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Endogenous Longevity and Optimal Tax Progressivity

Abstract

We study the impact of endogenous longevity on optimal tax progressivity and inequality in an overlapping generations model with skill heterogeneity. Higher tax progressivity decreases both the longevity gap and net income inequality, but at the expense of lower average lifetime and lower aggregate labor supply and income. We find that the welfare-maximizing income tax is less progressive than in the case of exogenous longevity and that the present US income tax should redistribute less. Our result is robust to the empirically observed range of labor supply elasticity and the assumptions of both missing annuity markets and tax deductibility of private health expenditures.

JEL-Codes: I140, J100, H210, H510, D310.

Keywords: health and inequality, demography, second-best, optimal taxation, personal income distribution, overlapping generations.

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1 Introduction

Many studies report large differences in longevity across socioeconomic characteristics such as income and education level (see, e.g., Sorlie and Keller (1995), Cristia (2009) and Pijoan-Mas and Ríos-Rull (2014)). Additionally, there is strong empirical evidence that medical expenditures increase longevity; Lantz et al. (1998), for example, report significant effects of income on mortality after controlling for various socioeconomic factors, while Martin et al. (2008) find that higher health expenditures reduce the mortality from cancer and circulatory disease. Moreover, Cremieux et al. (1999) show that health care spending decreases infant mortality and increases life expectancy, while Mays and Smith (2011) find a reduction in infant mortality and mortality related to heart disease, diabetes, and cancer through higher health expenditures.

The presence of endogenous longevity sheds new light on the importance of income redistribution by the government. Conventionally, economists argue in favor of income redistribution from rich to poor households because the latter are characterized by a higher marginal utility of consumption. If utility is concave in consumption, a redistribution of income increases average utility, ceteris paribus.

In the present study, we also analyze the role of income redistribution, emphasizing a new transmission channel of inequality. If longevity is endogenous and depends on the individual's income, a redistribution of income also helps to increase welfare by reducing the variance of longevity among individuals. Poorer households that benefit from higher transfers increase their savings and investment in health. As a consequence, they both work and live longer at the expense of the income-rich households that, in turn, decrease their savings and health spending. Since the health production function is very likely to be concave in private health spending in developed countries (see, e.g., Hall and Jones (2007) or Baltagi et al. (2012)), we would expect a stronger gain in the longevity of households with low income than the corresponding loss in longevity among households with high income. Therefore, redistribution from high- to low-income households increases both average lifetime and, hence, utility in partial equilibrium.

In general equilibrium, there are many effects on aggregate income and savings that may counteract the two aforementioned positive partial-equilibrium effects that result from the concavity of the utility and health production function. Since high-income households are characterized by higher productivity than low-income households, the reduction in labor supply and savings among the former is quantitatively more significant than the respective increases among the latter. As a consequence, aggregate labor and savings might decline, meaning that aggregate income also decreases. Therefore, the general equilibrium is likely to reduce both the lifetime and utility of all households, which may even outweigh the positive partial equilibrium that stems from the redistribution to the poor. Therefore, the optimality of redistribution in the presence of endogenous longevity can only be studied in a general-equilibrium model.

In the present study, we analyze the optimal second-best policy when the government can only redistribute among individuals with the help of a progressive labor income tax. In our simple two-period overlapping generations (OLG) model, households are heterogeneous with respect to labor productivity. We distinguish two types of workers, skilled and unskilled. In the first period of life, households work and choose their labor supply. They save for old age and purchase private health services that determine their health and longevity during old age. In old age, the agents simply consume their savings. We calibrate the model with respect to the characteristics of the US economy. As our main result, we find that the argument for redistributing income with the help of progressive income taxes is undermined due to endogenous longevity. Our result is also shown to be robust to a variety of sensitivity analyses, including the application of empirically observed values for the Frisch labor supply elasticity or the elasticity of longevity with respect to individual health. Moreover, our result also holds in the absence of annuity markets or when private health expenditures can be deducted from taxable income. In addition, we find that the present US income tax should be less progressive.

This paper contributes to the literature on the optimal income tax progressivity in general equilibrium. In this literature, reducing inequality increases average utility due to the concavity of the utility function. In addition, these studies introduce idiosyncratic wage risk against which progressive taxes also provide social insurance in the absence of perfect insurance markets. As one of the earliest studies in this area, Ventura (1999) considers the revenue-neutral tax reform in which a flat-rate income tax replaces the progressive income tax in the US economy. He finds that, although income becomes more concentrated, average utility is increased because the lower distortions on labor supply and savings outweigh the detriments from higher inequality. Conesa and Krueger (2006) consider a similar model of the US economy but also derive the optimal US progressive income tax schedule consisting of a linear tax of 17.2% with a fixed deductions of $9,400, which is much less progressive than the current US tax system. Krueger and Ludwig (2016) argue that the optimal progressivity of the income tax code might also be reduced in the presence of endogenous college education. In this case, redistribution should rely more heavily on education subsidies than on income transfers. If, as a consequence, more individuals attend college, the college wage premium falls in equilibrium, which constitutes a policy substitute for redistributive tax progressivity. Heathcote et al. (2017) develop a simple tractable model that combines all the channels mentioned above. In addition, they introduce a poverty trap constraint for low-income households that prevents them from investing in their skills. They find that optimal progressivity should be notably less than that in the current US tax system; in particular, the optimal average marginal tax rate should amount to 26%, while it is equal to 34% in the US economy. However, they also find their results to be sensitive to the consideration of the endogenous provision of public goods, higher aversion to inequality, or larger constraints on skill investment. None of these studies, however, considers endogenous longevity.

Our paper is organized as follows. In Section 2, we present our OLG model with heterogeneous agents (skilled and unskilled). The model is calibrated with respect to the characteristics of the US economy in Section 3. In Section 4, we derive our main results that optimal income tax progressivity is lower in the presence of endogenous longevity and below the present progressivity in the US economy. The sensitivity of these results is examined in Section 5. Section 6 concludes the paper. Mathematical derivations and additional sensitivity analyses are relegated to the Appendix.

2 Model

We consider a standard two-period OLG model augmented by endogenous survival and progressive (labor) income taxation. Households are heterogeneous in their labor productivity during working life and their assets in old age. We distinguish two productivity types, unskilled (L) and skilled (H).

2.1 Demographics

Let N_t denote the measure of young households in period t, which grows at the constant population growth rate n

$$N_t = (1+n)N_{t-1}. \tag{2.1}$$

In each generation, the shares of unskilled and skilled workers amount to ϕ and $1-\phi$, respectively.

2.2 Households

Households are heterogeneous in their labor productivity e^i with $i \in \{L, H\}$. The unskilled and skilled productivity types are meant to capture differences in education and abilities $e^L < e^H$.

The gross labor income of a working household with productivity level e^i in period t, y_t^i, is given by the product of its productivity e^i and labor supply l_t^i and the wage rate w_t:

$$y_t^i = e^i l_t^i w_t. \tag{2.2}$$

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

$$T(y_t^i) = y_t^i - \theta_{0,t}(y_t^i)^{1-\theta_1}, \tag{2.3}$$

implying a marginal income tax of

$$\tau(y_t^i) = 1 - (1-\theta_1)\,\theta_{0,t}(y_t^i)^{-\theta_1}. \tag{2.4}$$

The parameter θ_1 measures the (constant) degree of tax progressivity, while $\theta_{0,t}$ defines the tax level in period t. The tax system is progressive for $\theta_1 \in (0,1)$, regressive for $\theta_1 < 0$ and linear for $\theta_1 = 0$. Net income $\hat{y}_t^i$ is presented by

$$\hat{y}_t^i = \theta_{0,t}(y_t^i)^{1-\theta_1}. \tag{2.5}$$

The health state of an individual with productivity level e^i at the end of his or her first period, h_t^i, is endogenous and depends on private health expenditures x_t^i and public health expenditures per capita η_t:[1]

$$h_t^i = \left(x_t^i\right)^{\gamma} \left(\eta_t\right)^{1-\gamma}, \tag{2.6}$$

where γ describes the elasticity of the health state with respect to private health expenditures. In old age, the household does not invest privately in its health but only enjoys public health expenditures η_t.[2]

The survival probabilities of households are endogenous and depend on the household's health status h. The survival probability $\psi(h)$ at the end of an individual's youth follows a strictly increasing function satisfying

$$\psi(0) = \underline{\psi} \geq 0,\ \psi' > 0,\ \psi'' \leq 1, \tag{2.7}$$

with $\underline{\psi}$ describing the lower bound of the probability function. Following Chakraborty

[1] Fiorini (2010) presents empirical evidence that private and public health expenditures are substitutes in the health production function. In our sensitivity analysis in Appendix A.3, we consider a more general form of the health production function (CES function) but find our results to be robust to the degree of substitution elasticity.

[2] Since we are interested in the mechanism of endogenous longevity, we refrain from modeling the health expenditures of the elderly, e.g., on chronic and nonfatal diseases. Nevertheless, we consider the effects of a change in average longevity on aggregate public health expenditures.

and Das (2005), we model the survival probability function as follows:[3]

$$\psi(h_t^i) = \psi_0(h_t^i)^\varepsilon, \quad 0 < \epsilon \leq 1. \tag{2.8}$$

A young household with productivity level e^i maximizes expected lifetime utility U in period t

$$U(c_t^i, d_{t+1}^i, l_t^i, x_t^i) = u(c_t^i) + \beta\psi(h_t^i)u(d_{t+1}^i) - v(l_t^i), \tag{2.9}$$

where c_t^i and d_{t+1}^i denote consumption at young and old age of a household with productivity e^i in periods t and $t+1$, respectively, and $\beta > 0$ denotes the discount factor.

When young, households face a budget constraint equal to

$$c_t^i + x_t^i + a_t^i = \hat{y}_t^i, \tag{2.10}$$

with a_t^i describing savings.

The old household only receives income from savings. We assume perfect annuity markets without transaction costs.[4] Consequently, consumption of an old household with productivity e^i in period $t+1$ is described by[5]

$$d_{t+1}^i = \frac{(1 + r_{t+1})}{\psi(h_t^i)} a_t^i. \tag{2.11}$$

The first-order conditions of the utility maximization problem with respect to c_t^i, d_t^i, l_t^i and x_t^i are given by

$$\frac{v'(l_t^i)}{u'(c_t^i)} = (1 - \theta_1)\frac{\hat{y}_t^i}{l_t^i}, \tag{2.12a}$$

$$u'(c_t^i) = \beta(1 + r_{t+1})u'(d_{t+1}^i), \tag{2.12b}$$

$$\psi'(h_t^i)h'(x_t^i)u(d_{t+1}^i) = (1 + r)u'(d_{t+1}^i), \tag{2.12c}$$

[3]Bhattacharya and Qiao (2007) and Chakraborty (2004) also apply a survival probability function that is concave in health. Empirical evidence for this hypothesis is provided by Hall and Jones (2007) and Baltagi et al. (2012).

[4]We consider the absence of annuity markets in our sensitivity analysis in Section 5.

[5]Note our assumption that the financial intermediary can ascertain the health level of an individual with productivity e^i in period t, h_t^i, without any transaction costs.

where (2.12a) describes the tradeoff between consumption and leisure, (2.12b) is the Euler equation and (2.12c) describes the tradeoff between the quantity of life (longevity) and quality of life (old-age consumption).

We follow Dalgaard and Strulik (2014) and assume logarithmic instantaneous utility from consumption $u(c)$ (and analogous for $u(d)$) such that[6]

$$u(c) = b + \ln c, \tag{2.13}$$

where the constant term $b \geq 0$ ensures that utility from consumption always takes a positive value, as discussed by Hall and Jones (2007) and Dalgaard and Strulik (2014).[7] Disutility from labor $v(l)$ is specified as

$$v(l) = \nu_0 \frac{(l)^{1+\frac{1}{\nu_1}}}{1+\frac{1}{\nu_1}}, \tag{2.14}$$

where $\nu_1 > 0$ represents the Frisch elasticity of labor supply and $\nu_0 > 0$ measures the disutility level of work effort.

2.3 Government

The government uses the tax revenues from labor income to finance public consumption G_t and public health expenditures X_t^{pub}. The government budget balances in every period t:

$$\phi N_t T(y_t^L) + (1-\phi) N_t T(y_t^H) = G_t + X_t^{pub}. \tag{2.15}$$

Total public health expenditures are equal to the sum of health expenditures on all young and old households:

$$X_t^{pub} = N_t \eta_t + N_{t-1} \left[\phi \psi(h_{t-1}^L) + (1-\phi)\psi(h_{t-1}^H) \right] \eta_t. \tag{2.16}$$

[6]Logarithmic utility finds empirical support from Chetty (2006), who presents estimates of the intertemporal elasticities of substitution (IES) close to 1. Furthermore, Browning et al. (1999) argue that if constancy of IES across the population is imposed, there is no strong evidence against its absolute value being slightly above one.

[7]If c is sufficiently small, $u(c) < 0$. Therefore, in the case of $b = 0$, a household would be better off if not alive in the second period of life since utility from being dead is zero (see, e.g., Rosen (1988)).

2.4 Production

Production Y_t is characterized by constant returns to scale in aggregate capital K_t and labor supply L_t and specified as a Cobb-Douglas function:

$$Y_t = AK_t^{\alpha} L_t^{1-\alpha}, \tag{2.17}$$

where α is the production elasticity of capital. Aggregate labor supply L_t comprises skilled and unskilled labor supply:

$$L_t = (\phi N_t)e^L l_t^L + ((1-\phi)N_t)e^H l_t^H. \tag{2.18}$$

Goods and factor markets are competitive such that input factors are rewarded with their marginal products:

$$w_t = (1-\alpha)AL_t^{-\alpha} K_t^{\alpha}, \tag{2.19a}$$

$$r_t = \alpha AL_t^{1-\alpha} K_t^{\alpha-1} - \delta, \tag{2.19b}$$

where δ denotes the depreciation rate.

2.5 Competitive equilibrium

Let X_t, C_t, and I_t denote aggregate private health expenditures, aggregate consumption (of both the young and the old agents), and aggregate investment. To express the competitive equilibrium in terms of stationary variables, we need to divide all aggregate variables $\{Y_t, K_t, L_t, X_t^{pub}, X_t, C_t, I_t\}$ by the number of young agents, N_t, and denote them by a tilde, e.g., $\tilde{Y} \equiv Y_t/N_t$.

Given the government policy $(\tilde{X}_t^{pub}, \tilde{G}_t, \theta_1)_{t=0}^{\infty}$, the initial capital stock $\tilde{K}_0$ and the initial distribution of the health status among the young households, (h_0^L, h_0^H), a stationary competitive equilibrium for our economy is a tax level $\theta_{0,t}$, factor prices w_t and r_t, individual decision rules c_t^i, d_{t+1}^i, x_t^i, a_t^i, and l_t^i for $i \in \{L, H\}$, and aggregate quantities $(\tilde{Y}_t, \tilde{K}_t, \tilde{L}_t, \tilde{X}_t^{pub}, \tilde{X}_t, \tilde{C}_t, \tilde{I}_t)$ in periods $t = 1, \ldots$ such that the following hold.

1. Aggregate variables are equal to the sum of individual variables:

$$\tilde{X}_t = \phi x_t^L + (1-\phi) x_t^H, \tag{2.20a}$$

$$\tilde{C}_t = \phi c_t^L + (1-\phi) c_t^H + \frac{1}{1+n}\left[\phi\psi(h_{t-1}^L) d_t^L + (1-\phi)\psi(h_{t-1}^H) d_t^H\right], \tag{2.20b}$$

$$\tilde{L}_t = \phi e^L l_t^L + (1-\phi) e^H l_t^H, \tag{2.20c}$$

$$\tilde{X}_t^{pub} = \eta_t \left(1 + \frac{\phi\psi(h_{t-1}^L) + (1-\phi)\psi(h_{t-1}^H)}{1+n}\right). \tag{2.20d}$$

2. Households maximize expected intertemporal lifetime utility, implying the first-order conditions (2.12).

3. Firms maximize profits, implying the first-order conditions (2.19).

4. The government runs a balanced budget (2.15).

5. The capital market is in equilibrium, implying

$$(1+n)\tilde{K}_{t+1} = \left[\phi a_t^L + (1-\phi) a_t^H\right]. \tag{2.21}$$

6. The dynamics of the aggregate capital stock are described by

$$(1+n)\tilde{K}_{t+1} = \tilde{I}_t + (1-\delta)\tilde{K}_t. \tag{2.22}$$

7. The goods market equilibrium is depicted by

$$\tilde{Y}_t = \tilde{C}_t + \tilde{G}_t + \tilde{X}_t^{pub} + \tilde{X}_t + \tilde{I}_t. \tag{2.23}$$

In the following, we consider a steady state where stationary variables are constant. The conditions of the steady state are described in greater detail in Appendix A.1.

3 Calibration

We calibrate the model to match empirical characteristics of the US economy. Model periods correspond to 40 years in real life. Households start their working life at age 25 and retire at age 65. The maximum lifetime amounts to 104. Since we calibrate and analyze the model in steady state, the stationary variables are constant, so we can drop the period index t in the following.

In our calibration strategy, we distinguish three sets of parameters: 1) parameters $(\phi, n, \varepsilon, \gamma, \nu_1, \alpha, \delta, e^H, e^L, \theta_1, g_H, g_C)$, which we can observe directly, such as the capital share α; 2) parameters $(\psi_0, \beta, \nu_0, \theta_0)$, which we can calibrate to match one individual empirical observation, e.g., the utility parameter ν_0, implying an average labor supply equal to 0.3; and 3) parameters (A, b), which we choose jointly to match the following five empirical characteristics of the US economy as closely as possible:[8]

1. Annual real interest rate equal to $r - \delta = 4\%$,
2. Private consumption share in GDP equal to $(\tilde{C} + \tilde{X})/\tilde{Y} = 67\%$,
3. Total health share in GDP equal to $(\tilde{X} + \tilde{X}^{pub})/\tilde{Y} = 12\%$,
4. Public to total health spending equal to $\tilde{X}^{pub}/(\tilde{X} + \tilde{X}^{pub}) = 55\%$,
5. Longevity education gap (difference in life expectancy of the skilled and unskilled) equal to 4.8 years.

In the following, we will describe the parameters related to demographics and health, preferences, production, and the government in turn. The calibrated parameters are listed in Table 3.1.

[8]The data on the real interest rate and longevity gap are taken from the World Bank and Pijoan-Mas and Ríos-Rull (2014), respectively, while the other empirical estimates are provided by the OECD.

Description	Parameter	Value	Source/target
Demographics and health			
Group size	ϕ	0.5	CPS data
Population growth	n	0.55	United Nations (2015)
Elasticity of longevity	ε	0.20	Hall and Jones (2007)
Scaling parameter for longevity	ψ_0	0.776	life expectancy equal to 84.4
Elasticity of health status			
w.r.t. private health spendings	γ	0.5	Lichtenberg (2004)
Preferences			
Discount factor	β	0.3	annual discount rate of 3.0%
Frisch elasticity of labor supply	ν_1	0.25	MaCurdy (1981), Altonij (1986)
Weight of labor	ν_0	430	average labor supply of 0.30
	b	1.0	aggregate targets (1)-(5)
Production			
Capital share	α	0.3	empirical capital share
Depreciation rate	δ	1.00	full depreciation
Productivity	A	20	aggregate targets (1)-(5)
Skill premium	$\frac{e^H}{e^L}$	2.5	BLS data
Government			
Tax progressivity	θ_1	0.137	Brinca et al. (2016)
Weight of income tax	θ_0	0.929	average labor income tax of 28%
Public health spending to GDP	g_H	0.06	OECD data
Public consumption to GDP	g_C	0.15	OECD data

Table 3.1: Calibrated parameters

Demographics and health. We set the shares of the groups of skilled and unskilled households equal to 0.5, which is approximately equal to the average number of high school and college graduates during the period 1940-2019 as reported by the US Bureau of Labor Statistics.[9] In accordance with United Nations (2015), we assume an average annual population growth rate of 1.1%, implying a 40-year population growth rate $n = 0.55$.

With respect to the calibration of the survival probability function (2.8), we set the elasticity of longevity with respect to health status equal to the average of the empirical estimates for age groups 20-65 reported by Hall and Jones (2007), $\varepsilon = 0.20$. This value is also in accordance with the results of Baltagi et al. (2012), who report elasticities for males at age 65 ranging between 0.05 and 0.26.[10] The scaling parameter ψ_0 is chosen to match the average life expectancy at the beginning of model period 2 (corresponding to real-life age 65) with the life expectancy at age 65 reported by National Center for Health Statistics (2018), which amounts to 84.4 years for the years 2012-2017.

The empirical evidence with respect to the parameter γ of the health production function (2.6) is less clear-cut. There is vague evidence that the health production elasticity of public health expenditures, $1-\gamma$, is slightly higher than that of private expenditures, γ. Lichtenberg (2004) finds that public health expenditures have a higher marginal effect on longevity than private health expenditures. However, the difference is not statistically significant. Self and Grabowski (2003) find similar results for developed countries. Focusing on developing countries, Novignon et al. (2012) report a stronger correlation of health status with public health spending than with private health expenditure. Therefore, we use a benchmark value $\gamma = 0.50$ but provide a sensitivity analysis for $\gamma \in [0.3, 0.7]$ in Appendix A.3.[11]

[9] We set the relative numbers equal to the mean for households with high school degrees and those with more schooling as the highest level of education during this period. The data are taken from the CPS Historical Time Series Tables, Table A-1: Years of School Completed by People 25 Years and Over, by Age and Sex: Selected Years 1940-2019.

[10] Pestieau et al. (2008) use a slightly lower value of $\varepsilon = 0.1$.

[11] For logarithmic utility, we must restrict the calibration of ε and γ to $1 > (\varepsilon\gamma)$. Otherwise,

Preferences. We choose $\beta = 0.3$, which corresponds to an annual discount rate equal to 3%. The Frisch elasticity of labor supply, $\nu_1 = 0.25$, is chosen from the middle range of empirical estimates. MaCurdy (1981) and Altonij (1986), for example, report Frisch elasticities of 0.23 and 0.28, respectively. Moreover, we set ν_0 such that the average labor supply equals 0.30. The constant term b in the utility function (2.13) is set equal to unity. As a consequence, we ensure that, in our model, a longer life is consistent with both a positive marginal utility from health expenditures and positive utility from consumption at any level.

Production. As we consider a period length equal to 40 years, we assume that capital depreciates fully, implying $\delta = 1.0$. We set the capital share $\alpha = 0.3$. The productivity parameter $A = 20$ (together with the parameter b) is chosen to minimize the divergence of our model statistics from aggregate targets (1)-(5) above. We set the skill premium (e^H/e^L) equal to 2.5, as we find weekly hourly earnings of college graduates to be approximately 2.5 times higher than those of high school drop-outs.[12]

Government. We follow Brinca et al. (2016) and set the tax progressivity $\theta_1 = 0.137$ to replicate the average tax progressivity for US households.[13] We calibrate θ_0 such that the average labor tax rate is 28%, as reported by Mendoza et al. (1994) and Trabandt and Uhlig (2011). Finally, we assume that, in the benchmark case, public health expenditures and public consumption take fixed values relative to GDP

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consumption and health expenditures become luxury goods, as shown by Chakraborty and Das (2005) and Bhattacharya and Qiao (2007). Moreover, Bhattacharya and Qiao (2007) show that $1 > (\varepsilon\gamma)$ provides a unique solution of the household's problem with logarithmic utility.

[12]To construct the skill premium, we use data from the U.S. Bureau of Labor Statistics on median weekly earnings of those aged 25 years and older for workers with less than a high school diploma (LEU0252916700) on the one hand and those with a bachelor's degree or higher (LEU0252918500) on the other hand. The skill premium has remained relatively stable at approximately 2.5 since 1994. However, we are aware of the increasing trend prior to 1994.

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

described by $\tilde{X}_t^{pub} = g_H \tilde{Y}_t$ and $\tilde{G}_t = g_C \tilde{Y}_t$, respectively. We set the shares of public health expenditures and government consumption to GDP, g_H and g_C, equal to their mean values between 1970 and 2018 amounting to 6% and 15%, respectively.

Description	**Value**	**Target**	**Data source**
1. Real interest rate p.a. $r - \delta$	4.2%	4.0%	World Bank data
2. Private consumption share $\frac{C+X}{Y}$	72%	67%	OECD data
3. Total health share to GDP	8.3%	12.0%	OECD data
4. Public to total health spending	72%	55%	OECD data
5. Longevity education gap	2.77 yrs	4.8 yrs	Pijoan-Mas and Ríos-Rull (2014)

Table 3.2: Calibration fit

Aggregate targets. In Table 3.2, we present the macroaggregates implied by the calibration of the benchmark case and compare them to our target values. In general, we are able to provide a close fit to our targets with some minor exceptions. 1) We are able to closely match our (annualized) real interest rate of 4.0% (third column). In our model, the value reported in the second column is equal to 4.2%. 2) The share of private consumption in GDP in our model (72%) is also in good accordance with the empirical value in the US economy (67%). Our model slightly overstates the empirical value, as we count all health expenditures as consumption rather than, at least in part, investment expenditures. 3) The longevity gap of the two educational groups is lower in our model than empirically, 2.8 years versus 4.8 years. Therefore, we understate the longevity gap by approximately half. However, our model assumes that longevity depends only on income and education, whereas in reality, other sources also affect longevity, such as health behavior, marital status, or simply genes, as emphasized by Pijoan-Mas and Ríos-Rull (2014). Since we omit these other causes, we end up with a relatively small longevity gap. 4) Our total health share is slightly below the target value (8.3% versus 12.0%), whereas 5) the ratio of public to total health spending is above the mean value during 1970-2018 (72% versus 55%). However, note that our latter value of 72% is in close accordance with the values observed after the introduction of Obamacare in 2014. As a consequence of Obamacare, the ratio of public to total health expenditures rose from approximately 48% (during 2009-2013) to approximately 84% (during 2014-2018) according to the OECD.

4 Results

In this section, we present our steady-state results for a variation of the progressivity parameter θ_1 of the labor income tax rate schedule. When progressivity θ_1 increases, the government has to adjust the steady-state tax level θ_0 to finance constant government expenditures on public consumption and health, $\tilde{G}$ and $\tilde{X}^{pub}$. First, we examine the general equilibrium effects on the individual and aggregate variables before we study the optimal tax schedule for the two cases of endogenous and exogenous longevity.

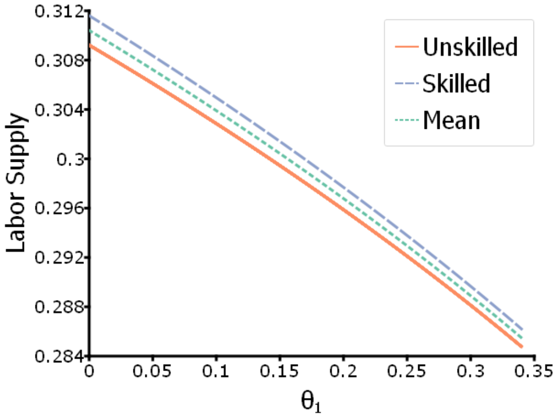
4.1 General equilibrium effects of tax progressivity

Fig. 4.1 presents the behavior of the individual variables for a variation of the tax parameter θ_1 over the interval $[0, 0.34]$. From upper left to the lower right, the figure displays the steady-state values of the labor supply l^i, marginal tax rate $\tau(y^i)$, net income $\hat{y}^i$, savings a^i, private health expenditures x^i, and life expectancy in years, $40(1+\psi^i)$, for the unskilled with $i = L$ (solid red line), skilled with $i = H$ (broken blue line), and the average worker (dotted green line). $\psi^i \equiv \psi(h^i)$ denotes the steady-state survival probability of the household with productivity e^i, $i \in \{L, H\}$.

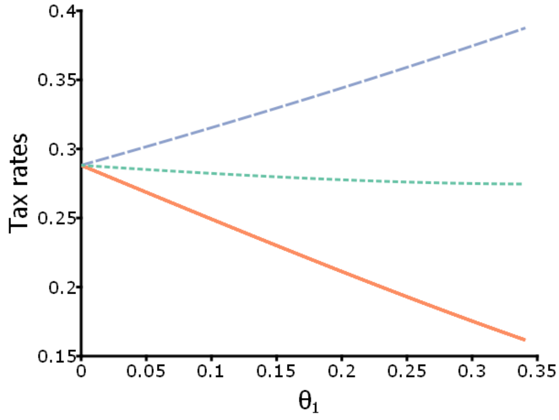
When the government increases tax progressivity θ_1, all households decrease their individual labor supply, as displayed in the upper-left panel in Fig. 4.1. The labor supply of both the unskilled (solid red line) and the skilled (broken blue line) are downward sloping. As a consequence, the average labor supply (dotted green line) also falls. Note that the skilled provide a higher labor supply than the unskilled because the substitution effect of a higher hourly net wage rate, $\theta_0(e^H w)^{1-\theta_1}/(l^H)^{\theta_1} > \theta_0(e^L w)^{1-\theta_1}/(l^L)^{\theta_1}$, outweighs the income effect for our choice of the utility function.[14]

[14]This property of our model is in accordance with empirical observations for the US economy.

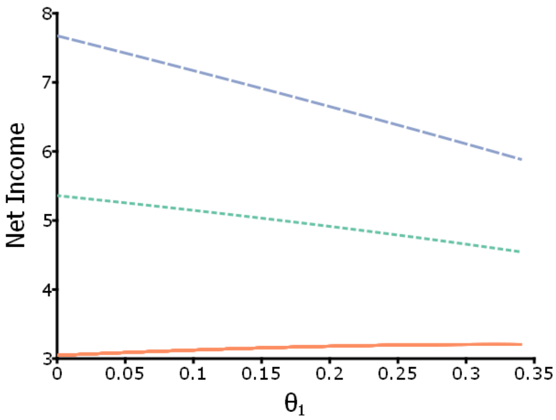
Figure 4.1: Steady-state effects of tax progressivity θ_1



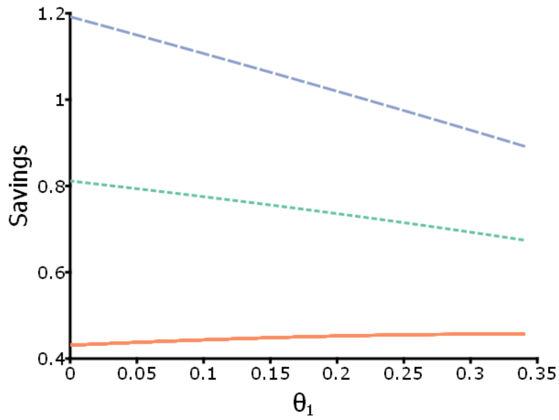
(a) Labor supply



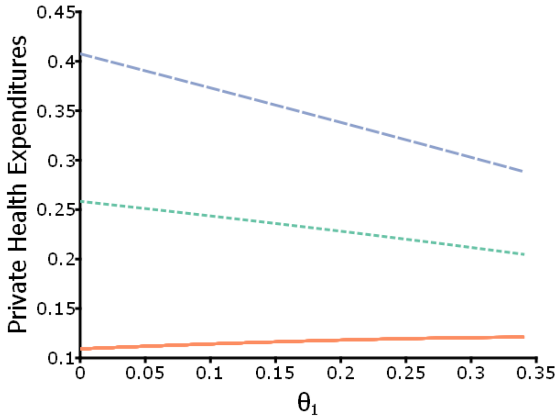
(b) Marginal tax rate



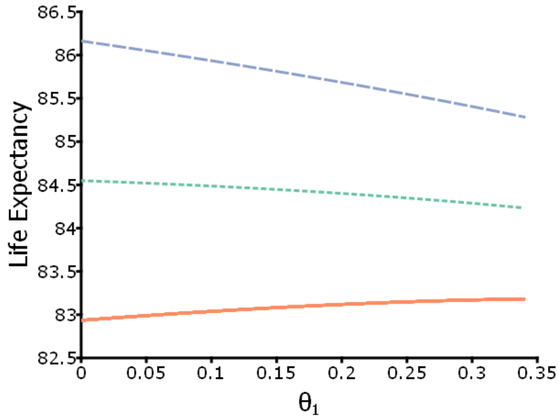
(c) Net Income



(d) Savings



(e) Private health expenditures



(f) Life expectancy

To balance its budget, the government has to adjust the tax level parameter θ_0 in response to the change in the progressivity parameter θ_1 and, hence, lower aggregate labor supply. In particular, θ_0 increases with θ_1 for our calibration.[15] Therefore, as depicted in the upper-right panel of Fig. 4.1, marginal taxes increase (decrease) for the skilled (unskilled) worker.

While the net income of the skilled, $\hat{y}^H$, unanimously falls with higher tax progressivity θ_1, the net income of the unskilled, $\hat{y}^L$, increases with θ_1 because the effect of lower average income taxes dominates the effect from lower labor supply. Consequently, (net) income inequality falls with higher tax progressivity θ_1, as depicted in the middle-left panel of Fig. 4.1. Since the households allocate their net income to consumption c^i (not presented), savings a^i, and private health expenditures x^i, $i \in \{L, H\}$, all three budget components mirror the behavior of the respective net income of the unskilled and skilled workers. For example, private health expenditures x^i increase for unskilled workers but decrease for skilled workers. Therefore, we find that the longevity gap declines from 3.3 years under proportional taxation (with $\theta_1 = 0$) to 2.5 years with tax progressivity $\theta_1 = 0.34$.

As the distortion of the labor supply increases with θ_1, aggregate income and, hence,

---

Blundell et al. (2018) find a significant difference in both male and female employment at the intensive margin across skill groups. According to their Fig. 4, for example, men aged 25-55 with college, high school, and no high school worked approximately 45, 43, and 41 hours per week on average during the period 1978-2007.

[15] In Appendix A.1, we present a graphical exposition of the behavior of additional variables in response to a change in θ_1, including θ_0. There, we show that θ_0 has to increase so that the government budget balances. There are two effects on tax revenue from a higher θ_1. First, skilled workers have to pay higher average taxes than unskilled workers. Since their income is higher than that of the unskilled, tax revenue increases. For this reason, θ_0 can be increased. Second, in general equilibrium, aggregate capital will also fall, and thus total production $\tilde{Y}$ and, therefore, aggregate labor income, $(1-\alpha)\tilde{Y}$, declines even further. For this reason, θ_0 needs to be decreased to keep tax revenue constant. The net effect of these two effects on θ_0 is positive, and hence θ_0 increases with θ_1. To keep the exposition as concise as possible, we only present the most important variables in this section and refer the interested reader to the Appendix A.1.

aggregate private health spending $\tilde{X}$ decline, so the average life expectancy in the economy falls with higher θ_1 (see the dotted green line in the lower-right panel of Fig. 4.1).[16] Therefore, we conclude as our first main result that the decline in both the longevity gap and inequality comes at the expense of a lower average lifetime and lower average disposable income. Accordingly, the general equilibrium effect outweighs the partial equilibrium effect on longevity, where the latter derives from the concave nature of the health production function.

4.2 Optimal income tax progressivity

In this subsection, we study optimal tax progressivity for income-neutral tax reform. Therefore, we search for the optimal policy (θ_0, θ_1) where we vary the progressivity θ_1 and adjust θ_0 such that the fiscal budget (2.15) remains balanced. Public expenditures on government consumption $\tilde{G}$ and health expenditures $\tilde{X}^{pub}$ are kept constant at the benchmark level. We distinguish the two cases of endogenous lifetime, which is our benchmark model with endogenous individual health status h^i, $i \in \{L, H\}$, from Section 2, and exogenous lifetime where we keep expenditures on private and public per capita health spending and, therefore, the survival probability ψ^i, $i \in \{L, H\}$, constant.

Welfare is measured by the average lifetime utility of newborns.[17] Notice that we distinguish four different types of households, skilled and unskilled on the one hand and households that live one or two periods on the other hand. The four types are characterized by an endogenous distribution function over the four types, $(\phi\psi^L, \phi(1-\psi^L), (1-\phi)\psi^H, (1-\phi)(1-\psi^H))$. To compare different tax policies (θ_0, θ_1), we compute

[16] However, there is a counteracting subordinate general equilibrium effect on average life expectancy. If life expectancy falls, public health spending per capita η increases (for a given $\tilde{X}^{pub}$). See also Fig. A.1 in Appendix A.1 for the response of η to a change in θ_1. Since this is a second-order effect, average life expectancy nevertheless falls with θ_1.

[17] In Appendix A.2, we consider a decomposition analysis of ex post welfare effects for the individual types of households.

the consumption equivalent change (CEC) in comparison with the benchmark calibration $\theta_1 = 0.137$, i.e., the percentage change in total consumption that makes the average newborn under $\theta_1 = 0.137$ indifferent with respect to the allocation prevailing after a change to the new tax progressivity θ_1.

Endogenous longevity. In the case of endogenous individual health expenditures x^i and, hence, survival probability ψ^i, $i \in \{L, H\}$, we find that the optimal degree of progressivity amounts to $\theta_1^* = 0.0642$, which is considerably lower than the present value in the United States, $\theta_1 = 0.137$. Due to the lower degree of progressivity, labor supply increases for both groups such that total production increases by 2.25% relative to the benchmark calibration. The labor income tax rate of unskilled workers increases from 23.50% to 26.31%, while it decreases from 32.58% to 30.55% for skilled workers. As the drop in taxes from skilled workers is quantitatively larger than the increase in taxes from unskilled workers, the government has to increase average labor income taxes from 28.04% to 28.43% to balance the budget. Therefore, the net income of an unskilled worker, $\hat{y}^L$, decreases by 1.56%, while that of a skilled worker, $\hat{y}^H$, increases by 5.34%. Due to the lower tax progressivity, income inequality increases for both net and gross income.[18] The Gini coefficients of net (gross) income increase from 0.197 (0.249) to 0.212 (0.252) in our model.[19] With higher inequality of net income, unskilled households also decrease their private health expenditures relative to those of skilled workers, and hence the longevity gap increases from 2.77 years to 3.02 years. Table 4.1 summarizes our results.

[18] We define income as the sum of labor and interest income.

[19] For the United States, Budría Rodríguez et al. (2002) find a Gini coefficient of gross income equal to 0.553. Our simple 2-period life-cycle model is unable to match the empirical Gini coefficient of income, as we do not consider age-dependent productivity, the skewness of the income distribution (in particular, the top percentile), or self-employment, among other factors.

	Benchmark		Endogenous longevity		Exogenous longevity	
θ_1	0.137		$\theta_1^* = 0.0642$		$\theta_1^* = 0.0806$	
Aggregates and averages						
$\tilde{Y}$	10.333		10.565		10.503	
$\bar{\tau}$	28.04%		28.43%		28.37%	
Longevity gap	2.77 yrs		3.02 yrs		2.77 yrs	
CEC^{agg}			+0.19%		+0.11%	
Gini coefficients						
Net income	0.197		0.212		0.209	
Gross income	0.249		0.252		0.251	
Individual variables						
i	L	H	L	H	L	H
$\hat{y}^i$	3.147	6.979	3.098	7.352	3.108	7.257
l^i	0.300	0.302	0.305	0.307	0.304	0.306
τ^i	23.50%	32.58%	26.31%	30.55%	25.71%	31.03%
CEC^i			-3.22%	+3.65%	-2.59%	+ 2.85%

Table 4.1: Optimal tax policies θ_1^* and steady-state allocation

Aggregate welfare increases by 0.19% of total consumption if tax progressivity decreases from $\theta_1 = 0.137$ to $\theta_1^* = 0.0642$. The increase in aggregate welfare is caused by the general equilibrium effects, which overcompensate for the partial equilibrium effect on welfare from the redistribution of income from the poor (the unskilled) to the rich (the skilled). Per capita production $\tilde{Y}$ increases by 2.2%, from 10.333 to 10.565, and thus total consumption also increases. However, not all types of households benefit from tax policy θ_1^*. The expected lifetime utility of unskilled households decreases by 3.22% of consumption, while it increases by 3.65% of consumption for skilled households.

Exogenous longevity. To isolate the impact of endogenous longevity, we study the model of Section 2 for comparison but under the assumption of exogenous longevity.

For this reason, we keep private health expenditures x^i and, hence, the survival probabilities ψ^i constant at the benchmark level for both skill groups $i \in \{L, H\}$. We find that optimal tax progressivity θ_1^* amounts to 0.0806 in this case and, again, is much lower than the calibrated value $\theta_1 = 0.137$ in the benchmark case. In addition, we derive as our main result of this study that optimal progressivity with exogenous longevity is higher than in the case with endogenous longevity. The explanation for this observation is straightforward. Although higher progressivity in the case of endogenous longevity reduces the private health spending of the poor due to the reduced redistribution – the poor workers are characterized by a larger marginal product of health production with respect to private health spending due to the concavity of the health production function (2.16) – welfare nevertheless continues to increase for values of the progressivity parameter θ_1 below 0.0806 because the general equilibrium effect of higher average income increases average private health expenditures and, therefore, aggregate welfare.

The equilibrium effects of higher income tax progressivity θ_1 under exogenous longevity are similar to those under endogenous longevity and are presented in the two rightmost columns of Table 4.1. Due to a higher θ_1, the individual labor supply of both skilled and unskilled workers increases such that per capita production $\tilde{Y}$ rises from 10.333 to 10.503. The welfare effect of the optimal tax policy amounts to only 0.11% of total consumption and is smaller than in the case of endogenous longevity. Similarly, inequality as measured by the Gini coefficient of gross (and net) income increases, albeit by less than under endogenous longevity. Of course, since we assume exogenous longevity, the longevity gap remains unchanged at 2.77 years.

5 Sensitivity analysis

In this section, we study the sensitivity of our two results: 1) the optimal progressivity of the US income tax system is below the present value, and 2) the optimal progressivity is lower in the case of endogenous longevity than in the case of exogenous longevity. First, we analyze the parameterization of the model with respect to two sensitive parameters: i) the Frisch labor supply elasticity ν_1 and ii) the elasticity of the survival probability with respect to the health status ε. The empirical estimates for these parameters vary over a relatively large interval. Second, we analyze the sensitivity of our results to the variation of two model assumptions: i) the absence of perfect annuity markets, which introduces accidental bequests into our model, and ii) the tax deductibility of private health spending. Additional sensitivity analysis with respect to the specification and parameterization of the health production function is presented in Appendix A.3.

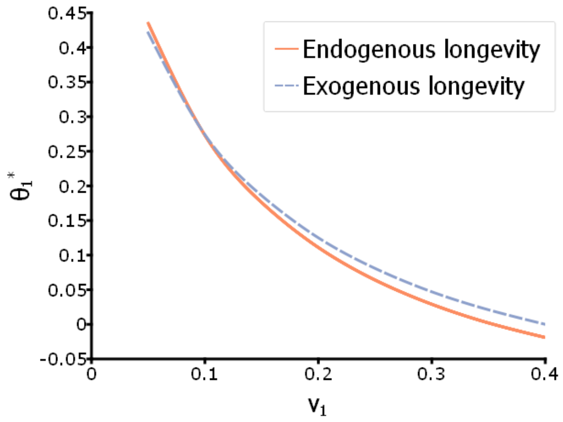
5.1 Parameterization

Frisch elasticity of labor supply, ν_1. The tradeoff between higher income redistribution and tax distortions on welfare depends critically on the reaction of the individual labor supplies l^i to higher marginal tax rates τ^i, $\in \{L, H\}$, which is described by the Frisch elasticity of labor supply, ν_1. In our benchmark calibration, we applied the value $\nu_1 = 0.25$. Estimates of ν_1 implied by microeconometric studies vary considerably. MaCurdy (1981) and Altonij (1986) both use PSID data to estimate values of 0.23 and 0.28, respectively, while Killingsworth (1983) finds a US labor supply elasticity equal to $\nu_1 = 0.4$. Domeij and Floden (2006) argue that these estimates are biased downward due to the omission of borrowing constraints. In macroeconomic studies such as Trabandt and Uhlig (2011), a value of unity is often chosen to account for the effects of higher wages on labor along both the intensive and extensive margins.

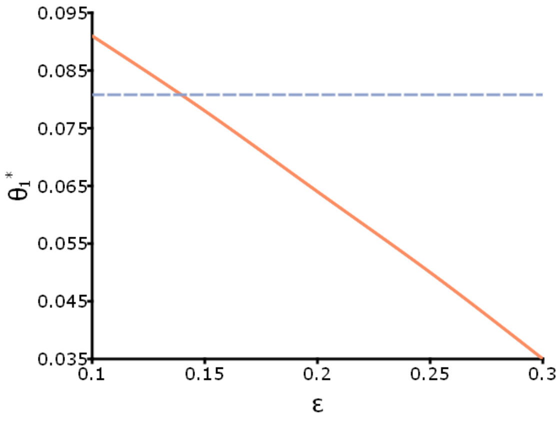
The left-hand side of Fig. 5.1 describes the effect of ν_1 on the optimal tax progressivity θ_1^* for different values of $\varepsilon \in \{0.2, 0.1, 0.25\}$, the elasticity of the survival probability with respect to health status.[20] In the top-left panel of Fig. 5.1, the benchmark value of $\varepsilon = 0.20$ is depicted. Evidently, the optimal progressivity decreases with higher labor supply elasticity ν_1. For empirically plausible values close to $\nu_1 = 0.40$, the optimal labor income tax rate is even found to be proportional with $\theta_1^* = 0$. This result holds

[20]For each value of ν_1, we recalibrated the model. In particular, ν_0 was set to imply an equilibrium labor supply of 0.30, among other changes. The goodness of fit is reported in Appendix A.3

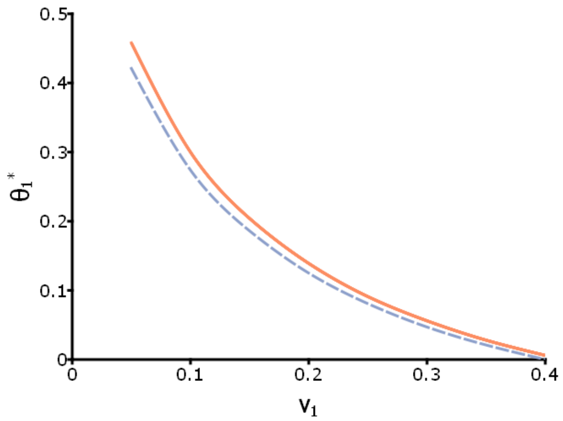
Figure 5.1: Sensitivity of optimal tax progressivity θ_1^* to variations of ν_1 and ε



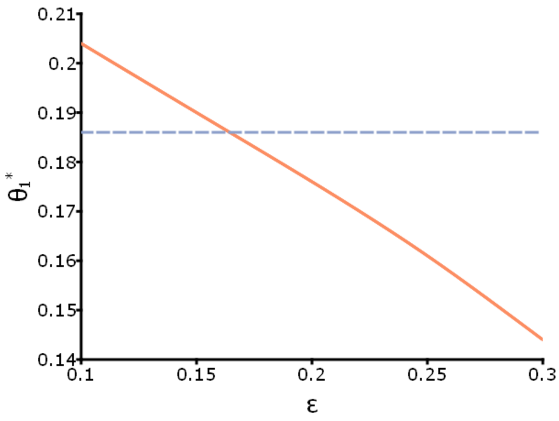
(a) Variation of ν_1, given $\varepsilon = 0.2$



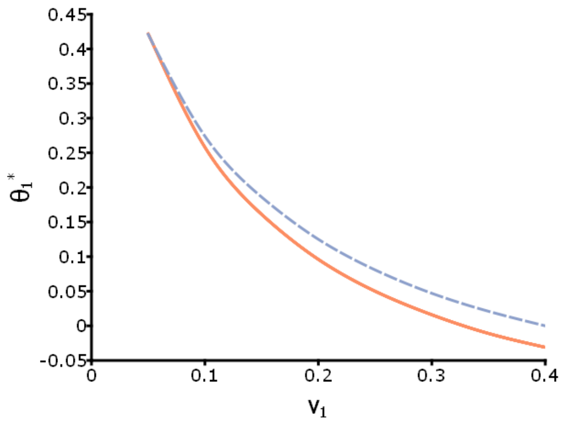
(b) Variation of ε, given $\nu_1 = 0.25$



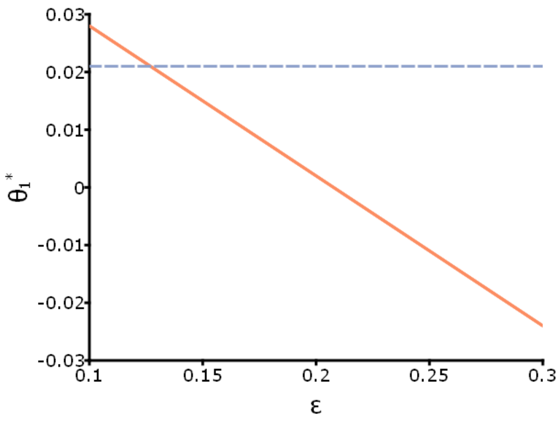
(c) Variation of ν_1, given $\varepsilon = 0.1$



(d) Variation of ε, given $\nu_1 = 0.15$



(e) Variation of ν_1, given $\varepsilon = 0.25$



(f) Variation of ε, given $\nu_1 = 0.35$

unanimously for the different values $\varepsilon \in \{0.2, 0.1, 0.25\}$.

For $\nu_1 = 0.30$, the optimal tax progressivity θ_1^* amounts to 0.0294 and 0.0470 in the cases of endogenous and exogenous lifetimes, respectively, as reported in Table 5.1. Associated with these optimal progressivity values θ_1^*, we find welfare gains in the amount of 0.44% and 0.31% of total consumption (see the number in parentheses below the entries for θ_1^* in Table 5.1), respectively.

In addition, we find that for a given $\varepsilon = 0.20$, the break-even point between the optimal tax progressivity in the two cases of endogenous and exogenous longevity lies at $\nu_1 = 0.0936$, as shown in panel (a) of Fig. 5.1. Below this value of the Frisch labor supply elasticity, the effect that stems from the concavity of the health production function dominates the general equilibrium effect of higher average private health expenditures, and thus θ_1^* is higher with endogenous longevity. However, this value of ν_1 is far below any empirically reported value for the Frisch elasticity. Therefore, our second result is also found to be robust to the empirically observed values of ν_1.

	Longevity	
	Endogenous	**Exogenous**
Benchmark	0.0642	0.0806
	(0.19)	(0.11)
Model parameters		
$\nu_1 = 0.3$	0.0294	0.0470
	(0.44)	(0.31)
$\varepsilon = 0.15$	0.0780	0.0806
	(0.12)	(0.11)
Model assumptions		
Accidental bequests	0.0543	0.0617
	(0.23)	(0.19)
x_t^i is tax deductible	0.0318	0.0425
	(0.42)	(0.31)

Table 5.1: Sensitivity analysis of optimal progressivity θ_1^* (CEC in percentage points in parentheses)

Longevity function $\psi(h)$. The channel of transmission from tax policy and redistribution to the equilibrium allocation and, hence, welfare also depends on the elasticity ε of the survival probability $\psi(h)$ with respect to the health status h. The economic mechanism is as follows. A rise in progressivity θ_1 decreases net income inequality ceteris paribus. As a consequence, unskilled (skilled) workers increase (decrease) their private health expenditures x^i, $i \in \{L, H\}$, such that health status h^i increases (decreases) for unskilled (skilled) workers. With a higher elasticity ε, the longevity gap decreases to a larger extent.[21] The effect on welfare, however, is not straightforward. On the one hand, average lifetime increases because of the concavity of the longevity

[21] Again, we recalibrated our model for each value of the parameter ε. In particular, we adjusted ψ_0 to imply a life expectancy of 84.4 years at age 65 for the benchmark progressivity $\theta_1 = 0.137$.

function $\psi(h)$, and therefore, aggregate lifetime utility increases (recall that we calibrated the utility parameter b such that a longer lifetime also results in higher utility). On the other hand, the instantaneous utility of skilled workers in old age is higher than that of unskilled workers, as the former enjoy higher old-age consumption $d^H > d^L$. If higher income tax progressivity reduces the number of old-age workers with high utility relative to those with low utility, aggregate welfare decreases. In addition, we also observe general equilibrium effects that reinforce the negative effect of higher progressivity on welfare. If the expected lifetime of skilled (unskilled) workers decreases (increases), they reduce (increase) savings a^H (a^L). Since the savings of the skilled are much larger than those of the unskilled, total savings and, hence, the capital stock decreases. As a consequence, total production and consumption also decline, which further depresses average lifetime utility.

We find that the negative welfare effects of higher income tax progressivity unanimously increase with elasticity ε. The top-right panel of Fig. 5.1 describes the effect of ε on the optimal tax progressivity θ_1^* for the benchmark calibration with a Frisch labor supply elasticity $\nu_1 = 0.25$. For empirically reasonable values $\varepsilon \in [0.1, 0.3]$, θ_1^* decreases with increasing ε. Over the whole range of ε, optimal tax progressivity is considerably lower than the present value in the United States (amounting to 0.137). For $\varepsilon = 0.15$, for example, the optimal tax progressivity amounts to $\theta_1^* = 0.0780$ with a corresponding welfare gain of 0.12% of total consumption (see also Table 5.1). Of course, if we consider exogenous longevity, the optimal tax progressivity is constant at $\theta_1^* = 0.0806$. For a given $\nu_1 = 0.25$, we find that endogenous longevity results in lower optimal progressivity (our second main result) as long as $\varepsilon \geq 0.1403$ holds.

In panels (d) and (f) of Fig. 5.1, we consider the effects of ε on optimal progressivity θ_1^* for the Frisch labor supply elasticities 0.15 and 0.35, respectively. The optimal progressivity θ_1^* continues to decrease with higher ε. For the low value $\nu_1 = 0.15$, we find that endogenous longevity implies lower optimal tax progressivity than exogenous longevity (our second result) if $\varepsilon \geq 0.1643$; if we set $\nu_1 = 0.35$, we find that this threshold decreases to $\varepsilon \geq 0.1269$. Thus, the higher ν_1 is, the lower the threshold of ε below which our second finding is reversed. We summarize the results of our sensitivity analysis with respect to the two parameters ν_1 and ε by the observations that our first main result continues to hold for empirically observed values of the Frisch labor supply elasticity, $\nu_1 \geq 0.25$, and that our second main result continues to hold if longevity is sufficiently elastic with respect to health.

5.2 Specification of the model

Accidental bequests. In our benchmark model, we assumed perfect annuity markets. In particular, the financial agents were able to ascertain the type of the worker (skilled and unskilled) and their survival probabilities and to provide annuities without any transaction costs. In the following, we assume instead that annuity markets are absent. Households leave behind accidental bequests that are redistributed among all survivors of the same skill group $i \in \{L, H\}$.[22] The budget constraint of young households (2.10) changes to

$$c_t^i + x_t^i + a_t^i = \hat{y}_t^i + tr_t^i, \tag{5.1}$$

and that of old households (2.11) to

$$d_{t+1}^i = (1 + r_{t+1})a_t^i + tr_t^i. \tag{5.2}$$

Transfers are equal to accidental bequests in each skill group $i \in \{L, H\}$:

$$tr_t^i = \frac{1 - \psi_{t-1}^i}{1 + n + \psi_{t-1}^i} a_{t-1}^i (1 + r_t). \tag{5.3}$$

The first-order conditions (2.12a)-(2.12c) become

$$\frac{v'(l_t^i)}{u'(c_t^i)} = (1 - \theta_1)\frac{\hat{y}_t^i}{l_t^i} \tag{5.4a}$$

$$u'(c_t^i) = \beta\psi(h_t^i)(1 + r_{t+1})u'(d_{t+1}^i) \tag{5.4b}$$

$$\frac{\psi'(h_t^i)}{\psi(h_t^i)} h'(x_t^i)u(d_{t+1}^i) = (1 + r)u'(d_{t+1}^i). \tag{5.4c}$$

[22] Wolff and Gittleman (2014) provide evidence that households with high income inherit considerably more than those with low income. The same difference appears when comparing skill levels. Therefore, we refrain from lump-sum distribution of bequests across all households.

As presented in Table 5.1, optimal tax progressivity θ_1^* decreases slightly in the absence of annuities markets, from 0.0642 to 0.0543 in the case of endogenous longevity and from 0.0806 to 0.617 in the case of exogenous longevity. The reason for the lower optimal values of tax progressivity than in the case with perfect annuity markets can be explained with the help of the reaction of aggregate savings in the two cases. Notice first that skilled workers contribute a larger share to aggregate savings than unskilled workers. With perfect annuity markets, the real interest rate on household savings amounts to $(1 + r)/\psi^i - 1$, $i \in \{L, H\}$, while it falls to r in the case of imperfect financial markets. Accordingly, if tax progressivity θ_1 increases and the survival probability of skilled (unskilled) workers declines (rises), the real return increases (decreases) for the skilled (unskilled) workers in the case of perfect annuity markets, ceteris paribus. As a consequence, skilled workers who contribute a larger share to aggregate savings have a higher incentive to accumulate savings, and vice versa, unskilled workers who only contribute a small share to aggregate savings have a smaller incentive to accumulate savings in the case of perfect annuity markets (than in the case lacking annuity markets). For this reason, higher tax progressivity in the case of perfect annuity markets is associated with larger savings (and, hence, income) than in the case of imperfect capital markets, and therefore, optimal tax progressivity is also higher in that case. The welfare effects of a fiscal policy that implements the optimal tax progressivity θ_1^* amounts to 0.23% (under endogenous longevity) and 0.19% (under exogenous longevity) of total consumption. In sum, our two main results are found to be robust to the assumption of (im)perfect annuity markets.

Tax deductibility of private health expenditures. The US tax system allows for the deductibility of private health expenditures from total taxable income. Following Heathcote et al. (2017), we allow private health expenditures to be tax deductible in the following sensitivity analysis. Therefore, taxable income amounts to $y_t^i - x_t^i$ such that a household's tax liability (2.3) changes to

$$T(y_t^i, x_t^i) = (y_t^i - x_t^i) - \theta_0(y_t^i - x_t^i)^{1-\theta_1}, \tag{5.5}$$

and net income (compare with (2.5)) is presented by

$$\hat{y}_t^i = \theta_0 (y_t^i - x_t^i)^{1-\theta_1} + x_t^i. \tag{5.6}$$

The first-order conditions of the workers with respect to the substitution between leisure and young consumption from equation (2.12a) and the health Euler equation (2.12c) need to be adjusted as follows:

$$\frac{v'(l_t^i)}{u'(c_t^i)} = \theta_0(1-\theta_1)\left(e^i w_t l_t^i - x_t^i\right)^{-\theta_1} e^i w_t, \tag{5.7a}$$

$$\psi'(h_t^i) h'(x_t^i) u(d_{t+1}^i) = (1+r) u'(d_{t+1}^i)\left[\theta_0(1-\theta_1)(e^i w_t l_t^i - x_t^i)^{-\theta_1}\right]. \tag{5.7b}$$

With private health expenditures x_t^i being tax deductible, the incentives to invest in health increase, implying higher x_t^i and thus a higher health state and longevity. This, in turn, leads to lower gains in average longevity from the redistribution of income due to the concavity of the health production function. Hence, optimal progressivity θ_1^* declines notably from 0.0642 to 0.0318 in the case of endogenous longevity (see Table 5.1), and the welfare effects of optimal tax progressivity are even more pronounced and amount to 0.42% of total consumption. Our two main results, that the progressivity of the US tax system is much higher than the optimal value and that the consideration of endogenous longevity rather than exogenous longevity decreases optimal income tax progressivity, are quantitatively magnified in the case of tax-deductible private health expenditures.

6 Conclusion

Income inequality is increasing in many industrialized countries, including the United States. Governments around the world are exploring different ways to redistribute income from rich to poor agents. Progressive income taxation is a natural candidate; other measures include better access to education and health by subsidizing tertiary education and fostering the public health system.

In this paper, we investigated the optimal tax progressivity for a revenue-neutral income tax reform under endogenous longevity. The optimal tax policy must address the tradeoff between the positive welfare effects from redistribution on the one hand and the negative welfare effects from tax distortions on labor supply and accompanying general equilibrium effects on the other hand. We find that labor income taxes should be much less progressive than in the US economy. In addition, we show that endogenous longevity diminishes the optimal degree of tax progressivity in general. An extensive sensitivity analysis confirms the negative impact of endogenous longevity on optimal tax progressivity; optimal labor income taxes should only be more progressive if the values of the Frisch elasticity and the elasticity of longevity with respect to health are unrealistically low.

Regarding the relevance of our results for policy, we emphasize that we have neglected various aspects of the existing US health system and causes of inequality. Therefore, one should be careful to directly implement our results in policy recommendations. We would like to mention the following three extensions of our model in future research. First, we only consider a two-period model of the life cycle. A more extensive 60-period model based on the work by Auerbach and Kotlikoff (1987) that also includes a social security system implies a much more realistic description of the individual optimization problem and, hence, equilibrium savings and factor prices. Savings provide an essential means for the self-insurance of individuals against negative income and health shocks. Second, we assume income certainty, while stochastic income and the risk of unemployment are important motives for government to redistribute income between individuals. Third, households in our model are only heterogeneous with respect to individual productivity but not with respect to innate abilities and health conditions. We also refrain from modeling the endogenous choice of education. Therefore, we do not answer the question of whether the government should redistribute with the help of public spending on health and/or education rather than with more progressive income taxes. We consider this question central to the study of optimal redistribution.

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A Appendix

A.1 Steady state

In steady state, the stationary variables are constant, and thus, we can drop the period index t. The steady state can be described by the following 16 equations in the 16 steady-state variables a^L, a^H, l^L, l^H, c^L, c^H, d^L, d^H, x^L, x^H, w, r, $\tilde{K}$, $\tilde{Y}$, $\tilde{L}$, and $\tilde{X}^{pub}$:

$$\frac{v'(l^L)}{u'(c^L)} = (1-\theta_1)\frac{\theta_0(e^L l^L w)^{1-\theta_1}}{l^L}, \tag{A.1.1a}$$

$$u'(c^L) = \beta(1+r)u'(d^L), \tag{A.1.1b}$$

$$\psi'(h^L)h'(x^L)u(d^L) = (1+r)u'(d^L), \tag{A.1.1c}$$

$$a^L = \theta_0\left(e^L l^L w\right)^{1-\theta_1} - c^L - x^L, \tag{A.1.1d}$$

$$d^L = \frac{1+r}{\psi^L}a^L \tag{A.1.1e}$$

$$\frac{v'(l^H)}{u'(c^H)} = (1-\theta_1)\frac{\theta_0(e^H l^H w)^{1-\theta_1}}{l^H}, \tag{A.1.1f}$$

$$u'(c^H) = \beta(1+r)u'(d^H), \tag{A.1.1g}$$

$$\psi'(h^H)h'(x^H)u(d^H) = (1+r)u'(d^H), \tag{A.1.1h}$$

$$a^H = \theta_0\left(e^H l^H w\right)^{1-\theta_1} - c^H - x^H, \tag{A.1.1i}$$

$$d^H = \frac{1+r}{\psi^H}a^H \tag{A.1.1j}$$

$$w = (1-\alpha)A\tilde{L}^{-\alpha}\tilde{K}^{\alpha}, \tag{A.1.1k}$$

$$r = \alpha A\tilde{L}^{1-\alpha}\tilde{K}^{\alpha-1} - \delta, \tag{A.1.1l}$$

$$\tilde{Y} = A\tilde{L}^{1-\alpha}\tilde{K}^{\alpha} \tag{A.1.1m}$$

$$\tilde{Y} = \tilde{C} + \tilde{X} + \tilde{I} + \tilde{G} + \tilde{X}^{pub}, \tag{A.1.1n}$$

$$(1+n)\tilde{K} = \phi a^L + (1-\phi)a^H, \tag{A.1.1o}$$

$$\tilde{T}^L + \tilde{T}^H = \tilde{G} + \tilde{X}^{pub} \tag{A.1.1p}$$

with

$$\tilde{C} = \phi \left[c^L + \frac{\psi(h^L)}{1+n} d^L \right] + (1-\phi) \left[c^H + \frac{\psi(h^H)}{1+n} d^H \right] \tag{A.1.2a}$$

$$\tilde{X} = \phi x^L + (1-\phi) x^H \tag{A.1.2b}$$

$$\tilde{I} = (n+\delta)\tilde{K} \tag{A.1.2c}$$

$$\tilde{L} = \phi e^L l^L + (1-\phi) e^H l^H, \tag{A.1.2d}$$

$$\tilde{T}^L = \phi \left[y^L - \theta_0 (y^L)^{1-\theta_1} \right], \tag{A.1.2e}$$

$$\tilde{T}^H = (1-\phi) \left[y^L - \theta_0 (y^L)^{1-\theta_1} \right], \tag{A.1.2f}$$

$$y^L = e^L l^L w \tag{A.1.2g}$$

$$y^H = e^H l^H w, \tag{A.1.2h}$$

$$h^L = (x^L)^\gamma \eta^{1-\gamma}, \tag{A.1.2i}$$

$$h^H = (x^H)^\gamma \eta^{1-\gamma}, \tag{A.1.2j}$$

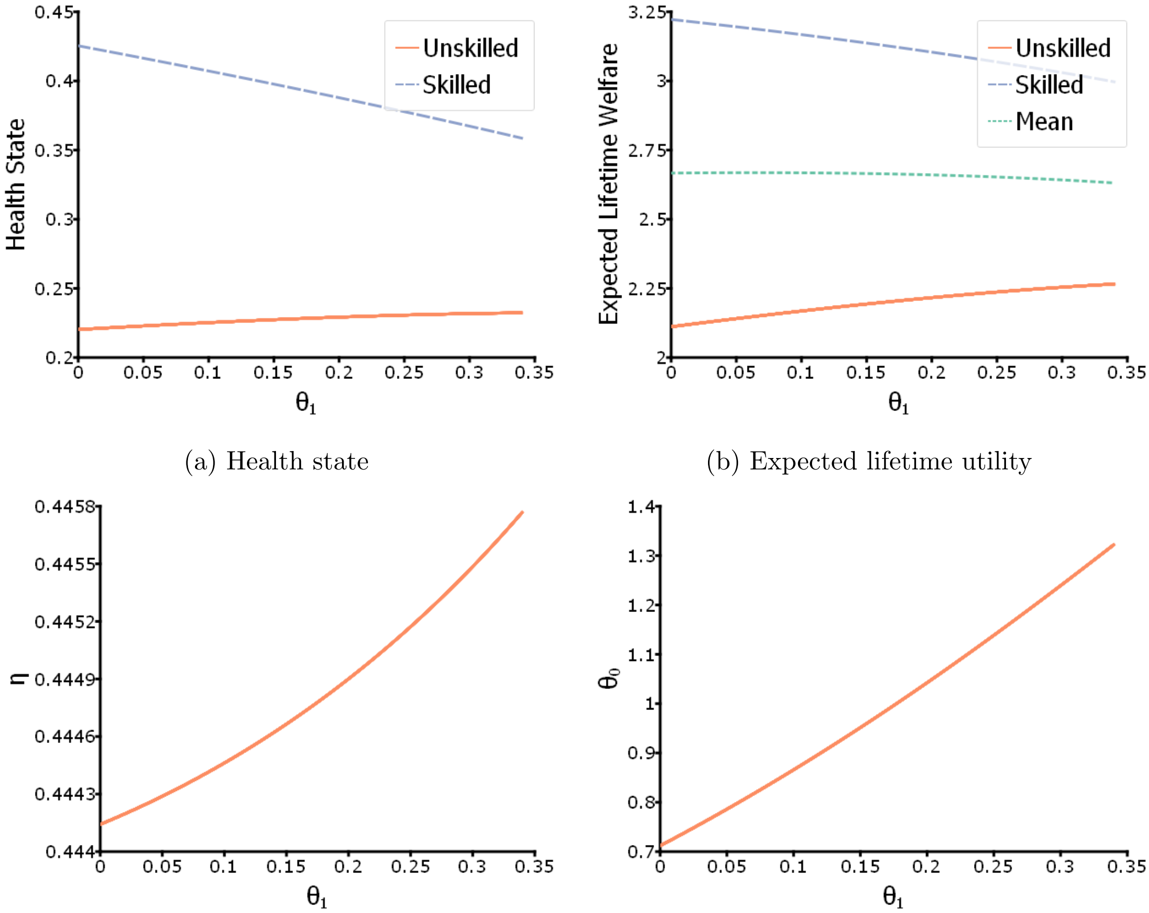
$$\psi^L = \psi(h^L), \tag{A.1.2k}$$

$$\psi^H = \psi(h^H), \tag{A.1.2l}$$

$$\eta = \frac{(1+n)\tilde{X}^{pub}}{1+n+\phi\psi^L + (1-\phi)\psi^H}. \tag{A.1.2m}$$

The behavior of the individual state variables labor supply l^i, marginal tax rate $\tau(y^i)$, net income $\hat{y}^i$, savings a^i, private health expenditures x^i and life expectancy $\psi^i \equiv \psi(h^i)$ for $i \in \{L, H\}$ are illustrated as a function of the progressivity parameter θ_1 in Fig. 4.1. The behavior of the individual variables health h^i and expected lifetime utility, $u(c^i) - v(l^i) + \psi^i \beta u(d^i)$, as well as public health expenditures per capita, η, and the fiscal tax level parameter θ_0 are displayed in Fig. A.1. Note that an increase in θ_1 implies a narrowing of the health gap, $h^H - h^L$, and a smaller difference in the expected lifetime of the newborn skilled and unskilled workers. With more progressive income taxes, the tax level parameter θ_0 and public health expenditures per capita rise.

Figure A.1: Steady-state effects of tax progressivity θ_1: Additional variables



(a) Health state

(b) Expected lifetime utility

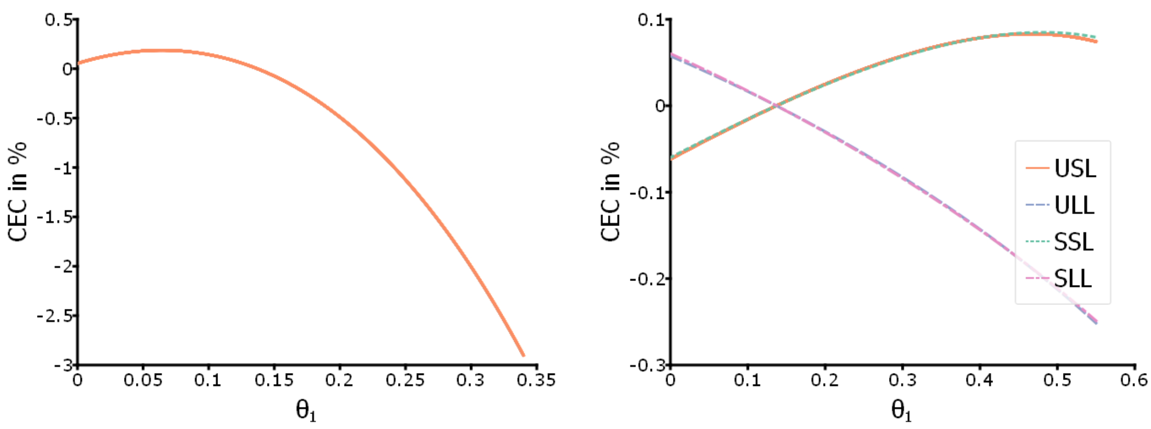
(c) Public health expenditures per capita η

(d) Level of the tax system θ_0

A.2 Welfare decomposition analysis

Fig. A.2 shows the welfare analysis for the average expected lifetime utility (panel a) and its decomposition by skill levels and lifetime (panel b). The left-hand side of the figure displays the consumption equivalent change of the average newborn associated with a change in the tax progressivity parameter θ_1. The average expected lifetime utility of the average newborn is a hump-shaped function of θ_1 and is maximized at $\theta_1^* = 0.0642$. The right panel (b) of Fig. A.2 displays the ex post consumption equivalent changes for the skilled and unskilled as well as that for those who survive or do not survive until old age (period 2). Evidently, lifetime utility and, hence, the consumption equivalent change is a monotone falling function for the skilled worker who has either a short or long lifetime, denoted by (SSL) and (SLL), respectively. For unskilled workers with both short and long lifetimes, (USL) and (ULL), lifetime utility is hump-shaped. If we apply Rawls' maximin criterion according to which the minimum lifetime utility of the workers is maximized, we find an optimal tax progressivity, $\theta_1^{Rawls} = 0.4664$, that is much higher than the present tax progressivity in the United States. Nevertheless, we find that our second main result also holds if we apply Rawls' maximin instead of the utilitarian concept. In the case of an exogenous lifetime, the maximum of the minimum lifetime utility for the unskilled worker is attained at a higher tax progressivity, $\theta_1^{Rawls} = 0.4866$, than in the case of an endogenous lifetime.

Figure A.2: Decomposition of welfare effects

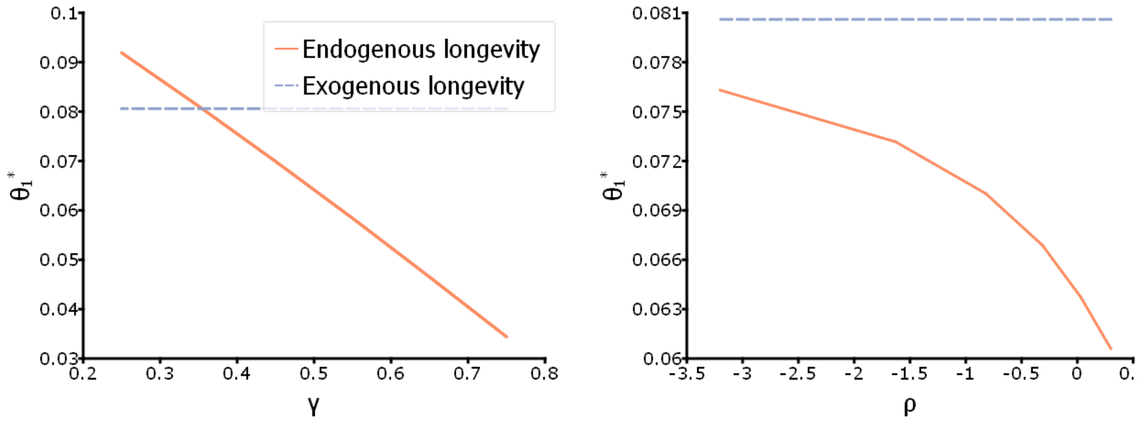


(a) Average expected lifetime utility

(b) Welfare decomposition by skill level and ex post lifetime

A.3 Additional sensitivity analysis

In Section 3, we presented evidence from empirical studies that the production elasticities of health with respect to private and public health expenditures, γ and $1-\gamma$, are not significantly different from one another, implying our calibration $\gamma = 0.5$. In addition, we assumed that the substitution elasticity between private and public health expenditures, x and η, is equal to unity. In the following, we consider the sensitivity of our results with respect to these two parameters. In addition, we present statistics on how the model under the alternative scenarios in the sensitivity analysis fits our calibration targets.



(a) Variation of γ (b) Variation of ρ

Figure A.3: Sensitivity of optimal tax progressivity to γ and ρ

Health production elasticity γ. The effects of a variation of γ on θ_1^* are presented on the left-hand side of Fig. A.3. Evidently, the optimal progressivity θ_1^* decreases with the health production elasticity of private health expenditures, γ. For higher γ, private health expenditures x play a more significant role in increasing longevity. Consequently, higher tax progressivity results in a larger decline in the longevity gap and, for this reason—as argued in the sensitivity analysis for ε in Section 5—optimal progressivity θ_1^* should be smaller due to general equilibrium effects. Note that both of our main results are robust to the choice of γ. First, the optimal progressivity θ_1^* is below the present US tax progressivity, $\theta_1 = 0.137$. Second, the optimal tax progressivity θ_1^* is lower under endogenous than under exogenous longevity as long as the value of γ exceeds 0.3538.

Substitution elasticity between private and public health expenditures. Next, we consider the sensitivity of our results to the substitution elasticity of private and public health expenditures. Following Bhattacharya and Qiao (2007), we apply a CES health production function

$$h_t^i = \left[\gamma \left(x_t^i\right)^{\rho} + (1-\gamma)\eta_t^{\rho}\right]^{\frac{1}{\rho}}, \tag{A.3.1}$$

where $\frac{1}{1-\rho}$ defines the elasticity of substitution between x_t^i and η_t. Our health production function (2.6) presents the special case with $\rho = 0$ (corresponding to a substitution elasticity equal to unity).

The empirical evidence regarding whether to regard private and public health expenditures as substitutes ($\rho > 0$) or complements ($\rho < 0$) is mixed. Fiorini (2010) uses World Bank data from 1997 to 2005 to estimate that public and private health expenditures are substitutes. Using US data from between 1987 and 2002, Cutler and Gruber (1996a), Cutler and Gruber (1996b), and Gruber and Simon (2008) report that public health expenditures crowd out private health expenditures. Accordingly, we test the sensitivity of our results to the parameter ρ over a wide range $[-3.2, 0.3]$.

Our results are presented on the right-hand side of Fig. A.3. The optimal θ_1 decreases with higher substitutability between private and public health expenditures. With increasing ρ, individual private health expenditures x_t^i, $i \in \{L, H\}$ and, hence, health are more sensitive to the effects of income redistribution such that the longevity gap declines more strongly with higher tax progressivity. Therefore, we again observe that this effect necessitates a lower optimal tax progressivity (analogous to the cases of ε and γ above). Moreover, the optimal tax progressivity θ_1^* is smaller for endogenous than exogenous longevity. Hence, our results are also robust to the value of the substitution elasticity between private and public health expenditures.

Calibration fit in the sensitivity analysis. In Table A.1, we present the calibration fit for all scenarios studied in the sensitivity analysis. We attempted to keep the matching as close as possible to that in the benchmark case reported in Table 3.2. Under all scenarios, the real interest rate and the consumption-output ratio are closely matched. We find some minor variations in the matching of the health share to GDP, the ratio of public to total health expenditures, and the longevity gap. The largest deviations are observed for the case with $\varepsilon = 0.15$. Due to the reduced concavity of the longevity function, the longevity gap declines more strongly than in the other cases.

Moreover, the share of public to total health expenditures increases while the share of total health expenditures to GDP declines due to a lower impact of private health expenditures on longevity.

	$r-\delta$	$\frac{\tilde{C}+\tilde{X}}{\tilde{Y}}$	$\frac{\tilde{X}+\tilde{X}^{pub}}{\tilde{Y}}$	$\frac{\tilde{X}^{pub}}{\tilde{X}+\tilde{X}^{pub}}$	Longevity gap
US economy	4.0%	67%	12.0%	55%	4.8 yrs
Benchmark	4.2%	71.6%	8.3%	72%	2.77 yrs
$\nu_1 = 0.3$	4.3%	71.6%	8.3%	72%	2.78 yrs
$\varepsilon = 0.15$	4.2%	71.6%	7.7%	77%	2.04 yrs
Accidental bequests	4.2%	71.7%	8.4%	71%	2.90 yrs
x_t^i is tax deductible	4.2%	71.6%	9.0%	67%	3.35 yrs

Table A.1: Calibration fit