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On the Optimal Capital Tax Rate in Overlapping Generations Models with Capital - Skill Complementarity

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On the Optimal Capital Tax Rate in Overlapping Generations Models with Capital–Skill Complementarity¹

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Abstract

The optimal capital income tax rate has been shown to be nonzero in overlapping generations (OLG) models, as it helps redistribute income between cohorts and individuals with different labor supply elasticities and individual productivities. We show in a medium-scale OLG model that the optimal capital income tax rate is highly sensitive to the assumption of capital–skill complementarity in production technology. The imposition of the production function of Krusell et al. (2000) rather than the standard Cobb–Douglas function increases the optimal capital tax from 9.2% to 27.3% in our benchmark model. We also study the sensitivity of this result in the context of an aging economy and find that the optimal capital income tax increases over the upcoming decades depending on possible pension reforms and debt policies.

¹I would like to thank Andreas Irmen and Vito Polito for helpful comments. All remaining errors are mine.

1 Introduction

Chamley (1986) and Judd (1985) show that the optimal long-run capital tax rate is zero in the standard neoclassical growth model with infinitely lived agents. The intuition for the result is straightforward. The distortion in the intertemporal consumption allocation introduced by a capital income tax is compounded over the lifetime and outweighs the intratemporal distortion from a labor income tax. In models with finite lifetimes, however, Alvarez et al. (1992) and Erosa and Gervais (2002) demonstrate that the Chamley–Judd result does not hold because the distortion in savings is not compounded infinitely; in addition, workers at different ages are characterized by different labor supply elasticities such that a uniform labor income tax schedule is not optimal and a capital income tax might help substitute for age-specific labor income taxes.

A second strand of literature has identified 1) borrowing constraints and 2) uninsurable income risk as potential reasons why the Chamley–Judd result does not hold, e.g., in Hubbard and Judd (1987) and Aiyagari (1995). Again, the intuition for their results is very straightforward. 1) If a borrowing constraint on the household is binding, the Euler condition for the intertemporal allocation of consumption is violated, and consumption deviates from the Pareto-optimal condition in which the marginal rate of substitution between consumption in two periods is equal to the gross rate of return on capital. If fiscal revenue stems from capital rather than labor income taxes, borrowing constraints, particularly in the early periods of life, become less binding as net labor income increases. 2) In the case of uninsurable stochastic income shocks, capital income taxes help redistribute income from rich to poor agents and increase aggregate welfare if society values a more equal distribution, as reflected, for example, in a welfare criterion in the form of ex ante expected lifetime utility.¹ To derive a quantitative

¹A third strand of literature, e.g., Jones et al. (1997), has noted that the result of a zero optimal tax rate on capital income need not hold in models with human capital accumulation and innovation. Gross and Klein (2022) consider endogenous growth through innovation in a model based on Romer (1990) and find that the optimal capital tax rate is negative and capital taxes should not be used to raise government revenues. The optimal tax rate on labor versus capital income is also sensitive to the accumulation technology of human capital. If the opportunity costs of accumulating human capital accrue in the form of time rather than goods, Grüner and Heer (2000) find an optimal tax rate on physical capital of 32% in the supply-side model of Lucas (1990). For a survey on optimal capital income taxes, see Bastani and Waldenström (2020).

estimate of the optimal capital income tax in life-cycle models with idiosyncratic income uncertainty, Conesa and Krueger (2009) consider a quantitative medium-scale overlapping-generations (OLG) model. They find that the optimal capital income tax amounts to 36% and is sensitive to government debt.

As the main contribution of this paper, we consider the effects of production technology on optimal capital taxes. While the literature cited above considers only the standard Cobb–Douglas production function, we analyze the production of Krusell et al. (2000) with capital–skill complementarity. We set up a medium-scale OLG model with progressive income taxes and public pay-as-you-go pensions and find, in our benchmark calibrated with the characteristics of the US economy during 1980–2020, an optimal capital income tax rate of 27%, whereas the optimal tax rate in the corresponding model with Cobb–Douglas production equals only 9%. We identify two main channels through which production technology affects the welfare effects of high capital taxes. 1) The marginal product of capital is more sensitive to aggregate capital in the case of capital–skill complementary production technology than in the case of Cobb–Douglas technology. Therefore, higher capital taxes imply a stronger decline in net real interest rates and a stronger adjustment of the allocation of labor over the life cycle. The flatter labor-supply profile that results is welfare-increasing. 2) The skill premium is constant for the Cobb–Douglas technology, whereas it decreases with higher capital taxes in the case of the technology with capital–skill complementarity. Through this channel, higher capital taxes support redistribution from the rich to the poor and, given the concave functional form of utility, increase the average lifetime utility. We subject our analysis to a series of sensitivity analyses and show that the optimal capital income tax rate is even larger in the case of a flat-rate income tax or with low economic growth and, in the presence of a progressive income tax, is rather insensitive to the introduction of stochastic idiosyncratic uninsurable income risk.

As one interesting application, we analyze the effects of demographic change on optimal capital taxes. We assume that the population characteristics of the US economy are as predicted by United Nations (2022) for the year 2050. We demonstrate that the optimal capital income tax increases in an aging economy and reaches 35% in 2050. In addition, we study two immanent economic policies of the upcoming years. 1) As many industrialized countries face a problem in terms of the fiscal sustainability of their pension system (for a cross-country study, see Heer et al. (2020)), many countries may or must consider a reduction in pensions. 2) In addition, we observe that public debt

has surged in most industrialized countries, especially since the COVID-19 pandemic. For the US economy, Congressional Budget Office (2025) projects an increase in US public debt to 156% of GDP by 2055. We show that the optimal capital income tax is mildly sensitive to such policies; it decreases with lower pensions and increases with higher public debt.

The paper is structured as follows. Section 2 presents the medium-scale overlapping generations model with skilled and unskilled workers and a public social security system. Section 3 calibrates the model with the help of observations from the US economy from 1980-2020. Section 4 presents our results, while Section 5 concludes. Part of the sensitivity analysis is delegated to the Appendix.

2 OLG Model

The economy is described by a perfect foresight life-cycle model comprising three sectors: households, a representative firm and the government.

2.1 Demographics

In every period $t \geq 0$, a new generation of households is born. The age of newborns is $s = 1$. All generations retire at the end of age $s = T^W > 1$ and live up to a maximum age $s = T > T^W$. Population growth varies over time and is denoted as n_t . The total population in a given period t is N_t , and the number of households of age s is $N_t(s)$. Consequently, the share of the s -year-old cohort in the total population in period t is defined as $\mu_t^s \equiv N_t(s)/N_t$. All agents of age s survive until age $s + 1$ with probability ϕ_t^s . Thus, $\phi_t^0 = 1$ and $\phi_t^T = 0$.

2.2 Households

Each household comprises one individual. Households are heterogeneous with respect to labor productivity. We distinguish two types of workers, skilled (S) and unskilled (U). The shares of the household types are denoted by ψ^i , $i \in \{S, U\}$, are constant across cohorts and sum to one, $\psi^S + \psi^U = 1$.

In every period t , newborn households with skills $i \in \{S, H\}$ maximize the expected intertemporal lifetime utility:

$$U_t^i = \sum_{s=1}^T \beta^{s-1} \left(\prod_{j=0}^{s-1} \phi_{t+j-1}^j \right) u(c_{t+s-1}^{s,i}, l_{t+s-1}^{s,i}), \quad (2.1)$$

where β , $c_t^{s,i}$ and $l_t^{s,i}$ denote the household's discount factor and consumption and labor supply at age s in period t for workers with skill $i \in \{S, H\}$.

The instantaneous utility $u(\cdot)$ is specified as in King et al. (1988):

$$u(c, l) = \frac{\left(c^\gamma (1-l)^{(1-\gamma)} \right)^{1-\eta} - 1}{1-\eta},$$

where η is the inverse elasticity of intertemporal substitution and where γ denotes the weight of consumption in utility.

The wage rate of the worker at age s and with skill type i , $w^i \bar{y}^s$, depends on both the household type $i \in \{U, S\}$ and the age s . In particular, we assume that the age efficiency \bar{y}^s of the household is described by a hump-shaped function, as estimated by Hansen (1993). Accordingly, total labor income at age s for the efficiency type i in period t , $w_t^i \bar{y}^s l_t^{s,i}$, is the product of the wage rate per efficiency unit, w_t^i , the age-efficiency factor \bar{y}^s , and working hours $l_t^{s,i}$:

$$y_t^{s,i} = \bar{y}^s l_t^{s,i} w_t^i. \quad (2.2)$$

To model a progressive tax system for labor income, we follow Holter et al. (2019) and define a household's total tax burden as

$$T(y_t^{s,i}) = y_t^{s,i} - \theta_{0,t} (y_t^{s,i})^{1-\theta_{1,t}}, \quad (2.3)$$

which implies a marginal income tax of

$$\tau(y_t^{s,i}) = 1 - (1 - \theta_{1,t}) \theta_{0,t} (y_t^{s,i})^{-\theta_{1,t}}. \quad (2.4)$$

The parameter $\theta_{1,t}$ measures the degree of tax progressivity, whereas $\theta_{0,t}$ defines the tax level in period t . The tax system is progressive for $\theta_{1,t} \in (0, 1)$, regressive for $\theta_{1,t} < 0$ and linear for $\theta_{1,t} = 0$.

Labor income is also subject to a social security contribution levied at the rate τ_t^p . Accordingly, the net labor income \hat{y}_t^i of the worker is presented as follows:

$$\hat{y}_t^i = \theta_{0,t} (y_t^{s,i})^{1-\theta_{1,t}} - \tau_t^p y_t^{s,i}. \quad (2.5)$$

The pension income received by the household upon retirement is denoted as pen_t^i and depends on skill type $i \in \{S, U\}$. Pension income is not subject to income taxation.

In any period t , the budget constraint of a household of age $s = 1, \dots, T$ with skill type i is given by:

$$(1 + \tau_t^c)c_t^{s,i} = \begin{cases} \hat{y}_t^{s,i} + [1 + (1 - \tau_t^k)r_t]a_t^{s,i} + tr_t - a_{t+1}^{s+1,i}, & s = 1, \dots, T^W \\ pen_t^{s,i} + [1 + (1 - \tau_t^k)r_t]a_t^{s,i} + tr_t - a_{t+1}^{s+1,i}, & s = T^W + 1, \dots, T \end{cases} \quad (2.6)$$

where τ_t^c is the tax rate on consumption, τ_t^k is the tax rate on capital income, $a_t^{s,i}$ denotes the stock of assets held by the s -year-old household with skills i at the beginning of period t , r_t is the rate of return on assets, and tr_t denotes non-pension-related transfers from the government received by the household in period t . As the household does not work during retirement, $l_t^{s,i} = 0$ for $s = T^W + 1, \dots, T$ and $i \in \{S, U\}$. Furthermore, the household starts and terminates life without assets; thus, $a_t^{1,i} = a_{t+1}^{T+1,i} = 0$. In particular, depreciation is tax deductible, which is the standard assumption in the US calibration of dynamic general equilibrium modeling for the analysis of optimal capital taxation, as, for example, in Conesa and Krueger (2009).

The household can hold two forms of assets, bonds $b_t^{s,i}$ and physical capital $k_t^{s,i}$, $a_t^i = b_t^{s,i} + k_t^{s,i}$. In equilibrium, the household is indifferent between holding assets in the form of either physical capital or government bonds since both yield the same (certain) after-tax return. With a single household living for two periods, the proportion of asset holdings would be the same at the household and aggregate levels, but with many periods, the portfolio allocation is indeterminate. Consequently, without loss of generality, we assume that each household holds the two assets in the same fixed proportions. This is determined in the aggregate as the share of capital in total assets $K_t/(K_t + B_t)$, where K_t and B_t denote aggregate capital and government bonds, respectively.

In every period t , maximization of lifetime utility in (2.1) subject to (2.2)-(2.6) yields equilibrium conditions for the optimal allocation of consumption, labor and assets given by:

$$u_{c,t}^{s,i} = \lambda_t^{s,i}(1 + \tau_t^c), \quad s = 1, \dots, T, \quad (2.7)$$

$$-u_{l,t}^{s,i} = \lambda_t^{s,i} (1 - \tau(y_t^{s,i}) - \tau_t^p) w_t^i \bar{y}^s, \quad s = 1, \dots, T^W, \quad (2.8)$$

$$\lambda_t^{s,i} = \beta \phi_t^s \lambda_{t+1}^{s+1,i} [1 + (1 - \tau_{t+1}^k)r_{t+1}], \quad s = 1, \dots, T - 1, \quad (2.9)$$

where $u_{c,t}^{s,i}$ and $u_{l,t}^{s,i}$ denote the derivatives in period t of the household's utility at age s with skill level $i \in \{S, U\}$ with respect to consumption and labor, respectively, whereas $\lambda_t^{s,i}$ is the Lagrange multiplier of the budget constraint in equation (2.6).

2.3 Production

We consider two different production technologies. As our benchmark, we analyze capital–skill complementarities. As an alternative scenario, we consider the model with the standard Cobb–Douglas production technology.

2.3.1 Benchmark Case: Capital–Skill Complementarity

As our benchmark case, we use the nested CES production function suggested by Krusell et al. (2000):

$$Y_t = A_t \left[\mu (L_t^U)^\sigma + (1 - \mu) (\alpha K_t^\rho + (1 - \alpha) (L_t^S)^\rho)^{\frac{\sigma}{\rho}} \right]^{1/\sigma}, \quad (2.10)$$

where $\frac{1}{1-\sigma}$ and $\frac{1}{1-\rho}$ denote the production elasticity of high-skilled labor L_t^S and capital K_t , on the one hand, and the production elasticity of low-skilled labor L_t^U and high-skilled labor L_t^S and capital K_t , on the other hand. If $\sigma > \rho$, capital is highly complementary with skilled labor. A_t denotes total factor productivity.

Aggregate high- and low-skilled labor are simply the sums of the efficient labor supplies of the two types of households:

$$L_t^i = \sum_{s=1}^{T^w} \psi^i N_t(s) \bar{y}^s l_t^{s,i}, \quad i \in \{U, S\}. \quad (2.11)$$

Capital depreciates at the rate δ .

Firms maximize profits

$$\Pi_t = Y_t - r_t K_t - w_t^U L_t^U - w_t^S L_t^S - \delta K_t \quad (2.12)$$

resulting in the first-order conditions

$$r_t + \delta = \alpha(1 - \mu)A_t \left[\mu (L_t^U)^\sigma + (1 - \mu) (\alpha K_t^\rho + (1 - \alpha) (L_t^S)^\rho)^{\frac{\sigma}{\rho}} \right]^{1/\sigma-1} \times (\alpha K_t^\rho + (1 - \alpha) (L_t^S)^\rho)^{\frac{\sigma}{\rho}-1} K_t^{\rho-1}, \quad (2.13a)$$

$$w_t^U = \mu A_t \left[\mu (L_t^U)^\sigma + (1 - \mu) (\alpha K_t^\rho + (1 - \alpha) (L_t^S)^\rho)^{\frac{\sigma}{\rho}} \right]^{1/\sigma-1} (L_t^U)^{\sigma-1}, \quad (2.13b)$$

$$w_t^S = (1 - \alpha)(1 - \mu)A_t \left[\mu (L_t^U)^\sigma + (1 - \mu) (\alpha K_t^\rho + (1 - \alpha) (L_t^S)^\rho)^{\frac{\sigma}{\rho}} \right]^{1/\sigma-1} \times (\alpha K_t^\rho + (1 - \alpha) (L_t^S)^\rho)^{\frac{\sigma}{\rho}-1} (L_t^S)^{\rho-1}, \quad (2.13c)$$

Profits are equal to zero in equilibrium.

2.3.2 Comparison Case: Cobb–Douglas Production Function

As a comparison case, we consider the standard Cobb–Douglas production function with labor-augmenting technological progress:

$$y_t = K_t^\alpha (A_t L_t)^{1-\alpha}, \quad (2.14)$$

where α is the share of capital in output. In this case, we assume that skilled and unskilled workers have permanent productivity ϵ^i , $i \in \{S, U\}$ so that the effective labor of the worker at age s with skill i in period t is given by $\bar{y}^s \epsilon^i l_t^{s,i}$. Accordingly, the aggregate labor in efficiency units L_t is given by:

$$L_t = \sum_{i \in \{S, U\}} \sum_{s=1}^{T^w} \psi^i N_t(s) \bar{y}^s \epsilon^i l_t^{s,i}. \quad (2.15)$$

Technology grows over time at the exogenous rate $g \geq 0$, which is also equal to the balanced growth rate of the economy. Since production is perfectly competitive, in equilibrium, labor and capital are remunerated at their marginal products, that is:

$$w_t = (1 - \alpha) K_t^\alpha (A_t L_t)^{-\alpha}, \quad (2.16a)$$

$$r_t^k = \alpha K_t^{\alpha-1} (A_t L_t)^{1-\alpha} - \delta, \quad (2.16b)$$

with δ denoting the rate of physical capital depreciation, and the wages of skilled and unskilled workers, w_t^i , $i \in \{S, U\}$, in (2.2) are presented by $w_t^i = A_t w_t \epsilon^i$.

2.4 Government

Government expenditure is allocated to public consumption G_t , aggregate transfers Tr_t and interest payments on public debt $r_t^b B_t$, with r_t^b denoting the after-tax return on government bonds. Government revenue is increased through taxation Tax_t , new debt issuance $B_{t+1} - B_t$ and the confiscation of accidental bequests Beq_t . In total, the government budget constraint is as follows:

$$G_t + Tr_t + r_t^b B_t = Tax_t + B_{t+1} - B_t + Beq_t, \quad (2.17)$$

where tax revenue from the taxation of aggregate consumption C_t , capital K_t and labor is given by:

$$Tax_t = \tau_t^c C_t + \tau_t^k r_t K_t + \sum_{s=1}^{T^W} \sum_{i \in \{S, U\}} \psi^i T(y_t^{s,i}) N_t(s). \quad (2.18)$$

The government sector also includes a pay-as-you-go pension system. In the aggregate, pension expenditure is the sum of pension payments made to retired households:

$$Pen_t = \sum_{s=T^W+1}^T \sum_{i \in \{S, U\}} \psi^i pen_t^{s,i} N_t(s) \quad (2.19)$$

and the social security budget is formulated as:

$$Pen_t = \tau^p (w^U L^U + w^S L^S). \quad (2.20)$$

2.5 Equilibrium and Aggregate Conditions

At the aggregate level, consumption, assets, transfers and accidental bequests are determined as the sum of the corresponding individual variables; thus:

$$C_t = \sum_{s=1}^T \sum_{i \in \{S, U\}} \psi^i N_t(s) c_t^{s,i}, \quad (2.21)$$

$$\mathcal{A}_t = \sum_{s=1}^T \sum_{i \in \{S, U\}} \psi^i N_t(s) a_t^{s,i}, \quad (2.22)$$

$$Tr_t = \sum_{s=1}^T \sum_{i \in \{S, U\}} \psi^i N_t(s) tr_t, \quad (2.23)$$

$$Beq_{t+1} = \sum_{s=1}^{T-1} \sum_{i \in \{S, U\}} \psi^i N_t(s) (1 - \phi_t^s) [1 + (1 - \tau_{t+1}^k) r_{t+1}] a_{t+1}^{s+1,i}. \quad (2.24)$$

Equilibrium in the goods market requires that aggregate output is equal to aggregate demand:

$$Y_t = C_t + G_t + K_{t+1} - (1 - \delta)K_t, \quad (2.25)$$

whereas equilibrium in the capital market requires that aggregate assets purchased by the households are equal to the sum of aggregate capital and government bonds demanded by firms and the government, respectively:

$$\mathcal{A}_t = K_t + B_t. \quad (2.26)$$

The no-arbitrage condition implies that in equilibrium, all assets have the same after-tax rate of return:

$$r_t^b = (1 - \tau_t^k)r_t. \quad (2.27)$$

3 Calibration

The benchmark calibration is designed to approximate a steady state for the US economy on the basis of data averages from 1980 to 2020. Table 3.1 summarizes our parameter choices.²

Demographics A period t in the model corresponds to one year. Newborns are assumed to have a real-life age of 20, corresponding to $s = 1$, and live up to a real-life age of 99; thus, $T=80$. Retirement ages $T^W + 1 = 48$ (corresponding to the real-life age of 67) are calculated as the average of the effective age of retirement for the years 2014, 2018 and 2020 obtained from OECD (2021). The population growth rates n are calculated as the averages of the annual population growth rates from 1980 to 2020, obtained from United Nations (2022). Survival probabilities ϕ_t^s are computed from annual data on life expectancy for both sexes combined (from age 20 to age 99), which are also obtained from United Nations (2022). The calibration employs the average survival probabilities from 1980 to 2020.

²The GAUSS computer code for the calibration and all applications is available from the author upon request.

Parameter	Value	Description
<u>Household types</u>		
(ψ^S, ψ^U)	(0.5, 0.5)	share of household types $i \in \{S, U\}$
<u>Preferences</u>		
$1/\eta$	1/2	intertemporal elasticity of substitution
γ	0.226	utility weight of consumption
β	1.010	discount factor
<u>Production</u>		
$1/(1 - \sigma)$	1.67	substitution elasticity of high-skilled labor
$1/(1 - \rho)$	0.67	substitution elasticity of low-skilled labor
(α, μ)	(0.657, 0.261)	weight of production factors in (2.10)
δ	8.3%	depreciation rate of capital
g	1.529%	labor productivity growth rate
<u>Government</u>		
$(\tilde{\theta}_0, \theta_1)$	(0.757, 0.137)	income tax parameters
τ^k	22.8%	tax on capital income
τ^c	6.2%	tax on consumption
G/Y	19.4%	share of government spending in steady-state production
B/Y	72.8%	debt-output ratio
$(repl^S, repl^U)$	(32.6%, 40.6%)	gross pension replacement rate of (un)skilled workers

Table 3.1: Calibration of parameters for the US economy during 1980–2020

Household Types We set the shares of skilled and unskilled households equal to $\psi^S = \psi^U = 0.5$, corresponding to the average number of college graduates during the period 1980–2020 reported by the U.S. Bureau of Labor Statistics.³ The age–productivity file $\{y^s\}_{s=1}^{47}$ is taken from Hansen (1993) and extrapolated linearly to the real-life age of 66.

³The data are taken from Table A-1 of the Historical Time Series Tables. The average share of those with a college education relative to the total number of households for 1980–2020 was 0.4863.

Preferences We choose an intertemporal elasticity of substitution, $1/\eta$, equal to $1/2$. We set the weight of utility from consumption, $\gamma = 0.226$, to imply average working hours of 0.25 in this case. The discount factor $\beta = 1.010$ implies a real interest rate of 4.0%.⁴

Production The average growth rate of per capita GDP from 1980–2020 amounts to $g = 1.529\%$. This is calculated using data obtained from OECD (2022) by scaling the annual nominal value of the gross domestic product at market prices by the corresponding deflator and then dividing by the total population. Capital depreciates at the annual rate $\delta = 8.3\%$.

In production function (2.10), we set $\sigma = 0.401$ and $\rho = -0.495$ as estimated by Krusell et al. (2000). The remaining production parameters α and μ are calibrated to simultaneously satisfy the following conditions:

1. The skill premium is set so that skilled workers receive a skill premium of 150% above the wage of the unskilled workers:⁵

$$\frac{w^S}{w^U} = 2.50.$$

2. Total wages are equal to 65% of GDP:

$$\frac{w_t^U L_t^U + w_t^S L_t^S}{Y_t} = 0.65.$$

We find that $\alpha = 0.657$, $\mu = 0.261$.

In the case of the Cobb–Douglas production function (2.14), we set $\alpha = 0.35$ and $(\epsilon^S, \epsilon^U) = (1.43, 0.57)$ to imply the same skill premium and aggregate the labor share as in the case of the production function (2.10).⁶

⁴Hurd (1989) provides an empirical estimate of 1.011 for the discount factor after accounting for stochastic survival.

⁵A skill premium of 150% is in accordance with data from the U.S. Bureau of Labor Statistics on the median weekly earnings of workers with a bachelor’s degree or higher (LEU0252918500) relative to those with less than a high school diploma (LEU0252916700). Krueger and Ludwig (2007) apply the same skill premium.

⁶We also need to recalibrate the parameters $(\beta, \gamma, \theta_0) = (1.0095, 0.211, 0.804)$ that are set with the help of the steady-state conditions of the model (not presented in Table 3.1).

Government The government parameters are also chosen as averages from empirical data from 1980–2020. In particular, we follow Brinca et al. (2016) and set the tax progressivity $\theta_1 = 0.137$ to replicate the average tax progressivity in the United States.⁷ The average labor income taxes (both income tax and social security) are 21.7%, implying that $\tilde{\theta}_0 = \theta_{0,t}/A_t = 0.757$, whereas the capital income tax and the consumption tax are equal to $\tau^k = 22.8\%$ and $\tau^c = 6.2\%$.⁸ Government consumption G is 19.4 % of GDP, whereas the debt–GDP ratio during this period averaged 72.8%. To calibrate the replacement rate of pensions pen_t^i with respect to the average gross income of worker type $i \in \{U, S\}$, $(w_t^{isl,i}\bar{y}^s)$, we use linear interpolation of the replacement rate with respect to gross income provided by OECD (2021) for men with 50% and 200% of the average wage, 49.4% and 27.8%, respectively, implying replacement rates $repl^S = 32.6\%$ and $repl^U = 40.6\%$.

In the benchmark equilibrium, the social security tax τ^p must be set equal to 7.51% to balance the budget of the social security authority. The share of capital (government bonds) in total assets amounts to 79.6% (20.4%).

4 Results

In this section, we present our results. First, we demonstrate that the optimal capital income tax rate is much higher in the case of capital–skill complementarity in production than in the case with the standard Cobb–Douglas production function. Next, we consider the effects of income uncertainty in the form of idiosyncratic uninsurable productivity shocks and find that the optimal capital tax rate is rather insensitive to it. Finally, we study the effects of aging on the optimal capital income tax and show that, owing to the demographic transition, optimal capital income taxes increase over time. An additional sensitivity analysis of our results is presented in Appendix A.

⁷Heathcote et al. (2017) apply a slightly higher value of $\theta_1 = 0.18$ because they include capital income as part of taxable income.

⁸We calculate the average tax rates on income from labor, capital and consumption using the revision of the method of Mendoza et al. (1994) proposed by Carey and Rabesona (2003).

4.1 Optimal Capital Taxes

Fig. 4.1 displays the effects of capital income taxes on welfare for the benchmark with capital–skill complementarity in production (solid blue line ‘Krusell’) and the standard Cobb–Douglas technology (broken black line ‘Cobb–Douglas’). As our welfare criterion, we employ the ex ante expected lifetime utility of the newborn in the steady state. Thus, the unborn individual does not know her ability type $i \in \{S, U\}$ and forms expectations with respect to her stochastic survival. Welfare changes relative to the benchmark with $\tau^K = 22.8\%$ are expressed in consumption equivalent changes. The optimal capital income tax rate is 27.3% in the model with capital–skill complementarity in production technology, as in Krusell et al. (2000), whereas it decreases to 9.2% in the case of the standard Cobb–Douglas technology.⁹ The associated welfare gains needed to move from the present capital tax rate of $\tau^K = 22.8\%$ to the new optimal tax rates amount to 0.01% and 0.25% of total consumption, respectively. If capital income taxes are reduced to zero, as suggested by the results of Chamley (1986) and Judd (1985), welfare decreases by 0.28% in the case of capital–skill complementarity and increases by 0.13% in the Cobb–Douglas case. Table 4.1 summarizes the optimal capital income taxes and the welfare gains from changing the present capital income tax of 22.8% to the optimal and zero tax rates (expressed in consumption equivalent changes) for various scenarios.

To understand these welfare effects, we must consider the different behaviors of factor prices for the two production technologies. In accordance with Conesa and Krueger (2009), we find that a change in the capital income tax τ^K , which is financed by an adjustment of the labor income tax, has a strong effect on the aggregate capital stock but a negligible effect on average working hours and the aggregate labor supply. Table 4.2 presents the effects of abolishing capital income tax τ^K on aggregate factor supplies. In both technology cases, the changes in the capital stock are 10–30 times greater than the changes in the aggregate labor supplies. For example, in the case of skill-capital complementarity, the capital stock increases by 7.02% if capital taxes τ^K are cut from 22.8% to 0%, whereas the average working hours of skilled and unskilled

⁹Conesa and Krueger (2009) find an optimal capital income tax rate of 36% for the Cobb–Douglas technology (as presented in the ‘Bench’ scenario in Table 4). We replicate their result in a modified version and calibration of our benchmark model, which is described in the next section. The main reason why these authors derive a much higher optimal capital income tax rate in comparison with our benchmark calibration is their assumption of an economic growth rate of zero.

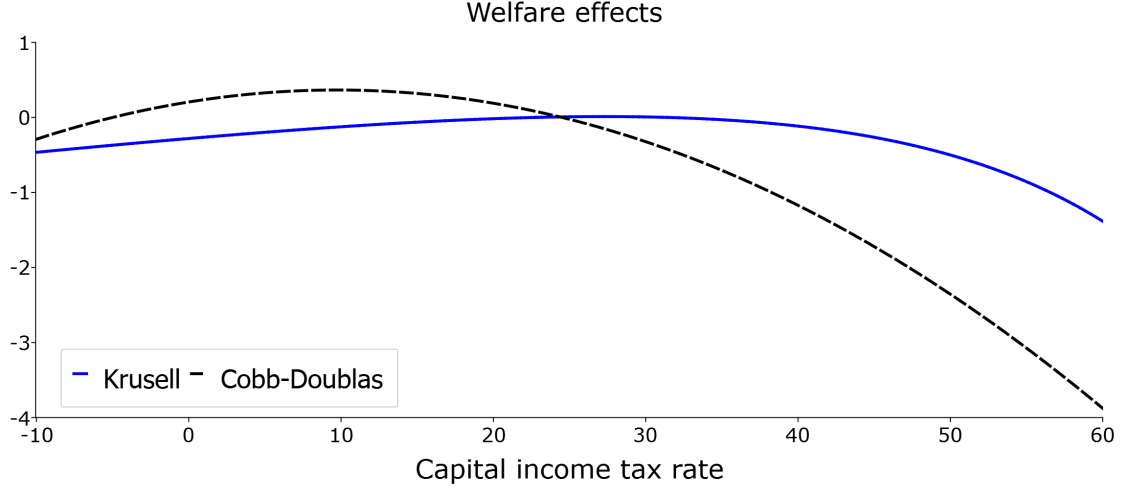


Figure 4.1: Welfare effects of capital income taxes τ^K (in percentage points)

workers adjust by 0.20% and -0.14%, respectively.¹⁰ Therefore, to understand the effects of technology, we first need to analyze how a change in the capital stock affects factor prices and, subsequently, study how these factor price changes affect individual behavior.

Fig. 4.2 presents the effects of capital stock on the real interest rate for constant labor inputs. The capital stock in the steady state with capital income tax rate $\tau^K = 22.8\%$ is normalized to one in both cases with skill-capital complementarity ('Krusell') and Cobb-Douglas technology ('Cobb-Douglas'). In the steady state, the real interest rate before taxes (corresponding to $r = \partial Y / \partial K - \delta$ in the model) amounts to 4.0% with both technologies. We consider a change in the capital stock in the range $\pm 20\%$ and note that the associated changes in the real interest rate are approximately 40% greater with capital-skill complementarity than in the case of the Cobb-Douglas technology. For example, for a reduction in the capital stock of 20%, interest rates increase to 6.66% and 5.92%, respectively. This reflects our calibration of the production function (2.10) with a substitution elasticity of the composite of capital and high-skilled labor,

¹⁰The small quantitative response of labor is not surprising. The Frisch labor supply elasticity amounts to $\frac{1-l}{l} \frac{1-\gamma(1-\eta)}{\eta}$ and averages 3.68 in our benchmark model. Frisch elasticity, however, isolates the substitution effect. As is well known, the uncompensated labor supply elasticity for the Cobb-Douglas utility in the simple one-period model is zero if nonlabor income is zero and becomes negative in the presence of positive nonlabor income, such as transfers or capital income. As the income effect almost offsets or even overcompensates for the substitution effect in our model, aggregate and average labor do not change much in response to a change in net wages.

Case	Optimal	Welfare effects	
	$\tau^{K,*}$	$\tau^{K,*}$	$\tau^K = 0$
Benchmark	27.3%	0.01%	-0.28%
Cobb–Douglas technology	9.2%	0.25%	0.13%
<u>Income Uncertainty</u>			
– benchmark, $g = 1.529\%$	23.1%	0.12%	-1.01%
– Cobb–Douglas, $g = 0, \eta = 4$	34.7%	0.65%	-3.31%
<u>Population in 2050</u>			
– constant pensions	35.2%	0.10%	-0.43%
– 30% cut in pensions	31.5%	0.19%	-0.63%
– debt-GDP ratio $B/Y = 150\%$	38.4%	0.03%	-0.23%

Table 4.1: Optimal tax rate $\tau^{K,*}$

Variable	Krusell	Cobb–
		Douglas
K	7.02	11.39
\bar{l}^S	-0.14	-0.33
\bar{l}^U	0.20	-0.33
L^S	-0.40	-0.42
L^U	0.04	-0.41

Table 4.2: The effects of abolishing capital income taxes τ^K on factor supplies (percentage changes)

$Z_t = (\alpha K_t^\rho + (1 - \alpha) (L_t^S)^\rho)^{1/\rho}$, and the labor supply of low-skilled labor, L_t^U , below one, $1/(1 - \rho) = 0.67$, which is amplified by a substitution elasticity of high-skilled labor and capital above one, $1/(1 - \sigma) = 1.67$.

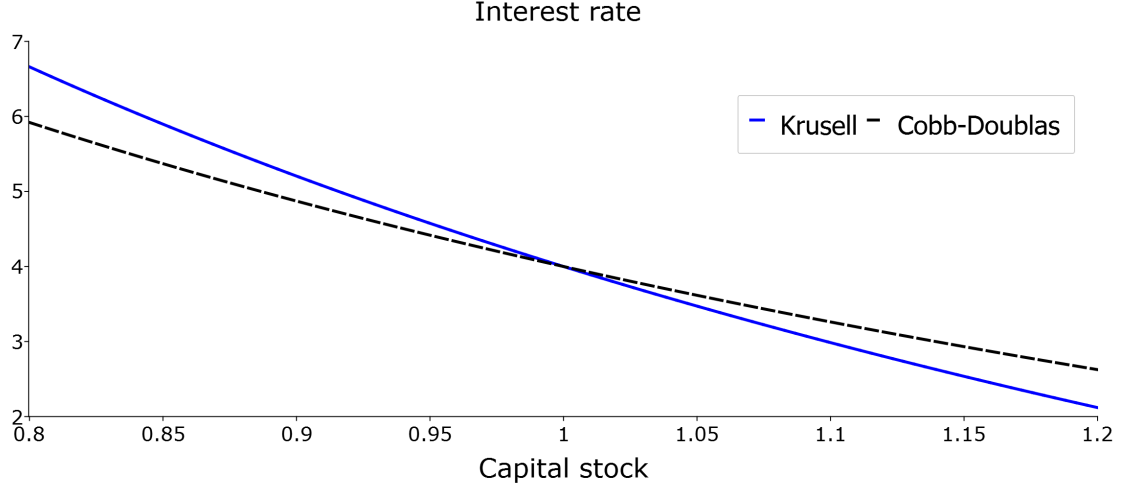


Figure 4.2: Capital stock and interest rates

Figure 4.3 presents the life-cycle profiles of labor supply for skilled and unskilled workers for technology with capital–skill complementarity and for Cobb–Douglas technology. It compares the case of zero capital taxation (broken black line) with the benchmark, $\tau^K = 22.8\%$ (solid blue line). In all cases, the labor-supply profiles become flatter as the capital tax increases from 0% to 22.8%, and therefore, the net interest rate decreases. The quantitative response of the labor supply is much more pronounced in the case of the skill complementarity of capital than in the case of the Cobb–Douglas technology, by a factor of approximately 3. For example, the working hours of the 20-year-olds decline by 3.82% for higher taxes in the ‘Krusell’ case but by only 1.01% in the ‘Cobb–Douglas’ case. Similarly, the working hours of the 65-year-olds increase by 7.40% and 2.76% in the two cases, respectively. The stronger response in the ‘Krusell’ case follows directly from the stronger decline in the interest rate depicted in Fig. 4.2. For a lower interest rate, the household reallocates labor intertemporally and increases labor in old age.¹¹

¹¹İmrohoroglu and Kitao (2009) consider a related phenomenon. In a life-cycle model similar to ours, they consider different social security reforms and their effects on the intertemporal allocation of labor. They find that the privatization of social security has a strong effect on capital but a negligible effect on aggregate labor; importantly, individuals shift their labor supply from younger to older years as the real interest rate falls.

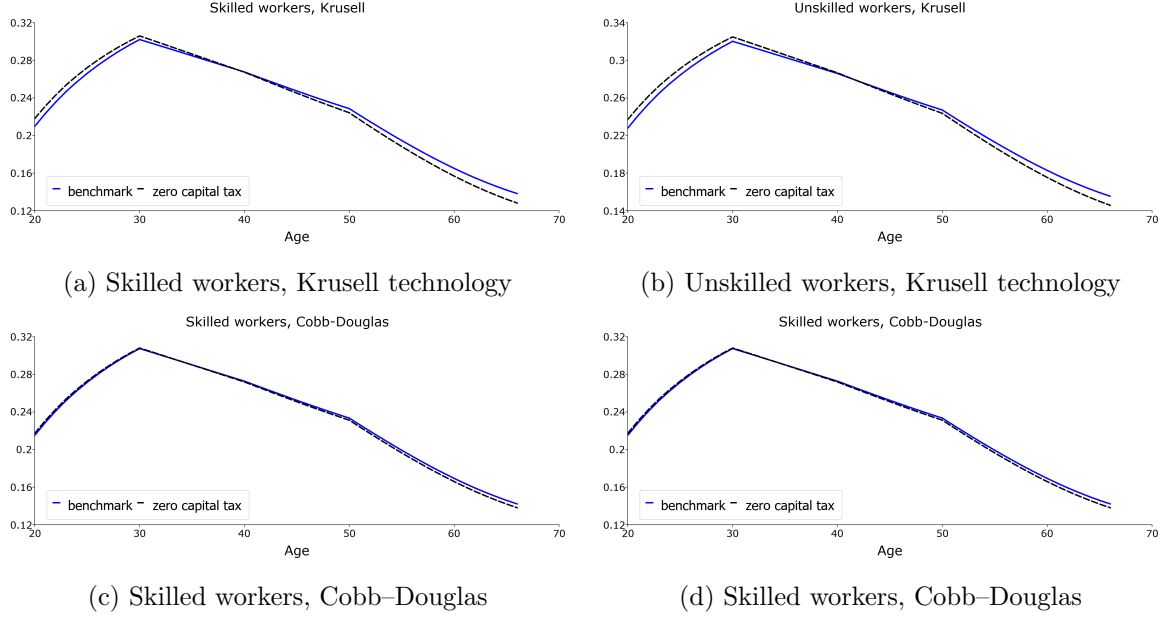


Figure 4.3: Life-cycle profiles of working hours and capital income taxes

As argued in detail by Erosa and Gervais (2002) in a theoretical analysis and by Conesa and Krueger (2009) in a quantitative analysis, the intertemporal reallocation of labor/leisure is the main explanation for the welfare-increasing effects of a (strictly) positive optimal capital income tax rate. The formal argument has also been advocated by Erosa and Gervais (2002). If the government could use age-dependent labor income taxes, it would be efficient in the present model with a declining labor supply over the life cycle to impose labor taxes that also decline with age.¹² If, as in the present model, labor income rates cannot be conditioned on age, the government can imitate this age-dependent tax policy by taxing capital income and increasing the net present value of older workers' labor income so that the opportunity costs of leisure in old age increase.

Next, we analyze how a change in the capital stock (while keeping the labor supplies constant) affects the wages of unskilled and skilled workers for the two different technologies. Fig. 4.4 presents the wages of skilled and unskilled workers for the 'Krusell' technology (blue solid line) and the 'Cobb-Douglas' technology (black broken line). All wages are normalized to one in the benchmark steady state for ease of comparison.

¹²To see this point intuitively, consider the *Ramsey* rule emanating from the classic work of Ramsey (1927). In our model, the Frisch labor supply elasticity initially decreases with age until the age of 30 and subsequently increases over the life cycle so that, *ceteris paribus*, the optimal labor income tax should decline with age (beyond the threshold of 30 years) according to this principle.

Evidently, the wages of unskilled labor react less strongly to a change in the aggregate capital stock K in the case of skill–capital complementarity than they do in the case of the Cobb–Douglas technology, and vice versa for the wages of skilled workers. This observation follows directly from the production technology of Krusell et al. (2000), where higher σ and lower ρ amplify the increase in inequality between skilled and unskilled workers as capital deepening increases. Therefore, the skill premium decreases with lower capital stock in the case of skill–capital complementarity, whereas it remains constant in the Cobb–Douglas case. For example, the skill premium decreases from 150% to 128% with 'Krusell' technology if the capital stock decreases by 20%.

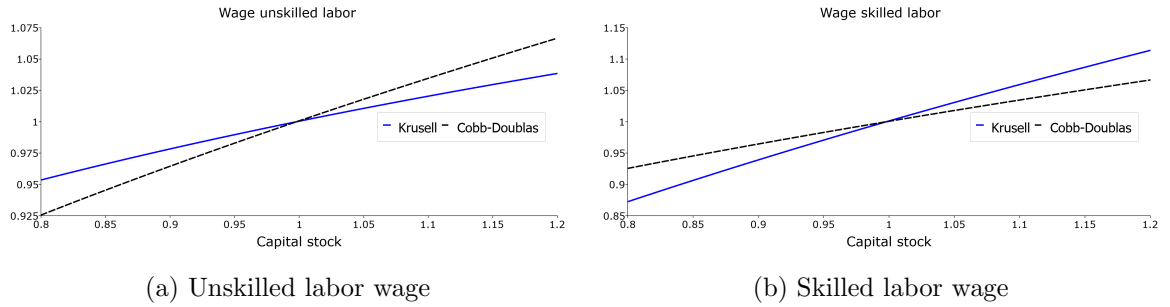


Figure 4.4: Aggregate effects of capital income taxes τ^K on wages

In the general equilibrium model with endogenous capital and labor, high capital income taxes reduce savings and, hence, aggregate capital stock, whereas labor remains rather constant; therefore, wage inequality decreases in the case of 'Krusell' technology but not in the case of Cobb–Douglas technology. As a consequence, the declining skill premium helps improve the lifetime utility of unskilled workers in comparison to skilled workers in the case of 'Krusell' technology. Fig. 4.5 presents the lifetime utilities of skilled and unskilled workers as a function of the capital income tax rate τ^K for both technology types. For the Cobb–Douglas technology, the lifetime utilities of both unskilled workers and skilled workers are concave functions of the capital income tax rate and peak around a tax rate of 10%. The lifetime utilities of workers behave fundamentally differently in the case of technology with skill–capital complementarity. In this case, the lifetime utility of the unskilled worker is found to increase with τ^K over the whole range considered, $\tau^K \in [-10\%, 60\%]$, whereas it decreases in the case of the skilled worker. As utility is a concave function of consumption, a redistribution of income from rich (skilled) workers to poor (unskilled) workers increases average utility and, hence, welfare as measured by the ex ante expected lifetime utility.

In summary, we find that the skill complementarity of capital provides a rationale for

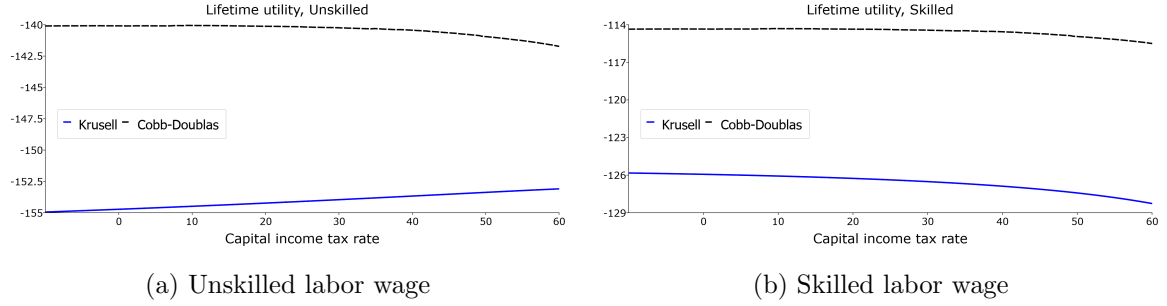


Figure 4.5: Lifetime utilities of unskilled and skilled workers

redistribution via capital income taxation both through its redistribution between skill types of workers and its strong effect on interest rates.

4.2 Income Uncertainty

The various and, to some extent, opposing welfare effects of capital taxes are magnified in the presence of income uncertainty. On the one hand, stochastic income increases the need to build up precautionary savings. Therefore, a capital tax that introduces a wedge in the optimality condition on savings inhibits the individual from insuring himself against the bad luck of negative idiosyncratic productivity shocks by means of savings. On the other hand, income uncertainty increases the welfare-improving effects of redistribution and insurance. In dynamic general equilibrium models with infinite and finite lifetimes, respectively, Hubbard and Judd (1986) and İmrohoroglu (1998) show that the optimal capital income tax is positive if households are subject to uninsurable idiosyncratic income risk and/or borrowing constraints.

In this section, we introduce income uncertainty, which is standard in the quantitative analysis of medium-scale OLG models, e.g., as in Huggett (1996), Conesa and Krueger (2009) or Kitao (2014). In particular, we add a multiplicative stochastic component ζ to individual productivity so that the gross labor income of the s -year-old worker with idiosyncratic productivity ζ and permanent productivity $i \in \{S, U\}$ in period t , $y_t(s, \zeta, i) = \zeta \bar{y}^s w_t^i l_t$, consists of the product of his idiosyncratic productivity ζ , the age component \bar{y}^s , the wage of the skill type i , w_t^i , and his working time $l_t(s, \zeta, i)$. We assume that the logarithm of the idiosyncratic component ζ follows a simple AR(1) process with persistence parameter ρ_ζ and unconditional variance σ_ζ^2 . We select $\rho_\zeta = 0.97$ and $\sigma_\zeta^2 = 0.02$ in accordance with Kitao (2014).¹³ In the numerical procedure,

¹³The calibration $\rho_\zeta = 0.97$ constitutes the median value in the three studies cited in the paragraph.

we discretize the state space for the stochastic component ζ using 7 values and choose the grid size so that the Gini coefficient of hourly wages is 0.374, as estimated by Heer and Maußner (2024) using PSID data.¹⁴ In addition, we impose a borrowing constraint $a_t(s, \zeta, i) \geq 0$. We find that 23% of the households are credit constrained in the benchmark economy, which is in accordance with the empirical observations of Budría Rodríguez et al. (2002) and Krueger et al. (2016).

In accordance with Conesa and Krueger (2009), we find that the various effects of income uncertainty and borrowing constraints on welfare approximately cancel each other in the presence of progressive labor income taxation. The optimal capital income tax rate is 23.1% in our model, and the welfare effects of implementing the optimal tax policy or abolishing the capital income tax amount to 0.12% and -1.01% of total consumption, respectively (as presented in Table 4.1).

For comparison, we also recalculate the model to replicate the basic elements of the model in Conesa and Krueger (2009). To do so, we set the parameter $\eta = 4.0$ and the economic growth rate g equal to zero; we assume a Cobb–Douglas production technology and recalibrate the parameters α , γ and β to imply a wage share of 65%, a real interest rate of 4% and average working hours of 0.25. The results are presented in the fourth entry row of Table 4.1. We find an optimal capital income tax rate of 34.7% for this case, whereas Conesa and Krueger (2009) estimate an optimal tax rate of 36%. The very small remaining difference can be explained by the use of a different calibration period and slightly different pension and income tax schedules.

4.3 Demographic Change

The demographic transition is likely to affect the capital stock per worker over the upcoming years. Starting with the seminal paper by De Nardi et al. (1999), studies

For example, Huggett (1996) and Conesa and Krueger (2009) apply values of 0.96 and 0.98 for ρ_ζ .

¹⁴The Gini coefficients of gross income, wealth and consumption in the benchmark equilibrium are 0.47, 0.666 and 0.426, respectively. Quadrini and Ríos-Rull (2015) present empirical evidence that the the Gini coefficients of US earnings and wealth in 2010 were 0.65 and 0.85, respectively, according to data from the Survey of Consumer Finance (SCF), whereas Krueger et al. (2016) find a Gini coefficient of earnings of 0.43 when using PSID data. Heathcote et al. (2010) presents empirical evidence for the US economy that the Gini coefficient of nondurable consumption was substantially smaller than the Gini coefficient of income from 1990–2006, with a Gini coefficient of consumption ranging between 0.32 and 0.40.

such as Krueger and Ludwig (2007), Kitao (2014) or Heer et al. (2020) have examined the effects of aging on factor supplies and prices depending on possible pension reforms. In essence, the projected increase in capital stock relative to working hours implies a lower real interest rate and a higher wage rate, with the quantitative effect depending on pension policies. Applying our arguments based on the production technology described above—that is, higher taxes are associated with lower net real interest rates and a more equal wage distribution—we find that the higher capital intensity in the upcoming years increases the optimal capital income tax rate. Considering our model in the steady state for the benchmark calibration but changing the population parameters, survival probabilities and population growth rate to the values projected for the year 2050 by United Nations (2022), we find that the optimal capital income tax rate $\tau^{K,*}$ increases strongly, from 27.3% in 2020 to 35.2% in 2050. In addition, the quantitative welfare effects measured by consumption equivalent changes approximately double in size, as presented in Table 4.1.

Pension and debt policies affect capital intensity during the demographic transition and in the long-run equilibrium. An increase in retirement age or a decrease in pensions will reduce the quantitative effect of aging on capital per worker. In addition, some of the transition costs can be expected to be financed by higher debt as the baby boomers retire. Accounting for the debt increase during the COVID-19 pandemic and the recent changes in the US budget deficit, Congressional Budget Office (2025) projects an increase in public debt to 156% of GDP by 2055. We study the sensitivity of our results to pension policies and debt policies using two exemplary cases. First, we consider a 30% reduction in US pension entitlements. Second, we consider an increase in the debt-to-GDP ratio from 73% in the benchmark in 2020 to 150% in 2050. Both policies affect the optimal capital tax only mildly, as it declines by one percentage point to 47.1% in the case of a pension cut and increases by 1.6 percentage points in the case of increased debt (see Table 4.1).¹⁵ In summary, optimal capital income taxes increase strongly for an aging economy, whereas pension and debt policies have a relatively small quantitative impact.

¹⁵Our result that the optimal capital income tax rate increases with increased debt is in accordance with the findings of Conesa and Krueger (2009). These authors also find that, for sufficiently high negative public debt, the optimal capital income tax rate falls to zero.

5 Conclusion

The optimal tax rate on capital income is sensitive to the underlying production technology. We compare the standard Cobb–Douglas technology with the technology of Krusell et al. (2000), where capital is complementary to skilled work. We find that the optimal capital tax rate is significantly higher in the case of capital–skill complementarity and reaches 27% (versus 9% in the Cobb–Douglas case) in our benchmark economy of the US economy. Importantly, the optimal capital tax rate increases in an aging economy and is equal to 35% in the US by 2050. There are two properties of technology with skill–capital complementarity that account for these results. First, high capital taxes imply a significantly greater decline in the net interest rate under such technology than in the case of a Cobb–Douglas technology and, therefore, provoke a flatter life-cycle profile of labor. Second, with high capital taxes and low capital in production, the skill premium declines in the case of skill–capital complementarity. As a consequence, the distribution of income becomes more equal. Both effects are welfare-enhancing.

In conclusion, we highlight three directions for future research to extend and improve upon the assumptions of our model. First, we consider a variation of labor in response to fiscal policies along the intensive margin. Technological progress is very likely to affect labor along the extensive margin as well. Robots and automation may be perfect substitutes for workers. Second, we assume that capital deepening benefits mainly skilled workers by increasing the skill premium. One of the most dramatic underlying current trends in production technology, however, is the shift from unskilled to skilled worker replacement because of AI. As emphasized by Acemoglu and Restrepo (2018), the net impact of AI depends on the speed and magnitude of the displacement of old tasks versus the creation of new tasks. We expect the optimal capital tax rate to be sensitive to the nature and direction of technological change. Third, we neglect any effect the capital tax rate may have on the growth rate. High capital taxes, however, reduce the incentives to invest in research and human capital and may harm technological progress.

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Appendix

A Sensitivity Analysis

In this section, we study the sensitivity of the optimal capital tax rate to the growth rate g , the intertemporal elasticity of substitution IES , and income tax progressivity θ_1 . In particular, we conduct three experiments: 1) no growth ($g = 0$), 2) $\eta = 4.0$, and 3) a flat-rate income tax with $\theta_1 = 0$. All these experiments are likely to increase the optimal capital income tax rate, as we argue below. As experiments 1) and 3) are counterfactual assumptions, we keep the benchmark calibration presented in Table 3.1. In case 2, where the IES lies within the range of empirical estimates from microeconomic studies, we recalibrate the model. In particular, γ , α and μ are set to imply an average labor supply of 0.25, a skill premium of 150% and a labor share of 65%.

A.1 Growth rate

The economic growth rate is an important determinant of savings. In the presence of a public pay-as-you-go system, the incentives to save increase with a lower growth rate, $g = 0$, as the return from the pay-as-you-go system falls. As a consequence, savings are less sensitive to a change in the net real interest rate. This result also appears in our quantitative analysis, as presented in Table A.1. As the economic growth rate falls to zero, the optimal steady-state capital tax rate $\tau^{K,*}$ increases from 27.3% to 36.7%, whereas the quantitative welfare gains of a rise from the present level of 22.8% to the optimal level of 36.7% are rather small and amount to only 0.03% of total consumption.

Case	Optimal	Welfare effects	
	$\tau^{K,*}$	$\tau^{K,*}$	$\tau^K = 0$
Benchmark	27.3%	0.01%	-0.28%
no growth, $g = 0$	36.7%	0.03%	-0.10%
$\eta = 4$	38.9%	0.17%	-0.44%
flat income tax, $\theta_1 = 0$	37.8%	0.15%	-0.52%

Table A.1: Optimal capital tax $\tau^{K,*}$: Sensitivity analysis

When we interpret this finding and apply it for policy advice, we need to be careful,

however. First, we need to ascertain that the economy is dynamically efficient. A positive welfare effect of increased capital taxes arises trivially in an overlapping-generations model that is characterized by dynamic inefficiency, $\partial Y/\partial K - \delta < n + g + ng$. This condition, however, does not hold in any of the quantitative experiments considered in this paper and would be at odds with recent empirical evidence provided for the US economy estimated by Heylen et al. (2024). Second, we must remember that we assume that technological growth is exogenous. However, in models of endogenous growth, savings and, therefore, the investment rate may increase the growth rate, and the assumption that the growth rate is independent of the capital tax is not an innocuous simplification.

A.2 Intertemporal Elasticity of Consumption

With a reduced intertemporal elasticity of substitution, $1/\eta$, savings react less sensitively to a change in the net interest rate. Accordingly, the detrimental welfare effects of increased capital taxes are reduced, and the welfare-enhancing effects of compensatory lower labor income taxes increase in relation to these costs. As a consequence, it is optimal to tax capital at a higher rate. As presented in Table A.1, the optimal capital tax rate increases from 27.3% in the benchmark with $1/\eta = 1/2$ to 38.9% in the case with $1/\eta = 1/4$. In addition, the quantitative welfare gains are magnified. A decline in the capital income tax rate from its optimal level to zero is associated with a welfare loss of 0.61% of consumption, whereas the corresponding welfare costs in the benchmark case amount to only 0.29% of consumption.

A.3 Income Tax Progressivity

With a flat-rate income tax, $\theta_1 = 0$, the capital income tax is used as a substitute for the labor income tax to redistribute income from the rich to the poor. As a consequence, the optimal capital income tax rate increases from 27.3% to 37.8%. Note that, in this case, the welfare effects of a long-term change from the optimal capital tax rate to zero are also much greater than those in the benchmark case and amount to 0.67% of total consumption. We thus confirm the results of Conesa and Krueger (2009) that the optimal capital tax depends on the presence of progressive labor income taxes and is significantly higher in a flat-rate income tax regime.