (AIME) and cap imposed by Old-Age, Survivors, and Disability Insurance (OASDI).[10] Let w_t be aggregate wages. We denote AIME accumulation

[9] The specifics of the pension wealth are discussed later in text.

[10] We compute AIME based on the whole working period rather than 35 years with the highest earnings, as it would be redundant in a setup with 5-year periods. Our implementation of the contemporaneous U.S. social security is in line with the earlier literature (e.g. Nishiyama and Smetters 2007, McGrattan and Prescott 2017).

by $f^A_{j,t}$. Further, for convenience denote by L_t the aggregate labor supply and payroll growth by $g_t = \frac{w_t L_t}{w_{t-1} L_{t-1}} - 1$. AIME is implemented as:

$$f^A_{j+1,t+1} = \frac{1}{j}((j-1) \cdot f^A_{j,t} \cdot (1+g_t) + \min\{\omega_{j,t} w_t l_{j,t}, \omega w_t l^{max}_t\}), \tag{7}$$

where $\omega w_t l^{max}_t$ denotes OASDI cap. To replicate the progressive nature of the replacement rate we rely on bend points $(F_{1,t}, F_{2,t})$ expressed as a fraction of average earnings. We then define the replacement rate ρ to be consistent with:

$$\rho_{\bar{J},t} = [f^A_{\bar{J},t}]^{-1} \cdot \left[0.9 \cdot \min\{f^A_{\bar{J},t}, F_{1,t}\} + 0.32 \cdot \min\{f^A_{\bar{J},t} - F_{1,t}, F_{2,t}\} + 0.15 \cdot (f^A_{\bar{J},t} - F_{2,t})\right]. \tag{8}$$

The actual value of the old age pension benefit for a cohort retiring in period t is given by

$$b^A_{\bar{J},t} = \rho_m \rho_{\bar{J},t} \cdot f_{\bar{J},t} \quad \text{and} \quad b^A_{j,t} = (1+g_t) b^A_{j-1,t-1} \qquad \forall j > \bar{J}, \tag{9}$$

where a scaling factor ρ_m is set to match steady state pension benefit to GDP ratio.

The budget constraint of the social security is given by

$$\sum_{j=\bar{J}}^{J} N_{j,t} \int_{\Omega} b^A_{j,t}(s_{j,t}) d\mathbb{P}_{j,t} = \tau_t w_t L_t + subsidy_t, \tag{10}$$

where $subsidy_t$ denotes the deficit in social security (negative in the case of surplus) which, if necessary, is financed by the government. Note that while this system is redistributive (the effective pensions are higher than proportional for low incomes and lower than proportional for high incomes), it is not the maximal insurance, which would be achieved with equal benefits to all agents within a cohort.

2.3 The social security reform

Our model economy is subjected to an unexpected systemic change in social security: we introduce a defined contribution system with partial funding.[11] In the reformed system, individuals contribute to a PAYG pillar and a funded pillar, but the benefits are based on individual earnings trajectories.

Reform scenario The reform creates two pillars. The first pillar is financed on a pay-as-you-go basis: the contributions are used to finance the contemporaneous benefits. The contributions are accrued in the notional terms and this notional amount converted to an annuity at retirement. In the contributing periods as well as in the retirement periods, the notional value of the contributions is indexed with g_t. The second pillar is of funded nature: the contributions accrue to individual pension savings, which earn the market interest rate in the financial markets. These savings are exempt from capital income taxation and are converted to an annuity at retirement.

The PAYG pillar and the funded pillar of the reformed DC social security provide pension benefits denoted by b^I and b^{II}, respectively. The budget constraint of the PAYG pillar of social security is

[11] This type of reform was recommended as means to address fiscal vulnerability resulting from a rise in longevity; it has been implemented as of 1990s in many countries around the world (e.g., Sweden, Central Europe, Mexico, and Chile, among others, see Holzmann 2013) and is invariably under consideration in the US (Feldstein 2005, Diamond et al. 2016).

given by

$$\sum_{j=\bar{J}}^{J} N_{j,t} \int_{\Omega} b^{I}_{j,t}(s_{j,t}) d\mathbb{P}_{j,t} \quad = \quad \tau^{I}_{t} w_t L_t + subsidy_t, \tag{11}$$

which differs from equation (10): $b^I_{j,t}$ replaces $b_{j,t}$ on the expenditure side and τ^I_t replaces τ_t on the revenue side. Note that this social security is by design balanced; with longevity pension benefits decline for subsequent birth cohorts.

The formula for $b^I_{j,t}$, in the PAYG pillar of the DC system, differs substantially from equation (9) for $b_{j,t}$ in the DB social security. Namely, during the working period, agents accumulate a notional value of the contributions, indexed by payroll growth rate g_t, adjusted for cohort-specific mortality $\pi_{j-1,t-1,t}$. At retirement, the accrued notional value of contributions is divided by life expectancy of each cohort and henceforth paid out as pension benefit.

$$f^{I}_{j,t} \quad = \quad (1+g_t)\pi^{-1}_{j-1,t-1,t} \cdot f^{I}_{j-1,t-1} + \tau^{I}_{t}\omega_{j,t} w_t l_{j,t}, \tag{12}$$

$$b^{I}_{\bar{J},t} \quad = \quad \begin{cases} f^{I}_{j,t} \cdot \left(\sum_{i=0}^{J-j} \pi_{j,t,t+i}\right)^{-1} & \text{iff} \quad j = \bar{J} \\ (1+g_t) b^{I}_{j-1,t-1} & \forall j > \bar{J}. \end{cases} \tag{13}$$

The same applies to the funded pillar. The difference between the PAYG pillar and the funded pillar is that the latter invests the funds, hence the return is given by the market interest rate r_t. Thus pension wealth accumulation and then pension benefits follow:

$$f^{II}_{j,t} \quad = \quad (1+r_t)\pi^{-1}_{j-1,t-1,t} \cdot f^{II}_{j-1,t-1} + \tau^{II}_{t}\omega_{j,t} w_t l_{j,t} \tag{14}$$

$$b^{II}_{\bar{J},t} \quad = \quad \begin{cases} f^{II}_{j,t} \cdot \left(\sum_{i=0}^{J-j} \pi_{j,t,t+i}\right)^{-1} & \text{iff} \quad j = \bar{J} \\ (1+r_t) b^{II}_{j-1,t-1} & \forall j > \bar{J}. \end{cases} \tag{15}$$

Implementation The implementation is gradual. We set the reform date to 2020. Individuals born in the year of reform and later participate in the reformed two-pillar DC social security. Individuals active prior to the implementation of the reform have their pensions disbursed by the baseline social security (even though they live in a reformed economy). Hence, for a while, a deficit in social security is generated because (higher) baseline pensions have to be paid despite part of the contributions being directed to funded DC pillar of the system. This mechanism generates a transitory deficit and requires financing.

The gradual implementation has the following consequences. First, majority of the rise in longevity materializes in pension expenditure under status quo. This means that the fiscal gains from replacing the status quo with defined contribution are largely postponed to the future periods. Second, slower transition implies that contributions to the funded pillar are diverted at a slower rate (one birth cohort per period).

Such lengthy implementation may be viewed as politically not sufficiently credible. We thus study also an alternative, faster implementation, in which only cohorts older than 50 at the time of the reform ($j > 6$ at $t = 2$) remain in the status quo social security. For the transition cohorts who worked prior to the implementation of the reform and are shifted to the new scheme, we impute the initial values of $f^I_{j,2}$. This imputation is performed for the cohorts born between 1965-1995. We impute the counter-factual funds using the contribution rate τ from the initial steady state and the formula:

$$\text{if} \quad 2 \leqslant j \leqslant 6 \quad \text{in} \quad t = 2 \quad f^I_{j,2} = \sum_{i=1}^{j} \frac{1}{\pi_{i,1,j}} \tau w_1 \bar{l}_{i,1} (1 + g_1)^{j-i} \tag{16}$$

where $j = 6$ corresponds to the maximum age of agents assigned to DC scheme, once the reform is implemented, and $\bar{l}_{s,1}$ is the average labor supply of cohort s at time 1. Note that these imputed incomes are deterministic, as if the past – prior to the implementation of the social security reform – had no income dispersion. Hence, for the transition cohorts, the insurance inherent in AIME is preserved in the social security. Cohorts born in 1965 and later participate fully in the new, two-pillar DC system. The deficit of the PAYG DC pillar, the $subsidy_t$ in equation (10), is financed by the government. The speed of the reform implementation does not affect the overall results (even if results for specific birth cohorts are naturally different). We report the these results in Appendix I.

Parametrization of social security The reform does not change the overall contribution rate relative to the baseline scenario: $\tau_t = \tau_t^I + \tau_t^{II}$, where we denote by τ_t^I the mandatory contributions that go into the DC PAYG pillar and, by τ_t^{II} the mandatory contributions that go into the funded pillar. The split of the contribution to the two pillars may be of any proportion. In the simulation, we assume $\tau_t^I = \tau_t^{II} = 0.5\tau_t$, but study also the sensitivity of our main results to this assumption.

The link between social security contributions and labor supply distortion Compare equations (7) on the one hand and (12)-(14) on the other hand – they describe the link between current labor supply and future pensions, *ceteris paribus*. It has been a convention in the literature to assume that the agents perceive pensions from AIME to be independent of their current labor supply decisions, it is also consistent with the empirical evidence (Liebman et al. 2009). Meanwhile, formulae (12)-(14) yield clear derivative of the current labor supply in terms of future pension benefits. In other words, each additional hour worked under AIME yields lower life-time income than under reformed social security, *ceteris paribus*. Hence, replacing AIME with the reformed system substantially reduces distortion in labor supply decision associated with contributing to the social security. It is convenient to represent the distortion from social security contributions in the consumer problem as implicit taxation, to reduce the number of state variables (Butler 2002). The basic idea is to show the present value of pension claims in the form of *virtual assets* $\widehat{f}_{j,t}$, which directly enter the budget constraint. We portray it specifically by rewriting the budget constraint (2) for the respective social security systems.

In the accumulation period, the following holds:

$$\begin{aligned}
\text{Baseline}: \quad & a_{j+1,t+1} + \tilde{c}_{j,t} = && y_{j,t} - \mathcal{T}(y_{j,t}) + (1+\tilde{r}_t)a_{j,t} + \Gamma_{j,t} \\
\text{PAYG DC}: \quad & \widehat{f}^I_{j+1,t+1} + a_{j+1,t+1} + \tilde{c}_{j,t} = && y_{j,t} - \mathcal{T}(y_{j,t}) + (1+\tilde{r}_t)a_{j,t} + \Gamma_{j,t} \\
& && +(1+\tilde{r}_t)\widehat{f}^I_{j,t} + \tau_t w_t \omega_{j,t} l_{j,t} \cdot \mu^I_{j,t} \\
\text{Two-pillar DC}: \quad & \widehat{f}^I_{j+1,t+1} + \widehat{f}^{II}_{j+1,t+1} + a_{j+1,t+1} + \tilde{c}_{j,t} = && y_{j,t} - \mathcal{T}(y_{j,t}) + (1+\tilde{r}_t)a_{j,t} + \Gamma_{j,t} \\
& && +(1+\tilde{r}_t)\widehat{f}^I_{j,t} + \tau^I_t w_t \omega_{j,t} l_{j,t} \cdot \mu^I_{j,t} \\
& && +(1+\tilde{r}_t)\widehat{f}^{II}_{j,t} + \tau^{II}_t w_t \omega_{j,t} l_{j,t} \cdot \mu^{II}_{j,t},
\end{aligned} \tag{17}$$

where $\mu^I_{j,t} < \mu^{II}_{j,t}$ because $r < g$. During the deaccumulation period, the budget constraint takes the same form for each social security: it is given by equation (2) with $b_{j,t}$ from the applicable pension formula. The full derivation is relegated to Appendix C, but the key insight from this rewriting of the budget constraint is that through the budget constraint we can demonstrate two separate effects. First, the extent of labor distortion varies between the scenarios: PAYG DC and two-pillar DC are characterized by "additional" income coming from $\mu_{j,t} \neq 0$, with $\mu_{j,t} \equiv 0$ in baseline scenario. The second is the income effect associated with the virtual assets $\widehat{f}_{j,t}$, with strictly zero accumulation in baseline scenario.

2.4 Equilibrium and solution method

Recall that the state of an agent is fully characterized by $s_{j,t} = (a_{j,t}, \eta_{j,t}, f_{j,t}) \in \Omega$. We denote the probability measure describing the distribution of agents of age j in period t over the state space Ω as $\mathbb{P}_{j,t}$.

Definition 1 ***Recursive equilibrium.*** *A recursive competitive equilibrium is a sequence of value functions* $\{(V_{j,t}(s_{j,t}))_{j=1}^{J}\}_{t=1}^{\infty}$*, policy functions* $\{(c_{j,t}(s_{j,t}), l_{j,t}(s_{j,t}), a_{j+1,t+1}(s_{j,t}))_{j=1}^{J}\}_{t=1}^{\infty}$*, prices* $\{r_t, w_t\}_{t=1}^{\infty}$*, government policies* $\{\tau_{c,t}, \mathcal{T}(y_{j,t}), \tau_{k,t}, D_t\}_{t=1}^{\infty}$*, social security system* $\{\tau, subsidy_t, \rho\}_{t=1}^{\infty}$*, aggregate quantities* $\{L_t, A_t, K_t, C_t, Y_t\}_{t=1}^{\infty}$*, and a measure of households* $\mathbb{P}_{j,t}$ *such that:*

- ***consumer problem:*** *for each* j *and* t *the value function* $V_{j,t}(s_{j,t})$ *and the policy functions* $(c_{j,t}(s_{j,t}), l_{j,t}(s_{j,t}), a_{j+1,t+1}(s_{j,t}), f_{j+1,t+1}(s_{j,t}))$ *solve the Bellman equation* (4) *given prices and policies;*

- ***firm problem:*** *for each* t*, prices* (r_t, w_t) *satisfy equation* (5)*;*

- ***government sector:*** *the government budget and the PAYG social security are balanced, i.e. equations* (6) *and* (7) *and, depending on the scenario, equations* (10) *or* (11) *are satisfied;*

- ***markets clear***

$$\text{labor market:} \quad L_t = \sum_{j=1}^{\bar{J}} N_{j,t} \int_{\Omega} \omega_{j,t}(s_{j,t}) l_{j,t}(s_{j,t}) d\mathbb{P}_{j,t} \tag{18}$$

$$\text{capital market:} \quad A_t = \sum_{j=1}^{J} N_{j,t} \int_{\Omega} a_{j,t}(s_{j,t}) d\mathbb{P}_{j,t} \tag{19}$$

$$K_{t+1} = A_t + D_t \tag{20}$$

$$\text{goods market:} \quad C_t = \sum_{j=1}^{J} N_{j,t} \int_{\Omega} c_{j,t}(s_{j,t}) d\mathbb{P}_{j,t} \tag{21}$$

$$Y_t = C_t + K_{t+1} - (1-d)K_t + G_t; \tag{22}$$

- ***probability measure:*** *for all* t *and for all* j*,* $\mathbb{P}_{j,t}$ *is consistent with the transition probabilities* $\Pi(\eta_{j,t}|\eta_{j-1,t-1})$ *and policy functions.*

We discretize the reduced state space, with dimensionality of the state variables s, with three state variables $\hat{\Omega} = \hat{A} \times \hat{H} \times \hat{F}$ with $\hat{A} = \{a^1, ..., a^{n_A}\}$, and $\hat{H} = \{\eta^1, ..., \eta^{n_H}\}$, and $\hat{F} = \{f^1, ..., f^{n_F}\}$.We interpolate policy and value functions with piece-wise linear functions (using recursive Powell's algorithm). For each discrete $\hat{s}_{j,t} \in \hat{\Omega}$ we find the optimal consumption and labor supply of the agent using Newton-Raphson method.

For given initial distribution $\hat{\mathbb{P}}_{1,t}$ at age $j = 1$ and time t and transition matrix $\Pi(\eta_{j,t}|\eta_{j-1,t-1})$ and the policy functions $\{a_{j+1,t+1}(\hat{s}_{j,t}), f_{j+1,t+1}(\hat{s}_{j,t}))_{j=1}^{J}\}_{t=1}^{\infty}$ we can compute the distribution in any successive age j and period t. It can be interpreted as a fraction of cohort of age j at time t residing at each state of the state space $\hat{\Omega}$. Once we compute distributions and policy functions for each state, we compute aggregate quantities of consumption, labor and savings. To this end we use Gaussian quadrature method.

Once the consumer problem is solved for a given set of prices and taxes, we apply the Gauss-Seidel algorithm to obtain the general equilibrium. Using the outcome of the consumer problem, the value of aggregate capital is updated. The procedure is repeated until the difference between the aggregate capital from subsequent iterations is negligible, i.e. l_1-norm of the difference between capital vector in subsequent iterations falls below 10^{-12}. Once the algorithm converges, utilities at $j = 1$ for all generations are computed.

2.5 Fiscal closures

We use **capital income taxation** as a fiscal closure. Tax on capital income adjusts immediately in each period to balance the government budget constraint system. It implies

$$\tau_{k,t} = \frac{G_t + subsidy_t + r_t D_t - \tau_{c,1} C_t - \sum_{j=1}^{\bar{J}-1} N_{j,t} \int_{\Omega} \mathcal{T}\big(y_{j,t}(s_{j,t})\big) d\mathbb{P}_{j,t} - \Delta D_t}{r_t A_t}. \tag{23}$$

The previous literature did not study capital income taxation as a fiscal closure for the social security reform, but adjusted a broad variety of taxes in the economy. We report a systematic overview of the fiscal closures used in previous studies in Table A. As is clear from this table, the most popular fiscal adjustments are either consumption taxation or adjustments within the social security (contribution rates or replacement rates). We relate to this literature: we compare our results to analogous simulation with **consumption tax** as closure. Similar to equation (23), we formulate

$$\tau_{c,t} = \frac{G_t + subsidy_t + r_t D_t - \tau_{k,1} r_t A_t - \sum_{j=1}^{\bar{J}-1} N_{j,t} \int_{\Omega} \mathcal{T}\big(y_{j,t}(s_{j,t})\big) d\mathbb{P}_{j,t} - \Delta D_t}{C_t}. \tag{24}$$

In addition, we also consider fiscally neutral closures, which adjust either of the two key parameters of the social security: the contribution rates and the replacement rates. We describe details of these closures in Appendix B. We describe the details of welfare measurement in Appendix D.

3 Calibration and *status quo*

The model is calibrated to match features of the U.S. economy. The model period corresponds to five years. Using microeconomic evidence and the general characteristics of the U.S. economy, we established reference values for preferences, life-cycle productivity patterns, taxes, technology growth rates, etc. Given these, the discount factor δ was set to match the initial steady state capital to output ratio 2.7. Depreciation rate d is set to 5.6% per anum (25.8% for five-year periods). The implied aggregate investment rate is equal to 19.6%. The calibration of the model parameters is summarized in Table 1.

Demographics. The evolution of population is based on the projection by The United Nations and the US Census. As input data we use the number of 20-year-olds born at each period in time and mortality rates. Projection period is 50 years for population and 90 years for mortality rates. After periods covered by projection we assume that mortality stabilizes and that annual population growth rate converges to 1.002 in the final steady state, see Figure E.1. In scenarios without longevity increase, we keep $\pi_{j,t}$ constant $\forall t$, but allow for population increase due to a larger size of each subsequent birth cohort.

Productivity growth (γ_t). The model specifies labor augmenting growth of technological progress $\gamma_{t+1} = z_{t+1}/z_t$. The debate about the future of the US growth is ongoing (e.g. Fernald and Jones 2014, Gordon 2014). We assume a steady technological progress at the current rate of 2% per annum, constant over the whole transition path. Note that although the technological progress is the same in baseline and reform scenarios, higher values of γ are beneficial for the PAYG systems. With a stable technological progress, the main secular driver of the changes in the interest rate is demographics.[12] H).

Idiosyncratic productivity shock (η). The idiosyncratic component is specified as a first-order autoregressive process with autoregression $\bar{\varrho}_\eta = 0.95$ and variance $\bar{\sigma}_\eta = 0.0375$ which are based on estimates from Guvenen (2009).[13] In our model each period corresponds to 5 years. Hence we recalculate input variables according $\varrho_\eta = \bar{\varrho}_\eta{}^5 \approx 0.774$ and $\sigma_\eta = \bar{\sigma}_\eta \frac{1-\bar{\varrho}_\eta{}^5}{1-\bar{\varrho}_\eta} \approx 0.170$.

Preferences. We calibrate the preference for consumption parameter ϕ to match the observed share of hours worked in the economy, which is 33% on average. The implied median Frisch elasticity in our model is 1.26. The discount factor δ was set at 1.01^5 to match the interest rate of 4.5%. In the earlier research in the field the discount factor was in excess of 1 as well, as with mortality the effective discount rate is below 1 (e.g. Nishiyama and Smetters 2007, McGrattan and Prescott 2017). The risk preference parameter $\theta = 2$, following the standard in the macroeconomic literature.

Social security parameters. We set the replacement rate (ρ_m) to match the 5.2% ratio of pensions to GDP. The effective rate of contribution τ was set such that the social security deficit in the original baseline steady state is equal to 0. Retirement age eligibility in the US occurs at 66, which is equivalent to $\bar{J} = 10$. In scenarios with rising longevity, retirement age eligibility is increased in 2040 to $\bar{J} = 11$. This rise is commensurate with the change in life expectancy and is expected from the first period of the transition path.

Taxes and public debt. Taxes are calibrated using Mendoza et al. (1994) approach. The capital income tax was set to 18.5%, to match 5.4% ratio of the capital income tax revenues to GDP. The marginal tax rate consumption was set to 4.6% to match 2.8% radio of consumption income tax revenues to GDP. Progressive labor income tax function parameters $\lambda = 0.15$ and $\tau_l = -0.02$ were set to match elasticity of post-tax to pretax income and 9.2% ratio of the labor income tax revenues to GDP. Elasticity of post-tax to pretax income was based on Heathcote et al. (2017). The data on ratios between tax revenues and GPD come from the OECD data, see Table E.1. We calibrate the government expenditure $g = \frac{G}{Y} = 0.12$ in the initial steady state to match the debt/GDP ratio of 110%.[14] In the baseline and reform scenarios we keep debt as a constant share of GDP.

[12] As a robustness check, we introduce specifications with a gradually declining technological progress. Our conclusions are not dependent upon this assumption (see Appendix

[13] The same values have been used in Fehr et al. (2013), Braun et al. (2016), Heer (2018)

[14] Due to fiscal developments in the U.S., debt/GDP ratio is higher in our study than in the earlier literature.

Table 1: Calibrated parameters for the initial steady state

	Macroeconomic parameters	Calibration	Target	Value (source)	Model outcome
ϕ	preference for consumption	0.37	average hours	31% BEA(NIPA)	31%
θ	risk preference	2	literature		
δ	discounting rate	0.999^5	capital to output ratio	2.7	2.7
d	annual year depreciation rate	$1\text{-}(1\text{-}0.058)^5$	investment rate	21% BEA(NIPA)	19.6%
λ	labor tax progression	0.15	earnings distributions	Holter et al. (2019)	-
τ_l	labor tax	0.117*	revenue as % of GDP	9.2% OECD	9.2%
τ_c	consumption tax	0.041	revenue as % of GDP	2.8% OECD	2.8%
τ_k	capital tax	0.207	revenue as % of GDP	5.4% OECD	5.4%
ρ_m	pension scaling factor	1.015	benefits as % of GDP	5.2% BEA(NIPA)	5.2%
τ	social security contr.	0.078	pensions deficit as % GDP	0.00%	0.00%
g	government expenditure	0.124**	.		12%
	income shocks				
ϱ_η	shock persistence	0.774	Guvenen (2009)		
σ_η	shock variance	0.170	Guvenen (2009)		

* Average labor tax is equal to 13%.
** Used as a closure in initial steady state, then kept constant in per capita terms.
Notes: Holter et al. (2019), who use the change in government distribution pre- and post- taxes and transfers to calibrate the extent of tax progression. Tax rates calibrations following Mendoza et al. (1994), see Table E.1.

3.1 The *status quo* scenario

With changes in longevity, maintaining *status quo* social security necessitates considerable adjustments. Within the horizon of our analysis, the deficit in the social security increases to roughly 3% of GDP. Increasing lifespans raise the pension expenditure substantially despite an increase in eligibility age.[15] To give context to this number, the scale of the adjustment in the social security parameters necessary to prevent these imbalances amounts to a 30% rise in the contribution rate or a 40% decline in the replacement rate (these results are consistent with Fehr 2000, Braun and Joines 2015).

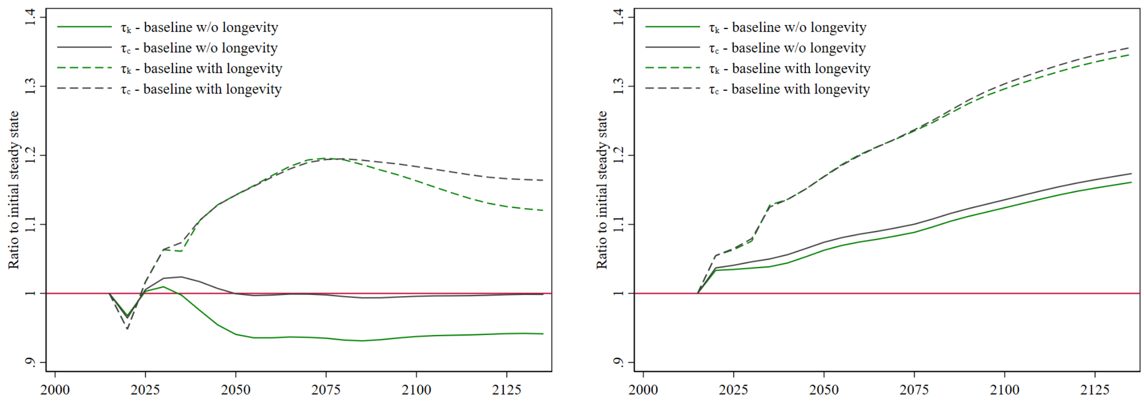
The powerful effects of the rise in longevity display through the adjustments in the economy. Figure 1 reports the adjustments in capital stock and in labor supply with and without a rise in longevity in the economy with the *status quo* social security. The behavior of labor supply is mostly driven by positive population growth (approx. 35% increase relative to the initial steady state within the next five generations) and changes in retirement eligibility age. The rising longevity adds to the labor supply due to the expectation of increased taxes in the future: the agents increase labor supply to raise income in the working ages to accumulate higher wealth for funding consumption in the old-age. The scale of labor supply adjustments is mostly independent of fiscal closure and is large enough to raise the tax base, thus raising overall tax revenues.

However, which tax base is selected as fiscal closure has important bearing on capital accumulation. In fact, capital accumulation is higher with τ_k adjustments than with τ_c adjustments. With no rise in longevity, taxes can decline due to the population growth. With τ_c as the fiscal closure, capital gradually declines (due to less expensive consumption), and it slightly increases with τ_k as a fiscal closure (due to higher effective rate of return on assets). With rising longevity, temporarily higher fiscal revenues require higher capital income taxation, which *increases* capital accumulation. Meanwhile, rising taxes on consumption make old-age consumption more expensive, which raises the stock of savings needed to finance old-age consumption. The former channel has stronger impact on capital accumulation than the latter one.

[15] Details of the fiscal adjustment are reported in section 4, the adjustments in deficit in the baseline scenario are reported in Figure G.2a for reference.

Figure 1: The effects of demographics on capital and labor supply in baseline scenario

(a) capital (b) labor supply



Note: Capital expressed per effective worker, relative to initial steady state. Aggregate labor expressed relative to initial steady state. The temporary drop of capital per effective unit of labor in the reform scenario (left panel) is due to the sharp increase of aggregate labor (right panel).

Overall, the baseline scenario provides two crucial insights. First, rising longevity makes capital accumulation much less sensitive to taxation. We inspect this observation formally when analyzing the channels of economy adjustments to social security reform. Specifically, we show the changes in elasticity of capital accumulation to taxing capital income gains across the analyzed scenarios. Second, rising longevity is a powerful mechanism for both labor supply decisions and capital accumulation; hence it generates strong effects on its own. To fully account for these patterns, we consider the effects of the reform separately for scenarios with and without rising longevity.

4 Results

We consider a change from the current US social security, characterized by progressive defined benefit pensions (due to regressive character of accumulation in AIME and cap from OASDI). This system provides insurance against income shocks. A non-redistributive defined contribution system propagates income shocks from the working period to the retirement period, hence reducing the scope of insurance. Meanwhile, the contributions to this social security are directly linked to future pension benefits, hence reducing the disincentives to labor supply (implicit taxation) nested in the redistributive pensions. Replacing of the redistributive social security with non-redistributive one reduces insurance in the economy and raises efficiency. In addition to reduced distortion (and insurance), the reform amplifies the efficiency gains: accumulation of pension wealth is higher with funding. Finally, with longevity, baseline social security experiences a deficit, which necessitates higher overall taxes compared to to the reform scenario.

The columns of Table 2 compare two demographic scenarios (constant life expectancy and rising life expectancy) and three variants of social security reform:

- replacing a redistributive DB social security, described by equations (7)-(9) by a non-redistributive social security, defined by equations (12)-(13) with $\tau^I = \tau$, i.e. without a capital pillar; these results are reported in columns (1) and (2);
- combining this reform with partial funding in column (3);

- reform as proposed by Nishiyama and Smetters (2007) which differs from our reform in one major way: we gradually achieve $\tau^{II} = 0.5\tau$ and $\tau^{I} = 0.5\tau$ whereas Nishiyama and Smetters (2007) gradually have $\tau^{I} = 0.5\tau$ and $\tau^{II} = 0$; and thus our reform provides longevity insurance on larger social security and unchanged social security contributions, whereas Nishiyama and Smetters (2007) end up with a smaller social security; these results are reported in columns (4) and (5).

Table 2: Welfare effects of social security reform

Reform scenario	Defined Contribution			Nishiyama and Smetters (2007)	
Social security	PAYG	PAYG	PAYG + funding	PAYG + savings	PAYG + savings
Life expectancy	constant	rising	rising	constant	rising
	(1)	(2)	(3)	(4)	(5)
Fiscal closure τ_c	0.31	0.83	0.33	-0.47	-0.22
Fiscal closure τ_k	0.92	1.12	0.48	-0.15	-0.10

Note: Results report aggregate welfare (consumption equivalent) effects for all cohorts in % of lifetime consumption, following equation (D.6). Consumption tax closure described by equation (24) and capital income taxation closure described by equation (23). The same fiscal closure is used in both baseline scenario of *status quo* and reform scenario. In Nishiyama and Smetters (2007) scenarios (4) and (5) we assume reduction of the social security contributions.

First, we compare capital income taxation to consumption taxation – the latter was used extensively in the prior literature. In column (1), we show that with no rise in life expectancy the efficiency gain dominates insurance loss in welfare terms. Indeed, with constant longevity, the system remains balanced even in the baseline scenario and no fiscal gap is created in the reform scenario (there is no fiscal cost to the reform). For a scenario with rising longevity, as reported in column (2), the social security is not balanced for the duration of the demographic transition: longer life at retirement forces a rise in taxation. With capital income taxation, the gains are larger than with consumption tax.

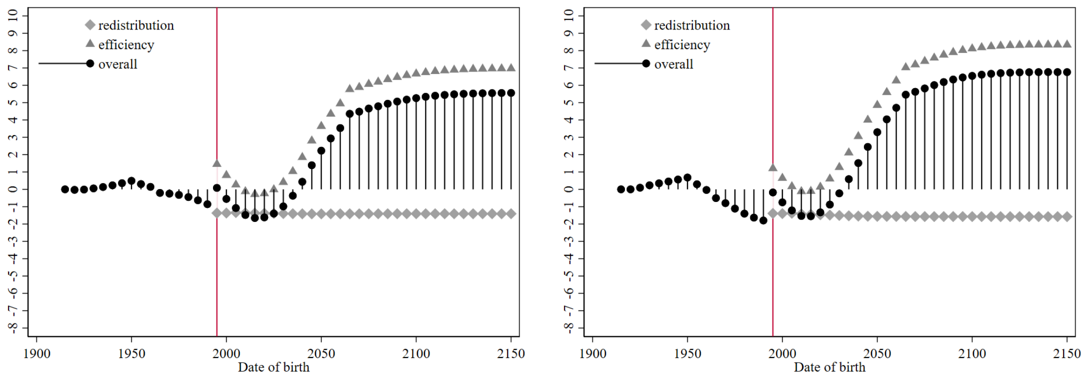
The scenario which combines DC formula and partial funding, as reported by column (3), accounts for an additional fiscal cost of the financing gap in social security, when part of the contributions is diverted away from the pay-as-you-go pillar and into the funded pillar and all prior pension obligations are honored. With rising longevity, *positive* welfare effect of the reform is achieved with both capital income taxation and with consumption taxation. The gains are larger for capital income taxation. This implies that even with transition costs of forming the funded pillar, capital income taxation amplifies the efficiency gains to such an extent that welfare costs associated with lower insurance are compensated.

The results from column (3) are best compared with the previously studied reform: a reduction in the size of social security and private voluntary savings (Nishiyama and Smetters 2007). Such reform yields aggregate welfare losses, as evidenced in columns (4) and (5). The reform which we propose delivers substantially larger welfare gains due to two channels: capital contributions to the funded pillar are exempt from capital income taxation, and funded social security offers annuity, which is absent in the private voluntary savings. Notwithstanding, with rising longevity, capital income taxation yields lower welfare losses than consumption taxation. In fact, with rising longevity (column 5), even scaling down social security to half the original size is close to being Hicks-neutral.

We provide intuition on the mechanisms behind these results, in Figure 2. We decompose the aggregate impact of the pension reform into change of redistribution implicit in social security and efficiency change for the subsequent cohorts. The decomposition is obtained through a partial equilibrium exercise We obtain the decomposition in the following manner. First, equation (7) is modified to

$f_{j+1,t+1} = \frac{1}{j}((j-1) \cdot f_{j,t} \cdot (1+g_t) + \tau \cdot \omega_{j,t} w_t l_{j,t})$. Second, equation (9) is modified to $b_{\bar{J},t} = \rho_m \bar{\rho}_{\bar{J},t} \cdot f_{\bar{J},t}$, where $\bar{\rho}_{\bar{J},t}$ is the average replacement rate. Hence, there is no efficiency gain from linking contributions to future pensions and there is no redistribution in this counterfactual social security in the decomposition exercise. Welfare effects of efficiency gains are measured as residual to aggregate welfare. Indeed the welfare effect of eliminating the redistribution are negative. However, the efficiency gains depend strongly on the fiscal closure and dominate welfare loss in the case of capital income taxation.

Figure 2: Consumption equivalent: reform to DC with partial funding and rising longevity



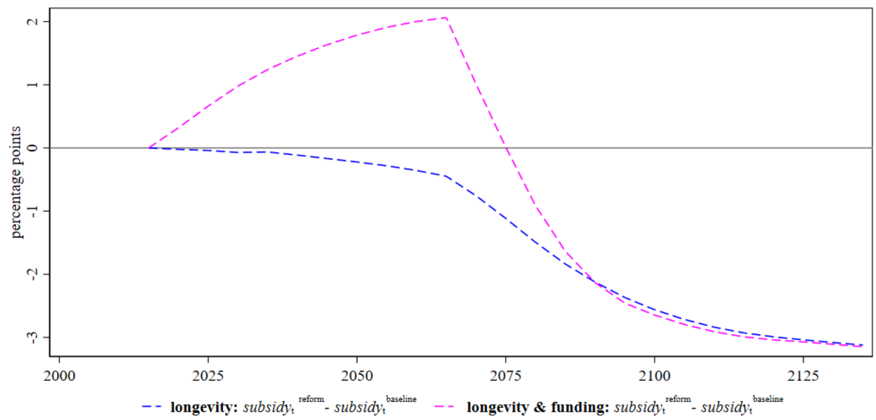
(a) τ_c (b) τ_k

Note: We report welfare by birth cohort for a scenario with partial privatization ($\tau^I = \tau^{II} = 0.5\tau$) and rising longevity. Vertical line denotes the cohort born at the moment of the reform. For the cohorts living at the time of reform ($j - t > 1$), the difference in utilities is computed as averaged for idiosyncratic income shocks within cohort. We report the consumption equivalents (% of permanent consumption in reform scenario) from scenarios where the same fiscal closure is assumed for the baseline and reform scenario. In the partial equilibrium decomposition equation (7) is modified to $f_{j+1,t+1} = \frac{1}{j}((j-1) \cdot f_{j,t} \cdot (1+g_t) + \tau \cdot \omega_{j,t} w_t l_{j,t})$ and equation (9) is modified to $b_{\bar{J},t} = \rho_m \bar{\rho}_{\bar{J},t} \cdot f_{\bar{J},t}$, where $\bar{\rho}_{\bar{J},t}$ is the average replacement rate. Welfare effects of efficiency gains are measured as residual to aggregate welfare.

Why is capital income taxation delivering higher efficiency gains? Notably, capital accumulation grows with rising longevity, with the reform and with introducing funded pillar to the social security. The same holds for labor supply: in general reform strengthens the link between contributions and future pensions, thus reducing labor market distortion, but this reaction is amplified in the presence of rising longevity and when funding is introduced.[16] These adjustments are coupled with the aggregate fiscal trends: in the baseline scenario, the public pension pillar becomes unbalanced due to a rise in longevity, eventually reaching 0.9% of GDP.[17] Meanwhile, in the reform scenario, a fraction of the contributions to the social security is diverted from the pay-as-you-go pillar to the funded pillar: during the transition to partially funded DC, social insurance fund deficit grows temporarily to roughly 2.4% of GDP (from a calibration of 0% in the initial steady state) to decline back to balance when the transition cohorts finish collecting their benefits. We report relative adjustments social security deficit in Figure 3, portraying the differences between reform and baseline. These differences are expressed in percentage points, because the deficits are expressed as % of GDP. The baseline and reform and adjustments in social security deficit are relegated to Figure G.2 in the Appendix.[18]

[16]We report adjustments in labor and capital (relative to the *status quo*) in Figure G.1.
[17]See Figure G.2 for comparison of baseline and reform.
[18]Note however, that strengthening the link between labor supply and the pension benefits substantially increases the labor supply, which raises the base for the contributions from labor taxation. This reduces the necessary rise in capital taxation, see Figure G.3.

Figure 3: The difference in social security deficit between reform and baseline



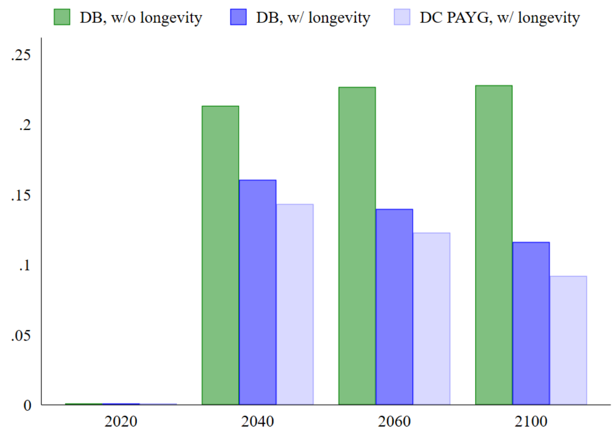
Note: $subsidy_t$ is expressed as a share of GDP. The figure portrays the difference between reform and baseline in percentage points. A positive number signifies that the deficit is higher in the reform scenario than in the baseline scenario. A negative number signifies that the deficit is higher in the baseline scenario. The figure portrays results for scenarios with longevity, other specifications available upon request.

We study the role of capital income taxation through the semi-elasticity of assets in reaction to changes in $\tau_{k,t}$. To obtain the (semi) elasticity of capital with respect to $\tau_{k,t}$, we use a partial equilibrium exercise. We keep taxes, bequests, and interest rate as in the initial steady state. In such a counter-factual economy, we obtain $\hat{A}_t$ from the household optimization. Next, in partial equilibrium, we increase $\tau_{k,t}$ by 1 percentage point in period t and only in that period. We then obtain $\check{A}_t$ from the household optimization. Semi-elasticity is computed as the absolute value of the following expression $100\% \times \frac{\hat{A}_t - \check{A}_t}{\hat{A}_t} \div 1\%$ (in the simulations a rise in $\tau_{k,t}$ reduces assets accumulation). For each horizon (period t) we run a separate counter-factual simulation. This way we obtain measures of semi-elasticity at various horizons. In the interest of clarity, we present the results for the periods when the biggest changes in taxation occur, see Figure G.3.

Figure 4 portrays jointly the three reasons for why capital becomes less responsive to hikes in capital income taxation in the reform scenario: rising longevity, declining pensions and more precautionary savings. The first of the three is associated with the fact that longer life expectancy generally translates to higher accumulated stock of wealth at lifetime maximum and higher share of high wealth individuals in the population, *ceteris paribus*. The second stems from the fact that pensions decline as longevity rises in the reform scenario, reinforcing the original mechanism associated with rising longevity. Finally, the third channel is related to the insurance motive: less redistributive pensions raise risk exposure and thus make agents accumulate their precautionary savings. As is presented step-wise in the Figure 4, gradually response of capital to capital income tax rates declines as: (i) introduce longevity; (ii) implement reform. This decline in responsiveness is what makes capital income tax a suitable candidate for a fiscal closure during the social security reform.

The obtained magnitude response of capital to hikes in capital income taxation cannot be readily compared to the estimates obtained from observational data. In fact, empirical literature typically finds little to no effect of variation of net returns on the aggregate assets (Bernheim 2002). However, in observational data one is challenged to observe long-term evolution of stocks, typically short-term variation in flows is available (Attanasio and Wakefield 2010, Bernheim 2002). By contrast, our implied elasticities are obtained for stocks. Furthermore, the empirical studies focus on a well identified but

Figure 4: Semi-elasticity of capital with respect to $\tau_{k,t}$ for $t \in \{2020, 2040, 2060, 2100\}$.



Note: Semi-elasticity obtained from a counterfactual increase in $\tau_{k,t}$ in a partial equilibrium exercise. First, we keep taxes, bequests, and interest rate as in the initial steady state, solve household optimization problem and obtain $\hat{A}_t$, where A_t is defined in equation (19). Subsequently, we increase $\tau_{k,t}$ by 1% and solve households problem to obtain counter-factual $\check{A}_t$. Semi-elasticity is obtained as the absolute value of the following expression $100\% \times \frac{\hat{A}_t - \check{A}_t}{\hat{A}_t} \div 1\%$. A positive value in the figure implies that a rise in $\tau_{k,t}$ reduces assets accumulation. This exercise is simulated for periods $t \in \{2020, 2040, 2060, 2100\}$.

instantaneous effect (Ramnath 2013, Seim 2017), which by design should be close to zero for stocks (Boskin 1978, Beznoska and Ochmann 2013). By contrast, our simulations reveal that over short horizon indeed the implied elasticity of capital to changes in interest rates is low, but as changes in flows start to accumulate, the compound effects are actually large. Finally, the literature typically estimates compensated elasticities (Bernheim 2002, Seim 2017). By contrast, our simulations report elasticities accounting for income effects.

4.1 Capital income taxation versus other fiscal closures

We consider a wide array of fiscal closures discussed in the earlier literature.[19] First, we consider fiscal adjustments which occur within the social security. We analyze a change in pension benefits and a change in the contribution rate such that social security is balanced ($\forall t \quad subsidy_t = 0$).[20] For each of the analyzed closures we show the aggregate welfare effects, welfare differentials in the final steady state and the share of living agents in support of the reform in the initial steady state. The results are reported in Table G.2.[21] This way we attempt to reconcile our results with the existing literature.

We replicate the findings of the earlier literature (e.g. Davidoff et al. 2005, Nishiyama and Smetters 2007, Fehr et al. 2008, Harenberg and Ludwig 2019). Indeed, positive welfare effects are possible in the long-run, but capital income taxation delivers superior welfare gains. An alternative with higher aggregate welfare gains is the decline in pension benefits, which is likely politically infeasible in aging democracies. Figure G.5 strongly corroborates the intuition that fiscal closures substantially which cohorts experience welfare gains and which are facing welfare losses. For example, closures with contribution rates are neutral to initial retirees and almost neutral to cohorts close to retirement. By

[19] Table A summarizes the use of these closures in the earlier literature.

[20] One final policy alternative is to increase retirement eligibility age. In a setup, where one period is equivalent to five years, experimenting with the retirement age is understandably questionable.

[21] We also present cohort based decomposition into efficiency gains and redistribution loss in Figure 2 and Figure G.5 in Appendix G. We also report aggregate macroeconomic effects for each fiscal closure, see Table G.1 in Appendix G.

contrast, adjustments in consumption tax imply that the welfare of these cohorts increases less (see Figure 2).

Note that each of the fiscal closures is implemented for the same social security reform, which strengthens the link between labor supply and future pension benefits, thus raising substantially labor supply.[22] Reduced labor distortion results in higher labor supply raises labor tax revenue despite unchanged labor taxation. Required hike in capital income taxation is thus lower and a decline in this tax more pronounced in the long run. In the effect of the reform, social security eventually becomes balanced, so taxation declines across all fiscal closures, see for details Figures G.3 and G.4.

In terms of magnitude, the overall effects we find are similar for the final steady states when compared to studies which utilize an OLG model with individual uncertainty. For example Fehr and Kindermann (2010) find long run welfare gains of roughly 0.2% for Germany, whereas Kitao (2014) finds 0.7% for the case of the US although his social security has a somewhat different design (benefits increase with earned incomes, but do not decline with rising longevity).

4.2 Sensitivity of the results

Productivity slowdown Our results carry over to a calibration which features declining rate of exogenous technological progress. We document the full set of results in Appendix H. This is not surprising, because relatively higher rate of technological progress favors the current social security in the US. If we observe welfare gains from reforming with higher exogenous technological progress in our main results, lower rate of technological progress can only raise gains from privatizing social security with partial funding under rising longevity.

Speed of phasing in the reform Admittedly, our original timing of the reform is rather slow; such lengthy implementation may be viewed as not credible. We thus study also an alternative, faster implementation, in which only cohorts older than 50 at the time of the reform ($j > 6$ at $t = 2$) remain in the status quo social security. For the transition cohorts who worked prior to the implementation of the reform and are shifted to the new scheme, we impute the initial values of $f^I_{j,2}$. This imputation is performed for the cohorts born between 1965-1995. We impute the counter-factual funds using the contribution rate τ from the initial steady state and the formula:

$$\text{if} \quad 2 \leqslant j \leqslant 6 \quad \text{in} \quad t = 2 \qquad f^I_{j,2} = \sum_{i=1}^{j} \frac{1}{\pi_{i,1,j}} \tau w_1 \bar{l}_{i,1} (1 + g_1)^{j-i} \tag{25}$$

where $j = 6$ corresponds to the maximum age of agents assigned to DC scheme, once the reform is implemented, and $\bar{l}_{s,1}$ is the average labor supply of cohort s at time 1. Note that these imputed incomes are deterministic, as if the past – prior to the implementation of the social security reform – had no income uncertainty. Hence, for the transition cohorts, the insurance motive is preserved in the social security. Cohorts born in 1965 and later participate fully in the new, two-pillar DC system. The deficit of the PAYG DC pillar, the $subsidy_t$ in equation (10), is financed by the government. The

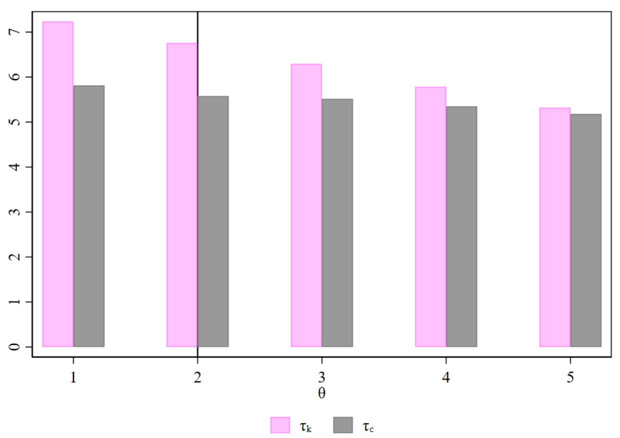
[22]The quantitative role of this channel may be gauged by comparing our results to Imrohoroglu et al. (2003). In their setup the link is not strengthened. Also, in their setup fiscal closure of pension contributions is equivalent to an increase in labor taxation. In fact, our results provide an intuition for why Imrohoroglu et al. (2003) find large, negative effects in a model with uncertainty: labor taxation as fiscal closure reinforces the negative welfare effects of reducing the insurance motive. However, the negative welfare effects in this study are not as much due to the reform itself, as due to the model setup combined with fiscal closure. Unlike our setup, the increase in labor supply in the setup of Imrohoroglu et al. (2003) is insufficient to finance the reform, which triggers upward adjustment in taxes.

speed of the reform implementation does not affect the overall results (even if results for specific birth cohorts are naturally different).

The results remain unaffected by how fast the reform is implemented. Recall, that the main results in this study assume that only future cohorts will be subjected to the new pension rules, which in practical terms would imply uncertainty about whether in the future the gains would actually materialize i.e. once the loosing cohorts start influencing the political process; we do not explicitly model the political process, but we study if a more rapid implementation of the reform delivers different macroeconomic and welfare outcomes. We find that the key results remain the same, which we report in Appendix I.

Risk aversion There is a concern for the quantitative role for redistribution. Our simulations are obtained with CRRA utility function with a risk aversion parameter $\theta = 2$. While such calibration is consistent with the prior literature on social security privatization, the empirical estimates of the coefficient of relative risk aversion are highly dispersed (e.g. Chetty 2006, Andersen et al. 2008, Charness et al. 2013, Outreville 2014). Indeed, for higher levels of risk aversion, welfare loss related to replacing redistributive with non-redistributive social security could be larger. To study this question quantitatively, we replicate our original simulations for alternative calibrations of $\theta \in [1, 5.5]$. We present the results of this exercise in Figure 5. Our key argument in this paper states that if there are reasons for capital elasticity to decline, financing social security reform with capital income taxation generates higher welfare gains than if consumption taxation is used as fiscal closure. We find this pattern for all studied values of θ. Admittedly, with high levels of risk aversion the insurance channel becomes quantitatively dominant and thus we no longer find large differences between fiscal closures. The detailed results are reported in Appendix J.

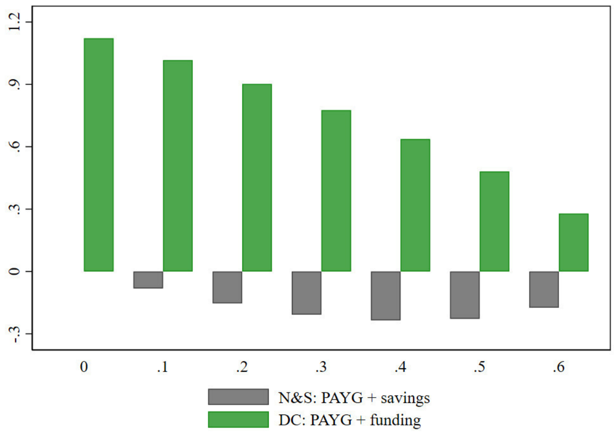
Figure 5: Final steady state: welfare effect for different θ values



Note: We recalibrate other parameters in the model, see Table J.1. Note that in contrast to Table 2 here we present only final steady state welfare effects.

The size of the funded pillar Following prior literature, we set the size of the funded pillar to be 50% of the total social security contributions. This parameter determines indirectly two important elements: the size of the fiscal gap to be financed when funding is introduced and the increase in pension benefits due the fact that $r > \gamma$. In Figure 6 we demonstrate that our main result survives regardless of the size of the funded pillar.

Figure 6: Agregate welfare effect for different $\frac{\tau^{II}}{\tau}$ values, τ_k closure



Notes: Vertical axis measures aggregate welfare effect as in equation (D.6). The horizontal axis reports the share of contribution which is diverted to the funded pillar.

Summarizing, the welfare effect of privatizing social security with funding consists of three effects. First, labor incentives are improved with privatization, as contributions to social security become less distortionary. The flip side of this mechanism is the second effect: the insurance inherent in the redistributive social security is lost – the second effect. The third effect relates to pension wealth: it accumulates faster in two-pillar system with funding. The efficiency gains are amplified when the transitory fiscal gap in social security is closed with capital income taxation. Longevity reduces the response of capital to hikes in capital income taxation with helps tilting the aggregate welfare effects.

4.3 Discussion

Given that our results are in part driven by the labor supply response by households to better aligned incentives, one can ask if the size of the reaction is plausible. Admittedly, the reform immediately reduces labor distortions by literally the entire social security contribution: agents used to treat the contributions as a tax and suddenly treat them as postponed stream of revenue. Given the magnitude of the contribution rate, the sizable increase in labor supply – roughly 6.5% to 9% – may be justifiable in a macroeconomic model. A large selection of studies reviewed empirical evidence from numerous labor taxation reforms, yielding the plausible Hicksian labor supply elasticities of roughly 0.3-0.4 for the intensive margin and roughly 0.1 for the extensive margin (e.g. Keane and Rogerson 2012, Chetty 2012). Such estimates would be consistent with our outcomes. Also some empirical studies analyzing the shifts from defined benefit to defined contribution plans around the world suggest that the labor supply incentives play a substantial role in explaining the rise in labor force participation (Bairoliya 2019).

Admittedly, most of the studies in the literature concern labor taxation *per se*, not long-term optimization between contributions, benefits and labor supply, as such studies are rare. A large response here is conditional on workers internalizing the entire adjustment in their decision-making process. Concerning this point, empirical literature is not as optimistic. For example, using evidence from Denmark, Chetty et al. (2011) show that people tend to respond to nominal taxation (and their changes) and are relatively inattentive to real taxation changes, even if the latter are relatively large.

The reform we model would fit the latter type. However, people tend to react to changes in the nature of the social security much stronger than to changes in tax rates per se (Bairoliya 2019).

Note that our key result does not depend on the labor supply response. Trivially, if labor does not react at all to social security reform (for example: if labor supply is inelastic), then there is no change in labor distortion due to replacing redistributive defined benefit system with a defined contribution social security. However, as stems from our paper, even in this extreme case, if funding was to be introduced, in the context of longevity, it is better to finance this process with capital income taxation than with consumption taxation. Likely, with unresponsive labor, simulation of such economy will not produce welfare gains from privatization (no room for efficiency gain due to reduced labor distortion), however, so long as longevity increases, the loss of welfare will be lower if funding occurs via a tax raised on capital.

A growing body of the literature demonstrates that inter-temporal elasticity of substitution is quantitatively relevant for the magnitude of capital adjustment in response to capital taxation (Diamond and Spinnewijn 2011, Golosov et al. 2013, Straub and Werning 2020). This hints that in reality the magnitude of the efficiency gain may depend on the calibration of the inter-temporal elasticity of substitution.

Our approach abstracts from a bequest motive: if parents are inclined to accumulate capital also for their off-spring, population growth in the US economy raises further incentives to save, which makes capital income tax base even less responsive than in our simulations (De Nardi and Yang 2014). In such a setup, optimal capital income tax rate would be higher than in our simulations (and likely higher than in the US economy currently). Accounting for the effects of the bequest motive would result in lower response of capital to taxation and amplify the positive welfare effects which we identify in this study.

Likewise, longevity may translate to changes in the policy preferences in the economy. In our setup, we consider government expenditure as a fixed percentage of GDP in baseline, taken in per capita terms to the reform scenarios. With declining pension benefits, one may expect that in per capita terms public expenditure will have to rise. Modelling these effects is beyond the scope of our paper. However, longevity may introduce important changes to social policy on the expenditure side, with many implicit and explicit mechanisms of between-cohort and within-cohort redistribution. For example, incentives for old-age savings may be reduced if more health care in the old age is provided. Likewise, egalitarian access to health care system in the old age attenuates the role idiosyncratic income shocks, reducing the precautionary motive. Accounting how these policy relevant scenarios interact with capital income taxation is similarly promising research area.

5 Conclusions

Growing life expectancy marks our future, necessitating adjustments in pension systems and on the fiscal side. Public finance literature broadly suggests to raise taxes on inelastic tax base. We quantify that rising longevity makes capital particularly unresponsive to tax hikes. We further show that privatization of pensions with funding can – contrary to prior literature – deliver welfare gains if the transitory fiscal costs are financed through capital income tax rather than other taxes. Social security reform from a redistributive pay-as-you-go system to a defined contribution system allows for better alignment in the labor supply incentives between macro and micro-levels, reducing the scope for labor supply distortions. However, individual productivity risk becomes more afflicting. Our contribution is to show that financing social security reform with adjustments in capital income taxes delivers superior welfare effects, when compared to other fiscal closures. We show that in the context of growing life expectancy, capital income taxation is a particularly suitable candidate: the responsiveness of capital to tax hikes is lower with rising longevity. We thus contribute to a debate in the literature on the social security reform and show that fiscal closures deliver first order rather than minor effects.

The policy implications of our study are quite optimistic: reforming the social security from redistributive pay-as-you-go system to a privatized and partly funded system may improve welfare, with the efficiency gain sufficient to outweigh the insurance loss. This result is robust to several sensitivity checks and holds even for quite a rapid implementation of the reform. However, for the gains to actually materialize, strong labor supply reaction is imperative, some effort may be necessary to inform citizens about nature of the reform and thus encourage adequate response to the changing incentives.

Summarizing, our study has challenged the consensus in the literature concerning the relative size of the efficiency gain and insurance loss in determining the effects of social security privatization. The decomposition through a partial equilibrium exercise reveals that the insurance loss is indeed sizable, but the overall welfare effect may be positive if the efficiency gains associated with the social security reform are amplified by an adequate fiscal closure.

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Appendices intended for online distribution

A Literature overview

Table A.1: Modeling options taken in the earlier literature

Paper	Problem	Solution	Soc. sec. parameters	Introducing	Fiscal closures	Implicit tax	Idiosyncratic shocks
Belan and Pestieau (1999)	aging	p and s	τ_I	FF	debt	NO	NO
Fehr (2000)	aging	p	$\tau_I, \bar{J}, \tau_b$		τ_c	YES	NO
Imrohoroglu et al. (2003)	aging	p and s	τ_I	DC		NO	YES
Lindbeck and Persson (2003)	aging	s		DC, DC+FF	debt	NO	NO
Krueger and Kubler (2006)	risk	PAYG DB	τ_I			NO	NO
Keuschnigg et al. (2012)	aging	p	$\bar{J}, \tau_I, \tau_b$		τ_c, τ_l, τ_k	NO	NO
Sanchez-Marcos and Sanchez-Martin (2006)	dem. uncert.	PAYG DB	τ_l			NO	YES
Verbič et al. (2006)	aging	p	τ_I		τ_c, τ_l	NO	NO
Aglietta et al. (2007)	aging	p	$\bar{J}, \tau_I, \tau_b$			NO	NO
Nishiyama and Smetters (2007)	aging	s		PRIV	τ_c	NO	YES
Verbič (2007)	aging	p	τ_l		τ_c	NO	YES
Andolfatto and Gervais (2008)	aging	p	τ_I			NO	NO
Bassi (2008)	aging	p	$\bar{J}, \tau_I$			NO	NO
Heer and Irmen (2014)	aging	p	$\tau_b, \tau_I, \bar{J}$	M	Υ	NO	NO
Díaz-Giménez and Díaz-Saavedra (2009)	aging	p	$\tau_I, \bar{J}$		τ_c	YES	NO
Fehr and Kindermann (2010)	aging	s		FF	τ_c	YES	YES
Kuhle (2010)	aging	s		PRIV	debt	NO	NO
Kumru and Piggott (2010)	aging	s		M, PRIV	τ_c	NO	YES
Kumru and Thanopoulos (2011)	aging	s		FF, PRIV	τ_I	NO	YES
De la Croix et al. (2012)	aging	s	$\bar{J}$	FF	τ_c	NO	NO
Wright et al. (2012)	aging	p	τ_I		debt	NO	NO
Cipriani and Makris (2012)	aging	p and s	τ_I	FF		NO	NO
Bruce and Turnovsky (2013)	aging	p	τ_I		τ_I	NO	NO
Börsch-Supan et al. (2014)	aging	p or s	$\tau_b, \tau_I, \bar{J}$			YES	NO
Kitao (2014)	aging	p or s	$\tau_b, \tau_I, \bar{J}$	M	τ_I	NO	YES
Song et al. (2015)	aging	s		FF	debt	NO	NO
Kitao (2015)	aging	s		FF	τ_c	NO	NO
Chen et al. (2016)	aging, risk	p or s	τ_b, τ_I	COL		NO	NO
Vogel et al. (2017)	aging	p	$\tau_I, \tau_b, \bar{J}$			NO	NO

Notes: p denotes parametric reform, s denotes systemic reform, NPS denotes fiscally neutral pension system; FF for introducing fully funded accounts; DEBT denotes debt repayment; PRIV denotes removing pension system; M denotes means-tested program, PAYG DB denotes introducing PAYG DB pension system; COL denotes collective pension fund, risks can be shared over many cohorts of participants. In addition, using various fiscal closures, Bouzahzah et al. (2002), Fehr et al. (2008), Roberts (2013), McGrattan and Prescott (2017), Börsch-Supan et al. (2014) model removing of the pension system at all.

B Additional fiscal closures

Fiscally neutral closures of the pension system reform focus on adjusting the two key parameters of the pension system: the contribution rates and the (effective) replacement rates. Recall that with $subsidy_t = 0$, equation (10) becomes:

$$\sum_{j=\bar{J}}^{J} N_{j,t} \int_{\Omega} b_{j,t}(s_{j,t}) d\mathbb{P}_{j,t} = \tau_t w_t L_t$$

We consider two closures: contribution rate and benefits. In the **contribution** closure (τ_t^{ρ}), the working agents are subjected to an additional contribution, in the magnitude needed to balance the pension system. In the baseline scenario it increases effective labor taxation. In the reform scenario, additional contributions would have translated to increased future pension benefits, following equations (12) and (14), i.e. postpone the imbalance, but not solve it. To avoid that, we treat the "additional" contribution as a one that does not enter $f_{j,t}^{I}$, nor $f_{j,t}^{II}$. In practice this is equivalent to increased labor taxation in the reform scenario. The adjustment in the contribution rate is portrayed by equation (B.1).

$$\sum_{j=\bar{J}}^{J} N_{j,t} \int_{\Omega} b_{j,t}(s_{j,t}) d\mathbb{P}_{j,t} = (\tau + \tau_t^{\rho}) w_t L_t, \tag{B.1}$$

In the **benefits** closure, the retired agents are subjected to an additional tax (τ_t^b). We compute the proportion of the pension benefits that needs to be taxed away to balance the pension system in baseline scenario, portrayed in equation (B.2).

$$(1 - \tau_t^b) \sum_{j=\bar{J}}^{J} N_{j,t} \int_{\Omega} b_{j,t}(s_{j,t}) d\mathbb{P}_{j,t} = \tau w_t L_t. \tag{B.2}$$

In addition, in the fiscally neutral closures within the pension system (adjustments in ρ and τ), we use the consumption tax, $\tau_{c,t}$, to balance the general equilibrium imbalances in the government (these imbalances follow from changed labor market incentives, changed capital accumulation due to rising longevity and the subsequent adjustments in wages, labor supply and interest rates).

C Pension benefits link to contributions and labor distortion

Let us start with the defining the value of this *virtual assets* $\widehat{f}$ and then adjusting budget constraint accordingly. In the accumulation period (for $j < \bar{j}$) the *virtual assets* from the reformed (defined contribution) pillars accumulate according to:

$$\widehat{f}^{I}_{j+1,t+1} = (1+(1-\tau_{k,t}))r_t\widehat{f}^{I}_{j,t} + \tau^{I}_t w_t\omega_{j,t}l_{j,t}\cdot\mu^{I}_{j,t} \tag{C.3}$$

$$\widehat{f}^{II}_{j+1,t+1} = (1+(1-\tau_{k,t}))r_t\widehat{f}^{II}_{j,t} + \tau^{II}_t w_t\omega_{j,t}l_{j,t}\cdot\mu^{II}_{j,t} \tag{C.4}$$

Calculating the present values of the streams of the benefit from the PAYG and funded pillar evaluated at time of the retirement is then straightforward. The worker who is j years old at the time t would reach retirement age at time $i = t + \bar{J} - j$. The first term represents the present value of that streams. The second term is simply lifetime expectancy at the age $\bar{J}$ of the worker who is j years old at the time t, thus the expected time over which these benefits are going to be obtained. Thus we can treat $\mu^{I}_{j,t,\bar{J}}$ and $\mu^{II}_{j,t,\bar{J}}$ as the market prices of such benefits.

To calculate the $\mu^{I}_{j,t}$ and $\mu^{II}_{j,t}$ we need to combine two elements: (i) present value of the stream of the benefit from the PAYG and funded pillar evaluated at time of the retirement, and (ii) the present value of this stream of future pension benefits.

For the PAYG DC pillar we have

$$\mu^{I}_{j,t,\bar{J}} = \left[\sum_{\kappa=0}^{J-\bar{J}} \frac{\prod_{s=1}^{\kappa}(1+g_{i+s})}{\prod_{s=1}^{\kappa}(1+(1-\tau_{k,i+s})r_{i+s})}\right]\left[\sum_{s=0}^{J-\bar{J}}\pi_{\bar{J},i,i+s}\right]^{-1}.$$

For the funded DC pillar we have

$$\mu^{II}_{j,t,\bar{J}} = \left[\sum_{\kappa=0}^{J-\bar{J}} \frac{\prod_{s=1}^{\kappa}(1+r_{i+s})}{\prod_{s=1}^{\kappa}(1+(1-\tau_{k,i+s})r_{i+s})}\right]\left[\sum_{s=0}^{J-\bar{J}}\pi_{\bar{J},i,i+s}\right]^{-1}$$

Taking into account discounting the retirement to the present age of the worker, we calculate the present value of the future pension. They are discounted at the market interest rate, adjusted for the survival probability.

$$\mu^{I}_{j,t} = \mu^{I}_{j,t,\bar{J}}\left[\pi_{j,t,i}\prod_{s=1}^{\bar{J}-j}(1+(1-\tau_{k,t+s})r_{t+s})\right]^{-1}$$

$$\mu^{II}_{j,t} = \mu^{II}_{j,t,\bar{J}}\left[\pi_{j,t,i}\prod_{s=1}^{\bar{J}-j}(1+(1-\tau_{k,t+s})r_{t+s})\right]^{-1}$$

D Measuring welfare effects

The cohort-specific welfare effects of the reform are defined as a consumption equivalent, expressed as a percent of a lifetime consumption. Consumption equivalent for each agent is a percent of post-reform consumption that she would be willing to give up (or has to receive) in order to be indifferent between baseline and reform scenario. For a newborn with a CRRA instantaneous utility function, the consumption equivalent in percent of a lifetime consumption is given by:

$$M_{1,t} = \left(\frac{V_{1,t}^R}{V_{1,t}^B}\right)^{\frac{1}{\phi(1-\theta)}} - 1 \tag{D.1}$$

In this expression, $V_{1,t}^B$ and $V_{1,t}^R$ refer to lifetime utility of the newborn at period t in baseline and reform scenarios, respectively. In order to compute the consumption equivalent for agents alive in the first, pre-reform period, we have to take in to account their distribution $\mathbb{P}_{j,t}$ over state space Ω. Thus for cohort j years old at period 1 consumption equivalent is constructed by the following formula:

$$M_{j,1} = \left(\frac{E(V_{j,1}^R)}{E(V_{j,1}^B)}\right)^{\frac{1}{\phi(1-\theta)}} - 1 \tag{D.2}$$

Details of derivation of equations (D.1) and (D.2) are as follows. Assume $j = J$

$$V_{J,t}(s_{J,t}) = \max_{c_{J,t}, l_{J,t}, a_{J+1,t+1}} u(c_{J,t}, l_{J,t}) \tag{D.3}$$

Denote $x^{\{R,B\}}$ as a optimal choice in reform and baseline scenario. Then μ, share of consumption i reform scenario which consumer is willing to give up to be indifferent to the baseline scenario, is such that

$$\begin{aligned} V_{J,t}^B(s_{J,t}) &= \frac{1}{1-\theta}\left([c_{J,t}^B]^\phi(1-l_{J,t}^B)^{1-\phi}\right)^{1-\theta}, \\ V_{J,t}^R(s_{J,t}) &= (1+\mu)^{\phi(1-\theta)} V_{J,t}^B(s_{J,t}) \\ \mu &= \left(\frac{V_{J,t}^R(s_{J,t})}{V_{J,t}^B(s_{J,t})}\right)^{\frac{1}{\phi(1-\theta)}} - 1 \end{aligned}$$

For agent at age $j = J - 1$ at time t and state $s_{j,t}$.

$$V_{j,t}(s_{j,t}) = \max_{c_{j,t}, l_{j,t}, a_{j+1,t+1}} u(c_{j,t}, l_{j,t}) + \delta\pi_{j,t,t+1}\mathbf{E}\big(V(s_{j+1,t+1}) \mid s_{j,t}\big) \tag{D.4}$$

Denote probability of transition to stage $s_{j+1,t+1}^q \in S$ as ξ_q, then μ hast to bu such that

$$\begin{aligned} \mathbf{E}(V_{j+1,t+1}^R(s_{j+1,t+1})) &= \sum_{s_{j+1,t+1}^q \in S} \xi_q (1+\mu)^{\phi(1-\theta)} V_{j+1,t+1}^B(s_{j+1,t+1}) \\ \mathbf{E}(V_{j+1,t+1}^R(s_{j+1,t+1})) &= (1+\mu)^{\phi(1-\theta)} \mathbf{E}(V_{j+1,t+1}^B(s_{j+1,t+1})) \end{aligned}$$

Substitute above formula to equation (D.4)

$$\begin{aligned} V_{j,t}^R(s_{j,t})) &= \frac{1}{1-\theta}\left([c_{J,t}^R]^\phi(1-l_{J,t}^R)^{1-\phi}\right)^{1-\theta} + \delta\pi_{j,t,t+1}\ \mathbf{E}(V_{j+1,t+1}^R(s_{j+1,t+1})) \\ V_{j,t}^R(s_{j,t})) &= (1+\mu)^{\phi(1-\theta)} V_{J,t}^B(s_{j,t}) \end{aligned}$$

Repeat these steps for each $j = \{J-2, J-3, ..., 1\}$, eventually obtaining for $j = 1$

$$M_{1,t} = \left(\frac{V^R_{1,t}(s_{J,t})}{V^B_{1,t}(s_{J,t})}\right)^{\frac{1}{\phi(1-\theta)}} - 1. \tag{D.5}$$

The total welfare effect of the reform M is given by:

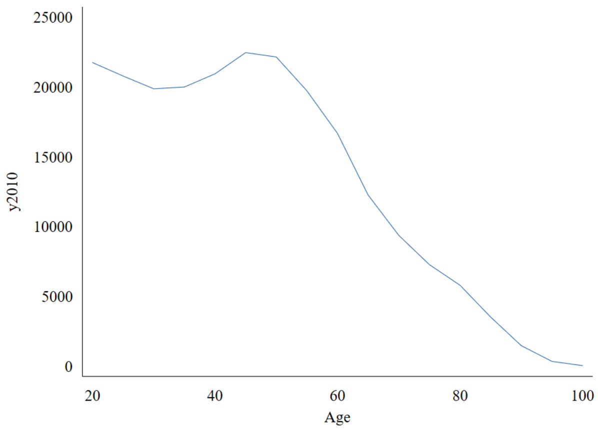
$$\begin{aligned} M\sum_{t=1}^{\infty}\sum_{j=1}^{J} N_{j,t}\left(\sum_{i=1}^{J-j}\prod_{k=2}^{t-1+i}\frac{1}{r_k}\mathbf{E}(c_{j+i,t+i})\right) = \\ = \underbrace{\sum_{j=1}^{J} N_{j,1}\left(M_{j,1}\sum_{s=1}^{J-j}\prod_{k=2}^{i}\frac{1}{r_k}\mathbf{E}(c_{j+i,1+i})\right)}_{\text{discounted value for cohorts living at t=0}} + \underbrace{\sum_{t=2}^{\infty} N_{1,t}\left(M_{1,t}\sum_{i=1}^{J}\prod_{k=2}^{t-1+i}\frac{1}{r_k}\mathbf{E}(c_{i,t-1+i})\right)}_{\text{discounted value for cohorts in future generations}} \end{aligned} \tag{D.6}$$

M is the measure of the welfare effects of the reform in a Hicksian sense. $M > 0$ means that reform improves welfare; after compensation of potential losses there is still welfare surplus generated by reform.

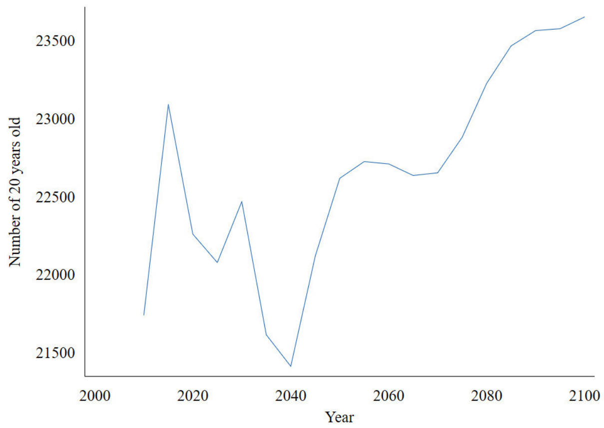
E Model calibration

Figure E.1: Population in the initial steady state, number of 20-year-olds arriving in the model in each period, 5 years probability of surviving across time for 65-year-olds.

(a) population in the initial steady state



(b) number of 20-year-olds



(c) probability of surviving the next 5 years for 65-yo

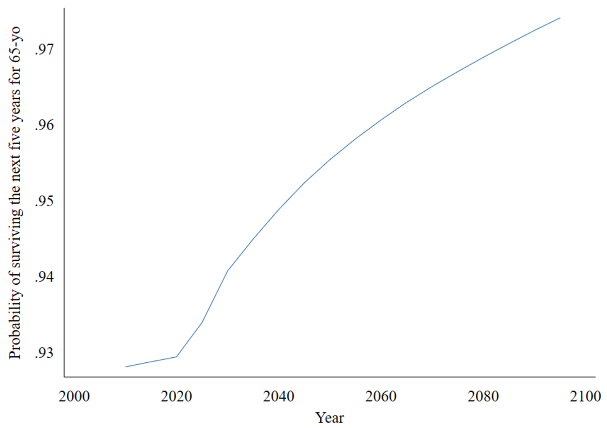


Table E.1: Tax revenue

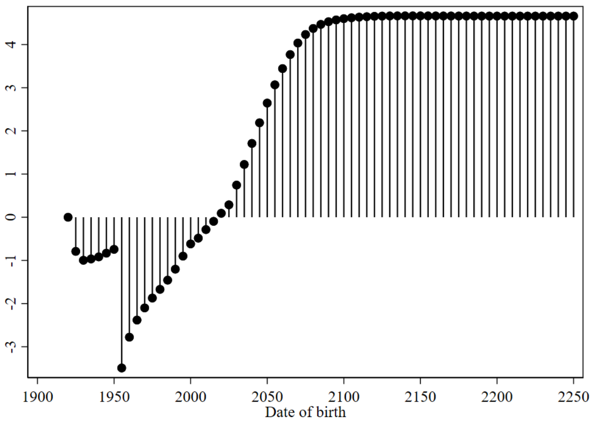
Macroeconomic parameters		Calibration	OECD code	revenue as % of GDP
τ_l	labor tax	0.117	1110	9.2%
τ_c	consumption tax	0.041	5110, 5121	2.8%
τ_k	capital tax	0.207	1120, 1200, 4100, 4400	5.4%

Notes: Tax rates calibrations following Mendoza et al. (1994), using 5 year averages of tax shares in GDP from (2011-2015).

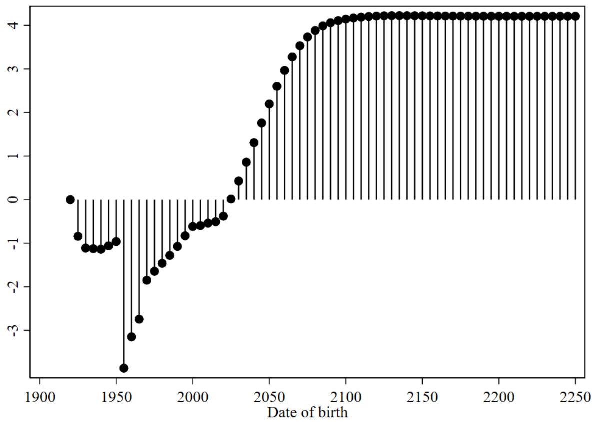
F Comparison to Nishiyama and Smetters (2007) reform

Figure F.1: Consumption equivalent: N&S reform

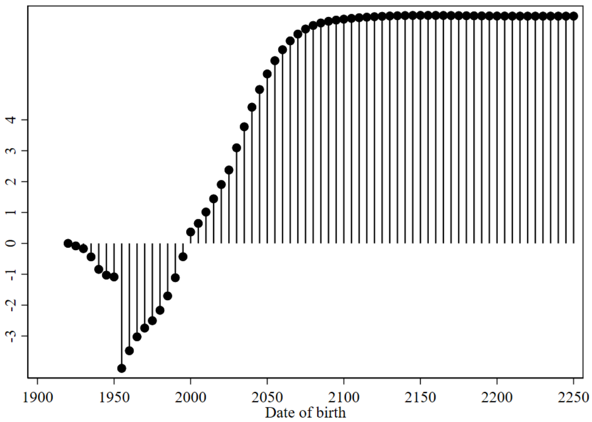
(a) consumption tax τ_c



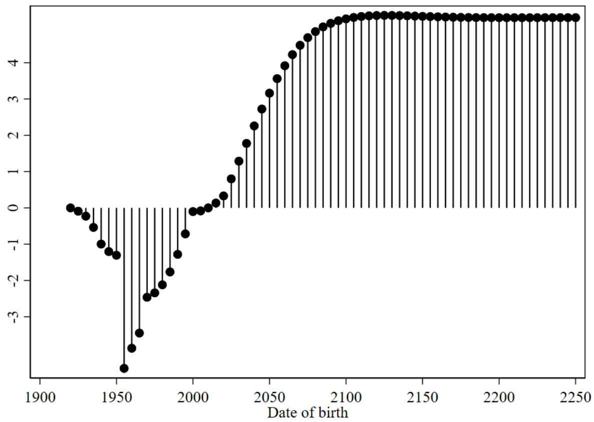
(b) consumption tax τ_c with rising longevity



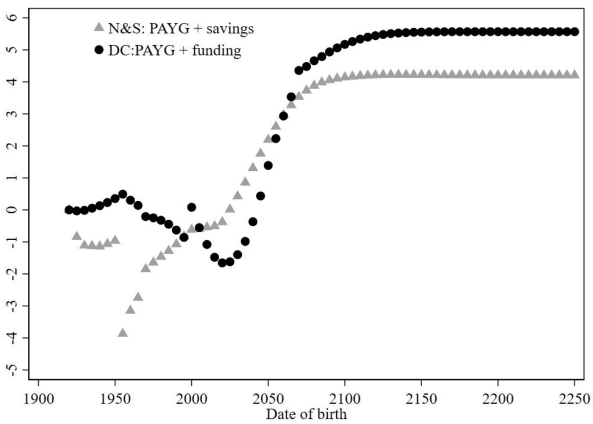
(c) capital income tax τ_k



(d) capital income tax τ_k with rising longevity



(e) comparison of N&S reform (with and without re-calibration of interest rate) and DC with funding



Note: We report the consumption equivalents (% of permanent consumption in reform scenario) from scenarios where the same fiscal closure is assumed for the baseline and reform scenario separately for each birth cohort.

G Results for the main macroeconomic indicators

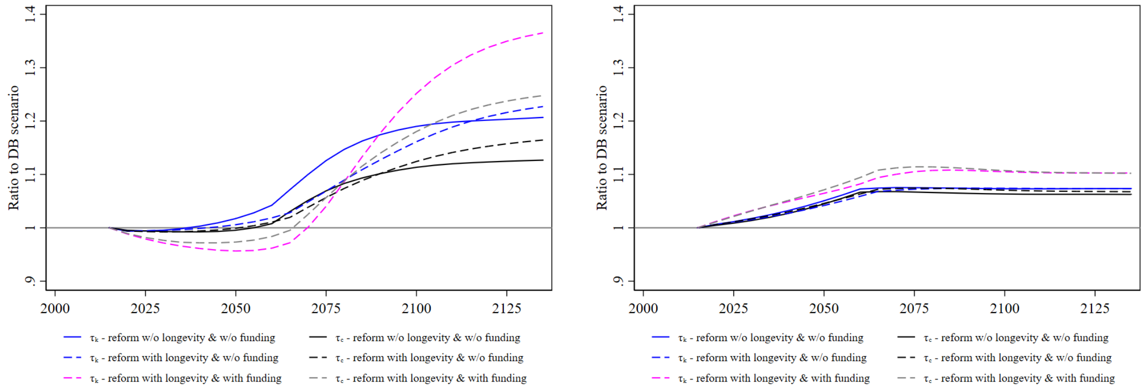
Table G.1: Macroeconomic effects

Macroeconomic indicators	Fiscal closure for baseline and reform			
	capital income tax τ_k	consumption tax τ_c	raising contribution τ^ρ	reducing pension τ_b
	Final steady state relative to the initial steady state value (baseline scenario)			
aggregate labor [a]	1.56	1.57	1.54	1.58
aggregate K/L [a]	1.11	1.16	1.22	1.36
interest rate [b]	-0.66	-0.90	-1.22	-1.87
	Change in aggregate labor in reform scenario as a % deviation from baseline			
2020	1.17	1.08	1.10	1.25
2040	4.91	5.10	2.71	3.31
2060	8.21	9.43	10.05	8.32
final steady state	10.18	10.10	11.99	9.49
	Change in aggregate capital in reform scenario as a % deviation from baseline			
2020	[c]			
2040	0.85	2.14	0.11	1.79
2060	4.08	7.65	4.53	1.31
final steady state	52.40	39.05	34.05	17.23
	Change in (annual) interest rate in reform scenario in p.p. deviation from baseline			
2020	0.08	0.07	0.07	0.08
2040	0.25	0.18	0.16	0.09
2060	0.24	0.20	0.31	0.40
final steady state	-1.85	-1.34	-1.02	-0.38

Note: Results report aggregate labor and capital as a % change between reform and baseline, when the same fiscal closure is assumed in both baseline and reform scenarios, equivalent to the diagonal of Table 2 and Table G.2. Calibration presented in Table 1.
[a] – expressed as a factor of the initial steady state
[b] – expressed in pp. difference to initial steady state
[c] – by construction, there is no change in capital in the first period
Closure τ denotes the situation in which contribution rate is adjusting to make the pension system fiscally neutral, as in equation (10). Closure *pension* (τ_b) refers to reduction in pension benefits to assure pension system balance, see equation (10). Closures τ_c, and τ_k stand for immediate adjustment of consumption tax and capital income tax respectively, see with equations (24) and (23).

Figure G.1: The effects of pension reforms on capital and labor supply

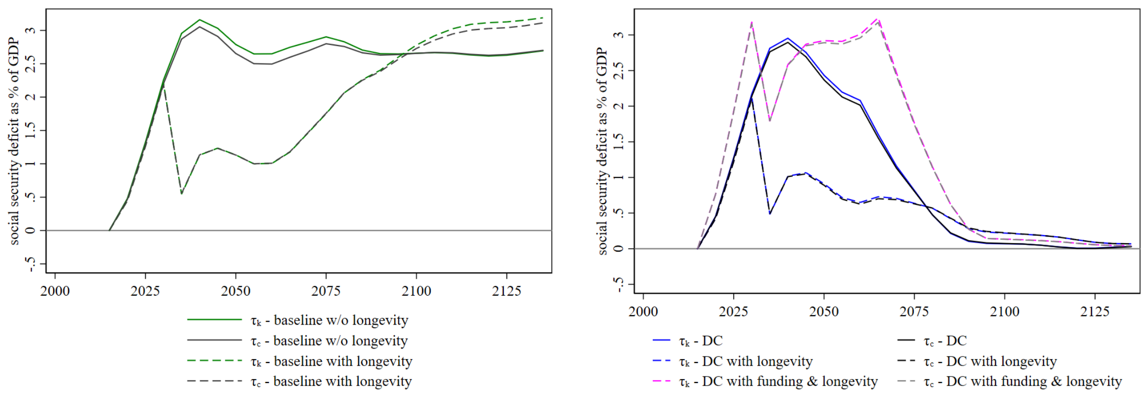
(a) capital (b) labor supply



Notes: Figures depict adjustment needed in the tax system to balance the pension system (left) or the adjustment in the pension system to maintain fiscal neutrality (right). The policy options reported follow the menu presented in section 2.5. The policy option denoted as τ_c balances the pension system with a contemporaneous increase in consumption taxation as in equation (24), analogously τ_k stands for adjustment in capital income tax, as in equation (23).

Figure G.2: The effects of pension reforms on pension system deficit as % of GDP

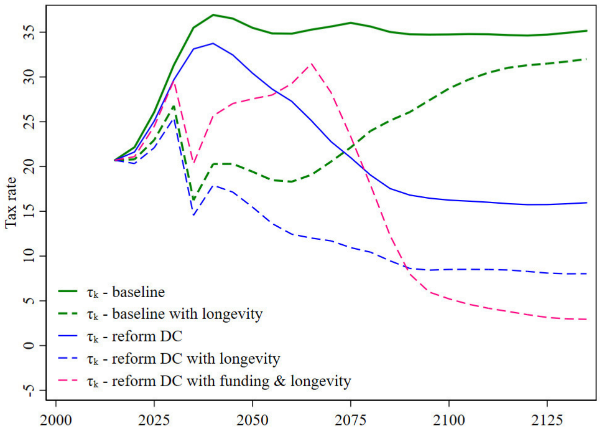
(a) baseline (b) reform



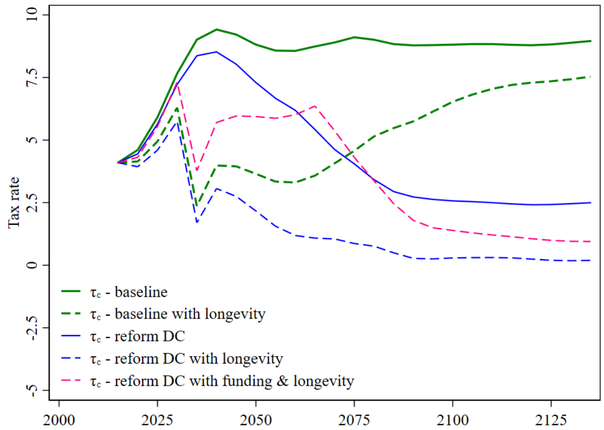
Notes: Notice that in scenarios with longevity, we increase the retirement age.

Figure G.3: Capital income and consumption tax adjustment

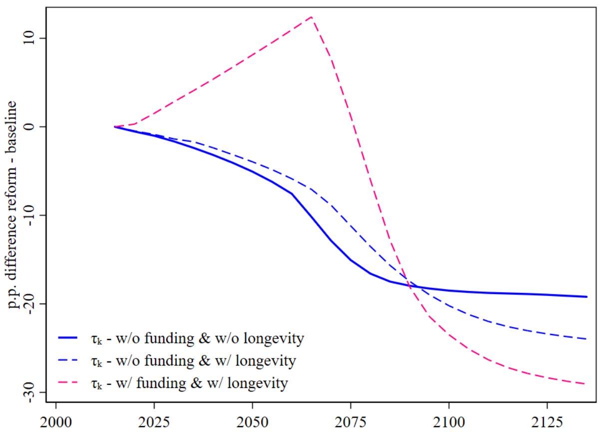
(a) τ_k - capital income tax



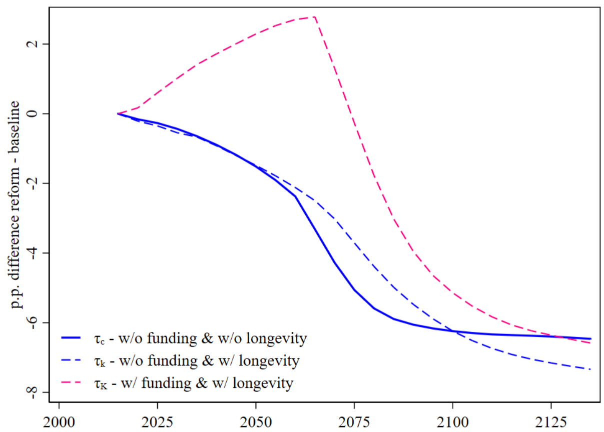
(b) τ_c - consumption tax



(c) τ_k (p.p. difference $reform - baseline$)



(d) τ_c (p.p. difference $reform - baseline$)



Notes: tax rates are expressed in percentage across scenarios. Difference between baseline and reform scenarios in Figures G.3c and G.3d in percentage points.

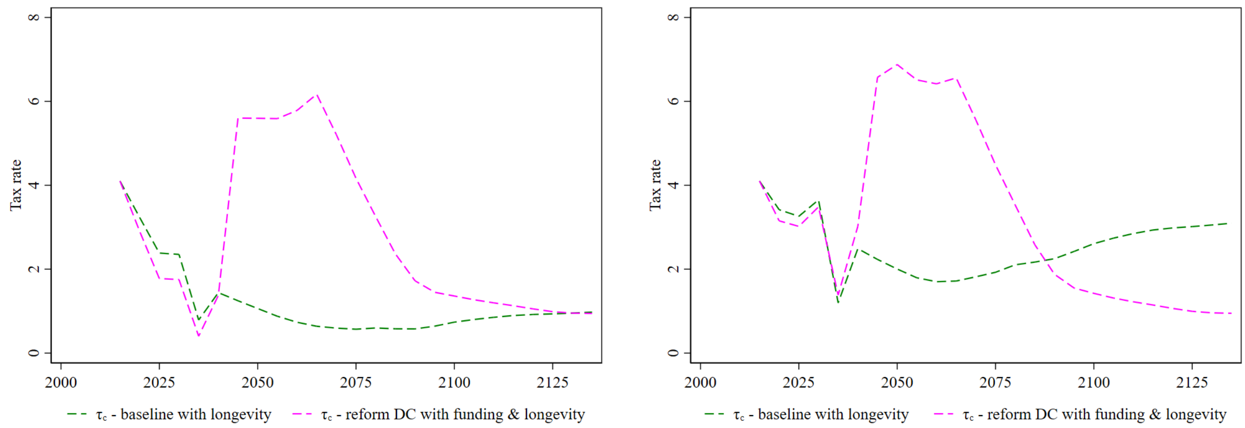
Table G.2: Welfare effects of the social security reform – alternative fiscal closures

Fiscal closure		Welfare effects	
		final steady state	aggregate
capital income tax	τ_k	6.74	0.48
consumption tax	τ_c	5.57	0.33
reducing pensions	τ^b	2.59	0.50
raising contributions	τ^ρ	5.62	0.19

Note: Results report final steady state level difference and aggregate welfare effects for all cohorts in % of lifetime consumption, equation (D.6). Political support computed as a fraction of cohorts living in the first year (steady state) benefiting from the reform, gray area denotes closures that yield the aggregate welfare gains. Closure τ denotes the situation in which contribution rate is adjusting to make the social security fiscally neutral, as in equation (B.1). Closure τ_b refers to situation in which pension benefits are reduced to ensure balance in social security, see equation (B.2). Closures τ_c and τ_l stand for immediate adjustment of consumption and labor and capital income tax respectively, compare with equations (24) and (23). In Table H.3 we report results from an analogous simulation calibrated to the case of declining rate of technological progress.

Figure G.4: Consumption tax τ_c for closures within pension system

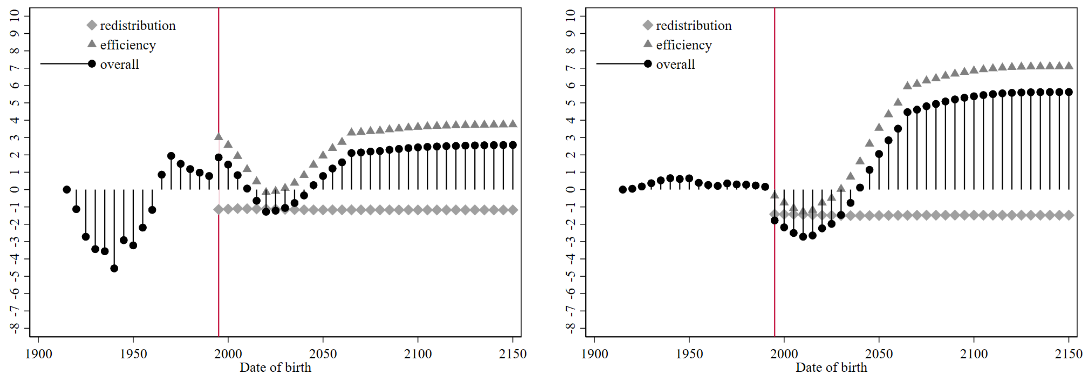
(a) reducing pensions τ^b (b) raising contributions τ^ρ



Notes: tax rates are expressed in percentage across scenarios.

Figure G.5: Consumption equivalent: reform to DC with partial funding and rising longevity

(a) reducing pensions τ^b (b) raising contributions τ^ρ



Note: see Figure 2.

H Results for declining rate of technological progress

Table H.1: Macroeconomic effects

	Final steady state relative to the initial steady state value (baseline scenario)			
aggregate labor [a]	1.55	1.57	1.54	1.57
aggregate K/L [a]	1.23	1.27	1.34	1.50
interest rate [b]	-1.26	-1.46	-1.77	-2.38
	Change in aggregate labor in reform scenario as a % deviation from baseline			
2020	1.18	1.07	1.09	1.24
2040	4.89	5.03	2.64	3.35
2060	8.10	9.26	9.89	8.18
final steady state	9.94	9.90	11.77	9.26
	Change in aggregate capital in reform scenario as a % deviation from baseline			
2020	[c]			
2040	0.82	2.09	0.06	1.74
2060	8.85	7.46	4.33	1.16
final steady state	51.39	39.47	34.42	17.54
	Change in (annual) interest rate in reform scenario in p.p. deviation from baseline			
2020	0.08	0.07	0.07	0.08
2040	0.25	0.18	0.16	0.09
2060	0.24	0.10	0.31	0.40
final steady state	-1.75	-1.31	-1.00	-0.39

Note: see Table G.1.

Table H.2: Welfare effects of the pension system reform

Reform scenario	Defined Contribution		
Social security	PAYG	PAYG	PAYG + funding
Life expectancy	constant	rising	rising
	(1)	(2)	(3)
Fiscal closure τ_c	0.32	0.83	0.36
Fiscal closure τ_k	0.90	1.09	0.45

Note: see Table 2.

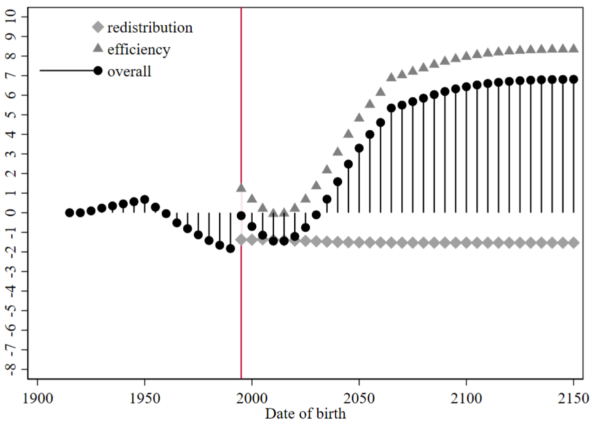
Table H.3: Welfare effects of the pension system reform – alternative fiscal closures

Fiscal closure		Welfare effects	
		final steady state	aggregate
capital income tax	τ_k	6.80	0.45
consumption tax	τ_c	5.77	0.36
reducing pensions	τ^b	2.72	0.50
raising contributions	τ^ρ	5.84	0.21

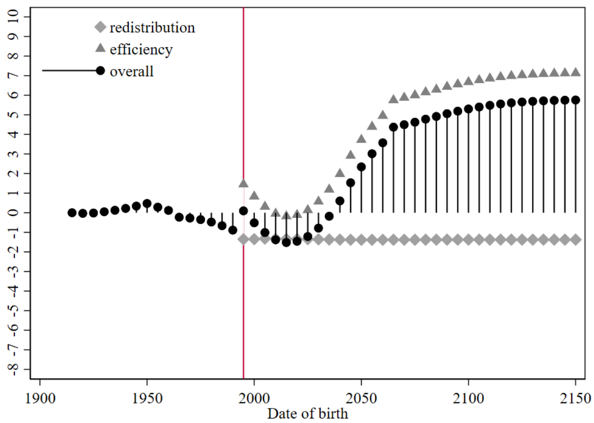
Note: see Table G.2.

Figure H.1: Consumption equivalent: reform to DC with partial funding and rising longevity

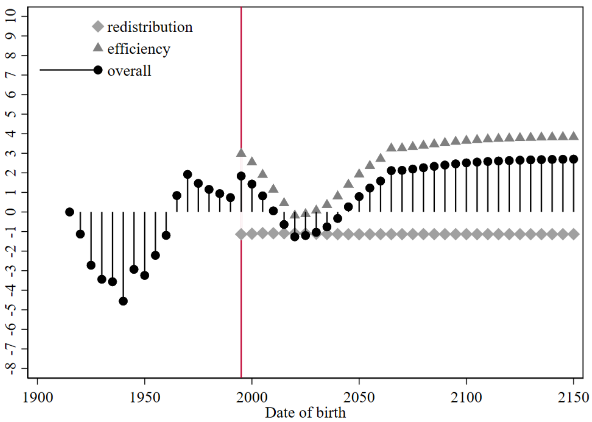
(a) capital income tax τ_k



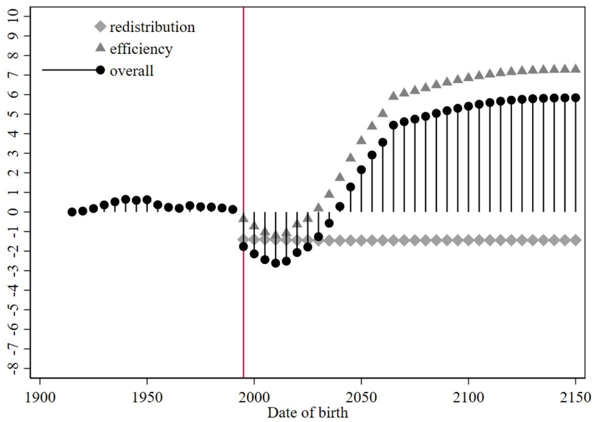
(b) consumption tax τ_c



(c) reducing pensions τ^b



(d) raising contributions τ^ρ



Note: see Figure 2.

I Results for more rapid policy implementation

Table I.1: Macroeconomic effects

Macroeconomic indicators	Fiscal closure for baseline and reform: capital income tax τ_k	consumption tax τ_c	raising contribution τ^ρ	reducing pension τ_b
	Final steady state relative to the initial steady state value (baseline scenario)			
aggregate labor [a]	1.56	1.57	1.54	1.58
aggregate K/L [a]	1.11	1.16	1.22	1.36
interest rate [b]	-0.66	-0.90	-1.22	-1.87
	Change in aggregate labor in reform scenario as a % deviation from baseline			
2020	6.54	6.12	6.10	7.20
2040	8.74	9.64	8.31	9.03
2060	10.25	11.42	11.64	9.94
final steady state	10.18	10.10	11.99	9.49
	Change in aggregate capital in reform scenario as a % deviation from baseline			
2020			[c]	
2040	3.87	6.43	7.72	13.86
2060	13.44	15.72	12.12	13.36
final steady state	52.40	39.05	34.05	17.23
	Change in (annual) interest rate in reform scenario in p.p. deviation from baseline			
2020	0.42	0.40	0.40	0.47
2040	0.29	0.18	0.03	-0.26
2060	-0.17	-0.23	-0.03	-0.18
final steady state	-1.85	-1.34	-1.02	-0.38

Note: see Table 2.

Table I.2: Welfare effects of the pension system reform

Reform scenario	Defined Contribution		
Social security	PAYG	PAYG	PAYG + funding
Life expectancy	constant	rising	rising
	(1)	(2)	(3)
Fiscal closure τ_c	0.26	1.03	0.44
Fiscal closure τ_k	1.18	1.38	0.70

Note: see Table 2.

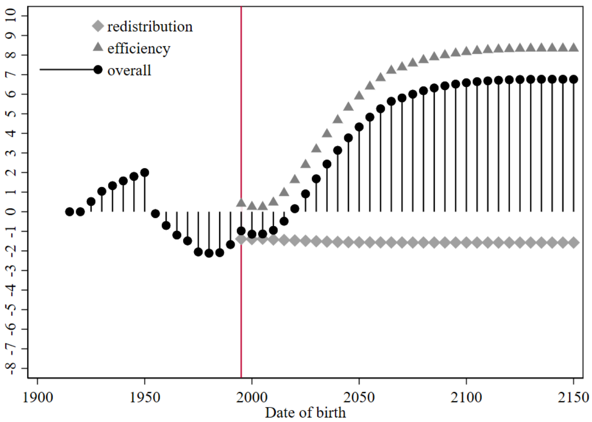
Table I.3: Welfare effects of the pension system reform – alternative fiscal closures

Fiscal closure		Welfare effects: final steady state	aggregate
capital income tax	τ_k	6.74	0.70
consumption tax	τ_c	5.57	0.44
reducing pensions	τ^b	2.59	0.61
raising contributions	τ^ρ	5.62	0.44

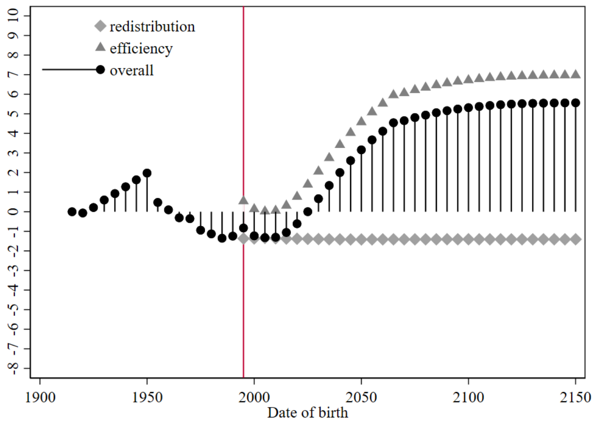
Note: see Table G.2.

Figure I.2: Consumption equivalent: reform to DC with partial funding and rising longevity

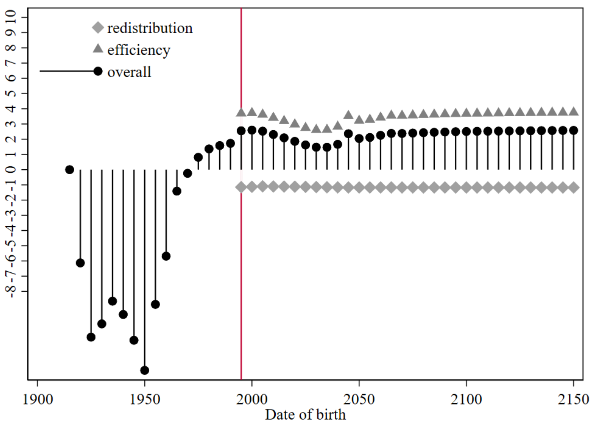
(a) capital income tax τ_k



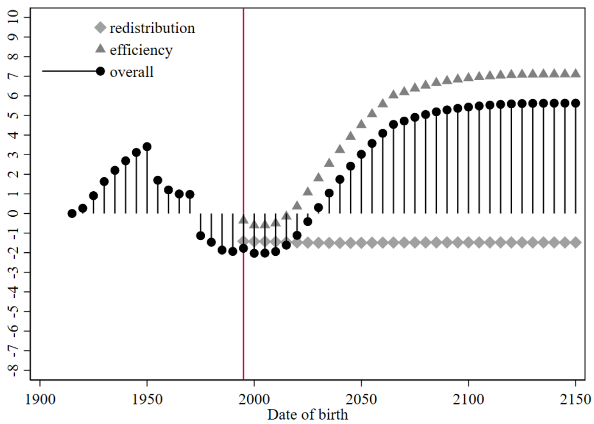
(b) consumption tax τ_c



(c) reducing pensions τ_b



(d) raising contributions τ^ρ (contributions)



Note: see Figure 2.

J Recalibrations across values of θ

Table J.1: Calibrated parameters for the initial steady state

Macroeconomic parameters		values of θ				
			2	3	4	5
ϕ	preference for consumption	0.369	0.370	0.370	0.371	0.369
θ	risk preference			2		
δ	discounting rate	0.989^5	0.999^5	1.008^5	1.017^5	1.026^5
d	annual year depreciation rate			$1\text{-}(1\text{-}0.058)^5$		
λ	labor tax progression			0.15		
τ_l	labor tax	0.114	0.117	0.118	0.118	0.118
τ_c	consumption tax	0.041	0.041	0.041	0.038	0.041
τ_k	capital tax	0.207	0.207	0.207	0.207	0.207
ρ_m	pension scaling factor	1.015	1.015	1.015	1.015	1.015
τ	social security contr.			0.078		
g	government expenditure	0.124	0.124	0.124	0.124	0.124